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Recycling of Leaf Litters: Biowaste Management for Resource Conservation

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ABSTRACT

The search for viable agricultural production systems in the era of unpredictable climate events has elevated the prospects of agroforestry practices for resilience and sustainability. The litter biomass in these ecosystems govern the biogeochemical nutrient cycling prevalent, but can also serve as organic inputs in crop production under situations where these are considered as menace and cumbersome to dispose. When left to decay under natural conditions litter takes a considerably long time for decomposition and release of nutrients entrapped in them. With the increasing need to conserve natural resources and energy, recycling of organic wastes assumes major significance. Leaf litters are untapped sources of nutrients and are generated in substantial quantities in most of the agroforestrty systems. Among the different alternatives available for recycling biomass residues, composting is considered most efficient and viable option, but recent innovations such as biochar production and thermochemical digestion have also been attempted. Organic farming strategies call for *in situ* production of nutrient inputs for economic viability of the practice and hence information on alternative technologies to enrich the repository of organic manures in the form of litter compost will be of immense importance. These composts could be recycled to soil for enriching soil organic carbon, plant nutrients and to sustain soil health in the long run. Proper utilization of the biowastes in the tree based systems will also ensure reduction in environmental pollution and forest fire incidents that otherwise threaten life. The review unveils the possible technologies for recycling the litter and use as a nutrient source but emphasizes the need for a suitable environment favouring the rapid decomposition.

Key words: Biochar, Compost, Nutrient, Organic, Quality.

Global agriculture is largely constrained by the vagaries of weather elements and production is significantly influenced by biotic and abiotic stresses that occur as a sequel to the climate change effects. To add to the unpredicted events of the climate change and pest and disease incidence, the technologies of intensive chemical use have hampered the soil health and quality, the net result being a downward trend in productivity compared to the genetic potential of the crop and variety. The flagship cultivation practice of every nation is more emphasised on organic inputs and integration of natural farming practices so as to maintain and sustain resources for improved productivity. Search for alternatives to chemical inputs has enhanced the production of eco-friendly and organic inputs in bulk quantities to meet the nutrient requirements as well as the repeated applications warranted to keep away the pests that can cause severe damage and crop losses. The biowastes - crop residues and animal wastes are potential inputs for use in agriculture. However, a major fraction is treated as a waste and incinerated.

Agroforestry systems are widely proclaimed as climate resilient, sustainable practices that offer solutions to current needs of product and ecosystem services (Parthibhan *et al.,* 2018). These are the traditional practices of tree- crop/ livestock combinations which dates back to years of shifting cultivation. They have transcended over the years from the primitive forms of shifting cultivation to agri silvicultural, silvo pastoral and agri silvo pastoral systems. With the inclusion of horticultural perennials, agri horticulture systems are also in vogue. Diverse species of crops are included alongside the trees. Livestock, poultry and other allied enterprises can also be components, but the woody perennials, trees, form the backbone of the system.

The multifaceted benefits rendered by the trees ranging from nutritional, economic and ecosystem services and climate change mitigation have been deliberated and illustrated by several workers (Nair, 1983; Verchot *et al.,* 2007). In agricultural systems, the litter fall surmises relevance on account of its potential as an organic input. Trees are characterised by an almost continuous litterfall which contributes significantly to the organic matter accretion in the system. The pattern of litterfall is unimodal or bimodal (Das and Das, 2010; Moosa, 1997) with peak falls during winter and or in summer. The tree litter is considered as a menace in lawns, ornamental gardens, courtyards and porches. According to Vasanthi *et al.* (2013), leaf litter accumulating in the urban and suburban locations adds to

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the overall problem of municipal solid wastes. Hence, removal of the litter conjectures importance so as to maintain the premises clean. Disposal of autumn foliage is not only cost intensive but an organisational challenge. Litter are removed for fuel, landfilling and/or burnt. From the agricultural point of view, the above mentioned methods lead to a considerable loss of a potential input that can otherwise be utilised in farming. The situation calls for a proper technology for safe disposal and utilisation of the biowastes.

The biogeochemical nutrient cycling in tree based systems is dominated by litter production and decomposition (O'Connell and Sankaran, 1997). Natural decomposition of the litter is constrained by a slow rate of decay due to the intrinsic properties of the litter, summarised as litter quality. As litter is the matured senescent part of the plant, it mostly contains more of recalcitrant substances such as lignin and polyphenols that make them less amenable to the soil organisms that initiate the decomposition process. Isaac and Nair (2005) enumerated the long time taken for the decay and release of nutrients under natural conditions. The presence of a soil cover is often considered advantageous (Abbasi and Ramasamy, 2001) but, in agroforestry systems, the litter can have negative implications such as harbouring pests and pathogens, allelopathic effects interfering with the germination of associated crop seeds *etc.* This has brought to focus the school of thought - hastening the decomposition process with proper additives, *i.e.* recycling of biowastes.

Leaf litter decomposition

Litter during decomposition is subjected various processes. It is initially fragmented by soil fauna, water soluble compounds are leached and later, carbon is mineralised and respired as CO_2 through the action of microorganisms. Thus, the entire process is reckoned to be controlled by the nature/ quality of the litter material, the microenvironment at soil surface and the qualitative and quantitative composition of the decomposer organisms. The significant role of the litter quality: initial N, lignin, polyphenols and the ratios of C/N, lignin/N and polyphenol/ N (Liu *et al.,* 2007), moisture content (Das, 2019; Thomas *et al.,* 2012), physical characteristics of litter material (Sundarapandian and Swamy, 1999) as the main variables controlling rates of decomposition have been elucidated. In addition, the soil properties, soil temperature (Hobbie, 1996), moisture (Naik *et al.,* 2018) and chemical properties (Coleman and Crossley, 1996; Cuevas and Medina, 1986) influence the degradation directly and/ indirectly through their influence on soil macro and microfauna regimes. Manipulating the environment favouring the activity of the soil decomposers or the physico-chemical processes that bring about the decomposition have been attempted. Further, recycling is widely proclaimed as an appealing alternative for the safe disposal and utilisation of biowastes.

A wide array of technologies have been evaluated and recommended for the conversion of litter waste into beneficial products. The different methods that can be competently adopted for litter recycling are reviewed herewith.

Litter recycling techniques

Composting

Recycling of biowastes via composting is regarded as an efficient technology to combat the problem of agricultural waste management. Composting is the controlled biological decomposition of organic materials and conversion to forms that can be used in soil. The anticipated benefits of composting include cost effective and sustainable procurement of a substitute for synthetic fertilizers (Moss *et al.,* 2002), conversion of objectionable wastes into stable benign substance with less volume (Dickson *et al.,* 1991) *and* reduction in odour (Dougherty, 1998). Sajnanath and Sushama (2004) opined that composting depends on the microorganisms which utilize decomposable organic waste both as an energy and food source. Under natural conditions, macroorganisms *viz*., earthworms, nematodes *and* soil insects (mites, ants, millipedes and beetles) initially breakdown the organic materials into smaller particles, which are then exposed to microbial degradation. Consequently, the composts can be used in crop production. Based on the organisms involved and/or materials used for the degradation process, composting may be:

Vermicomposting

Hastening the decomposition process involves addition of organisms or materials that augment the nutrient/ microbial population inherent in the biowaste. Earthworms are regarded potential accelerators of organic matter decomposition. Use of earthworms for composting, termed as vermicomposting is a practice that was started in the middle of twentieth century and is still popular as a rapid biodegradation technology. The final product of the organic material degraded by the earthworms is called vermicompost. Ndegwa and Thompson (2001) described vermicompost as a homogenous substance that tend to hold more nutrients over longer periods with desirable aesthetics, plant growth hormones and high levels of soil enzymes, while enhancing microbial populations and without causing any adverse effect on the environment. According to Hari and Sushama (2005), worm casts produced by earthworms have significantly higher nutrient composition, nearly five times more organic matter, total N and exchangeable cations than soil. Shouche *et al.* (2014) reported that degradation is the result of combined activity of microorganisms and earthworms wherein the primary decomposition take place outside and secondary decomposition takes place inside the earthworm. Earthworms are voracious feeders and consume approximately food amounting to one third of their body weight per day and achieve higher mass reduction than conventional composting (Pattnaik and Reddy, 2010).

According to Biddappa *et al.* (1996), plantation crops produce huge amount of biomass for recycling which

accounts for more than 30-50% of the produce. Coconut, a predominant tree in homestead based agroforestry systems adds on an average 6-8 Mg biomass ha^{-1} as wastes annually (Thomas *et al.,* 2012) while in arecanut it was quantified as 8 Mg ha^{-1} (Nampoothiri, 2001). The high lignin content (30-40%) in the coconut leaves and petioles impedes the decay in soil and hence remains as a recalcitrant material in the garden for long, nearly 18 months are required for their unassisted degradation (Thomas *et al.,* 1998). In this form it has the virtue of providing a soil cover and acts as mulch material. Nutrient contents in coconut leaves grown under adequate management have been estimated as 1.74, 0.10 and 1.24% N, P and K respectively (Maheswarappa *et al.,* 2014). The decomposition of coconut leaves under natural condition takes on an average 238 days (Harishma, 2017) and hence efforts were made to ensure recycling of the material through composting.

Prabhu *et al.* (1998) identified an indigenous strain of *Eudrilus* sp., capable of decomposing the highly lignified coconut leaves within a period of 75-90 days. The *in situ* vermicomposting technology developed at CPCRI ensures vermicompost from coconut leaves with a nutrient content of 1.80% N, 0.21% P, 0.16% K, 17.84% organic C and a C: N ratio of 9.95.

Vermicomposting of organic wastes (apple residue and leaf litter) from cashew orchards yielded a quality manure with 1.69% N, 0.44% P, 0.58% K in a period of 95 days (Mini *et al.,* 2005). Jayanthi (2010) illustrated that cashew leaf litter can serve as feed stock for earthworms and get converted into nutrient and microbial rich organic manure/ vermifertilizer by the action of *Perionyx excavates* and other species of earthworms, particularly indigenous earthworms. Annual leaf litter fall in cashew amounts to 25-30 kg per plant (Parthasarathi *et al.,* 2016) which if not properly managed, can cause environmental pollution problems.

Vermicompost from leaf litter biowastes has been attempted in different trees, leaf litters of sandalwood (Bhati *et al.*, 2019), rubber (Chaudhuri *et al.,* 2016), mango (Das *et al.,* 2020; Vasanthi *et al.,* 2013), coconut and jack (Harishma, 2017), asoka, teak and neem (Jayanthi *et al.,* 2010), tendu (Mushan and Rao, 2012), teak (Nagalakshmi and Prakash, 2016), eucalyptus (Nagar *et al.,* 2017), black plum (Nagar *et al.,* 2018) and guava (Vasanthi *et al.,* 2013).

Leaf litter with cow dung in the ratio of 1:1 was identified most suitable for composting in palash (Nagar *et al.,* 2019), cashew (Parthasarathi *et al.,* 2016), mango (Prakash and Karmegam, 2010) and Indian beech (Thangaraj, 2015). It needs to be borne in mind that the chemical properties of the litter greatly influences the activity of the earthworms. Exploring the leaf litter preference shown by the earthworm *Pontoscolex corethrurus* (Muller) for the wastes as food source, Ganihar (2003) illustrated that maximum preference was for *Phyllanthus reticulatus* and then on declined in the order, *Tamarindus indica* > *Anacardium occidentale* > *Casuarina equisetifolia* > *Acacia auriculiformis* > *Eucalyptus camaldulensis.* Increased mortality of the worms has been reported by Gajalakshmi *et al.* (2005) when mango litter was used as such as for the earthworms. Similar observations were documented with acacia (Ganesh *et al.,* 2009) and the results emphasized that leaf litter rich in polyphenols and lignin are not preferred by most species of earthworm. The time taken for compost production varied with the quality of the litter and Harishma (2017) observed a reduction of nearly 50% in the time taken compared to natural decomposition.

Microbial composting

Microorganisms are primarily responsible for composting and converting the wastes into a nutrient rich substance (Novinsak *et al.,* 2008). During composting, a succession of fungi and bacteria, including actinomycetes, chemically alter the compost constituents. Fungi and bacteria, the most important group among microbial agents of decomposition can colonize very quickly and they play an important role in the degradation of lignocellulosic organic waste. Several fungal and bacterial species such as *Rhizopus oryzae, Aspergillus oryzae, Aspergillus fumigates, Aspergillus terreus, Paecilomyces fusisporous, Bacillus sp., Trichonympha, Clostridium* and their consortium are capable of this function (Borah *et al.,* 2016; Goyal and Sindhu, 2011; Sinegani *et al.,* 2005).

According to Chander *et al.* (2018), maintaining a higher microbial population through added culture and systematic turnings at 10 day interval hastened the decomposition in aerobic composting. Gurumurthy (2018) reported that the characteristics of the inoculated population of microbes determine decomposition rate of organic matter throughout the process. Higher microbial population enhance the plant growth by production of growth hormones and also act as biological control agents against several soil borne diseases.

Co- composting

Biowastes with wide C: N ratio are slow to degrade and often necessitates the inclusion of N supplements and lignin degrading microbial cultures. Co- composting is a technique adopted for composting organic materials with low N content and wide C: N ratio, in which organic substrate with a higher N content and lower C: N ratio is added as a supplement to facilitate proper microbial activity. Poultry manure has been successfully used in the stabilization of organic wastes particularly high in lignin and cellulose, including wood wastes (Guerra-Rodriguez, 2001), barley waste (Guerra-Rodrýiguez *et al.,* 2000), wheat straw (Petric *et al*., 2009), coir pith (Thomas *et al*., 2013), pineapple residues (Ch'ng *et al.,* 2014) and jack and coconut leaves (Harishma, 2017). Mango leaves were enriched in N with the green leaf manure, Glyricidia leaves before composting and this could significantly accelerate the rate of decay (Das *et al.,* 2020).

Time taken for maturation of compost varies with the litter species as well as the method used for composting. The variation in time taken for composting with different litters are given in Table 1.

Biochar production

Biochar is a carbon-rich product defined as "a solid material obtained from the thermo-chemical conversion of biomass in an oxygen limited environment" (IBI, 2012). It is generated through pyrolysis, *i.e*. a thermal process carried out at temperatures that range from 250°C to >900°C and under limited oxygen availability. Experiments on biochar production reveal that the entire process can be completed in 5-6 days and application in soil endorses many positive effects *viz*., suppress soil borne pathogens (Bonanomi *et al.,* 2015), increased water retention capacity (Novak *et al.,* 2012), capability to adsorb phytotoxic organic molecules (Oleszczuk *et al.* 2012), liming effect (Van Zwieten *et al.,* 2010) and stimulate the activity of beneficial microbes (Warnock *et al.,* 2007). It is carbon-enriched, in most cases more than 60% and is recalcitrant to decomposition in comparison to the original biomass *and* hence can remain in the pedosphere for 100-1000 years. Biochar addition to ecosystems therefore has great potential in terms of carbon sequestration

Konaka *et al*. (2019) investigating the effects of leaf biochar as a soil amendment developed a simplified carbonizer from a used oil drum of 200 L capacity. The drum lid was replaced with a custom-made steel lid that contained a funnel in the centre and provisions for ventilation (holes at 10-15 cm interval) were given at the bottom of the drum. It was placed on top of four bricks to ensure air flow from the bottom at the beginning of ignition. Fallen leaves of Jatropha were pyrolysed in these drums and the final product had a porous surface structure characteristic of biochar which could effectively be used as a soil amendment in an acidic and undernourished soil for Swiss chard cultivation. Hashmi *et al*. (2019) attempted biochar production from pongamia leaves in which the leaves were air dried, hand-crushed, ground to a size of ≤0.45 mm and pyrolyzed (thermal decomposition) in a pyrolyzer at 380°C for 42 minutes under semi-anaerobic condition. The biochar had a pH of 8.15 and total nutrient contents, 0.83, 7.13 and 5.60% N, P and K respectively.

Leaf litter biochar was produced by carbonization of maple leaf litter under open fire using open burn kiln with pyrolysis temperature of approximately 500-600°C and the final product had a pH of 9.3, EC 2.1 mS cm^{-1}, total N 5.1 g kg^{-1}, total C 381.2 g kg^{-1} and C:N ratio of 74.8 (Oo *et al.,* 2020). It was also observed that the application of the leaf litter biochar in vegetable fields could reduce N_2O emissions and maintain vegetable yields leading to the conclusion that conversion of accumulated autumn leaf litter into biochar might be one of the solutions for municipal waste disposal and reducing N_2O emissions after its amendment to soils.

Gopal *et al*. (2020) documented the potential of pyrolysis as an innovative technology for quick recycling of highly recalcitrant coconut palm biomass residues, husk, leaf petiole and coir pith to biochars as a local source of soil amendment to aid regenerative agriculture in humid tropics. The effect of pyrolysis temperature on the characteristics of tea (*Camellia sinensis* L.) pruning litter biochar was studied by Borgohain *et al.* (2020) and the results demonstrated that yield, total nitrogen, H:C and O:C decreased steadily with increasing pyrolysis temperature whereas, water holding capacity, ash content, fixed carbon, C:N, NH^{4+}-N, NO^{3-}-N, trace elements, total P and K and germination index increased consistently with increasing pyrolysis temperature. All the prepared biochars were found suitable for field application as the H:C and O:C ratios were less than 0. 6 and 0.4 respectively. The low pyrolysis temperature (300°C) was found optimal for a more stable biochar from the prunings.

In addition, many scientists have explored the possibility of accelerating decomposition of leaf litters in soil with

Table 1: Time taken for composting in different leaf litter species.

Litter species	Composting method	Time taken for the decay (days)	Reference
Coconut	Vermicomposting (*Eudrillus sp*.)	90	Prabhu *et al.* (1998)
	Co- composting	121	Gokavi *et al.* (2016) Harishma (2017)
Mango	Microbial pre treatment + vermicomposting	110	Das *et al.* (2020)
Jack	Co- composting	105	Harishma (2017)
Guava	Vermicomposting	60	Vasanthi *et al.* (2013)
Cashew	Vermicomposting Microbial pre	120-180	Kalaivanan *et al.* (2017)
	treatment + vermicomposting	144	Das *et al.* (2020)
Neolamarkia cadamba,	Microbial composting	45	Divakar and Prasanthrajan
Acrocarpus fraxinifolius,	fruit based Effective	60	(2019)
Dalbergia sissoo and	Microorganisms @ 3	>60	
Grewia tiliifolia	L/ Mg of litter		
Tectona grandis, Madhuca indica and *Butea monosperma*	Vermicomposting	85	Manna *et al.* (2003)
Coconut coir pith	Co- composting	45	Thomas *et al.* (2013)

biochar. Bonanomi *et al.* (2017) reported antagonistic interactions when mixed with leaf litter, on the contrary, Minamino *et al.* (2019) observed that biochar addition enhanced litter decomposition rather than changing the decomposition pattern. This was attributed to the increased microbial activity with increased moisture content, theresultant of the moisture retention capacity of biochar. The carbon emission through changing leaf litter decomposition was small when compared with the carbon addition by biochar, indicating that biochar could be an effective material for carbon sequestration in forest ecosystems.

Thermochemical digestion

Organic materials can be degraded rapidly when subjected to hydrolytic degradation by treatment with acids and alkalis *and* the reaction can be further accelerated by heat (Sharma *et al.,* 2013). Based on this concept a novel technology for the rapid conversion of organic waste materials into value added fertilizers through chemical decomposition at 100°C was developed in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. It was observed that chemical treatment of well ground, fresh organic waste with HCl (0.25 N, 50 mL kg^{-1}) for 30 minutes followed by KOH (0.5 N, 100 mL kg^{-1}) for 30 minutes at 100° C and ambient pressure yielded a product that could substitute the conventional organic manure (Sudharmaidevi *et al.,* 2016). The thermochemical treatment required only 8-14 hours to produce a dried balanced organic fertilizer, including the time taken for sun-drying to attain moisture content suitable for packing. The technique was exploited for the degradation of leaf litters (Harishma, 2017) and it was observed that thermochemical composting of jack and coconut leaf litter resulted in comparatively higher NPK content than in the fallen litter.

Anaerobic composting

The products of anaerobic composting of organic residues include CO_2, methane, NH_3, organic acids and trace amounts of other gases, which adds to the global warming issues that are alarmingly on the rise. However, the higher amounts of methane released makes possible the utilisation of these as biogas for fuel *and* for production of slurry that could be used as manure in crop production. It has also opened vistas for a safe disposal and recycling of leaf litters in agroforestry systems. Chanakaya *et al.* (2005) opined that biogas plants that use non-dung herbaceous biomass residues such as leaf litter and agro-residues have a large potential and promise for the future. Stimulatory effects of powdered leaves of Gulmohar, *Leucacena leucocephala*, *Acacia auriculiformis*, *Dalbergia sisoo* and *Eucalyptus tereticonius* in biogas production (18-40%) have been elucidated by Kumar *et al.* (2013). It was also reported that alkali treated (1% NaOH for 7 days) apple and peach leaf litter added as supplements to the cattle dung could double the biogas and CH_4 production. This was in agreement with reports of Liew *et al.* (2011) who reported simultaneous alkali treatment and anaerobic digestion was suitable for enhanced anaerobic digestion and methane production from fallen leaves. Arisutha *et al.* (2014) evaluated the methane production from sisal and palash leaf litters mixed with different bulky materials such as vegetable market waste, hostel kitchen waste and digested biogas slurry in a laboratory scale anaerobic reactor in 1:1 proportion. Maximum methane content of 320 mL day^{-1} was observed in the case of sisal leaf residue mixed with vegetable market waste as the feed and the lowest when palash leaf litter was used as feed owing to the higher lignin and polyphenol contents making them less amenable to the microorganisms. The potentials of biogas slurry, the spent waste leaving the bio gas unit as a source of nutrient has been illustrated (Kumar *et al.,* 2015).

Muhammad and Chandra (2021) assessed the possibility of enhancing biogas and methane production from leaf litter of neem by co-digestion with vegetable waste and documented that the introduction of neem leaf litter to vegetable wastes improved biogas and methane yields by 87.27 and 91.47% and reduced H_2S by 146.73% compared to the mono digestion of the wastes. The methane content was sufficient for electricity and heat generation. They concluded that this could comprehend the management of leaf litter which is considered as an organic waste, trashing the environment.

Quality of litter compost

Several authors have opined that the quality and stability of compost are entirely dependent on its raw materials (Benito *et al.*, 2003; Ranalli *et al.,* 2001; Wang *et al.,* 2004). Sushama *et al.* (2010) based on their study emphasised that the nature of substrate used has a major influence over the ultimate composition of the matured compost. The parameters that indicate the quality and degree of stability include nutrient content, pH, moisture content, lignin, C: N ratio, time taken for composting and presence of any potential pathogens (Sanmanee *et al.,* 2011; Vikman *et al.,* 2002; Wu and Ma, 2002; Steger *et al.,* 2007).

Significant reduction in C: N ratio and increase in nutrient contents were reported in the composts and vermicomposts prepared from leaf litters (*Shorea robusta*, *Pinus roxburghii*, *Populus deltoides*, *Eucalyptus* hybrid) mixed with municipal solid waste (Aalok and Tripathi, 2010) and of the two, vermicomposted litter was superior in quality. Priya and Prabha (2011) assessed the physico-chemical parameters: pH, EC, moisture content, organic carbon and C: N ratio in vermicomposted leaf litter by the species *Lampito mauritii* and reported that there was an increase in all the parameters except the C: N ratio, with the progress of composting process.

Nutrient rich vermicompost from leaf litter of *Polyalthia* and sugarcane trash co-composted with pressmud was elucidated by Karmegam *et al.* (2012). The microbial counts and enzymes in the worm worked compost were ascertained to be significantly higher. Vasanthi *et al.* (2013) reported that vermicompost ensuing from mango (*Mangifera indica*) leaves was fine and odour-free with

considerable amount of N, P, K and optimum C: N ratio that could be used as suitable organic soil amendment. Harishma (2017) studied the recycling of leaf litters of jack and coconut by different composting methods and recorded significantly higher amounts of nutrients and lower C: N ratio in the final compost. Sandeep *et al.* (2017) evaluated the nutrient content of vermicompost prepared from leaf litters using the earthworm species, *Eisenia foetida*. They recorded a significant decrease in C: N ratio upto 32.6 per cent and organic carbon upto 10.8 per cent. Nutrient contents increased by 17.9, 44.7 and 18.2 per cent respectively for N, P and K on 90th day.

Gopal *et al.* (2009) documented an amplification in nine out of 15 microbial communities, particularly the plant beneficial ones in the vermicompost produced from coconut leaves + cow manure mixture compared to the five in the case of pure cow manure. The coconut leaves + cow manure mixture contained significantly high population of fungi, free-living N fixers, phosphate solubilizers, fluorescent pseudomonads and silicate solubilizers. Similar reports on enhanced microflora in composts have been documented (Ditta *et al.,* 2018; Karmegam *et al.,* 2012).

Agronomic effects of litter compost in crops

Composting provides as a fruitful disposable technology of the biowastes but the ultimate potential lies in its suitability as an organic input in crop production. Kale (1982) reported that vermicompost of guava leaf waste showed accelerated germination (100%), increased root length, shoot length, fresh and dry weight of shoots and roots and other yield responses in turmeric. Improved yields and nutrient uptake were documented in spinach with application of leaf litter compost (Chamle and Jadhav, 2007).

Experiments on the use of coconut leaf vermicompost as nutrient source in cowpea, bhindi and maize revealed that the application not only added nutrients to the soil, but also enriched the large and diverse pool of plant beneficial microorganisms (Gopal *et al.,* 2010). It was also documented that mixing coconut leaf vermicompost @ 20 per cent with soil helps in production of robust coconut seedlings (Thomas *et al.,* 2012).

Vermicomposted leaf litters were found ideal for inclusion in potting mixture for Eucalyptus (Aalok and Tripathi, 2013). Increased seedling germination and plant growth were recorded in soil to compost ratio of 1:2, while a higher proportion of litter compost decreased plant growth. In red gram, a higher plant dry weight and plant N uptake were recorded when mango leaf litter compost was used as the nutrient source (Vasanthi *et al.,* 2013). Similarly, Naikwade (2014) reported better uptake of nutrients and hence significant increase in growth and yield of fodder maize, reducing sugar content, N and crude protein content with application of leaf litter compost. In coconut, 25-50% of the N requirement of the palms could be effectively substituted with the vermicompost from coconut leaves (Maheswarappa *et al.,* 2014). Significant increases in the nut yield, nutritional status of the fronds and favourable influence on soil organic C and microbial population were illustrated.

Vermicomposted rubber litter was evaluated for its efficacy as nutrient source in pineapple (Chaudhuri *et al.,* 2016) and the results indicated the positive influence on the pineapple productivity. Nevertheless, the authors added that for better yields, an optimum amount of vermicompost is required beyond the level of which no further growth and yield occur inspite of increasing the amounts of vermicompost. Thus plots fertilized with 20 Mg ha^{-1} year^{-1} had significantly higher growth and yield than that in plots fertilized with 30 Mg ha^{-1} year^{-1}. Soil analysis post the application revealed increase in pH, EC, organic C and nutrient contents and lowered C: N in accordance with the increasing quantity of the compost applied.

According to Harishma (2017), substituting 50% recommended dose of N (RDN) with coconut leaf litter, composted with liquid composting inoculum and earthworm, could realise higher yields and economic returns in Amaranthus. The thermochemical digests of jack and coconut leaves though recorded lower yields when compared to microbial/vermicomposted litters, could significantly improve the K content in soil. Premalatha *et al.* (2017) found that leaf litter compost @ 2.5 t ha^{-1} and 75% of recommended inorganic fertilizers in black gram could realise profitable yields and also reduced the cost of production. Yield attributes and vegetable pod yields (7.82 t ha^{-1}) were maximum with the inclusion of mango leaf litter composted with glyricidia leaves and earthworms in the integrated nutrient management strategy of cowpea, nearly 9.85% greater than the package of practices recommendation for the crop (Das *et al.,* 2020).

Isaac (2020) documented that recycling of the litter as vermicompost would ensure productive disposal of the biowaste and can be recommended in elephant foot yam as a nutrient source at 50% substitution of the RDN along with P and K as chemical fertilizers.

The documented literature provides adequate evidence on the potentials of leaf litter composts as a supplementary nutrient source in crop production.

CONCLUSION

Sustainable production calls for the use of renewable resources in agriculture minimizing environmental damages and maintaining soil health for better yields. Agroforestry systems on account of the woody perennials included offer multifaceted benefits and ecosystem services which uphold the practice as a solution to the ever rising risks of climate change effects. Leaf litter continues to be an untapped resource that has immense potential as an organic input in crop production. The physical and chemical properties of the litter assume prime concern and thus the efficacy of the recycling method will vary with the species. Nevertheless, it brings focus the

vistas of using the neglected resource in agriculture as organic and eco-friendly management practices are being popularized globally.

Conflict of interest

All authors declare that they have no conflict of interest.

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