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PLANTATION CROPS WASTE

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1. INTRODUCTION

Plantation crops are high value commercial crops grown in humid tropics, mainly between 20°N and 20°S of equator. Being perennial in nature, these crops play a vital role to preserve and foster ecological balance by preventing soil erosion and providing vegetative cover throughout the year to the agro-ecosystem. These crops, besides contributing considerably to foreign exchange, generate lot of employment and sustain livelihood of millions, who depend on these group of crops for cultivation, processing and trade. As a perennial source of food, drinks, medicines and raw material for a number of small and large scale industries, the history of these crops is closely interwoven with socio-economic and cultural lives of people in several countries in the tropics. Among the important plantation crops, coconut is cultivated for multifarious uses including edible oil and food products, arecanut for masticatory nut, coffee, tea and cocoa for beverages, oil palm for edible and industrial oil, rubber for natural rubber, cashew tree for edible cashew nut kernel, and crops, such as black pepper, cardamom, nutmeg, clove, cinnamon and others as spices. Major producing states of different plantation crops, their area and production are presented in Table 1.

Table 1. Area and production of major plantation crops in India (2003).

Crop	Scientific name	Area ('000 ha)	Production ('000 tonnes)	Major producing states
Coconut	*Cocos nucifera* L.	1820.0	9500.0	Kerala, Tamil Nadu, Karnataka, Andhra Pradesh
Arecanut	*Areca catechu* L.	290.0	330.1	Karnataka, Kerala, Assam
Oil palm	*Elaeis guineensis* Jack.	33.4	NA	Andhra Pradesh, Tamil Nadu, Kerala
Cocoa	*Theobroma cacao* L.	16.2	6.4	Kerala, Karnataka, Andhra Pradesh
Coffee	*Coffea arabica* L.	323.0	275.0	Karnataka, Kerala, Tamil Nadu
Cashew	*Anacardium occidentale* L.	730.0	460.0	Karnataka, Kerala, Maharashtra
Tea	*Camellia sinensis* L.	443.0	885.0	Assam, West Bengal, Tamil Nadu, Kerala
Rubber	*Hevea brasiliensis* Muell. Arg.	435.0	694.0	Kerala

Source: FAO Production Statistics, Rome.

2. ORGANIC RECYCLING IN PLANTATION CROPS

2.1 Relevance

The economic produce of the plantation crops varies from nuts in coconut, arecanut, oil palm and cashew, buds and leaves in tea, berries in coffee, pods in cocoa and latex from the bark of rubber. Apart from the economic produce, the plantation crops produce large quantities of biomass and provide scope for organic recycling of farm wastes, which can enable to reduce cost of production and pave the way for production of organic products. The full yield potential of plantation crops are not realised due to their cultivation in resource poor soils and inadequacy of fertilizer inputs to meet the nutrient demand of the crops (Khan *et al.*, 2000). Intensification of agriculture without organic additions resulted in irreversible damage to the life supporting system, and the physical and biological resources of the soil. As a result, several problems such as low productivity, increased incidence of pests and diseases, and emergence of new pests are experienced on production front.

The decline in productivity has been attributed to factors, such as decrease in soil organic matter content, water holding capacity, loss of physical properties, and number and activity of soil flora and fauna. The adverse effect of inadvertent use of chemical nitrogenous fertilizers on eutrophication and nitrate poisoning of ecosystem has been reported (Commoner, 1968). The plantation sector is constrained by the unstable prices of commodities and increase in the cost of production. Under such a situation, a re-orientation of strategies is required to develop production systems that are agriculturally sustainable, economically viable and environmentally sound. The maintenance and conservation of soil fertility is an integral component of agricultural sustainability, which can be achieved through appropriate management of organic resources available in the ecosystem in plenty. Recycling of vast resources of crop residues containing appreciable quantity of nutrients, produced by plantation crops, offer new avenues for nutrient management in plantation crops and cropping systems.

2.2 Availability of Recyclable Biomass

The plantation crops produce large quantities of biomass which can be effectively recycled into the respective cropping systems to meet the nutrient demand of the crops to a large extent. The quantity of biomass available for recycling from the plantation crops, such as leaves, husk and bunch wastes from coconut; leaves, husk and rachis from arecanut; leaves, pod husk and prunings from cocoa; husk from coffee and wastes from tea is presented in Table 2. Coir pith is available as waste from coir processing factories after extraction of coir fibre. The biomass from plantation crops is a rich source of plant nutrients.

Table 2. Quantity of recyclable biomass available in plantation sector in India.

Crop	Waste	Quantity available
Coconut (excluding coir pith)	Leaves, bunch waste husk (million t)	11.20
	Coir pith (million t)	0.75
Areca	Leaves (million t)	0.13
	Rachis (million t)	0.08
	Husk (million t)	0.22
Cocoa	Shed leaves (t)	360.03
	Prunings (t)	12,056.33
	Pod husk (t)	32,900.00
Coffee	Husk (million t)	0.18
Tea	Waste (million t)	0.22

Source: Biddappa *et al.*, 1996.

Nair *et al.* (1996) estimated that the total quantity of nutrient supply that is potentially available through plantation crops is in the order of 9.2×10^4 tonnes N, 1.2×10^4 tonnes P_2O_5, 6.3×10^4 tonnes K_2O, annually.

3. ORGANIC RECYCLING IN DIFFERENT CROPS

3.1 Coconut (*Cocos nucifera* L.)

The coconut palm has multiple uses in the form of food, edible oil, health drink, desiccated coconut, coconut milk, cream, milk powder, and other confectionary and food products. Most of the coconut production comes from small and marginal holdings. The palm is predominantly grown in acidic nutrient poor laterite, sandy loam or sandy soils in the coastal region. Being a perennial crop, the coconut palm produces huge quantities of organic wastes throughout the year. The availability of organic recyclable biomass from a hectare of well managed coconut garden has been estimated to be about 14-16 tonnes annually in the form of leaves, spathe, bunch waste and husk. The use of these waste materials as domestic fuel and thatching material is now limited due to the change in life style of the rural population. Hence, enormous possibilities exist to recycle these wastes to organic manure to meet the nutrient demand of the crop. As the wastes are lignin rich materials, their decomposition is slow under natural conditions and utilization of biopolymer degrading organisms become important for the bioconversion of these valuable resources into agriculturally usable organic manure.

The waste biomass from coconut palm differ significantly in the chemical composition (Thomas *et al.*, 1998). They are characterized by high lignin and cellulose contents (Table 3). The nature of lignocellulosic complex and the high phenol content are the limiting factors in the easy decomposition of the waste biomass under natural conditions.

Table 3. Chemical composition of coconut waste biomass.

Recyclable biomass	Cellulose (%)	Lignin (%)	Cellulose : lignin ratio	Nitrogen (%)	Phenol (%)
Leaf stalk	31.73	25.08	1.31	0.31	2.84
Leaflets	23.83	38.68	0.58	1.00	8.45
Bunch waste	29.18	31.28	0.97	0.55	2.26
Coir pith	22.00	34.73	0.70	0.46	1.40
LSD (P=0.05)	5.93	8.74	0.06	0.41	1.28

3.1.1 Vermicomposting of coconut palm waste

A low cost technology has been standardised at Central Plantation Crops Research Institute, Kasaragod for bioconversion of coconut palm wastes into rich vermicompost using a local strain of epigeic earthworm belonging to the *Eudrilus* sp. (Prabhu *et al.*, 1998). The compost worm isolated from decomposing coconut waste heaps converted coconut leaves including the thick petiole into vermicompost (leaving behind only midrib of the leaves) within a period of 2-3 months with 70 percent recovery of the compost (Figs. 1, 2, 3). In this method, the waste can be used without chopping, thus saving a lot of labour and reducing cost of production. Vermicomposting of coconut wastes can be done in cement tanks, in coconut basins or interspaces by heap method, or in pits taken in interspaces. The vermicompost produced from coconut leaves had a nutrient content of 1.8 percent N, 0.21 percent P, 0.16 percent K, organic carbon content of 17.84 percent and C:N ratio of 9.95. The vermicompost was also rich in beneficial micro-organisms, plant growth promoting substances and humic acids. It is granular, less bulky and contains nutrients in easily available form. Experiments conducted with polybag raised coconut seedlings indicated the beneficial effect of vermicompost to enhance the vigour of the seedlings.

Fig. 1. Large scale vermicomposting of coconut leaves in a cement tank

Fig. 2. Local earthworm species feeding on coconut petiole

Fig. 3. Vermicompost produced from coconut leaves

3.1.2 Composting of coir pith with biopolymer degrading microbes

The process of extraction of fibre or coir from the husk results in the separation of non-fibrous, fluffy, light weight material known as coir pith or coir dust, which constitutes about 50-70 percent of the husk. The coir dust has many desirable characteristics such as high moisture retention capacity of 500 to 600 percent, high potassium content, low bulk density and particle density and high cation exchange capacity which enable it to retain large amounts of nutrients (Evans *et al.*, 1996; Verhagen and Papadopoulos, 1997). Despite many advantages and availability in large quantities, coir pith is not fully utilized for productive purposes. Coir pith accumulates near coir processing factories, causing disposal and environmental problems due to the release of phenolic compounds.

The decomposition and mineralisation of coir pith is very slow under natural conditions due to high C:N ratio of above 100:1, high content of lignin and cellulose (about 40% each) and high polyphenol content (about 100 mg/100 g coir pith). The amendment of soil with raw coir pith of very wide C:N ratio can result in immobilization of plant nutrients and adversely affect the plant growth.

Research efforts in different laboratories have enabled to develop technologies for bioconversion of coir pith to a stabilized product for use as a soil amendment. A number of biopolymer degrading fungi belonging to the basidiomycete group were found to be effective bioinoculants to bring about depolymerisation of lignins by elaboration of extracellular oxidative enzymes. The oyster mushroom, *Pleurotus sajor caju*, was initially used for degradation of coir pith (Nagarajan *et al.*, 1985). A comparative study of different *Pleurotus* spp. by Theradimani and Marimuthu (1992) indicated that *P. platypus* was better than the other species tested. *P. platypus* inoculation resulted in 58.6 percent reduction in cellulose and 78 percent reduction in lignin after 35 days of inoculation and the C:N ratio was minimum with this (18:1) as against the uncomposted coir pith. Biocontrol agents such as *Trichoderma* and *Chaetomium* were also effective biodegraders of coir pith (Ramamoorthy *et al.*, 1999). Nitrogen fertilization and inoculation with *Chaetomium globosum* resulted in enhanced biodegradation of hemicellulose, cellulose and lignin content of coir pith and the action resembled soft rot (Yau and Murphy, 1998).

Coir pith requires pre-treatment with chemicals and/or organics to make it amenable to microbial attack and subsequent decomposition. Addition of nitrogenous fertilizers, such as urea or nitrogen rich organic materials, legume biomass and oil cake enable to bring about reduction in C:N ratio to a level favourable for microbial action. Nagarajan *et al.* (1985) used urea @ 5 kg/tonne of coir pith alongwith the inoculation of *Pleurotus* in different layers to achieve composting of coir pith. Lime treatment has been shown to make coir pith more susceptible to the growth of lignolytic fungi, which subsequently ensures faster degradation of lignin and humification of coir pith (Anand *et al.*, 1999).

Efforts made at CPCRI to study the fungi involved in natural degradation of lignin rich coconut wastes resulted in the isolation of biopolymer degrading fungi, such as *Marasmiellus troyanus, Lentinus squarrosulus, Polyporus* sp., *Phanerochaete* sp. and

Leucocoprinus zelanicus. These fungi elaborated degradative ligninolytic and cellulolytic enzymes in culture media. A technology involving treatment with lime and rock phosphate with the inoculation of *Marasmiellus troyanus* and *Trichoderma* sp. has been standardised to produce acceptable organic manure from coir pith (Thomas *et al.*, 2001).

Vermicomposting with the local strain of *Eudrilus* sp. is another option for production of quality compost from coir pith. The technique involves pre-treatment with lime and rock phosphate at 0.5 percent level, amendment with cow dung @ 10 percent, and layering with coconut leaves @ 20 percent before release of earthworms. A granular vermicompost with 1.2 percent nitrogen and C:N ratio of 16.7:1 was obtained in two months (Thomas *et al.*, 2001).

3.1.3 Mushroom cultivation using coconut waste

Mushroom cultivation is an eco-friendly and economically profitable biotechnology process for recycling of lignocellulosic biomass from coconut palm for the production of high quality protein. Among the different waste biomass from coconut palm, leafstalk and bunch waste (Fig. 4) are superior to leaflet and coir pith in producing significantly more edible biomass of mushrooms (Table 4) (Thomas *et al.*, 1998). Mixing of biomass from coconut palm with paddy straw also enabled to achieve higher level of production of mushrooms. A low cost mushroom shed, built exclusively of coconut materials, such as coconut wood and plaited coconut leaves inside a coconut plantation, provided ideal conditions for mushroom production. Among the different species of *Pleurotus* tested on coconut bunch waste, *P. eous*, *P. flabellatus* and *P. sajor caju* yielded higher quantity of mushrooms and better biological efficiency of conversion than other species. The spent mushroom substrate (SMS) had many positive attributes still left for potential use as a good nutrient source for agricultural use. The compost prepared from bunch waste spent substrate had nitrogen content of 1.63 percent, phosphorus content of 0.18 percent and potassium content of 0.74 percent.

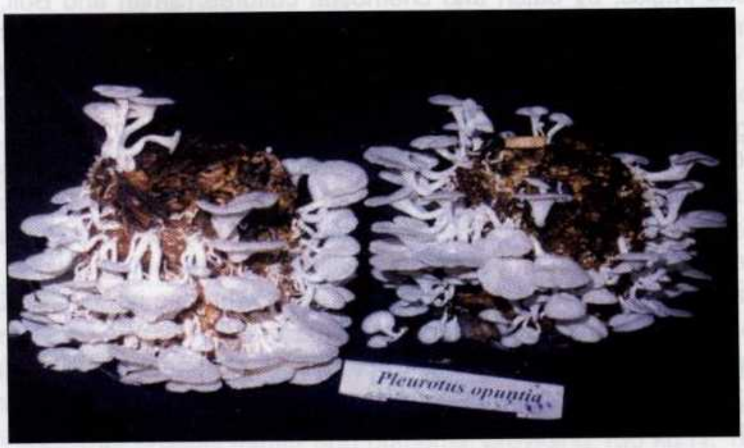

Fig. 4. Oyster mushroom production on coconut bunch waste

Table 4. Mushroom production (*Pleurotus sajor caju*) on lignocellulosic biomass from coconut palm.

Lignocellulosic biomass	Yield of fresh mushroom (g/bag)	Biological efficiency (%)
Leaf stalk	709.5	58.9
Bunch waste	611.7	56.9
Leaf stalk + paddy straw*	656.7	73.0
Bunch waste + paddy straw*	890.0	86.3
Leaf stalk + coir pith*	456.0	60.3

* 1:1 ratio.

3.1.4 Coconut waste as mulch

Organic waste from coconut palms, having high water holding capacity, can be effectively used as mulch by spreading these materials in the basins of coconut palms. Coconut leaves, husks and coir pith were found to be ideal mulching materials, which conserve soil moisture and create good micro-climate for the proper growth of plant roots and soil flora and fauna. Over a period of time, the mulches undergo decomposition resulting in their assimilation into soil organic matter reserves. Burial of husk in trenches, in between rows of coconut palms, is a recommended practice for both moisture conservation and nutrient release. One hundred husks will be able to give 1 kg potash apart from 270 g N and 150 g P_2O_5 (Jothimani, 1994). The effect of husk burial will be observed from third year onwards and beneficial effects last for 5-6 years.

3.1.5 Coconut water waste for microbial culture

The processing of mature coconuts for production of copra and oil results in the accumulation of coconut water as a waste material. Studies in The Philippines revealed the feasibility of utilization of coconut water waste for production of the food yeast, *Saccharomyces fragilis*, by batch and chemostat cultures (Smith and Bull, 1976a) as a source of microbial protein. In *S. fragilis* grown in coconut water, macromolecular components were present in quantities similar to those in other food yeasts and the amino acid profile was satisfactory from nutritional point of view, with lysine content of 8.47 mg/16 g N (Smith and Bull, 1976b), indicating its suitability as a source of single cell protein. Coconut water sucrose gulaman was found to be an excellent alternative culture medium for the edible oyster mushroom fungus, *Pleurotus sajor caju* (Reyes *et al.*, 1992). Supplemented coconut water medium was found most favourable for the growth of the mycelium of semi-temperate shiitake mushroom, *Lentinus edodes*. The culture fully ramified in this medium within 8-10 days, whereas it took 22-30 days on the potato dextrose/yeast extract agar medium (Vilela *et al.*, 1990). Coconut water wasted from copra making industry formed the best and cheapest medium for the mass production of the entomopathogen, *Metarhizium anisopliae*, which is used as an effective biocontrol agent for different insect pests of coconut including *Oryctes rhinoceros* (Danger *et al.*, 1991). When the yeast, *Candida tropicalis*, was used for fermentation of coconut water and alcohol distillery, the conversion of sugar from coconut water into yeast biomass was in the range of 90-94 percent. The BOD (biochemical oxygen demand) of the slops was reduced by approximately 55 percent in batch cultures of the yeast (Rosario, 1982).

"Nata-de-coco", a well known dessert delicacy, is a white or creamy-yellow to pinkish, firm gelatin like substance formed by bacterial action in coconut water. *Acetobacter xylinum* is the bacterium commonly used in the production of nata-de-coco. Another nata producing bacterial strain, *Acetobacter hansenii* has been identified (Gossele and Swings, 1985). Den and Marquez (1987) developed a small-scale technique of producing sparkling clear vinegar from coconut water, which remained stable even after one year of storage and was accepted in various food preparations.

3.2 Oil Palm (*Elaeis guineensis* Jack.)

Oil palm is the highest oil yielding perennial crop, which provides two types of oil, palm oil and kernel oil, used as edible vegetable oil and for industrial purpose. Oil palm has a very high level of nutrient demand due to the large vegetative growth and heavy removal of harvested bunches for extraction of oil. The higher dose of chemical fertilizer recommendation at 1200 g N, 600 g P_2O_5 and 1200 g K_2O per palm per year pose threat to soil health and environment, and constitutes 41 percent of the annual cost of cultivation of oil palm. The oil palm produces waste biomass in the form of pinnae, petiole and rachis, waste inflorescence, empty fruit bunches, mesocarp waste and shell (Table 5) (Varghese *et al.,* 2000).

Table 5. Quantity of waste biomass production in oil palm and nutrient contribution by components of waste materials.

Waste material	Production ($kg\ ha^{-1}\ yr^{-1}$)	Nutrient contribution ($kg\ ha^{-1}\ yr^{-1}$) N	P	K	Ca	Mg
Pinnae	2,975	75.3	4.5	24.9	18.7	9.2
Petiole and rachis	648	17.5	1.9	72.6	60.3	16.2
Male inflorescence	248	6.3	1.3	3.9	1.4	2.6
Empty fruit bunches	1,184	11.4	1.5	30.5	2.4	3.7
Mesocarp wastes	1,750	6.8	0.7	5.3	0.5	1.4
Shell	736	2.9	0.3	3.0	0.4	1.0
Total	**13,375**	**120.2**	**10.2**	**140.2**	**83.7**	**34.1**

Source : Varghese *et al.,* 2000.

Khalid and Tarmizi (2001) reported that the availability of pruned fronds (dry matter) biomass is to the tune of 14.75 tonnes annually from a hectare of plantation. The pruned frond is a rich source of organic matter and nutrients, providing 136 kg N, 10.3 kg P, 183 kg K and 16.5 kg Mg per hectare per year.

There is scope for substituting a significant portion of chemical fertilizers through recycling of biodegradable biomass. Direct utilization of these wastes is not advisable due to the wide C:N ratio of materials, such as petiole and rachis (90:1), empty fruit bunches (50:1) and pinnae (25:1) waste available from the plantation. Experiments conducted at National Research Centre for Oil Palm, Palode revealed that the organic wastes can be converted into good quality organic manure within a period of five months. Though methods such as aerobic composting with frequent mixing, anaerobic composting without disturbance, composting with microbial inoculant, *Pleurotus* sp. and composting using chemicals, vermicomposting using the epigeic earthworm, *Eudrilus eugineae* produced manure of more desirable handling quality, lower C:N ratio and higher concentration of nutrients (Varghese *et al.*, 2000). With 90 percent conversion rate, nutrient contribution through organic recycling of wastes accounted for 175 kg N, 73 kg P_2O_5, 129 kg K_2O, 70 kg CaO and 71 kg MgO per ha annually. Hence, recycling of huge quantity of organic wastes could play a vital role in integrated plant nutrient management in oil palm plantations to meet the heavy and continuous demand for different nutrients by oil palm.

A unique method of crop residue management is described, in which oil palm seedlings are planted onto the residue piles from the old plantations in the replanting programme (Khalid and Tarmizi, 2001). The old palm stands contribute 85 tonnes of dry matter of above ground biomass, and an additional 16 tonnes per hectare of below ground biomass, which contributed significantly to pool of nutrients for recycling in plantations. The palms planted in residue piles gave significantly higher yield than those planted in an area from where oil palm residues were removed.

Processing of 100 tonnes of fresh fruit bunches (FFB) of oil palm results in production of 22 tonnes of empty fruit bunches (EFB), which requires proper disposal. Manual in-field FFB mulching has proved to be practical, cost effective and substituted for mineral fertilizers in oil palm cultivation (Chee and Chiu, 1999). Effective treatment system developed for palm oil mill effluent (POME) enabled to reduce pollution in oil palm industry, and reduced reliance on inorganic fertilizers and creation of zero waste (Yusof-Basiron and Ariffin Darus, 1996). The biological treatment of palm oil mill effluent is a complex multistep process carried out by group of organisms, which yield acids and methane. The biological treatment process is divided into three phases; anaerobic digestion in the acidification phase, anaerobic digestion in the methanogenic phase and the aerobic digestion phase (Tobing *et al.*, 1983).

The processing of fresh fruit bunches (FFB) in oil palm factories results in accumulation of two types of sterile byproducts viz., bunch refuse and mesocarp waste. Processing of 1000 kg of FFB yielded 350 kg bunch refuse and 150 kg mesocarp waste. Successful cultivation of oyster mushroom has been reported in mesocarp waste, yielding 800-1200 g of fresh mushroom from a bed of 2 kg substrate. The *Pleurotus* species, which gave higher bioconversion efficiency of mesocarp waste, are *P. florida*, *P. sajor caju*, *P. citrinopileatus* and *P. flabellatus*. Bunch refuse, another lignocellulosic waste was suitable for cultivation of paddy straw mushroom, *Volvariella volvacea* and *Volvariella diplacea*. A yield of 2 kg fresh mushroom was obtained from a bed of 75x45x30 cm size. For utilization of bulk quantity of bunch refuse, cultivation under shade in palm basin is recommended.

3.3 Arecanut (*Areca catchu* L.)

The arecanut palm is primarily grown for the masticatory nut which is consumed either raw or as a value added product. The palm is cultivated in high rainfall regions in the plains, in laterite or clay loam soils. The arecanut palm yields annually, 7,015 kg dried leaves (with leaf sheath), 375 kg dried arecanut bunch waste and 1,404 kg dried arecanut husk from one hectare of plantation. Arecanut wastes can be converted to vermicompost by using the earthworm, *Eudrilus eugeniae* (African night crawler) with a recovery of 87.75 percent in a composting period of 3 months (Chowdappa *et al.*, 1999). There was more than two-fold increase in biomass production of earthworms (2.1 kg) over initial earthworm inoculum (1 kg) applied. The vermicompost had higher nutrient content and lower C:N ratio than the base material, making it an ideal organic manure for agricultural applications (Table 6).

Table 6. Nutrient composition of vermicompost and the base materials (areca leaves).

Nutrient content	Dried areca leaves	Vermicompost
Organic carbon (%)	44.20	33.10
N (%)	0.71	1.38
P(%)	0.08	0.35
K (%)	0.94	0.98
C:N ratio	62.25	23.18
Cu (ppm)	100.59	120.18
Fe (ppm)	1745.61	2,561.00
Zn (ppm)	307.08	395.68
Mn (ppm)	81.73	241.62
Moisture (%)		31.82
pH		7.30

Source: Chowdappa *et al.*, 1999.

The technology for production of oyster mushroom from whole leaf, arecanut bunch waste and arecanut husk has been standardized using three species of *Pleurotus* viz., *P. sajor caju*, *P. flabellatus* and *P. membraneous*. Arecanut bunch waste was found to be better substrate and biological efficiency of conversion for the three species was 61, 84 and 58 percent, respectively (Chandra Mohanan and Madhusudhanan, 2002). Proper utilization of arecanut waste as substrate for oyster mushroom cultivation will help to recycle the waste in a profitable way, and enable to generate additional income per unit area of arecanut plantation.

3.4 Cocoa (*Theobroma cacao* L.)

Cocoa, the crop which provides beans with confectionary value, is ideally cultivated as a mixed crop in coconut and arecanut gardens. A study on the availability of plant residue and nutrient recycling in cocoa plantations under different agro-ecosystems in Brazil revealed highest quantity of plant residue in plantations without shade, where it reached 8500 kg/ha. The remaining agro-ecosystems which were under shading with various tree species produced residues that varied between 6,000 and 8,200 kg/ha (Santana *et al.,* 1988). Compost was made from rotten cocoa pods and salvaged pod husk and its application at the base of cocoa trees had beneficial effect on soil organic matter, biological activity and the growth of cocoa trees.

A technology for production of good quality vermicompost from cocoa leaves has been developed using *Eudrilus eugeniae* (Chowdappa *et al.*, 1999). The recovery of vermicompost was 74.65 percent and the earthworm population doubled during the composting process. The vermicompost produced from cocoa leaves had C:N ratio of 14.78 and a nitrogen content of 1.65 percent (Table 7). The vermicompost also had higher concentration of other major nutrients and micronutrients.

Table 7. Nutrient composition of vermicompost and the base materials (cocoa leaves).

Nutrient content	Dried cocoa leaves	Vermicompost
Organic carbon (%)	47.10	24.40
N (%)	1.27	1.65
P(%)	0.17	0.19
K (%)	0.27	0.32
C:N ratio	37.00	14.78
Cu (ppm)	32.66	83.60
Fe (ppm)	1,157.41	2,593.00
Zn (ppm)	228.39	367.70
Mn (ppm)	363.10	679.84
Moisture (%)	–	29.94
pH	–	7.50

Source: Chowdappa *et al.*, 1999.

3.5 Coffee (*Coffea arabica* L.)

Coffee, an important beverage crop, is the second largest traded commodity in most of the developing countries. The by-products of coffee processing are mainly coffee pulp, processing effluent, parchment husks and coffee husks. Wet processing of coffee in the estates results in production of large quantities of pulp or epicarp as a by-product (Table 8), disposal of which is a serious problem faced by coffee growers.

Various methods of utilization of pulp have been suggested such as single cell protein production and extraction of pectin (Francis and Bell, 1975; Rolz *et al.*, 1980), production of biogas (Sanchez and Matin, 1993) and as animal feed. The alternative uses of coffee by-products include the production of soil conditioner, manure, mulch, alcohol, caffeine, sugar, charcoal, wax and acids (Mburu and Mwaura, 1996). The turnout for every 100 kg of ripened *arabica* fruits was 23.90 kg of clean coffee (dry parchment) and 16.0 kg of dry fruit skin pulp. The pulp contained 4.21 percent K, 2.38 percent N, 1.07 percent Ca, 0.55 percent P and 0.42 percent Mg (Korikantimath and Hosmani, 2000). The coffee pulp compost can provide significant quantity of nutrients to partly substitute the inorganic fertilizers in coffee cultivation.

Table 8. Annual coffee production, quantum of pulp and effluent generated during wet processing in India.

	Arabica	*Robusta*	Total
Production (MT)	1,03,250	1,19,750	2,23,000
Wet processed coffee (MT)	82,600	17,963	1,00,563
Fruits processed (MT)	45,430	89,815	5,49,115
Pulp generated (MT)	1,81,720	29,640	21,136
Effluent generated (m^3)	6,60,000	5,40,000	12,00,000

Source: Nagaraja *et al.* 2000.

Coffee effluent is another by-product of processing coffee, which cannot be directly utilized due to its acidic pH (4.0-5.5), presence of suspended solids (2.0 to 2.3 g/l), chemical oxygen demand (COD 7.2 to 14.8 g/l) and biological oxygen demand (BOD 2.3 to 5.0 g/l).

Experiments conducted at Central Coffee Research Institute, Balehonnur, Karnataka indicated that coffee pulp can be converted into valuable manure with a desirable C:N ratio of 10:1 by a systematic composting by addition of nutrients in the form of urea and rock phosphate (Nagaraja *et al.*, 2000). Addition of coffee effluent to the pulp encouraged the growth of micro-organisms, and fastened the degradation process. Coffee effluent mostly contained the mucilage, composed of proteins, sugars and pectins which formed a good substrate for growth of micro-organisms. This has got practical significance as part of the effluents could be used in composting.

Organic coffee production is gaining importance due to the changing preference of the international coffee consumer and premium price for organic coffee in the world market. In organic farming practices, emphasis is put on nutrient recycling, such as laid use of dry pulp and cherry husks both in compost and for mulching (Raghuramulu and Naidu, 1995).

3.6 Tea (*Camellia sinensis* L.)

Tea is a widely consumed non-alcoholic beverage, grown in plantations in hilly regions. The crop residue biomass in tea gardens includes shade tree litters, loppings, tea litters, tea prunings and weeds. The annual average addition of organic matter by these sources is as much as 23 t/ha at mid elevation and reduces to 14 t/ha at high elevations. High phenol content of tea plant residue enabled formation of true humic matter and incorporation of greater portion of nitrogen in the humic matter (Sivapalan, 1984).

Tea waste was the best medium for the mass multiplication of the antagonistic fungi, such as *Trichoderma harzianum* and *Trichoderma virens,* which are used for biological control of soil borne plant pathogens (Prakash *et al.,* 1999). Cultures mass multiplied in tea waste and coffee husk could be stored for three months without much reduction in population of the organism. Economic cultivation of *Pleurotus sajor caju* in mixture of used tea leaves and waste paper has been reported (Mehrotra *et al.,* 1982). Fruiting continued for 4-5 months and the total yield of 75-90 percent of the weight of the substrate was obtained when the cultivation was done in trays.

3.7 Cashew (*Anacardium occidentale* L.)

Cashew, which leads the edible nuts in international trade, was primarily introduced in India by Portuguese as a soil-binding crop. The edible cashew nut, cashew apple *fenni* and cashew nut shell liquid are important products of nutritive and commercial value. The crop is cultivated on poor soils, on steep slopes on the west coast, and in sandy soils in east coast, without intensive management. As a crop of marginal land with marginal productivity, recycling of cashew litter holds the key to productivity and improvement in soil fertility. Usha and Nair (2002) quantified annual litter fall as 5014 kg/ha in a ten-year cashew graft plantation. The cashew litter had 0.65 percent N, 0.02 percent P, 0.72 percent K, 0.22 percent Ca, 0.19 percent Mg, 369 ppm Fe, 14.6 ppm Cu, 16.5 ppm Zn and 283 ppm Mn. The availability of cashew leaf litter from 10-40 years old plantations ranged from 1.38 to 5.20 t/ha (Kumar and Hegde, 1999). They reported that nutrient value of the cashew leaf litter could be improved by composting. Application of nutrient enrichment technique and use of microbial cultures and maintenance of optimum moisture and aeration enables to produce cashew leaf litter compost of better nutritional values. Cashew wastes consisting of leaf litter, dried leaves and cashew apples were composted by Japanese method in compost chambers with 10 percent cow dung slurry in different layers. Within a period of 5 to 6 months, compost with a nutrient content of 1.59 percent N, 0.53 percent P and 0.33 percent K was obtained (NRCC, 2000).

3.8 Rubber (*Hevea brasiliensis* Muell. Arg.)

Leaf litter fall and disappearance were investigated in three monoclonal plantations of rubber in Nigeria (Onyibe and Gill, 1992). The mean annual litter produced by the clones RRIM 600, PR 107 and GTI was 13,676, 12,961 and 10,228 kg ha $^{-1}$ yr $^{-1}$, respectively. The turn over time, Ko of the litter in the three clones was 0.7, 0.6 and 0.5 years, respectively. The rate of decomposition of rubber litter was much faster during the rainy season when the microbial activity was higher (Deka *et al.,* 1998) as indicated in a study involving burial of nylon litter bag containing the leaf litter in adult rubber plantations. The loss of hemicelluloses was the most rapid, followed by cellulose and lignin.

Krishnakumar and Potti (1992) calculated that 6 tonnes/ha of leaf litter falls in a mature rubber plantation. Growing of leguminous cover crops is an accepted practice especially in young rubber plantation, which provides 3-5 tonnes of crop residue/ha in a period of four years.

Rubber wood sawdust formed a suitable substrate for summer mushroom (*Calocybe indica*) cultivation and yielded 538 g fresh weight of mushrooms per kg of saw dust (Joseph *et al.*, 1998).

3.9 Byproducts of Mixed Farming/Cropping Systems

The growth habit and planting methods of coconut makes it possible to accommodate a number of annuals and perennials as inter/mixed crops in the system and for effective utilization of natural .resources in the garden (Figs. 5 and 6), as well as to achieve

Fig. 5. Coconut based high density multi-species cropping system, having black pepper, clove, banana and pineapple as component crops produce large quantities of biomass for recycling

Fig. 6. Mixed farming in coconut garden generates large quantities of biomass for recycling

economic viability in coconut farming. Huge quantities of organic materials also become available from intercrops grown in coconut garden. Cocoa, a successful mixed crop in coconut gardens, contributed 818 and 1785 kg/ha/yr dry cocoa litter under single and double hedge system of planting, respectively. In the mixed cropping system of coconut and cocoa, 50 kg N, 11 kg P_2O_5 and 35 kg K_2O/ha can be recycled through leaf litter of cocoa.

High density multispecies cropping systems (HDMSCS) involving growing of a large number of crops, at very high plant population per unit area, has been recommended to meet the diverse needs of the farmers, and to enhance income from unit area of plantation. The HDMSCS model at CPCRI, Kasaragod involving coconut, clove, banana and pineapple (Fig. 5) produced 17.00 to 22.58 t/ha/yr biomass under different fertilizer treatments (CPCRI, 2002). By recycling of these wastes in the system, it is possible to reduce the fertilizer inputs to achieve economic as well as soil fertility benefits.

Mixed farming is high income generating and self sustaining system in which animal enterprises are integrated with coconut cultivation. In the mixed farming system in 1.2 ha at CPCRI, Kasaragod involving coconut, fodder grass, dairy unit, poultry and rabbitry (Fig. 6), 15 tonnes of farm yard manure, 2 tonnes of poultry manure as well as 50,000 litres of cow urine and cowshed washings were obtained annually (Maheswarappa *et al.*, 1998). Recycling these biomass in the system contribute 125 kg N, 78 kg P_2O_5 and 115 kg K_2O. There was resultant buildup of organic carbon, N,P,K and Fe status in soil (Table 9).

Table 9. Nutrient recycling from the by-products in a mixed farming system of coconut.

By-product	Quarterly	Per year		
		N (kg)	P (kg)	K (kg)
Farm yard manure	15 MT	75	40	75
Poultry manure	2 MT	20	38	12
Cow's urine and cowshed washings	50,000 litres	30	-	28
Total		**125**	**78**	**115**

In the cropping and farming systems, each component of the system has been found to exert a synergistic effect leading to overall efficiency of the agro-ecosystem. The internal cycling of nutrients, the conducive microclimate in the system, augmented level of beneficial microflora and synergistic interaction of crops enhance the nutrient use efficiency of crops which in turn has enabled to achieve higher productivity with low level of external inputs.

3.10 Nitrogen Fixing Green Manure Crops

An agrotechnique has been standardised to generate significant quantities of organic manure and nitrogen in coconut basins utilizing the leguminous cover/green manure crops (Thomas and Shantaram, 1984). Cultivation of leguminous creepers having symbiotic association with efficient *Rhizobium* strains, and incorporation of biomass generated at the maximum vegetative growth of the legumes resulted in a contribution of 15-25 kg green matter per basin of 1.8 m radius around the trunk of the palm during a growth period of 140-150 days in monsoon season. Among the ten species of legumes screened, *Pueraria phaseoloides, Mimosa invisa* and *Calopogonium mucunoides* were superior in biomass generation and nitrogen contribution in coconut basins. The perennial fast growing leguminous green manure crop, *Glyricidia sepium*, can be grown either by alley cropping or along the boarders of coconut plantations to generate large amounts of nitrogen rich green matter. In the coconut – *Glyricidia* alley cropping system in a littoral sandy soil, cultivation of three rows of *Glyricidia* in between two rows of coconut palms with three prunings per year (February, June and October) resulted in higher biomass productions of 7970 kg/ha (Subramaniam *et al.*, 2000). Application of the *Glyricidia* prunings from interspace of one hectare of coconut garden could meet a major portion of nitrogen (90%), part of phosphorus (25%) and potassium (15%) requirement of coconut palms.

4. APPLICATION OF COCONUT RESIDUES IN HORTICULTURE

A number of trials in different countries have revealed that decomposed coir pith can be used as a cheap but effective substitute for peat because of its peat like characters. Suitability of coco peat (decomposed coir pith) as a growth medium for container grown plants has been well established (Prabhu and Thomas, 2001). There are reports that coco peat can suppress fungal diseases (Kumar and Marimuthu, 1997) and because of this property, it could very well become a part of integrated disease management system of horticultural crops. Coco peat has a number of other applications in horticulture including its use as a medium for rooting of cuttings, air layering and hardening of air layers, storage of scions, and storage of horticultural produce. It also finds application as a mulch and soil amendment to enhance nutrient supply to plants. The utility of coir pith as a carrier material for production of biofertilizers, bedding material in poultry farms and substrate for edible mushroom cultivation has also been reported.

In a green house trial in Malaysia, the coco peat, either alone or as a mixture with charcoal dust, was found suitable for cultivation of tomato. The total weight of fruits produced in coco peat (100%) and coconut + charcoal dust was nearly twice that produced by plants grown in peat and peat + perlite (Teo and Tan-Ewe-Hoe, 1993). A media composed of 25 percent volume fine coconut husk and 75 percent volume sand provided the best conditions for the growth of cocoa seedlings (Evwiyono and Geonadi, 1990). A linear decrease in the bulk density associated with increasing coconut husk/sand ratios in the medium was followed by a linear increase in the total porosity, water holding pores and air filled pores.

5. IMPACT OF RESIDUE MANAGEMENT ON ENVIRONMENT

The positive influence of coir pith application in promoting soil health and the growth and yield of cowpea has been reported (Logamadevi, 1997). Organic carbon of the postharvest soil proved the positive role of coir pith either as raw or composted pith. The beneficial attributes in physical properties of soil, due to the incorporation of raw and composted coir pith included reduction in bulk density, increase in maximum water holding capacity and percentage increase of pore space in amended soils. Amendment with organic materials, such as coir dust, coconut sheddings, forest leaves and cattle manure was found effective for the management of coastal sandy soils for establishment and production of coconuts. The treatment for a period of ten years improved growth and vigour of palms and reduced mortality of the seedlings. The organic sources also had profound influence on soil physical properties and water retention of the coastal sand (Joshi *et al.*, 1982; Nambiar *et al.*, 1983). The available water capacity of 0.78 percent increased to 1.94, 0.87, 1.39 and 1.13 percent, respectively with the application of organic residue, such as coir dust, coconut sheddings, forest leaves and cattle manure, respectively.

Composted coir pith also had significant beneficial impact on soil properties, growth and yield of tomato. The soil moisture retention, bulk density and soil strength were strongly influenced by incorporation of composted coir pith (Ahamed, 1993). In cashew plantations, a 7.5 cm thick layer of coir pith weighing 105 kg, when applied around the tree trunk in a radius of 1.5m, resulted in 14.15 percent more moisture retention and suppression of weeds to an extent of 73.52 percent (Kumar *et al.*, 1989). Heavy leaching losses of nutrients to the extent of 70 percent of applied nitrogen take place in coconut growing red sandy loam soils. The combined application of urea and coir dust was effective to reduce the leaching loss of nitrogen by effecting controlled and gradual release of urea nitrogen. Production of total mineralised nitrogen was consistently lowest, when urea was blended with retted coir dust (Joshi *et al.*, 1985).

Use of coconut husk or coir dust in pits, taken between two rows of coconut palms, was beneficial to increase coconut production, recording a yield improvement of 15-20 percent. In terms of copra yield per palm, coir dust appeared to be more effective than husk in laterite soils (Liyanage *et al.*, 1991). Placement of the residue in pits was more effective and economical than in circular trenches round each palm.

In the mixed farming experiment, consisting of cultivation of fodder grasses in the interspaces of coconut, maintaining dairy cows and poultry and recycling of farm yard manure and poultry manure, resulted in improvement in soil fertility status. Soil test values revealed increase in maximum water holding capacity and porosity and decrease in bulk density as well as buildup of N,P,K and Fe status (Maheswarappa *et al.*, 1998). Intercropping of spices and grasses is practised in coconut and arecanut gardens in Andaman and Nicobar Islands, with recycling of organic matter generated in the system, including leaves and branches of the intercrops. The system approach helped not only to increase the profit, but also arrested the colossal loss of soil and water and enhanced soil fertility.

A study conducted by United Planters Association of South India (UPASI) at Nilgiris in Tamil Nadu has revealed the beneficial effect of management of prunings on tea yield and organic matter status of soil in tea plantations (Table 10) (Pandiaraj, 1991).

Table 10. Effect of management of tea prunings on productivity and soil organic matter status.

Treatment	Average made tea yield (kg/ha)		Organic matter (%)			
	I cycle	II cycle	I cycle		II cycle	
			Surface soil	Sub-soil	Surface soil	Sub-soil
Pruning removed (control)	3,105	2,980	4.1	2.7	3.6	2.3
Burial of prunings	3,287 (+5.9%)	3,248 (+9.0)	5.4	3.6	5.9	4.0
Chopping and spreading of prunings on the surface	3,234 (+4.1%)	3,068 (+3.0%)	5.0	2.9	4.9	3.0

Source : Pandiaraj, 1991.

The tea yield increased by 9 and 3 percent in the second cycle, when the prunings were buried and spread over the surface of the soil, respectively. There was improvement in the organic matter status of surface and sub-soils in the above treatments, when compared to the control, where the prunings had been removed.

Land degradation has been associated with declining crop productivity. Rubber is widely accepted to be an environment friendly crop. Mathematical modelling studies revealed land degradation by way of soil loss and reduced soil fertility, as indicated by organic carbon content for the observed variation in output of rubber (Samarappuli *et al.*, 1999). Reduction in rubber yield to the extent of 175 kg/ha/year has been attributed to the loss of one cm of top soil whereas the output increases by kg for every 0.1 percent increase in soil organic carbon content.

6. SUMMARY

Modern agriculture relies heavily on high analysis chemicals to achieve higher productivity. Plantation crops are no exception, barring small holders plantation crops like coconut and cashew, which are grown by majority of farmers without significant nutrient inputs. The perils of continuous chemical inputs on the environment and life supporting system, which maintain the productivity of soil, are now well recognized. In this context of integrated nutrient management with judicious use of organics, in organics and biofertilizers, that are not only complementary, but also synergistic and environmental friendly, has emerged as an alternative nutrient management strategy to achieve higher productivity. The concept of organic farming assumes greater significance in plantation sector due to the increasing demand for organically grown products. Organic farming strategies lay emphasis on natural resource management and generation of organic manure within the farm itself to meet the nutrient demand of crops exclusively with organic source.

Sustainability in plantation agriculture, requires utilization of huge quantities of crop residues, which are renewable resources, and storehouse of plant nutrients. With the objective of sustaining the yields, a number of concepts, principles and agro-techniques have been developed, and all of them have a common theme of recycling of nutrients in the system. The low cost on farm technology of recycling of wastes at the vicinity of waste generating site, is both environment friendly and farmer friendly approach for crop residue management. The wide acceptance of the technology for degradation of coconut waste using epigeic earthworm, by farming community and increasing demand for earthworm, bear testimony to the movement already taking place in this direction. Research on production of good quality organic manure and compost from a wide range of crop residues available in plantation sector, using biopolymer degrading organisms in shortest period, should be given priority in research programmes. Recycling of waste biomass will make it a self-supporting nutrient utilization system, with both economic and ecological benefits, which will ensure proper disposal of wastes, healthy environment, and a sustainable plantation system.

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