SAMPLING AND IDENTIFICATION OF TERMITES IN NORTHEASTERN PUDUCHERRY AND EXPLORATION OF THEIR USE IN TREATING LIGNINOUS SOLID WASTE

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by

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CERTIFICATE

This is to certify that **Ms. Gurjeet Kaur** has herself carried out the work embodied in her thesis entitled '***Sampling and identification of termites in Northeastern Puducherry and exploration of their use in treating ligninous solid waste***' being submitted to Pondicherry University for the award of the degree of **Doctor of Philosophy** in **Environmental Technology.** She has complied with all the relevant academic and administrative regulations, and the thesis embodies a bonafide record of the work done by her under our guidance. The work is original and has not been submitted for the award of any certificate, diploma, or degree, of this or any other university.

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DECLARATION

I hereby declare that the thesis entitled **"*Sampling and identification of termites in Northeastern Puducherry and exploration of their use in treating ligninous solid waste*"** submitted to Pondicherry University for the award of the degree of **Doctor of Philosophy** is a record of original work done by me under the guidance of **Dr.S.Gajalakshmi**, Assitant Professor, Centre for Pollution Control and Environmental Engineering, Pondicherry University, and that it has not formed the basis for the award of any other degree, diploma, certificate or any other title by any university or institution before.

Date:

Place: Puducherry **(Gurjeet Kaur)**

Dedicated to

My Late Grand Mother (Biji) and Father

A few thanks…

First of all I touch the feet of ***God***, the Superpower whom I believe is always with me to help and guide me to take the right decision at the right time and to proceed with confidence in my life. I bestow my sincere prayer for this success.

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Tera tujko sopaya, kya lagat hai mera”

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List of abbreviations

MSW	Municipal solid waste
e.g.	For example
PW	Paper waste
Kg	Kilogram
2-PE	Phenoxyethanol

Abstract

Two of the most simple-to-execute, inexpensive, and remunerative processes for biodegradable solid waste management, and which also have the unique attribute of being viable at all scales of operation ranging from a single household to a large-scale industry, are composting and vermicomposting. But neither of the options is capable of degrading lignin or 'hard' biowaste such as coconut shells, stems and branches of weeds like ipomoea, and thermocol. This gives rise to an urgent need to find other processes having virtues of inexpensiveness, simplicity of execution, and viability at varying scales, that distinguish composting/vermicomposting but which can do what the two named processes cannot.

'Termigradation' as coined by Abbasi (2007) denote termite-based biodegradation processes. Abbasi, along with Gajalakshmi further conceived two kinds of termite-based reactors ─ *in-situ* and *ex-situ* ─ of which patent claim has been registered (Abbasi and Gajalakshmi, 2012). The former involves bringing termireactors to the nature and the latter involve bringing termites to the confines of a laboratory or a processing unit. *In-situ* termigradation of solid waste appears to have the obvious advantages of a) very low capital and operational cost, and b) simplicity, due to which it can be easily used by lay-persons with minimal training. Those of the species which are already established underground can be used to degrade specific waste *in-situ* without spending any effort to culture or maintain the animals. This aspect immediately gives this option a niche totally different from other biotechnologies in which maintaining the culture of the main animal protagonist is absolutely essential. But major hurdles were also foreseen in the use of termites in disposing solid waste. The biggest stemmed from the fact that termites are highly eu-social and the social class that is utilizable to feed upon the waste (i,e the worker termites) do not breed (except in case of very few of the species and in special circumstances). Therefore, use of termites for 'termigradation' or 'termicomposting' is not something that can be accomplished as easily as vermicomposting. Secondly it is crucially important to ensure that the species chosen and the manner of their utilization does not lead to any harmful spin-off (such as causing infestation in a hitherto termite-free area).

The present work is one of the attempts to put the above mentioned ideas into practice. In it we have tried to meet both the challenges that were foreseen. The thesis has six parts. Part I is the introduction to the study. Part II is on the identification of termite species. To identify the species with which we must work, an in-depth survey of termite species in two areas in north eastern Pondicherry was carried out. It was aimed not only to identify the species that are present but also to quantify their richness and relative abundance, as it would be indicative of which species are relatively better settled in this region. Biotic indices were developed with which the community structures of different areas could be quantitatively compared.

Parts III to V are on termigradation of highly ligninuous wastes. Termigradation studies were carried out on the processing of three highly pernicious terrestrial and aquatic invasive plants: lantana

Abbasi, S.A., 2007. Emerging frontier in bioprocess engineering: termigradation. Proceedings of the International Conference on cleaner technologies and environmental management, Pondicherry Engineering College, Puducherry, Jan 4 – 6.

Abbasi, S.A. and Gajalakshmi, S., 2012. A novel process for eco friendly treatment of ligninous biowaste, claim filled with CDAC,GOI, Reference number E-2/12682/2013/DEL.

(*Lantana camara*), ipomoea (*Ipomoea carnea*) and water hyacinth (*Eichhornia crassipes*). In case of ipomoea and lantana, the'termigradation' of twigs was explored as they are highly ligneous and cannot be degraded by composting or vermicomposting. If the weeds can be 'termigraded' it would basically mean converting the weeds into termite zoomass and termicast; in turn contributing in two major ways to enhanced rejuvenation and agricultural productivity of soils. In addition to these weeds, termigradation of hard substrates such as coconut shells and near-pure cellulosic substrates like paper cups was studied. Processing of industrial wastes such as pressmud and coir pith was also explored.

Attempts were then made to enhance the efficiency of the termireactors by using baits and trails to attract larger number of termites towards the substrate in shorter time. It is well-known that in most termite species there are scout workers who search around for food. They mark their movements by dotted trails of pheromones. On finding a food source the scouts make a continuous trail which serves as biological signal for recruitment as well as orientation of workers to exploit the food source. Also some chemicals which are simpler than pheromones (hence easier to obtain and use), besides some of the fungi which Macrotermitinae cohabit, can also induce trail-forming behaviour in termites. But we have chosen, in the first instance, to use trails of materials like paper waste rather than chemical trails because scouts can reach such trails from various points (as these trails are small-sized food source in themselves). On reaching the trails and exploring them right up to the termireactor the scouts are likely to lay very strong pheromone trails over and above the artificial trails laid by us. Hence, based on extensive trials, inexpensive and non-toxic materials paper waste and sawdust were used as trails to not only enhance the reactor efficiency but also to exercise process control.

Part VI is on the exploratory studies of 2-phenoxyethanol (2-PE) as a possible trail-forming substance. Various authors have studied the trail forming behaviour of termites using 2-PE. But none of the authors have studied the effect of 2-PE with any of the species reported from Northeastern Puducherry. Hence a preliminary study was conducted to study the trail eliciting behaviour of 2-PE on the termite species *Hypotermes obscuriceps*.

Chapter 1

Problems associated with the disposal of lignocellulosic waste

Abstract

Lignocellulose is the major component of biomass and consists of lignin, hemicellulose, and cellulose. It is the most abundant natural material in the world. Methods which include anaerobic digestion, landfilling, composting or vermicomposting that are presently used on a large-scale to treat biodegradable solid waste are not successful in degrading lignocellulosic waste. Termites are among the very few species of insects which possess the ability to process lignin. In this chapter, the initiative on the controlled use of termites to degrade ligninous waste is discussed.

1.1 Lignocellulose : an overview

Lignocellulose is the major component of biomass and consists of lignin, hemicellulose, and cellulose (Sanchez, 2009). It is the most abundant natural material in the world. It is also released in large quantities as waste streams from various industries such as food, agricultural, forestry, paper pulp, and timber and poses serious disposal problems. Whereas, while the hemicellulose and cellulose components of lignocellulosic materials are biodegraded by numerous microorganisms, lignin is highly resistant to microbial degradation (Birhanli and Yeşilada, 2013).

Cellulose, which is generally (30–50%) of phytomass or phytomass-based waste, is a linear polymer of b–D–glucopyranose sugar units whose average chain has a degree of polymerization of about 9000–10,000 units. Approximately 65% of the cellulose is highly oriented and crystalline with no accessibility to water and other solvents, while the rest is composed of less oriented chains which have association with hemicellulose (20–40%) and lignin (15–25%).

Lignins are highly branched without crystalline structure and are composed of carbon units derived from substituted cinnamyl alcohol of which the structure and chemical composition are a function of their source. There are also small amounts of water, ash, cyclic hydrocarbons, organic and inorganic materials presented in lignocellulosic sources as extractives which contains a large number of both lipophilic and hydrophilic constituents (Cagnon *et al.,* 2009; O'Connell *et al.,* 2008). The accumulation of lignocellulosic wastes around the world and the efficient capture of their bioconversion potential have become issues that are yet to get resolved (Kumar and Singh, 2008).

1.2 Approaches to treat lignocellulosic waste, and their limitations

None of the methods presently used on a large-scale to process biodegradable solid waste ─ anaerobic digestion, landfilling, composting or vermicomposting ─ are capable of degrading lignocellulosic waste (Miller and Clesceri, 2003;Huang *et al.*, 2008; Zheng *et al.,* 2009; Wi *et al*., 2013). A brief recapulation of the methods and their limitations is given below.

1.2.1 Anaerobic digestion

During anerobic digestion of lignocellulose, the initial hydrolysis of polysaccharides has been identified asthe rate-limiting step (Zhao *et al.,* 2009). To accelerate the hydrolysis of polysaccharides, alkaline pre-treatment is usually done (Mosier *et al.*, 2005). Hence, most studies have focused on anaerobic biogasificationthrough alkaline pre-treatment, followed by anaerobicdigestion of lignocelluloses. But the alkaline incubation could inhibitthe subsequent methanogens (Zheng *et al.*, 2009).

1.2.2 Bioethanol production

Lignocellulosic biomass can be used to produce ethanol, a liquid biofuel that can replace fossil transportation fuels (such as gasoline). Unfortunately, the recalcitrant structure of lignocellulosicbiomass makes the hydrolysis to monomeric sugars much more difficult, as compared with starch (Dumitriu, 1998). The process for ethanol production from lignocellulosic biomass is more complicated than producing it from sugar or starch. Several different pretreatment methods can be used to facilitate the enzymatic hydrolysis of lignocellulosic material (Öhgren *et al.,* 2007). Thus the cost of the biofuel production from lignocellulosic waste is much higher due to the intensive labour and extra processing steps than using sources of sugar (Wi *et al*., 2013).

1.2.3 Composting

The complex structure of lignocellulose, inhibits its transformation, and consequently slows down the lignocellulosic waste degradation process in nature. Therefore, it is generally accepted that lignin decomposition is the rate-limiting step during composting (Huang *et al.,* 2008; López *et al.,* 2006). The optimum temperature for lignin degradation in composting is 40-50°C (Tuomola *et al.,* 2000). White-rot fungi secrete low specificity and strong oxidative ligninolytic enzymes which could oxidatively degrade lignin and mineralize them into CO_2 and water (Cohen *et al.,* 2009; Huang *et al.,* 2010). But white-rot fungi do not survive the thermophilic phase of composting, and thus cannot toplay any significant role in lignin degradation. However, if direct addition of fungi is done to degrade lignocellulosic waste, it may affect the diversity of microbial communities in different phases of composting (Feng *et al.,* 2011).

1.2.4 Landfilling

Lignocellulosic wastes in a landfill may last for several human generations (Miller and Clesceri, 2003). Lignin compunds and leachate in the landfills inhibit methanogenic metabolism. Attempts have been made to increase the rate of decomposition of organic matter by recirculation of leachate. However, the degradation of lignin by leachate recirculation alone is quite difficult.

1.3 The present initiative : controlled use of termites

1.3.1 Special ability of termites in processing ligninous waste

Two of the most simple-to-execute, inexpensive, and remunerative processes for biodegradable solid waste management, and which also have the unique attribute of being viable at all scales of operation ranging from a single household to a large-scale industry, are composting and vermicomposting. But neither of the options is capable of degrading lignin or 'hard' biowaste such as coconut shells, stems and branches of weeds like ipomoea, and thermocol. This gives rise to an urgent need to find other processes having virtues of inexpensiveness, simplicity of execution, and viability at varying scales, that distinguish omposting/vermicomposting but which can do what the two named processes cannot.

Abbasi (2007) was the first to conceptualize that among the myriad of potential bioagents, the termite family had the attributes that could make them succeed where other bioagents fail. To begin with termites are among the very few species of insects which possess the ability to 'grind down' even the kind of hard biowaste which defies composting and/or vermicomposting. Of these species, those belonging to the termite family are by far more common, numerous and widespread. There are a few other special attributes of termites which make them potential candidates for bio-processing of solid waste:

a) The capability of most of the termite species to ingest and then digest lignin.

b) The high rate of termite reproduction as also the animal's voracious appetite.

c) The high-quality protein, crude fat and other resources (such as biofuel) that are generated by way of termite zoomass in the process.

d) The presence of nitrogen fixing bacteria in the termite gut due to which soil gets enriched with nitrogen when worked over by termites.

1.3.2 'Termigradation' and 'Termitechnology': present approaches to harness termites for treating ligninous waste

Abbasi (2007) also coined the word 'termigradation' ─ to denote termite-based biodegadation processes.

Considering that, other aspects being equal, the cost of any process almost directly correlates with its speed, termigradation promised to be essentially an inexpensive process as well. Abbasi, along with Gajalakshmi further conceived two kinds of termite-based reactors ─ *in-situ* and *ex-situ* ─ of which patent claim has been registered (Abbasi and Gajalakshmi, 2012). The former involves bringing termireactors to the nature and the latter involves bringing termites to the confines of a laboratory or a processing unit. *In-situ* termigradation of solid waste appears to have the obvious advantages of a) very low capital and operational cost, and b) simplicity, due to which it can be easily used by lay-persons with minimal training. Those of the species which are already established underground can be used to degrade specific waste *in-situ* without spending any effort to culture or maintain the animals. This aspect immediately gives this option a niche totally different from other biotechnologies in which maintaining the culture of the main animal protagonist is absolutely essential.

But major hurdles were also foreseen in the use of termites in disposing solid waste. The biggest stemmed from the fact that termites are highly eu-social and the social class that is utilizable to feed upon the waste (i.e. the worker termites) do not breed (except in case of very few of the species and in special circumstances). Therefore, use of termites for 'termigradation' or 'termicomposting' is not something that can be accomplished as easily as vermicomposting. Secondly it is crucially important to ensure that the species chosen and the manner of their utilization does not lead to any harmful spin-off (such as causing infestation in a hitherto termite-free area).

The present work is one of the attempts to put the above mentioned ideas into practice. In it we have tried to meet both the challenges that were foreseen.

1.4 Termites as processors of lignocellulosic waste

As stated earlier, termites are among the few animals capable of degrading lignocellulose. As in other instances where fiber-rich but nutrient-poor material is being digested, this capacity is based largely on microbial symbionts housed in specialized regions of the animal's intestinal tract (Brune, 2009). The efficiency of digestion of woody (lignocellulosic) materials by termites is high; as much as 90% of the polysaccharide components of organic detritus (cellulose and hemicellulose) may be degraded in a single transit of the gut (Breznak and Brune, 1994; Hopkins *et al.,* 1998). While the efficiency of cellulose and hemicellulose digestion in some termite guts is very high, the extent of lignin breakdown is uncertain and processing by termites may be confined to alterations in chemical structure, accompanied by some demethylation and decarboxylation, rather than ring cleavage (Breznak and Brune 1994). Although the broad basis of lignocellulose digestion by termites has been known for more than 60 years (cf. Hungate, 1946), numerous refinements continue to be added to the picture. Improvement in our understanding of the roles of individual microbial taxa has been especially rapid in the past decade as high-resolution tools have become available, especially the use of microsensors and metabolic profiling based on molecular sequences. Schemata of the dissimilation process are given in Tholen and Brune (2000) and in Warnecke *et al.*, (2007), based on lower termites (those with flagellated protist symbionts included in the gut microbiota) and higher termites (those without protists), respectively. Through symbiotic associations with gut microorganisms, termites possess the ability to digest lignocellulosic material to meet their energetic needs, and fix nitrogen to meet their dietary needs (Toninger, 1997).

1.4.1: Microbial degradation of lignocellulose in termite gut

Degradation of lignin can include demethylation and hydrogenation, as well as cleavage of some inter-monomer linkages, which may explain the apparent mineralisation of carbon, but does not necessarily imply disruption of the aromatic ring (Kuhnigk *et al.*, 1994). Microorganisms able to degrade lignin preparations or lignin analogues in vitro continue to be isolated from both lower and higher termites, and remain of interest in the context of bioprospecting (Harazano *et al.,* 2007; Ngugi *et al.,* 2007), however the reactions involved are peripheral, for example oxidations of aromatic aldehydes and alcohols to the corresponding acids.

A fundamental function of the termite–symbiont system in the digestion of lignocellulose is the hydrolysis of cellulose and hemicelluloses (Figure 1). The symbiotic digestion of lignocellulose is a highly efficient process, resulting in assimilation rates of woodglucan by termites that are far higher than those of grasses by ruminants (Breznak and Brune 1994).

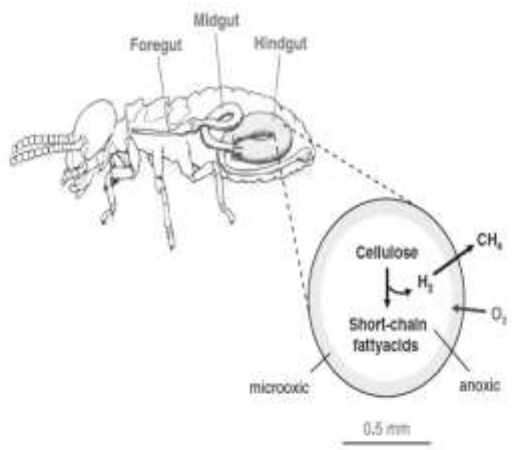

Figure 1: Lignocellulose is fermented to acetate and methane in the hindgut of wood-feeding termites. The fermentation products are the major carbon and energy sources for the host. However, a termite gut is not a purely anoxic fermenter but houses a very diverse community of aerobic and facultative bacteria as well (Warnecke *et al.,* 2007)

The symbiotic gut microbiota enables termites to thrive on a lignocellulosic diet. The roles of the microorganisms in C and N metabolism and the relative importanceof individual processes depend on the lifetype of the host and its particulardiet. Cellulose and hemicelluloses are depolymerized by both lower and higher termites, but the strategies employed by the two groups of termites differ. While lignocelluloses digestion in the hindgut of lower termites depends largely on symbiotic protists, bacteria are emerging as important players in higher termites.

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Chapter 2

Methods of faunal survey

Abstract

A brief account of the methods used for faunal survey is given. The challenges associated with sampling of termites are highlighted. There is also a brief discussion on the indices available to quantify species richness and diversity given.

2.1 General methods of survey

Depending on the body size, territorial span, and habits of species to be surveyed, and depending on the size of the area to be surveyed, different methods for faunal survey have been developed. Their distinguishing features are summarized in Table 1.

2.1.1 Challenges associated with the sampling of termites

Difficulties of sampling termites

Termites are eusocial insects with reproductive and non-reproductive castes (Bignell, 2011). Of these the latter, comprising of workers and soldiers, are usually seen foraging throughout the year, and can be sampled easily. But due to the cryptic and patchy spatial distribution of termite colonies and individuals within habitats, much greater sampling density has to be used than for more evenly distributed animals. Termites have a wide range of dietary, foraging and nesting habitsand are found in epigeal (on the ground) as well as arboreal nests, on dead wood, and in the soil in tunnels and galleries. The termite nest design also varies from simple diffuse galleries excavated in soil or wood, to the structurally complex edifices. In many species the nest is a single unit with a clearly delineated boundary, and is easily distinguishable from the surrounding substrate. In contrast several other species are polycalic and their clonies are distributed among numerous calies, interconnected via subterranean tunnels or arboreal runways (Jones *et al*, 2005).

Approaches to sampling of termites

Methodologies for sampling termites have been discussed by Lee and Wood (1971), Baroni-Urbani *et al.*, (1978), Nutting and Jones (1990), Eggleton and Bignell (1995), Jones *et al.*, (2005). The protocol for sampling is decided based on the objectives of the study which may encompass population density, species composition, food preference, foraging, nest building, etc. The method of sampling may be chosen accordingly. The decision tree proposed by Jones *et al.*, (2005) is useful for the purpose (Figure 1).

2.2 Biodiversity indices

The basic idea of a diversity index is to obtain a quantitative estimate of biological variability that can be used to compare biological entities, composed of discrete components, in space or in time (Heip *et al.*, 1998). A diversity index is a mathematical measure of species diversity in a community. It provides more information about community composition than simply species richness (i.e., the number of species present); they also take the relative abundance of different species into account. Hence diversity includes species richness and evenness. The most often used indices of diversity and evenness are:

2.2.1 Shannon index (H')

Shannon index accounts for both abundance and evenness of the species in the community. It is the most commonly used diversity index. The formula of Shannon Index is:

$$H = -\sum_{i=1}^{S} (P_i * \ln P_i)$$

where,
H'is the Shannon diversity index
P_i is the fraction of the entire population madeup of species i (proportion of a species I relative to total number of species present, not encountered)
S is the numbers of species encountered

Generally the value of H' falls between 0 to 4. A high value of H' would be a representative of a diverse and equally distributed community and lower values represent less diverse community. A value of 0 would represent a community with just one species.

2.2.2 Simpson index

Simpson index of diversity takes into account the number of species present, as well as the abundance of each species. It measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). There are two versions of the formula for calculating D**.**

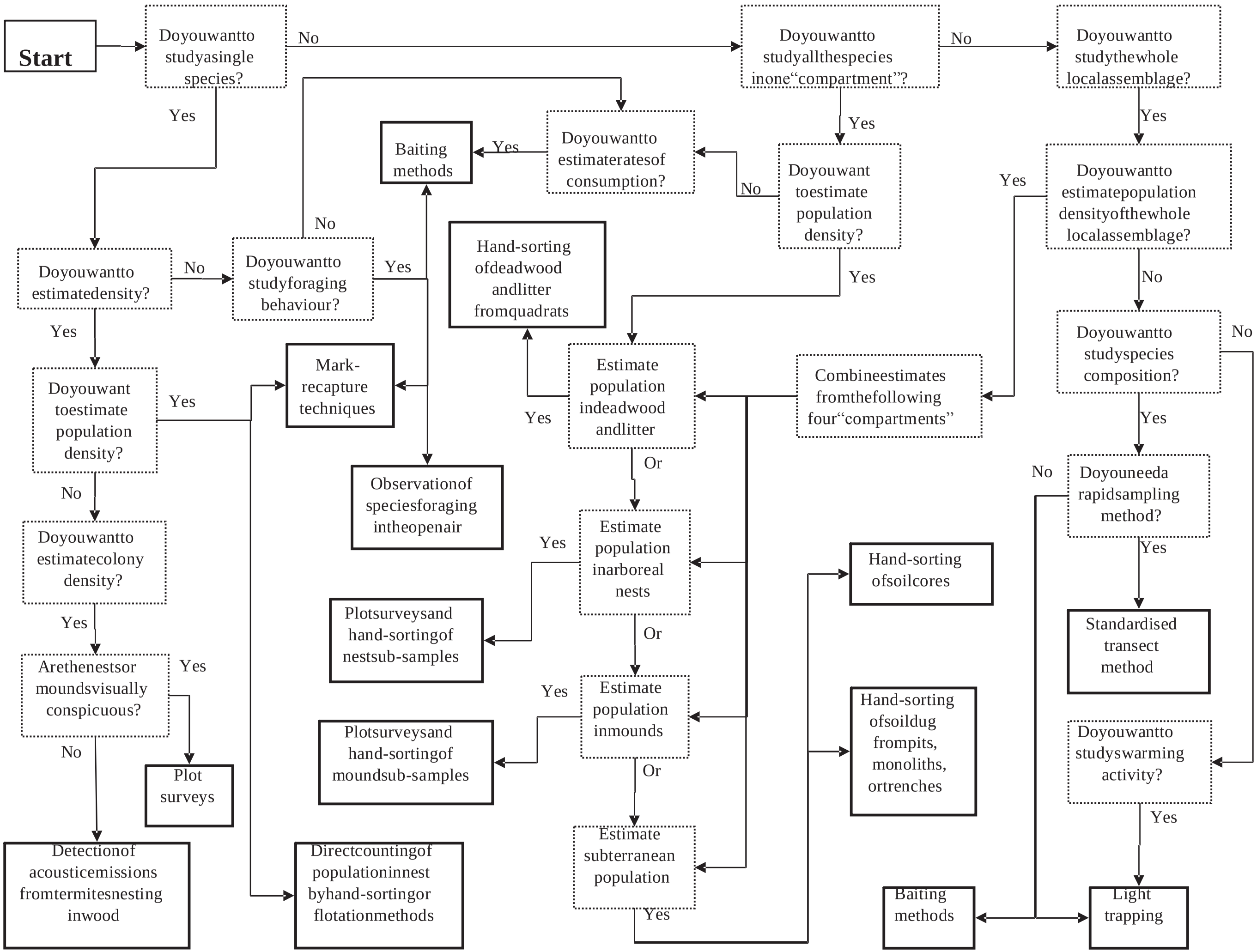

Figure 1: Decision tree giving a sequence of questions by which a method for sampling termites can be chosen (Jones *et al.*, 2005)

Table 1: Methods of faunal survey ─ a comparison

Aspect	Direct search	Transects	Quadrats	Mark-recapture	Baits	Record of movements
Methodology	The animals are spotted and counted. Searching is superior to the use of traps and collecting devices for sedentary species under bark and stones, and in dead wood, litter and moss, fungi and tussocks; crawling species in saturated habitats where pitfall traps fill with water; phytophagous larvae and adults where association with host plants is useful, single-species surveys where the exact niche of the species is known and it can be readily located without killing individuals; and conspicuous diurnal species (Sutherland, 1996). .	There are many variations of the transect-based survey methods, which rely on line transect, belt transect or point transect. In line transect, a measured line is laid across the study area and the animals touching the line are recorded along the whole length of the line or at specific points along the line. A belt transect is a strip, usually a metre wide, marked by putting a second line transect parallel to the first. The animals in between the lines are recorded. In point transect, the observer stands at a given position and counts the animals spotted. Generally all directions are recorded regardless of distance from the point. It is mostly used in avian surveys (Buckland, 2006). The length of the transect may vary as per the aim of the survey from a few centimeters to several kilometres (Sutherland,	Quadrats are plots of standard size. A series of quadrats are placed in the area and the animals with in those quadrats are identified and recorded. There are two types of quadrats: frame quadrat and nested quadrat. Frame quadrats are used in conjuction with a line transect. The quadrat is laid down alongside the line transect and the species within it is recorded. It is then moved along the length of the transect and the process is repeated (Toole and Toole, 2004) Nested quadrats include a series of different sized quadrats all placed at the same location; usually positioned so that all have a common starting point. Hence the area sampled by smaller quadrats is included in the progressively larger ones. It allows for the more abundant species to be efficiently assessed in the smaller	In this method, the animals are captured and mark is made on their body by a paint or by clipping the toe nails etc. Each time when the animals are spotted, same mark can be applied, so multiple spotting of the same animals can be recorded (Sutherland, 1996). .	This is an alternative to the mark-recapture method in which instead of catching and sampling animals, animals are lured with an attractant. Pheromones are also used as baits. It is used widely in pest control (Leather, 2005).	To track the movement of animals, recording is done by taking photographs and videos. Nowadays electronic tags that give signals that are picked up by radio devices or satellites are used.

Aspect	Direct search	Transects	Quadrats	Mark-recapture	Baits	Record of movements
		1996).	quadrats while increasing the likelihood of encountering the less common species in the larger quadrats.			
Advantages	Sampled animals are not harmed and released after identification.	Suitable for the identification of the effects of environmental gradients on invertebrate communities	Quadrat are very easy to use and can be employed in a wide range of studies.	Paint marking does not harm animal physically.	i. Without much efforts of sampling, active and live samples can be obtained. ii. Rare species can be sampled.	i. Presence of a observer is not required. ii. The locations and movement of the tagged animals can be recorded without recapturing using RFID technology or satellites.
Disadvantages	i. The observer should be capable of identifying the spotted animals. ii. If the animal population is high it cannot be used as counting may be very difficult.	i. In the dense vegetation, sampling may take very long time.	Quadrats are not good for cryptic, soil-dwelling nocturnal insects such as the large pine weevil *Hylobius abietis* (Leather, 2005).	i. The marked animals may become more visible to predators as markings may make camouflaging difficult for the sampled animals. ii. Apart from paint marking, toe clipping and tattoo may physically alter or harm animal.	–	i. Can be expensive as camera and other equipment are required. ii. Electronic tags are heavier than low-technology tags so may create drag on some animals, slowing them down (Cochran, 1980).
Biases	i. Any kind of disturbance during sampling may result in under estimation of the sampled animals. ii. Sampled animals may be counted more than once. iii. Cryptic and small invertebrates may be under recorded.	-	-	If the assumptions like marks are permanent, unique and does not affect behaviour of animal are not met, this method may be biased.	It is semi-quantitative as the area from which animal being attracted is not measurable on local scale (e.g. per m^2)	Photographic technique can give large discrepancies between the number of insects leaving the nest and the number returning (Collins 1979b).

$$D=\Sigma (n/N)^2 \text{ or } D= \Sigma\, n(n-1)/ N(N-1)$$

n = the total number of organisms of a particular species
N = the total number of organisms of all species.

Shannon index value of 0 represents infinite diversity and 1 represents no diversity. The bigger the value of D, the lower the diversity.

2.2.3 Pielou's eveness index

Evenness is the degree to which the abundances are equal among the species present in a sample or community (Molinari, 1989). The evenness of a community can be represented by Pielou's evenness index, which is denoted by:

$$J' = \frac{H'}{H'_{\max}}$$

Where H' is the number derived from the Shannon diversity index

$H'_{\max}$ is the maximum value of H' which is equal

$$H'_{\max} = -\sum_{i=1}^{S} \frac{1}{S}\, In \frac{1}{S} = In\, S$$

The value of J' generally falls between 0 and 1.
Higher value of J' indicate less variation in communities between the species.

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Chapter 3

Identification of sampled termifauna of North-eastern Puducherry and Auroville

Abstract

A scheme was developed by us to assist in termite species identification by compiling keys on the basis of information collated from the publications of the Zoological Survey of India and other reports on termite systematics (Bose, 1984; Roonwal *et al.*, 1961; Chhotani, 1997; Rathore *et al.*, 2004; Bose, 1999; Maiti *et al.*, 1994; Kambhampati and Eggleton, 2000). Details are presented in this chapter.

Termites were surveyed using standardized protocols from Pondicherry University campus as a representative location. Two methods of sampling were used: transect and quadrat. As there is no single systematized key available for the identification of the termite species we built up a scheme to assist us in termite species identification by compiling different keys from Zoological survey of India and other reports (Bose, 1984; Roonwal *et al.*, 1961; Chhotani, 1997; Rathore *et al.*, 2004; Bose, 1999; Maiti *et al.*, 1994; Kambhampati and Eggleton, 2000). All the surveyed species were identified by first morphological characters and then by taking measurements and matching them with the measurements as reported in the key. All the species were identified by us and confirmed by Emeritius Prof. Vikratamath at Gandhi Krishi Vigyan Kendra, Bangalore. The taxonomy and the characteristics of the identified species is given below.

Family: Rhinotermitidae

Soldier characteristics:

i. Monomorphic or dimorphic
ii. Head variable in shape either oval or subsquarish or rectangular
iii. Mandibles generally elongate with or without marginal teeth sometimes only with a few crenulations
iv. Pronotum: generally flat
v. Fontanelle always absent
vi. Labrum variable in shape; sometimes with fringe of hairs at anterior margin
vii. Tarsi 4-jointed

Worker characteristics:

i. Head subcircular or subsquarish.
ii. Fontanelle with fontanelle plate present, sometimes not distinct.
iii. Antennae with 12-18 segments.
iv. Postclypeus variable, either flat or swollen.
v. Pronotum flat or saddle shaped. Legs and abdomen as in soldier.

Sub family: Coptotermitinae

Soldier characteristics:

i. Head capsule pyriform to broadly oval.
ii. Mandibles sabre shaped and incurved distinctly.
iii. Left mandible with a few (upto 4) crenulations in basal half and a large, knob-like, basal projections.
iv. Monomorphic soldiers
v. Antennae with 13-17 segmented.

Worker characteristics:

i. Head subcircular.
ii. Fontanelle, eyes and ocelli absent.
iii. Antennae with 12-15 segments.
iv. Pronotum usually flat, sometimes upturned at anterior margin.
v. Legs and abdomen as in soldier.

Genus: Coptotermes

Same as in sub-family Coptotermitinae

Species: Coptotermes heimi

Soldier characteristics:

i. Total body length: 4.20-6.00 mm.
ii. Antennae with 14-16 segments, segment 3 smallest.
iii. Head capsule variable in shape, pyriform to sub-circular; generally longer than broad, abnormally as wide as long when subcircular
iv. Head capsule subrectangular; width more than half to a little less than 2/3 of length.
v. Postmentum long, club shaped.
vi. Pronutum generally, flat, sometimes slightly raised anteriorly.

vii. Mandibles with only a few crenulations in basal half (Figure 1).
viii. Fontanelle large, situated at base of clypeus, without any groove running onwards.
ix. Tarsi 4 jointed.

Figure 1: Head and manibles of *C.heimi* soldier

Worker characteristics:

i. Total body length 3.60-5.70 mm**.**
ii. Head capsule subrounded, broader than long (lengthto base of mandibles 0.74- 1.11 mm, max. width 0.88-1.30 mm).
iii. Fontanelle, eyes and ocelli absent.
iv. Antennae 12 to 15 segments, segments 3 shortest or subequal to either 2 or 4.
v. Clypeus, labrum and mandibles as in imago; labrum width 0.30-0.45, length 0.28-0.40.
vi. Pronotum pilose, much broader than long (length 0.25-0.44, width 0.51-0.80 mm); anterior margin wavy with a median depression; posterior margin weakly incurved.
vii. Legs and abdomen as in soldier.

Coptotermes ceylonicus

Soldier characteristics:
<
i. Head with a few erect bristles and with one bristle on either side of fontanelle; pronotum with a few small hairs on anterior margin and longer ones on body**.**
ii. Total body length 4.0-5.8 mm**.** Head capsule oval, longer than broad (lengthto base of mandibles 1.15-1.50 mm, max. width 1.0-1.20 mm); sides convexical, converging anteriorly; posterior margin rounded.
iii. Fontanelle gland tubular, visible from head-surface; opening at posterior margin of clypeus and with a brown chitinous rim.
iv. Eyes and ocelli absent.
v. Antennae 13-15 segments; segment 3 usually shortest, but variable. Either equal to or slightly longer than 2 or 4; 5 onwards gradually increasing in length.
vi. Postclypeus narrow, trapezoid; anteclypeus also narrow, trapezoidal and apilose.
vii. Labrum subtriangular; with a pointed, hyaline apex; a little longer than broad (length 0.30-0.35, width 0.25-0.28 mm).
viii. Mandibles thin, sabre- shaped, with inwardly pointed apices. Left mandibles with fairly large basal projection and 4 small well marked crenulations. Right mandibles also with 4 but small to minute crenulations basally.
ix. Postmentum long clup- shaped; broadest at anterior one-third and from thence narrowing down to a thick waist at middle and again widening out a base (length 0.85-1.00, max. width 0.35-0.40, min. width 0.20- 0.25 mm).
x. Pronotum flat, subreniform; a little broader than long (length 0.38-0.45 mm, width 0.68-0.91 mm); and narrower than head.

Worker characteristics:

i. Total body length 3.10-5.30 mm**.**
ii. Head capsule subcircular, broader than long (lengthto base of mandibles 0.75- 1.10 mm, max. width 0.88-1.25 mm).
iii. Fontanelle, eyes and ocelli absent.
iv. Antennae 12 to 15 segments.
v. Clypeus, labrum and mandibles as in imago.
vi. Pronotum flat, much broader than long (length 0.20-0.40, width 0.48-0.75 mm); anterior margin weakly convex, with deep, median notch; posterior margin substraight, with faint median depression.
vii. Legs and abdomen as in soldier.

Family: Termitidae

Soldier characteristics:

i. Soldier either present or absent, if present monomorphic or dimorphic.
ii. Pronotum saddle shaped.
iii. Mandibles prominent or reduced.

Worker characteristics:

i. Monomorphic or dimorphic.
ii. Head subcircular or subsquarish.
iii. Fontanelle plate distinctly marked or indistinct.
iv. Antennae with 13-20 segments.
v. Mandibles each an apical and two marginals.
vi. Pronotum and legs as in soldier.

Subfamily: Macrotermitinae

Soldier characteristics:

i. Monomorphic (*Odontotermes, Hypotermes, Microtermes*) or dimorphic (*Macrotermes, Pseudacanthotermes*).

ii. Mandible delicate and thin (*Microtermes*, *Ancistrotermes*) or thick and stout (*Odontotermes*, *Macrotermes*).

iii. Labrum with or without hyaline tip.

Worker characteristics:

Monomorphic or dimorphic.

i. Head subcircular or subsquarish.
ii. Fontanelle plate hyaline, spot-like or triangular.
iii. Eyes generally absent, sometimes whitish spots present.
iv. Pronotum saddle–shaped; either without or with sharp anterior and lateral processes. Legs, cerci and styli as in soldier.

Genus : *Macrotermes*

Soldier characteristics:

i. Dimorphic soldiers
ii. Very large
iii. Head: not nasutiform
iv. Labrum : triangular with a hyaline tip
v. Mandible large, well developed, symmetrical, curved inwards at tips.

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Head-capsule subcircular.
ii. Fontanelle distinct, round, whitish.
iii. Eyes rudimentary, pale but distinct and slightly raised.
iv. Ocelli rudimentary or indistinct.
v. Antennae 17- 20 segments.
vi. Postclypeus, labrum and mandibles as in imago.
vii. Pronotum, and legs as in soldier.

Worker Minor characteristics:

As in worker major but smaller in size.

Species: M.convulsionarius

Soldier Major characteristics:

i. Total body length: 11.0-14.0mm
ii. Postmentum subrectangular, a little wider posteriorly, length 2.90-2.96mm
iii. Antennae with 17 segments; segment 3 a little longer than 2.
iv. Serrated mandibles (Figure 2).

Figure 2: Mandibles of *M.convulsionarius* soldier major

Soldier Minor characteristics:

i. Total body length: 3.0-4.0mm
ii. Antennae with 17 segments; segment 3 a little longer than 2; 4 a little longer than 2
iii. Labrum : triangular with a hyaline tip

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length c 7.0 mm.
ii. Head round (length to tip of labrum 2.5-2.7).
iii. Head length to base of mandibles 1.80-1.90, max. width 2.15-2.20 mm.
iv. Fontanelle round, large.
v. Eyes whitish spots, raised a little.
vi. Antennae with 18 to 19 segments; segments 3 longer than 2, the latter longer than 4 (18 segmented) and 3 shorter than 2 and latter as long as 4 (19 segmented).
vii. Pronotum not notched anteriorly and distinctly emarginated posteriorly (length 0.38-0.40, width 0.95-1.00 mm).

Worker Minor:

i. Paler and smaller than worker major and with 17-segmented antennae; segments 3 shorter than 2, subequal to 4.
ii. Total body-length 5.5mm.
iii. Maximum width of head 1.41, max. pronotum width 0.87 mm.

Genus : *Microtermes*

Soldier characteristics:

i. Small and delicate species
ii. Head: oval converging in front
iii. Antennae 12-15 segmented

iv. Mandibles thin delicate, concave at base on outer margin and apically weakly incurved; left mandible either without or with a rudimentary tooth; right mandible without any denticle.

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Fontanelle indistinct.
ii. Eyes and ocelli absent.
iii. Antennae with 13-16 segments.
iv. Pronotum, legs and abdomen as in soldier.

Worker Minor characteristics:

i. Smaller, otherwise as worker major;
ii. Head somewhat rounded.

Species: M.incertoides

Soldier characteristics:

i. Total body length: 3.0-4.0mm.
ii. Head capsule oval; a little longer than wide; sides converging in front (Figure 3).
iii. Antennae with 14 segments; segment 2 subequal to 3+4
iv. Labrum lancet shaped, extending upto 2/3 of mandibles; tip narrow and pointed (Figure 3).
v. Postmentum a little longer than wide; sides weakly convex.

Figure 3: Head, mandibles and labrum of *M.incertoides* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 3.5- 4.30 mm**.**
ii. Head capsule subsquarish, sides faintly narrowed behind (length to base of mandibles 0.80, max. width 0.87 mm).
iii. Antennae 14 segments.
iv. Postclypeus swollen, length ½ of width. Pronotum saddle-shaped (max.width 0.46); anteriorly deeply notched and posteriorly substraight.

Worker Minor characteristics:

i. Head-capsule subcircular.
ii. Total body size c 3.0 mm.
iii. Width of head 0.68, width of pronotum 0.42 mm.

Species: M.obesi

Soldier characteristics:

i. Total body length 3.2-5.0 mm**.**
ii. Head capsule oval, a little longer than wide (lengthto base of mandibles 0.80-1.0 mm, max. width 0.74-0.90 mm), widest at middle of head.
iii. Antennae 14 segments; segment 2 subequal to 3 + 4; 4 shortest.
iv. Labrum long, lanceolate, reaching upto about 2/3 mandibles; tip comparatively wider than in other species.
v. Mandibles thin, delicate and weakly incurved apically (length 0.49-0.55mm); a little longer than ½ of head-length (index mandible- length/ head- length 0.55- 0.62).
vi. Postmentum a little longer than wide and slightly arched; sides weakly convex (length 0.40-0.59, width 0.35-0.52mm).
vii. Pronotum strongly saddle-shaped (length 0.33-0.50, width 0.50-0.76 mm); anterior margin deeply notched; posterior margin weakly emarginated.

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 3.0-5.0 mm**.**
ii. Head capsule subsquarish, (lengthto base of mandibles 0.80- 0.90, max. width 0.90-1.03 mm).
iii. Antennae with 13-14 segments. Segment 2 equal to 3+4.
iv. Postclypeus swollen, length almost half of width.
v. Pronotum saddle- shaped (length 0.25-0.33, max.width 0.45-0.50 mm).

Worker Minor characteristics:

i. As in worker major except for smaller size.
ii. Total body size 3.0-3.5,
iii. Length of head to base of mandible 0.60-0.65, max. width of head 0.65-0.73.
iv. Width of pronotum 0.35-0.43 mm.

Genus : Odontotermes

Soldier characteristics:

i. Moderately to fairly large species.
ii. Soldiers usually larger than workers.
iii. Monomorphic.
iv. Labrum without hyaline tip.
v. Mandibles delicate to strong; left mandible with a small rudimentary to a large and prominent tooth situated at variable position of inner margin.
vi. A small, rudimentary corresponding tooth present on right mandible.
vii. Antennae 15-18 segmented.
viii. Postmentum subrectangular, weakly to strongly arched; sides substraight to strongly convex.

Worker characteristics:

i. Monomorphic or dimorphic.
ii. Head capsule subsquarish, broader than long.
iii. Fontanelle plate round or oval, translucent spot.
iv. Antennae with 17-19 segments.
v. Labrum, postclypeus and mandibles as in imago.
vi. Pronotum, legs and cerci and styli as in soldier.

Species: O.annamallensis

Soldier characteristics:

i. Total body length: 4.9-7.4mm.
ii. Antennae with 17 segments, segment 3rd shortest.
iii. Labrum with 4 pairs of long bristles near tip.
iv. Angle between the tooth and inner margin of left mandible distinctly acute, tips strongly incurved, tooth bluntly pointed.
v. Postmentum sides straighter.
vi. Mandible sabre-shaped, strong and stout; length (1.10-1.30) (Figure 4).

Worker characteristics:

Dimorphic

Figure 4: Mandibles of *O.annamallensis* soldier

Worker Major characteristics:

i. Total body length 4.0-5.5 mm**.**
ii. Head capsule subcircular, broader than long (lengthto base of mandibles 1.2-1.65, max. width 1.35-1.78 mm).
iii. Fontanelle plate a small, whitish, translucent, round at middle of head.
iv. Antennae 17 to 19 segments, in 17 segmented antennae segments 3 shortest, in 18 segmented 4 shortest, and in 19 segmented one 3 either shortest or subequal to 4 or 5.
v. Postclypeus weakly swollen; length less than half of width.
vi. Pronotum saddle- shaped (length 0.40-0.58, width 0.75-1.03 mm); anterior margin round with a median notch and posterior margin convex with median emargination.
vii. Mesonotum narrower and metanotum a little wider than pronotum; posterior margin of former weakly emarginated and that of latter substraight.

Worker Minor characteristics:

i. Resembles worker major, but is smaller and has 15 to 16 segmented antennae.
ii. Total body size 3.0-4.0.
iii. Length of head to base of mandibles 0.80-0.88, max. width of head 0.93-1.00.
iv. Length of pronotum 0.30-0.35, width of pronotum 0.60-0.68 mm.

Species: O.brunneus

Soldier characteristics:

i. Total body length: 5-7mm.
ii. Antennae with 17 segments, segment 3rd shortest; 4 shorter than 2; 5 shorter than 4 antennae (Figure 5).
iii. Head lenghth to base of mandibles 1.75-2.03mm.
iv. Weakly oval to subrectangular, sides substraight to wealky convex.

v. Mandibles shorter, stouter and more curved distally.
vi. Tooth of left mandible forwadly placed (tooth distance from tip/ madible leghth 0.34-0.42mm); right mandible with a small tooth situated almost at middle (Figure 6).
vii. Postmentum subrectangular (length 0.95-1.20, maximum width 0.50-0.60mm).

Figure 5: Antennae of *O.brunneus* soldier

Figure 6: Mandibles of *O.brunneus* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 4.8-5.6 mm**.**
ii. Head capsule subsquarish (lengthto base of mandibles 1.25-1.45, max. width 1.45-1.60 mm).
iii. Antennae 17 to 19 segments; size of basal segments variable; 3 or 4 shortest.
iv. Postclypeus swollen, length a little less than half of width.
v. Pronotum as in soldier (length 0.45-0.53, width 0.80-0.88 mm).

Worker Minor characteristics:
i. Similar to worker major but smaller size and 16 to 17 segmented antennae.
ii. Total body size 3.6-4.5.
iii. Length of head to base of mandibles 0.75-0.88, max. width of head 0.93-1.00.
iv. Length of pronotum 0.40-0.45, width of pronotum 0.65-0.70 mm.

Species: O.globicola

Soldier characteristics:

i. Total body length: 3-4mm
ii. Antennae 15-16 segmented; segment 2 equal to 3+4, the latter shortest.
iii. Tooth of left mandible forwadly placed
iv. Mandibles thin, long and slender; straight and weakly incurved near distal end.
v. Left mandible with a prominent tooth near tip, tooth distance from tip 0.13-0.15mm.
vi. Labrum sharply pointed at tip.

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 3.4-4.1 mm**.**
ii. Head capsule subcircular, (lengthto base of mandibles 0.95-1.18, max. width 1.0-1.18 mm).
iii. Antennae with 17 segmented, 3 shortest.
iv. Postclypeus swollen; length a little less than to about ½ of width. Pronotum saddle-shaped (length 0.30-0.40, width 0.50-1.63 mm); anterior margin distinctly notched; posterior margin weakly emarginated.

Worker Minor characteristics:

i. Similar to worker major, except for smaller in size.
ii. Total body size 2.7-3.2
iii. Length of head to base of mandibles 0.60-0.88, max. width of head 0.68-0.88
iv. Length of pronotum 0.25-0.33, width of pronotum 0.48-0.53 mm.

Species: O.sp

Yet to be confirmed

Soldier characteristics:

i. Antennae 17 segmented, 2 shortest, 2 longer than 4.
ii. Head length with mandibles 2.06-2.26mm.
iii. Mandible length 0.76-0.85.

Species: O.redemani

Soldier characteristics:

i. Head capsule oval
ii. Antennae 16-17 segmented

iii. Labrum tongue shaped anterior margin broadly rounded (Figure 7).
iv. Pronotum saddle shaped weakly to deeply notched medially at anterior margin, posterior margin finely notched.
v. Postmentum moderately swollen, sub-rectangular.

Figure 7: Labrum of*O.brunneus* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 3.0-5.20 mm**.**
ii. Head capsule subsquarish, (lengthto base of mandibles 1.20-1.35, max. width 1.30-1.40 mm).
iii. Antennae 17 to 18 segments; segments 5 in 17 segmented antennae and 4 in18-segmented ones, shortest.
iv. Postclypeus weakly swollen; length nearly ½ of width.
v. Pronotum saddle-shaped, prominently notched at anterior and posterior margins (length 0.35-0.38, width 0.70-0.80 mm).

Worker Minor characteristics:

i. Resembles worker major, but for it is smaller size and 16 to 17 segmented antennae.
ii. Total body size 3.0-3.8
iii. Length of head to base of mandibles 0.70-0.78, max. width of head 0.85-0.90,
iv. Length of pronotum 0.30-0.35, width of pronotum 0.57-0.60 mm.

Species: O.feae

Soldier characteristics:

i. Head capsule subrectangular, larger than width. Widest in posterior region, width more than ¾ of length. Sides gradually narrowed in front, sometimes almost sub parallel.
ii. Antennae 17 segmented.
iii. Mandibles stout, strong, sabre-shaped; a little longer than half of head-length (length 1.20-1.65mm, mandible/head index 0.51-0.59) (Figure 8).
iv. Labrum tongue shaped narrowed in front to a pointed tip.
v. Pronotum saddle shaped, anterior margin with a weak medial notched, posterior margin weakly to deeply notched (Figure 9).
vi. Postmentum sub-rectangular, sub what swollen near basal third.

Figure 8: Mandible of *O.feae* soldier

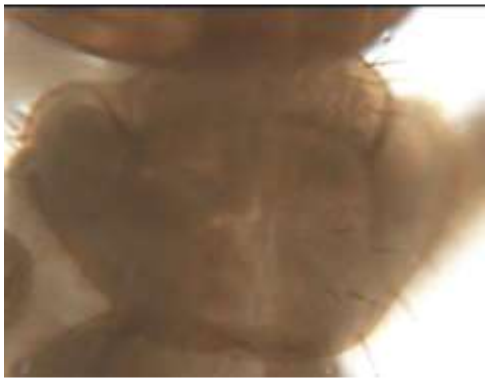

Figure 9: Pronotum of *O.feae* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 5.0-6.5 mm**.**
ii. Head capsule subsquarish, a little wider than long; sides subparallel, widest at base of antennae (length to tip of labrum 2.05-2.50, lengthto base of mandibles 1.50-1.85, max. width 1.68-2.10 mm).
iii. Fontanelle plate small, rounded..
iv. Antennae with 19 segments, 3 and 4 subequal, 5 shortest.

v. Postclypeus weakly swollen; length less than half of width.
vi. Labrum dome-shaped.
vii. Pronotum as in soldier (length 0.48-0.65, width 0.85-1.20 mm).

Worker Minor characteristics:

i. As worker major, but smaller in size (total body size 3.5-4.70).
ii. Head length to tip of labrum 1.70-2.0,
iii. Head to base of mandibles 1.10-1.48, max. width of head 1.15-1.50.
iv. Length of pronotum 0.35-0.53, width of pronotum 0.58-0.90 mm.

Species: O.horni

Soldier characteristics:

i. Total body length 6.7-10.4 mm.
ii. Head capsule subrectangular; sides substraight very slightly converged in front of antennae (length to base of mandibles 2.47- 3.00 mm, max. width1.82-2.30 mm).
iii. Antennae 17 segments; segment 3 much shorter than 2; 4 almost as long as 2; 5 shorter than 4.
iv. Labrum tongue-shaped; anterirorly with bluntly rounded tip.
v. Mandibles stong, sabre-shaped (length 1.27-1.60 mm, index mandible-length/head- length 0.53-0.66); left mandibles with a large, prominent tooth near base of middle third (tooth distance 0.70-1.00 mm. index tooth –distance/mandible-length 0.55-0.63); right mandibles with a minute tooth a little below level of tooth on left mandibles (Figure 10).
vi. Postmentum subrectangular; sides bulging out in proximal third (length 1.50-2.00, width 0.75-0.93mm).
vii. Pronotum saddle-shaped (length 0.80-1.03, width 1.40-1.80 mm).

Figure 10: Mandible of *O.feae* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 5.0-7.8 mm.
ii. Head capsule subsquarish, wider than length to base of mandibles (length to base of mandibles 1.50-1.80, max. width 1.75-2.10 mm).
iii. Antennae with 19 segments; segments 3 a little shorter than 2; 4 longer than 3; 5 shortest.
iv. Postcylpeus weakly swollen, length less than ½ of width.
v. Pronotum srongly saddle-shaped otherwise as insoldier (length 0.55-0.65, width 1.03-1.20 mm).

Worker Minor characteristics:

i. Like worker major but smaller in size.
ii. Antennae with 17 to 18 segments.
iii. Total body-length 3.5-4.7, head-length to base of mandibles 1.20-1.38, maximum width of head 1.35-1.58.
iv. Pronotumlength 0.40-0.58, width 0.73-0.93mm.

Genus : Hypotermes

Soldier characteristics:

i. Head capsule oval.
ii. Antennae 16-17 segmented; darker distally.
iii. Mandibles sabre-shaped, thick and strong; left mandible crenulations on basal part of inner margin, right without any crenulations or teeth.
iv. Labrum tongue shaped or oval.
v. Postmentum sub-rectangular; sides subparallel to strongly convex and arched.

Worker characteristics:

i. Head capsule subcircular or subsquarishly rounded; broader than long.
ii. Fontanelle plate round, translucent.
iii. Antennae with 16-18 segments.
iv. Pronotum, legs, cerci and styli as in soldier.
v. The Hypotermesworker is generally monomorphic but sometimes two types may be seen in some collections. It is almost identical with that of Odontotermes and is difficult to differentiate in the absence of soldier caste.

H.obscuriceps

Soldier characteristics:

i. Total body length: 3.5-5.75mm.
ii. Head capsule oval; sides weakly convex and slightly narrowing in front, widest at middle (Figure 10).
iii. Antennae 16-17 segmented, segment 3 shortest in 16 segmented one and 4 shortest in 17 segmented, 4 sometimes in process of division.
iv. Left mandible with three crenulations and a basal projection in promixal half (Figure 11).
v. Right mandible either without or with only a small crenulation a little below middle.
vi. Postmentum subrectangular, sides subparallel or very faintly incurved (length 0.60-1.20, maximum width 0.35-0.50mm).

Figure 11: Mandible of *H.obscuriceps* soldier

Worker characteristics:

Dimorphic

Worker Major characteristics:

i. Total body length 3.0-5.65 mm**.**
ii. Head capsule subcircular (lengthto base of mandibles 1.35-1.40, max. width 1.4-1.53 mm).
iii. Antennae 16 - 18 segmented basal segments variable in size (Figure 11).
iv. Postclypeus swollen, pilose.
v. Length less than half of width (length 0.30-0.33, width 0.70-0.73 mm in paralectotypes).
vi. Pronotum saddle-shaped; deeply emarginated at anterior margin and fairly prominently incurved at posterior margin (length 0.40-0.45, width 0.73-1.85 mm) (Figure 12).

Worker Minor characteristics:

i. As in worker major except for smaller size.
ii. Total body size 3.6-4.3mm.

Figure 12: Pronotum of *H.obscuriceps* worker

iii. Length of head to base of mandibles 0.75-1.20, max. width of head 0.83-1.25.
iv. Length of pronotum 0.30-0.40, width of pronotum 0.55-0.65 mm

Subfamily: Amitermitinae

Soldier characteristics:

i. Head triangular or oval.
ii. Fontanelle minute
iii. Mandibles are sabre or sicle shaped, generally with a tooth (except serrated in Microcerotermes).

Worker characteristics:

i. Head subcircular or subsquarish.
ii. Fontanelle plate small, minute or large and swollen (Speculitermes).
iii. Antennae with 13-15 segments.
iv. Pronotum and legs as in soldier.

Genus : Eremotermes

Soldier characteristics:

i. Head: with a frontal projection
ii. Head capsule : with frontal projection
iii. Mandibles: long, slender weakly incurved apically; inner margin not serrated. Both or left mandible with a prominent tooth.

Worker characteristics:

Dimorphic

*Worker Major***:**
i. Head–capsule subsquarish.
ii. Fontanelle indistinct.
iii. Antennae with 14 segments.
iv. Postclypeus swollen, about half as long as its width and divided into 2 by a median line.
v. Pronotum and legs as in soldier.

Worker Minor characteristics:

i. Smaller in size
ii. Mandibles with longish and pointed teeth otherwise as in worker major.

Species: E.paradoxalis

Soldier characteristics:

i. Body: smaller species
ii. Mandible : generally shorter than head
iii. Head width : 0.68-0.75mm
iv. Pronotum : width 0.40-0.45mm, Maximum width 0.40-0.45mm.

Worker characteristics:

Dimorphic

*Worker Major characteristics***:**

i. Total body length c 3.0-4.0 mm**.**
ii. Head capsule subsquarish (lengthto base of mandibles 0.70-0.75, max. width 0.75-0.80mm).
iii. Antennae 13 to 14 segments.
iv. Pronotum saddle- shaped; anterior margin faintly notched (length 0.25-0.35, width 0.45-0.50 mm).

Worker Minor characteristics:

i. Generally as in worker major, but smaller in size.
ii. Total body size 2.3-2.5,
iii. Length of head to base of mandibles 0.55-0.60,
iv. Maximum width of head 0.65-0.75.
v. Length of pronotum 0.25, width of pronotum 0.40 mm.

Genus : Microcerotermes

Soldier characteristics:

i. Head without any rostrum or nasute.
ii. Antennae with 12-13 segments.
iii. Labrum subsquarish or projected medially into a blunt tip.
iv. Postmentum narrow, not arched in middle.
v. Mandibles well developed and more or less symmetrical, non- twisted, sickle shaped, inner margin of mandibles faintly to strongly serrated.

Worker characteristics:

i. Head subrectangularly oval or subsquarish.
ii. Fontanelle indistinct. Antennae 13-segments.
iii. Postclypeus swollen, projected behind into frons; as long as half of its width.
iv. Pronotum, legs and abdomen as in soldier.

Species: M.pakistanicus

Soldier characteristics:

i. Head elongate, subrectangular; width about half of length; sides almost parallel
ii. Antennae with 13 segments; segment 2 equal to 3+4, 3 segment shortest
iii. Labrum pentagonal, tip broadly rounded; with few long and several short hairs
iv. Mandibles short, strong and apically strongly incurved (length 0.76-0.89mm); a little shorter to a little longer than half of head-length (index left mandible length/head-length to base of mandibles 0.46-0.56), coarsely serrated with one little larger serration slightly below middle (Figure 13).
v. Postmentum club shaped; with a long waist (length 0.83-1.00, maximum width 0.30-0.35, width at waist 0.18-0.20mm).
vi. Pronotum saddle shaped; anterior margin weakly notched; posterior margin sub-straight or slightly emarginated; length 0.25-0.35, width 0.53-0.60mm.

Figure 13: Mandibles of *M.pakistanicus* soldier

Worker characteristics:

i. Total body length 3.20-3.40 mm**.**
ii. Head capsule subsquarish (lengthto base of mandibles 0.83-0.89, max. width 0.89 mm).
iii. Fontanelle plate a small, circular, translucent spot.
iv. Antennae with 13 segmented; segments 3 smallest.
v. Postclypeus swollen; length slightly less than half of width.

vi. Pronotum saddle- shaped; anterior margin indistinctly notched; posterior margin weakly convex, length 0.19, width 0.50 mm.

Species: M.cameroni

Soldier characteristics:

i. Total body length: 4.3-5.2mm
ii. Head sides sub-paralled.
iii. Head capsule subrectangular; width more than half to a little less than 2/3 of length
iv. Antennae with 13 segments, segment 3 smallest.
v. Labrum with anterior margin bluntly rounded
vi. Mandibles shorter (mandible length 0.86-0.97)
vii. Postmentum weakly and gradually incurving at waist, club shaped; waist lying posteriorly.

Worker characteristics:

i. Total body length 3.6-4.8 mm.
ii. Head capsule subsquarish (length to base of mandibles 0.8-0.87, max. width 0.87 mm); sides subparallel.
iii. Fontanelle not visible.
iv. Antennae with 13 segments; segments 3 smallest.
v. Postclypeus swollen, hairy; length about half or a little more than half of width.
vi. Pronotum saddle–shaped (length 0.17-0.25, width 0.45-0.57 mm).

Sub family: Nasutitermitinae

Soldier characteristics:

i. Monomorphic or dimorphic
ii. Head capsule modified to form nasute
iii. Mandible fully developed or vestigial (with or without spine like process).
iv. Antennae with 11-21 segments. Mandibles fully developed or vestigial (with or without spine-like process).
v. Pronotum saddle-shaped.

Worker characteristics:

i. Monomorphic or dimorphic.
ii. Head capsule subsquarish or subcircular.
iii. Fontanelle plate generally prominent.
iv. Antennae with 13-20 segments.
v. Postclypeus swollen.
vi. Pronotum and legs as in soldier.

Genus : Trinervitermes

Soldier characteristics:

i. Dimorphic soldiers
ii. Head : nasutiform
iii. Head capsule : produced into a nasus
iv. Mandibles : small, degenerated, non functional

Worker characteristics:

i. Monomorphic.
ii. Head capsule subcircular, wider than length to base of mandibles; epicranial suture distinct.
iii. Fontanelle plate triangular, translucent.
iv. Antennae with 15 segments.
v. Postclypeus swollen, hairy; shorter than ½ width.
vi. Pronotum, legs and abdomen as in soldier.

Species: T.sen-sarmai

Dimorphic soldiers

Soldier major characteristics:

i. Total body length: 3.8-4.2mm
ii. Head : pear shaped (Figure 14).
iii. Head length: including rostrum 1.78-2.00mm.
iv. Antennae: 13 segmented, segment 2 and 4 subequal; 3 about twice the length of 2.

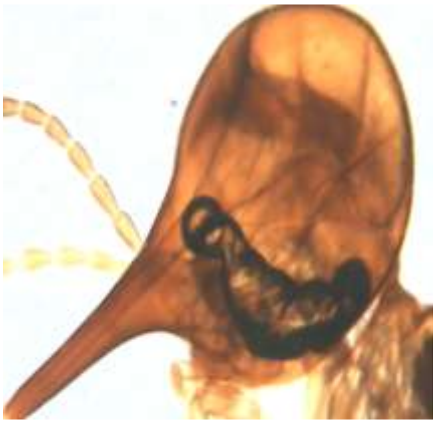

Figure 14: Head and rostrum of *T.sen-sarmai* soldier major

Soldier minor characteristics:

i. Total body length: 3.10-3.25mm
ii. Head length: including rostrum 1.40mm (Figure 15).

Figure 15: Head and rostrum of *T.sen-sarmai* soldier minor

Worker characteristics:

i. Total body length 5.2-5.5 mm**.**
ii. Head capsule subcircular, a little broader than long.
iii. Lengthto base of mandibles 1.10-1.23, max. width 1.30-1.43 mm.
iv. Fontanelle plate translucent, oval.
v. Antennae with 15 segments; segments 3 shortest, 4 and 5 subequal.
vi. Postclypeus swollen; length a little less than ½ of width.
vii. Pronotum saddle-shaped; with a large anterior lobe having a faint notch at middle; length 0.20-0.40, width 0.60-0.68 mm; posterior margin without notch.

Species: T. biformis

Dimorphic soldiers

Soldier major characteristics:

i. Head: Index head bulge/head length 0.33-0.48mm.
ii. Total body length: 4.00-5.30mm.

Figure 16: Antennae of *T.sen-sarmai* soldier major

iii. Antennae: 12-14 segmented, segment 3, two and half a times as long as 2, and subequal to 4 in 12 segmented, almost two and half times as long as 2 times as long as 4 in 13 segmented one and a little longer than 2 in 14 segmented one (Figure 16).

Soldier minor characteristics:

i. Total body length: 3.0-4.0mm.
ii. Antennae: 12-14 segmented, segment 3 more than twice to nearly three times that of segment 2 in length, segment 4 a little shorter than 3.

Worker characteristics:

i. Total body length 3.90-4.80 mm**.**
ii. Head capsule subcircular (lengthto base of mandibles 1.25-1.50, max. width 1.35-1.63 mm).
iii. Y-suture prominent.
iv. Fontanelle plate oval, whitish.
v. Antennae with 15 segments; segments 2, 3 and 4 subequal.
vi. Postclypeus swollen; length about ½ width (length 0.33, width 0.65-0.68 mm).
vii. Pronotum strongly saddle- shaped (length 0.25-0.38, width 0.55-0.73 mm); anterior lobe greatly upturned and weakly to strongly emarginated at middle; posterior margin convex, without notch.

Species: T.nigrirostris

Soldier characteristics:

Dimorphic soldiers

Soldier major characteristics:

i. Head : nasutiform
ii. Total body length: 4.1-4.7 mm
iii. Head capsule without rostrum, subcircular.
iii. Antennae 14 segmented, segment 3 one and half times bigger than segment 2 in length, segment 4 a slighltly larger than 4 and 5.
iv. Pronotum saddle shaped, anteriorly strongly raised anterior margin rounded with a broad shallow median depression, posterior margin convex.
v. Mandibles : small, degenerated, non functional.

Soldier minor characteristics:

i. Total body length: 3.2-3.5 mm.
ii. Head capsule without rostrum, subrectangular, side incurved behind antennae.

iii. Antennae: 13segmented, segment 3 more than twice as long as segment 2 in length, segment 4 about one and half times of 2.
iv. Pronutum saddle shaped, smaller than in soldier major.

Worker characteristics:

i. Total body length 4.0-5.0 mm**.**
ii. Head capsule subcircular, wider at base of antennae (lengthto base of mandibles 1.30-1.40, max. width 1.50-1.58 mm);epicranial suture distinct.
iii. Fontanelle plate long and translucent.
iv. Antennae with 15 segments; segments 3 longer than 2.
v. Postclypeus swollen; pilose; length nearly half of width.
vi. Pronotum strongly saddle- shaped; (length 0.30, width 0.55-0.65 mm); anterior margin deeply notched, posterior margin subconvex.

Sub family: Termitinae

Soldier characteristics:

i. Head capsule subsquarish to subrectangular; sometimes with frontal projection. Fontanelle open situated anteriorly or below frontal projection.
ii. Antennae with 13-17 segmented. Mandibles thin, long, rod-like or snapping-type and highly asymmetrical.
iii. Labrum broadly or sharply incurved; antero-lateral corners sometimes produced into pointed, spine-like process.
iv. Pronotum saddle-shaped.
v. Legs generally with 3: 2: 2 apical tibial spurs, dorsal spur of fore leg sometimes very much reduced or not discernible.

Worker characteristics:

i. Head capsule subcircular. Fontanelle plate translucent white, situated medially, sometimes hardly discernible.
ii. Antennae with 13-15 segmented.
iii. Pronotum and legs as in soldier.

Genus : Dicuspiditermes

Species: Dicuspiditermes sp.

Soldier characteristics:
i. Head subrectangular, with antero-lateral corners extending into tubercle-like projections and frons sloping in front.
ii. Antennae with 14 segments.
iii. Labrum asymmetrical with anterior margin deeply incurved; antero-lateral corners produced into needle- like, long processes; lateral margins with or without serrations anteriorly.
iv. Mandibles asymmetrical; left mandible strongly twisted at middle and with or without a beak at tip; right mandibles blade-like (Figure 17).
v. Pronotum strongly saddle-shaped. Legs with 3:2:2 apical tibial spurs; tarsi 4-jointed.

Figure 17: Mandible of *Dicuspiditermes sp.*

Worker characteristics:

i. Pale, delicate species.
ii. Head-capsule subcircular.
iii. Fontanelle plate translucent, round and oval.
iv. Antennae 14 segments.
v. Molar projection of left mandible more prominent than imago and 2nd marginal of right mandibles more incurved at posterior margin.
vi. Pronotum, strongly saddle-shaped.
vii. Legs with 3:2:2 apical tibial spurs; foreleg femur somewhat swollen; tarsi 4-jointed.

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A paper based on this chapter has been
submitted for publication

Chapter 4

A survey of termi-fauna of north eastern puducherry, India for developing termigradation strategy

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Abstract

As described in the preamble, the end-objective of the work described in this thesis has been to develop the process of termigradation. It involves the controlled use of appropriate species of termites in *ex-situ* and *in-situ* reactors for processing specific biowastes. Apart from other aspects a very important consideration is that termigradation at any place must be confined to only these species which are already established at that place. This is to ensure that the process doesn't lead to the introduction of any invasive species. This consideration, besides the need to identify substrate preference of different species, necessitates the development of a repertoire of locally established species and the types of waste they prefer to feed upon. Towards this objective a systematic survey of termite species in Northeastern Puducherry – which is part of peninsular India where the authors are located – has been carried out. As there is no pre-existing report on the richness or diversity of termifauna in this region, the present work aims to be fill a major knowledge gap. The findings are discussed in the context of the quantitative studies on termifauna carried out across the world as also in terms of the defining traits of the species identified in the survey *vis a vis* their relevance to termigradation.

Key words: Termigradation; Termites; Survey; Indices; India; Puducherry

1.0 Introduction

Among the nature's scavengers and earth-movers, termites play the most dominant role alongside ants and earthworms. But while the other two are very efficient in assiting decomposition of non-ligninous organic matter, termites are capable of processing lignin as well. Abbasi (2007) also coined the word termigradation ─ to denote termite-based biodegradation processes. Termigradation is a potential technology with which hard to biodegrade waste especially ligninous biowastes-which resist composting, vermicomposting and aerobic/anaerobic digestion can be handled. To ensure that the process doesn't lead to the introduction of any invasive species, the need to identify substrate preference of different species, necessitates the development of a repertoire of locally established species and the types of waste they prefer to feed upon.

There is little *quantitative* information on the richness and diversity of termifauna of India is available. There does exist a lot of information, of which a good part has been compiled by the Zoological Survey of India, on species available in different regions of India and on ways to control them but much less is available, if any, in the form of *quantified* measures of species richness, diversity, prevalence etc.

Moreover, most of the termite species surveys reported in India so far has been based on sampling of the animals as and where the surveyors spotted them. The usual practice has been to collect the animals, as and where they are spotted in good number, by sweeping them into a container by very soft alcohol-moistened brush (Pardeshi *et al.* 2010, Kumar & Thakur 2010). There have also been studies wherein the entire termite colonies (mounds) have been excavated and the animals enumerated Gupta (1953). These studies are very useful in their context which was essentially termite control/eradication but have little use in the study of beneficial aspects of termite. As these surveys have not been based on properly randomized and representative methods of sampling and enumeration, the findings are not amenable to quantification of species richness, diversity, or evenness as truly representing any study area. This also precludes a proper comparison across regions because of the basically ad-hoc and subjective nature of the surveys.

Despite a general consensus among ecologists of the importance of termites, considerable knowledge gap exists about the functional roles of different termite taxa and the significance of termite diversity to soil function. Much of the published data on termite species richness and population density is not only location-specific but is difficult to generalize because different studies have used different sampling methods and experimental designs (Kaur *et al.,* 2013). As a part of the efforts to cover the existing knowledge-gap, a systematic survey of termite species in Northeastern Puducherry – which is the area where the authors are located – has been carried out.

2.0 Methods

Study area: The study was carried out at Pondicherry University campus, which has 800 hectares area and is located in the North Eastern Puducherry.

Methodology: An authentic map of the Pondicherry University campus was obtained from the Engineering wing of the University. It is to a 1:3000 scale and represents an area of 780 acres. Three sets of experiments, designed and performed independently of each other were carried out to survey the distribution and prevalence of different species of termites. The experiments were based on transects, quadrats and baits (Kaur *et al.,* 2013). Each of these has been extensively used in faunal surveys and yields data that can be resolved into indices. The protocol, described by Jones and Eggleton (2000), was adapted from a similar method developed by Eggleton *et al.,* (1996). The protocol has been used in many tropical forests around the world (Gathorne-Hardy *et al.,* 2002; Davies *et al.,* 2003). The protocol describes sampling of termites using transects and quadrats.

Transect of 100 m long and 2 m wide, was marked and divided into 20 contiguous sections (each 5 m × 2 m) and numbered sequentially. Two trained people sampled each section for 30 minutes (a total of one hour of collecting per section). In each section the following microhabitats were searched for termites: 12 samples of surface soil (each 12 cm × 12 cm, to 10 cm depth); accumulations of litter and humus at the base of trees and between buttress roots; the inside of dead tree stumps, logs, branches, and twigs; the soil within and beneath very rotten logs; all mounds and subterranean nests encountered (checking for inquiline species); arboreal nests, carton runways, and sheeting on vegetation up to a height of 2 m above ground level.

The number of encounters with termites (hits) of a given species within a transect was taken as the relative abundance of that species within that transect. Termites specimens collected (Figure 1) for identification were stored in 80 percent isopropyl alcohol. Collected termites were identified by us with the key developed by us by compiling various books (Bose 1984, Chottani 1997, Abe *et al.* 2000). Sampled termites were placed in to feeding groups on their identity, using the classification of Donovan *et al.,* (2001).

3.0 Results and Discussion

A total of thirteen species were sampled. They belong to six genera of family Termitidae and one genus of the family Rhinotermitidae. Termitidae is represented by three sub-families. *Hypotermes obscuriceps, Macrotermes convulsionarius, Odontotermes anamallensis, O.brunneus, O.globicola, Odontotermes spp, Microtermes incertoides* and *Eremotermes paradoxalis* belong to the sub-family Macrotermitinae; *Microcerootermes cameroni* and *M.pakistanicus* are of the sub-family Amitermitinae; Nasutitermitinae represented by *Trinervitermes sensarmai, T.biformis*. *Coptotermes heimi* belong to the sub-familiy Coptotermitinae of the family Rhinotermitidae (Table 1).The proportion of the identified species based on the number of individuals sampled is shown in Figure 2. *H.obscuriceps* was the most abundant species (52 percent) in the University campus followed by *M.convulsionarius* (23 percent).

Feeding and nesting habit — Abe (1987) has given two classifications of termites. The first one is based on nest type and foraging habit. It distinguishes between single-piece nesters, intermediate nesters, and separate-piece nesters. Single-piece nesters feed and nest in the same discrete substrate; wood-feeding termites come into this category. Intermediate nesters nest in their feeding substrate but also forage out from the colony centre to find other patches of feeding substrate nearby. Again, these are all wood-feeding termites. Separate-piece nesters do not nest in their feeding substrate and actively forage for their feeding substrate away from the nest, which does not act as a primary feeding substrate. These have a wide range offeeding substrates. Abe’s second classification is based partly on the substrate consumed (wet wood, dry wood, ‘arboreal termites’, subterranean termites, and humus-feeding termites).

Sleaford *et al.,* (1996) have grouped the termites into four functional groups – soil feeders, soil/wood interface feeders, litter feeders, and wood feeders. They have followed this classification based on the site of collection, abdominal colour and feeding biology of the termites. Donovan *et al.,* (2001a) have given a quantitative functional classification of termite feeding groups based on gut content analysis correlated with the morphology and anatomy of worker termites. Hence this classification is followed widely and reported by other authors (Jones and Prasetyo, 2002; Davies *et al.,* 2003 Bignell, 2011).

(a) *Odontotermes annamallensis*

(b) *Microcerotermes cameroni*

(c) *Odontotermes brunneus*

(d) *Hypotermes obscuriceps*

Figure 1: Sampled termite species sampled during survey

Donovan classified termites into four feeding groups: feeding group I, which comprises wood, litter and grass feeders; feeding group II, comprising wood, litter and grass feeders; feeding group III, which includes very decayed wood or high organic content soil feeders; and feeding group IV, representing low organic content soil feeders (‘true soil feeders’).

Another classification has been represented by Eggleton & Tayasu (2001) which is called lifeway classification, which combines Abe’s lifetypes classification and Donovan’s feeding groups. It comprises of eight groups – six categories within the non-single piece nesters, dry wood and wet wood single-piece nesters. The eight groups are distributed across the two gradients (i) the state of humification of the feeding substrate; and (ii) the degree to which the feeding and nesting substrates overlap.

Yamada *et al.,* (2007) have classified termites into two major feeding groups ─ wood/litter feeders (including fungus-growers) and soil feeders.

Wood/litter feeders are involved in the decomposition of aboveground organic matter (i.e., fine litter as well as small and large woody litter), while soil-feeders contribute to the decomposition of below ground organic matter (i.e., soil organic matter).

Capinera (2008) has mentioned classification based on the habitat – drywood termites, dampwood termites, rotten wood termites, and subterranean termites.

DeSouza and Cancello (2010) have classified termite species into four feeding groups or functional taxonomic groups, according to the proportion of the humification gradient they feed on. Group I include termites feeding on dead wood and grass. Group II include termites with a range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus comb and conidia. Soil-wood feeders constitute the group III which includes termites feeding in the organic rich upper layers of the soil, presumably feeding on the soil-wood interface. Group IV are called ‘true soil-feeders’, ingesting mineral soil to feed on organic matter

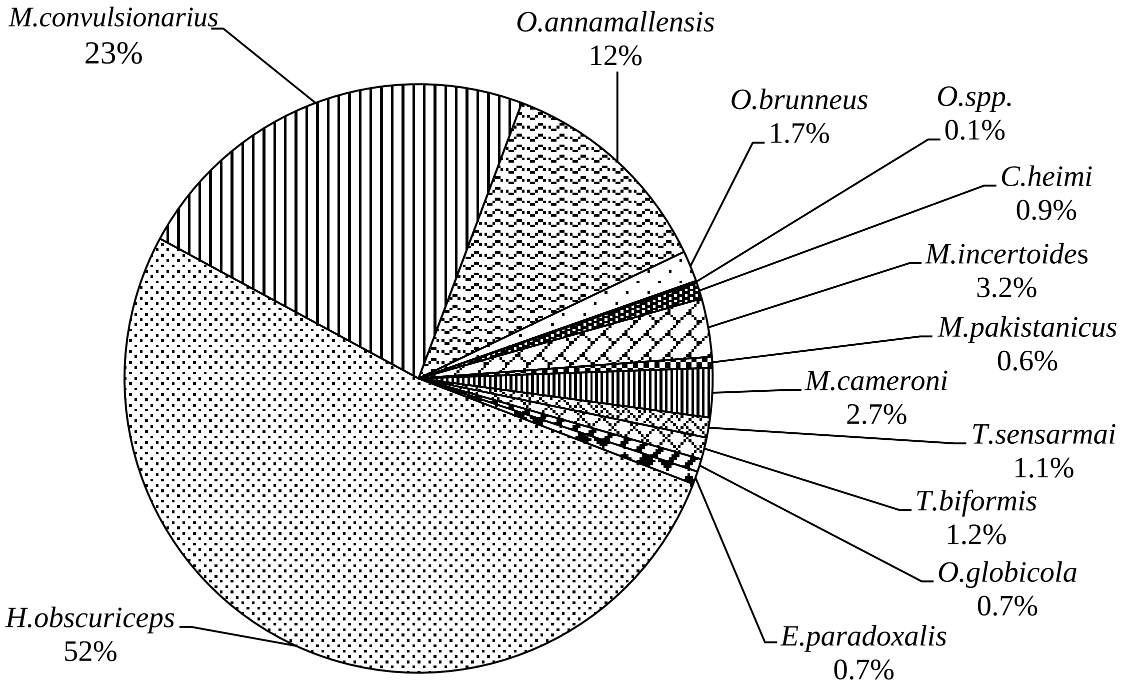

Figure 2: Proportion (number of individuals expressed in %) of the identified termite species

usually found highly dispersed therein. Group I comprise the lower termites, whereas other three groups are represented by Termitidae.

The substrates from where the termites were collected indicate their feeding preference. Based on this, the species have been matched with the feeding groups reported by different authors (Table 1).

The substrates from where the termites were collected indicate their feeding preference. Based on study, *C.heimi* is a single piece nester, feeding on dead wood. *E.paradoxalis* is the only true soil feeder with separate piece nest type. The remaining eleven of them are wood/litter feeders having a wide range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus-comb, conidia, etc. They are either separate piece nesters or intermediate nesters. There was no representative of soil-wood feeder which feeds on organic rich upper layer of the soil (Group III of Donovan, 2001). From this study, we can say that except *E.paradoxalis*, all the other species are suitable for termigradation.

Species dominance, diversity and evenness– Roonwal (1978) surveyed an area spanning 22,400 km^2 in three states: Karnataka (13,000 km^2), Kerala (9,000 km^2) and Tamil Nadu (400 km^2) to study the economic damage caused to forest trees and ecological habitat and recorded twenty five species of termites. Basu *et al.,* (1996) conducted comparative study of termite communities to understand impact of human disturbance on pristine ecosystems in the parts of the Western Ghats, South India and recorded twelve species. The samples were collected only from soil, and not from other habitats. Kumar *et al.,* (2011), recorded fifteen termite species in Vadodra district of Gujarat. Pardeshi *et al.,* (2010) recorded fifteen species from the four agricultural fields around Vadodara. As the focus of these two studies was to assess the damage to the agricultural crops, the samples of termites were taken only from the individual plant that was infested with termite. Kumar and Thakur (2010) sampled fifteen species of termites in the area of 7,219 acres of Haryana Agricultural University Campus, Hisar, Haryana. In another study, Kumar and Thakur (2013) have reported twenty seven species from different locality of Punjab.

Bama and Ravindran (2011) have studied the termite diversity under different land use regimes of Dindigul district, Tamil Nadu. They have used modified transect protocol and recorded ten species by sampling different land use patterns such as plains, woodlands and hilly areas. Rao *et al.,* (2012) conducted surveyed to investigate diversity of termite and their damage to living trees of forest region of Bhadrachlam forest (1,44,603 ha) in Andhra Pradesh by transect protocol and recorded thirteen species.Varma and Swaran (2007) studied diversity of termites in young eucalypt plantation in tropical forests in Kerala by transect sampling and additionally every month sampling of foraging termites for one year and reported fourteen species (eleven by transect and three by monthly sampling) and among fourteen species surveyed only four were found attacking eucalypt seedlings.

Akhtar and Rashid (2001) recorded six termite species from different localities of district Bahawalnagar, Pakistan. Diversity of termites based on the number of termites collected from 250 soil cores was calculated. Manzoor *et al.,* (2011) had taken soil core samples in Bhakkar, Pakistan and surveyed six species. Wood *et al.,* (1982) had conducted sampling in different plots in Riparian and semi-deciduous forest in Nigeria and recorded thirty three and thirty one species. These studies cannot be compared with our indices as the samples were collected only from soil cores.

An attempt has been made to compare the species richness and diversity of termites sampled in the present study with that of others who have also followed similar methods of sampling and indices development. Hemachandra *et al.,* (2010) examined termite assemblages in patches of undisturbed natural forest and secondary forest spanning 432 ha. In addition, random collections of termites were carried out in both the forests for species determination. They recorded eleven species overall: nine species in the secondary forest (four species by transect sampling, three by random sampling and two by both methods), and two species in the natural forest of which neither was recorded from secondary forest. As a consequence, the Shannon diversity index as computed by them was higher for the secondary forest (1.63) compared to natural forest (0.68).

In the present study, thirteen species were found; one soil feeder and the rest wood/litter feeders. The Shannon index of the study area is much higher (H'=1.45) compared to the natural forest surveyed by Hemachandra *et al.,* (2010). They recorded only soil feeders from natural forest, and attributed the absence of wood feeders there to the natural forest's altitude and climate. Moreover, they have reported only five dominant species of trees and the litter comprised of small twigs of pencil size and sparse leaf litter in the natural forest. The present study area has much more diverse tree species and the litter generated is of different types ranging from small to large leaves, small twigs to large barks, shallow patches of litter to thick mulch covering large spans. Hence, there is more number of litter/wood feeding termites in our study area than in the Hantane forest reported by Hemachandra *et al.,* (2010).

Carrijo *et al.,* (2009), who followed the same methodology as in the present study except that their transects were twice as long, surveyed two areas: pasture and natural vegetation of State Park, Goias, Brazil. They recorded a total of twenty nine species (seventeen in pasture and twenty one in natural vegetation). The Shannon diversity indices were 2.55 and 2.82 for pasture and natural vegetation respectively. Brazilian savanna is the richest tropical savanna in the world (Silva and Bates, 2002) and part of the world's 25 biodiversity hotspots. Hence, as expected, the Shannon diversity index in both vegetations (2.55 and 2.82 at pasture and natural vegetation respectively) are higher than our study area (1.45).

Zeidler *et al.,* (2002) surveyed for termites in five farms in the Southern Kuene region, Namibia. In each farm they studied a site each of high and low land use intensity. In each area 400 m^2 was surveyed which is twice the area normally used for representative sampling (Jones and Eggleton, 2000). They reported a total of ten species and concluded that termite species assemblages differed between the various forms, as well as across the land-use intensity gradients. The Shannon indices obtained by them ranged from 0─1.46, indicating zero diversity to moderate diversity.

Dosso *et al.,* (2010) while studying four different habitats differing in their vegetation and fire history: annually burned savanna, savanna woodland, forest island and gallery forest, in Cote d'Ivoire, West Africa, recorded a total of thirty species. The Simpson index for the areas ranged between 0.80 to 0.90 which indicates generally a low diversity compared to the present study in which the Simpson index value of 0.34 represents high diversity (Table 2).

Among the four habitats studied by them, the forest island was the richest, followed by the gallery forest and savanna woodland. The forest island and gallery forest has more number of species as they act as refuge to species that are sensitive to regular fire that occurs in annually burned savannah. Between savanna woodland and annually burned savanna, savanna woodland had more number of species as the woodland consisted of savanna patches randomly unburned for five years, whereas annually burned savannah being fuel rich is burned deliberately every year.

The Pileou's indices reported by Dosso *et al.,* (2010) ranged between 0.27–0.46 representing low to moderate evenness in distribution of species in four different study sites, whereas in our study, the Pileous index of 0.57 indicate moderate evenness in that respect. Pielou's evenness values reported by Carrijo *et al.,* (2009) are 0.94, 0.93 for pasture and for natural vegetation respectively. The higher value indicates less variation among the species distributed in the natural vegetation compared to our study area (0.57).

Hence it can be concluded that termite species in the present study area exhibit moderate evenness in distribution. The Simpson's index of 0.34 indicates more number of rare species (*M.pakistanicus, O.globicola, E.paradoxalis*) than abundant species. On the other hand, the high (1.45) Shannon diversity index indicates that there are a few abundant species as well (*H.obscuriceps, M.convulsionarius*).The authors have also conducted survey of termites by

Table 1: Taxa and the feeding groups of the termites recorded from the Pondicherry University campus

Name of the species	***Foraging/feeding substrate***	***Life type classification of Abe (1987) based on nesting type and foraging habit***	***Feeding group of Donovan et al., (2001)***	***Lifeway classification of Eggleton and Tayasu (2001)***	***Feeding group Yamada (2007)***	***Feeding group of DeSouza and Cancello (2010)***
*Hypotermes obscuriceps*Wasmann	Mound and leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
*Macrotermes convulsionarius*Konig	Leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
Odontotermes anamallensis Holmgren and Holmgren	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes brunneus Hagen	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
*Odontotermes globicola*Wasmann	Dead wood and leaf litter	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes spp.	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Microtermes incertoides Holmgren	Grass and cardboard	Separate-piece nesters	II	(III)	Wood/litter feeders	II
*Eremotermes paradoxalis*Holmgren	Leaf litter and soil	Separate-piece nesters	IV	(IV)	Soil feeders	IV
Microcerootermes cameroni Synder	Grass	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Microcerootermes pakistanicus Akhtar	Dead wood	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Trinervitermes sensarmai Bose	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Trinervitermes biformis Wasmann	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Coptotermes heimi Wasmann	Dead wood	Single-piece nesters	I	Sing(I)ww	Wood/litter feeders	I

Feeding groups of Donovan *et al.*,(2001): I= dead wood and grass-feeders, II= Termites with a range of feeding habits including dead wood, grass, leaf litter, and micro-epiphytes, III= feeding in the organic rich upper layers of the soil, IV= true soil-feeders, ingesting apparently mineral soil).(Feeding group of DeSouza and Cancello (2010): I=Wood and grass feeders, II= Litter feeders, III= Soil feeders, IV= Soil feeders) (Lifeway classification of Eggleton and Tayasu (2001): Sing(I)ww= Group I [wood (wet and dry), grass, detritus], lifetype single; Int(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype intermediate; Sep(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype separate; Group III= soil–wood interface, soil feeder;Group IV=soil feeder.Group III and IV are not classified by life types

Table 2: Comparison of the diversity and evenness indices of the present study with other studies

Range and inference	*Our study*	*Hemachandra et al., (2010)*	*Dosso et al., (2010)*	*Carrijo et al., (2009)*	*Zeidler et al., (2002)*
Study area	A thickly wooded campus (of Pondicherry University) at the East Coast of the Indian Peninsula	Two forest area : natural and secondary forest, Hantane forest range in Sri Lanka	Savanna, Cote d'Ivoire, Africa	Savanna, Brazil	Five farms in Northwestern Namibia
Number of species recorded	Thirteen	Eleven	Thirty one	Twenty nine	Six
Span of area covered	780 hectares	432 hectares	Not reported	2,862.3 hectares,	Not reported
Simpson's index Range: 0─1 0: Infinite diversity 1: No diversity	0.34 (High diversity)	─	0.80─0.90 (low diversity)	─	─
Shannon index Range: 0─4 Higher value represents greater diversity	1.45 (moderate diversity)	1.63 (secondary forest : moderate diversity) 0.68 (natural forest : lower diversity)	─	2.55 (pasture) (high diversity) and 2.82 (natural vegetation) (high diversity)	0 to 1.46 (no diversity to moderate diversity)
Pielou's index Range: 0─1 Higher the value more even the distribution	0.57 (moderate eveness in distribution)	─	0.27 to 0.46 (low to moderate distribution)	0.93 to 0.94 (even distribution)	─

bait method in the study area to check if any species is missed in the survey reported in this study (Kaur*et al.*, 2013). The baits had attracted six species which were otherwise also sampled using transect and quadrats.

4.0 Conclusion

A repertoire of locally established termite species was developed using a systematic survey. A total of thirteen species belonging to two families: Termitidae and Rhinotermitidae and four subfamilies: Macrotermitinae, Amitermitinae, Nasutitermitinae and Coptotermitinae and eight different genus were identified. Out of thirteen identified species twelve belonged to higher termites and one belonged to lower termite. *H.obscuriceps* was the most abundant and dominant species. The rare species were *M.pakistanicus, O.globicola,* and *E.paradoxalis*.

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Chapter 5

Termite biodiversity in Pondicherry University campus: a reappraisal on the basis of feeding preference studies

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Abstract

We have reported in Chapter 4 studies on the survey of termite species in the Pondicherry University campus by the transect and the quadrat methods. Subsequently an elaborate study was done on the feed preference of termites by using different types of baits singly and in combination. The study indirectly enabled us to augment the systematic biodiversity survey reported earlier as it provided us with the opportunity to a) witness the species which termigrade different types of ligninous biowaste in preference to other termite food like grasses, and b) check whether any species missed out in the previous survey shows up in this experiment.

Four types of baits were employed: unscented toilet paper roll, wood, paper and cardboard. The baits were placed at a few sites in the Pondicherry University campus, which had brisk termite activity as was noted by visual observation for a fortnight. The baits were then placed at the different sites individually as well as in combination and were left undisturbed for a period of one month to ensure unhindered foraging.

It was seen that baits containing multiple substrates attracted greater number of termite species than any substrate kept alone. The extent of foraging was also more than three times higher. Of the baits kept in isolation of each other, toilet paper roll attracted four species, cardboard and wood three species each, and writing paper, one. But, interestingly, writing paper was the most consumed of the four substrates, when kept in isolation as well as when kept together with the other baits.

The species observed in the study were among the thirteen identifed earlier by us through a systematic survey. Hence these experiments corroborate the previous report, besides providing interesting new information on the foraging behaviour of termites.

Key words: termites, baits, biodiversity, foraging behaviour, Pondicherry

Introduction

Alongside ants and earthworms, termites are called ecosystem engineers due to the role they play in soil processing, soil rejuvenation, and soil turnover (Dawes *et al*., 2003). As essentially detritivorous decomposers, termites strongly influence the ecological processes occuring in the soil (Lee and Wood, 1971; Jones *et al*., 1994; Lavelle *et al.*, 1997). Despite a general consensus among ecologists of the importance of termites, considerable knowledge gap exists about the functional roles of different termite taxa and the significance of termite diversity to soil function. Much of the published data on termite species richness and population density is not only location-specific but is difficult to generalize because different studies have used different sampling methods and experimental designs. The levels of animal collecting efforts have also varied (Eggleton and Bignell, 1995). As a consequence, it is not possible to make meaningful comparison between different findings or to identify generalities and differences among study sites. The information pertaining to termifauna of India is particularly sparse and it is also difficult to compare the reports of different authors.

As a part of the efforts to cover the existing knowledge-gap, a systematic survey of termite species in Northeastern Puducherry – which is the area where the authors are located – has been carried out. Initially two standard methods for faunal survey were employed, based on transects and quadrats, to ensure that the data is authentic and amenable to index development (Kaur *et al.*, 2010). The present study seeks to augment the previous survey, by using baits to attract termites. The baits consist of substrates which termites feed upon; hence this attempt is directed to attract foraging termites and the findings are expected to reflect relative intensity of the foraging activity of different taxa rather than relative population density. The method is useful in studying inter and intra specific foraging activity, size of foraging territory, rates of food consumption and estimation of local species richness.

Wooden stakes and rolls of unscented toilet paper have been the two most commonly used baits for termites (Jones *et al.*, 2005). Translocated dungpats (de Souza, 1993) and sawdust baits (Abensperg-Traun, 1993) have also been used. In the present study, four substances –unscented toilet paper, wood, paper waste and cardboard – have been used as baits, singly and in combination. The expectation was that it would provide an idea of which species prefers which substrate. The survey also provided an opportunity to check whether any species missed out in the previous surveys considerable.

Materials and methods

Study area

The study was carried out at Pondicherry University campus, located in the North Eastern Puducherry.

Methodology

The baits (unscented toilet paper rolls, wood, paper waste and cardboard) were placed at three sites. The sites were selected on the basis of brisk termite activity as determined by visual observation for a fortnight. These sites had less or no anthropogenic disturbance due to dense vegetation and limited access as compared to other sites in the University campus. At each site, baits were placed individually as well as in combination, but the stand-alone baits were atleast 5 meter away from the combined baits so that the presence of one does not influence the other. Indeed the baits were laid on the ground surface at 5 m intervals in a grid pattern, as shown in Figure 1. A total of 60 baits were placed and their influence was observed for four months. Each bait was examined for termite activity once in a week without disturbing the bait. The termites assembled at each bait were collected for identification. Signs of termite action included presence of termites or galleries, or hollowed areas where termites had consumed some of the substrate. Once in 30 days, the baits were assessed for the degree of consumption.

T_1	**W_2**	**PW_3**	**CB_4**
W_1	**PW_2**	**CB_3**	**T_4**
PW_1	**CB_2**	**T_3**	**W_4**
CB_1	**T_2**	**W_3**	**PW_4**

(a)

T	**W**
CB	**PW**

(b)

T-toilet paper roll, W-wood, P- paper waste, CB-card board

Figure 1: Positioning of baits (a) individual (b) mixed in grids of 5 m × 5 m

Termite sampling and identification

The sampled termites were identified with the help of a key compiled by us from various publications of the Zoological Survey of India (Bose, 1984; Rathore and Bhattacharyya, 2004; Maiti and Chakraborti, 1994) and other sources (Abe *et al.*, 2000; Bignell *et al.*, 2011).

The gist of the characters used for the identification are:

- Head: Shape, size, color, length and width (Figure 2)
- Antennae: Shape, number and size of the segments
- Mandible: Length, shape, size, arrangement of marginal teeth (Figure 2)
- Pronotum, Mesonotum and Metanotum: shape and margins (Figure 3)
- Labrum: Length, shape and hyaline tip
- Posmentum: Length, shape and size
- Legs: Number of tarsi segments
- Cerci: Number of cerci segments

Results and discussion

Six species in all were found to be attracted by the baits out of the thirteen species reported from the University campus by other methods. The six species belong to five genera and two sub-families: Amitermitidae and Termitinae of the family Termitidae ─ *Hypotermes obscuriceps*, *Macrotermes convulsionarius*, *Odontotermes anamallensis*, *O.globicola*, *Microtermes incertoides* and *Microcerotermes cameroni* (Figure 4). Termite activity on the baits was seen right from the first week.

Abensperg-Traun (1993) recorded wood-eating termite species at two food types ─ (i) at sound/undecayed artificial baits (seasoned wooden stakes of Jarrah, Karri, Pine, Batu, Oregon; Jarrah sawdust; paper rolls); and (ii) at naturally occurring timber, fallen logs and branches of eucalyptus, in varying stages of decay, in a *Eucalyptus capillosa* woodland in the Western Australian wheatbelt. They

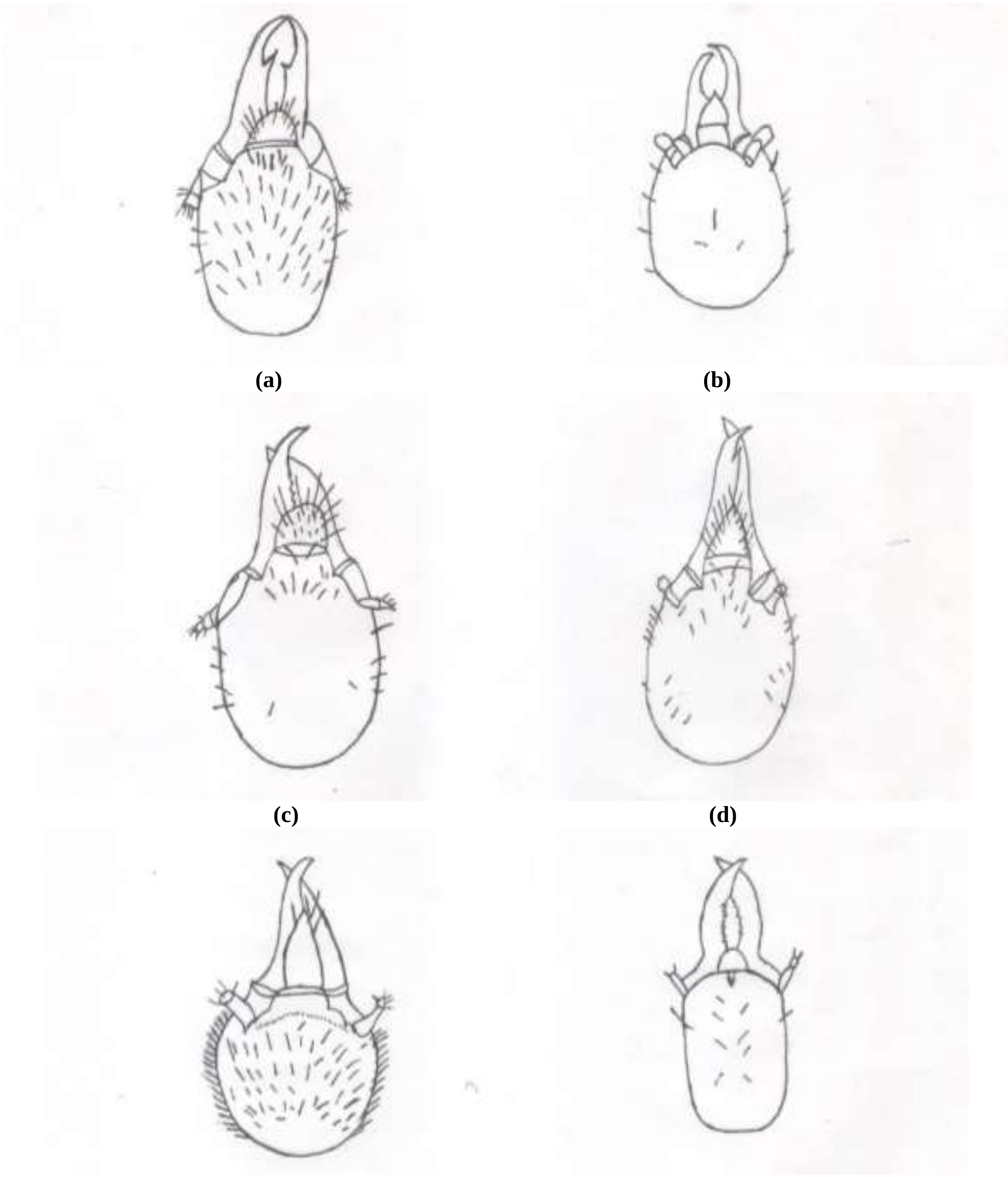


Figure 2: Head (in dorsal view) of the identified species

(a): *Odontotermes anamallensis*
(b): *Macrotermes convulsionarius*
(c): *Hypotermes obscuriceps*
(d): *Odontotermes globicola*
(e): *Microtermes incertoides*
(f): *Microcerotermes cameroni*

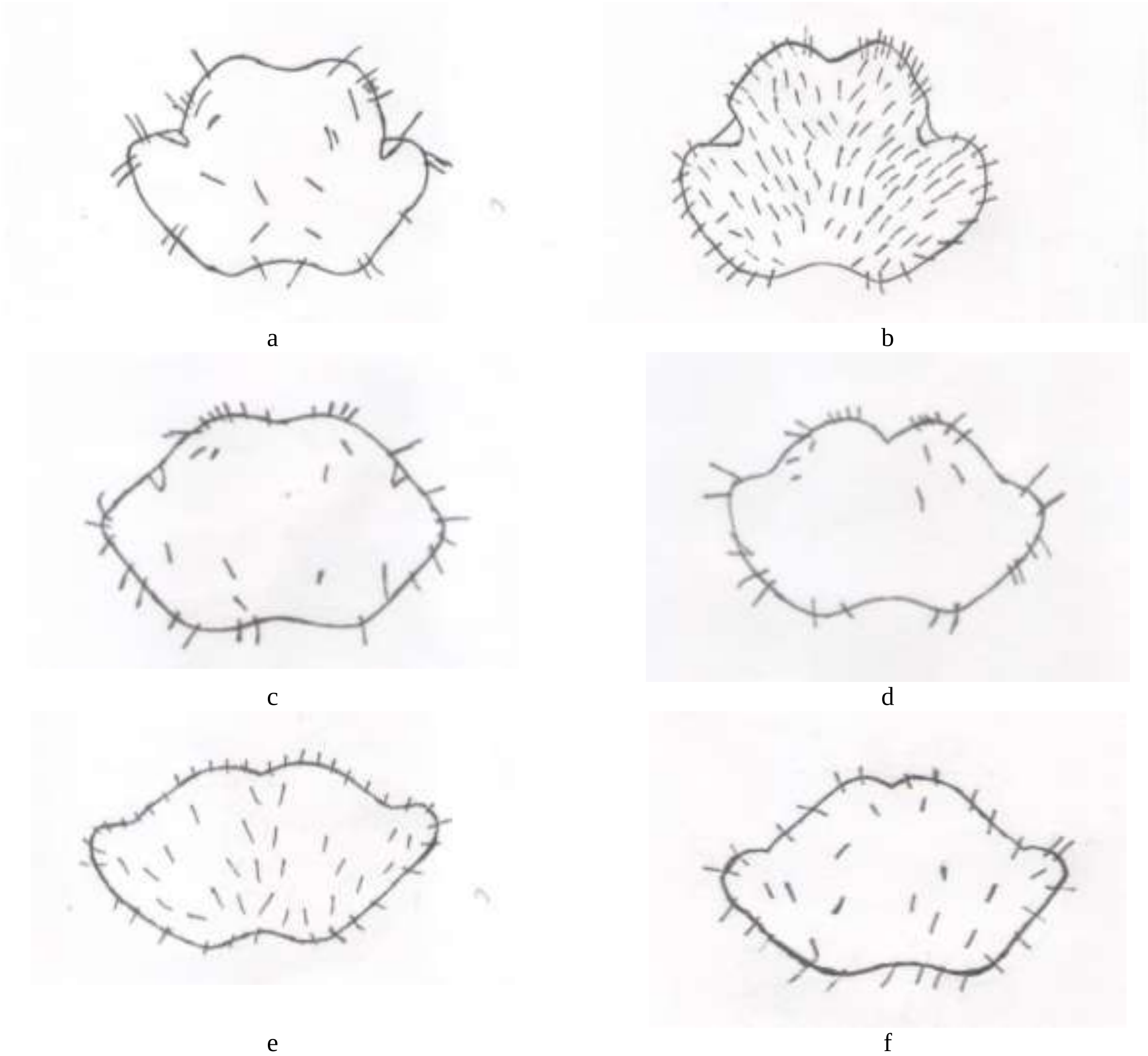


Figure 3: Pronotum (in dorsal view) of the identified species

(a): *Odontotermes anamallensis* (b): *Macrotermes convulsionarius*

(c): *Hypotermes obscuriceps* (d): *Odontotermes globicola*

(e): *Microtermes incertoides* (f): *Microcerotermes cameroni*

found that baits attracted 11 species while 18 species were recorded in the eucalyptus woodland, out of overall talley of 21 species. Sajap (1999) recorded attacks on buried stakes in a rubber plantation after 2 weeks. Haverty *et al.,* (1975) reported that bait units (toilet paper rolls) were attacked within first week of placing them.

Dawes-Gromadzki (2003) conducted baiting studies in two adjacent areas, 1-ha sites (closed v/s open vegetation structure) in wet–dry tropical savanna at the CSIRO Tropical Ecosystems Research Centre near Darwin, northern Australia. She recorded sixteen species, including eleven wood feeders on 144 baits comprising of twelve different substrates. Dawes-Gromadzki and Spain (2003) conducted studies in the same area and reported 11 species in three seasons (dry, wet and transistional).

Haverty *et al.,* (1976) studied comparison of two techniques: baits and circle quadrats for determining abundance of subterranean termites in an Arizona Desert Grassland. They reported two species: *Gnathamitermes perplexus* and *Heterotermes aureus* in toilet paper rolls baits, although none of the *Amitermes* species (*A.wheeleri* (Desneux), *A.minimus* Light, *A.emersoni* Light, and *A.silverstrianus* Light) attacked the bait. But all of these species were observed at least once during the sampling of wood present on surface and partailly buried by circle quadrat. Buxton (1981) studied communities of termites feeding on dead wood at surface of the ground by using discs of *Commiphors spp*. trees as baits in Tsavo National Park in South Kenya and observed seven termite species in 53 weeks study. de-Souza (1993) studied termite community structure in Brazilian cerrado, using rolls of toilet paper and attracted 41 species (including soil-feeding species).

Dawes-Gromadzki (2005) reported two species by using toilet paper rolls and stakes out of the five species collected by the direct search sampling strategy in Holmes Jungle Nature Reserve, a monsoon rainforest patch in northern Australia. In another study, Dawes-Gromadzki (2008), reported five species by using the same baits; whereas fourteen species were collected by the direct search sampling strategy in Charles Darwin National Park, a savanna woodland reserve in tropical northern Australia. But one genus was recorded using baits which was not observed by other methods. In the present study, the species recorded with baits were also reported by other direct sampling methods. Zeidler *et al.*, (2004) tested three methods (transect, visual searching and bait method) of sampling termite diversity in arid rangelands of Namibia. A total of 11 termite genera was found, including at least 19 species. No sampling method recorded all taxa. The baiting method detected 69% of the taxa, and the soil-excavating transect and the visual search method 63% each. In the present study, 46% of the species recorded by other methods was found using baits.

Most of the studies summarized above reveal that bait method is generally useful in augmenting direct search methods but does not, otherwise, normally generate as comprehensive a survey as the direct search methods do. In the present work, too, the number of species attracted by the baits (six) were far lesser than then the number of species (thirteen) revealed by direct surveys done earlier.

Table 1: Substrates consumed (g) when kept singly at three different sites

Days	Sites	Substrates							
		Paper waste		Cardboard		Toilet paper roll		Wood	
		Range	Average * ± SD	Range	Average* ± SD	Range	Average* ± SD	Range	Average* ± SD
0-30	I	65.1-75.6	67.3±3.0	65.6-68.6	67.3±1.2	59.2-61.2	60.3±0.9	47.0-49.0	48.0±0.9
	II	73.2-74.3	73.9±0.5	72.5-73.5	73.0±0.4	62.9-67.5	64.8±2.3	66.8-70.0	68.6±1.4
	III	78.9-81.9	79.9±1.4	77.0-78.0	77.4±0.5	69.9-73.0	71.1±1.3	67.6-68.4	67.9±0.4
31-60	I	11.8-12.7	12.3±0.5	10.8-12.8	11.5±0.6	9.6-10.8	10.2±0.5	9.0-9.8	9.3±0.4
	II	11.4-14.0	12.7±1.0	11.5-12.5	12.0±0.4	9.0-12.0	10.5±1.3	9.2-10.0	9.6±0.3
	III	12.9-14.1	13.5±0.5	13.0-14.1	13.4±0.5	11.7-13.1	12.2±0.6	10.7-12.0	11.3±0.6
61-90	I	17.8-19.1	18.5±0.5	18.3-19.4	18.7±0.5	14.0-14.4	14.2±0.1	11.8-13.7	12.8±0.7
	II	16.3-19.6	18.3±1.5	17.5-18.2	17.9±0.3	15.8-16.7	16.2±0.5	15.4-16.4	15.9±0.4
	III	18.9-20.7	19.5±0.8	17.9-19.2	18.3±0.6	15.8-16.8	16.2±0.5	13.4-14.8	13.9±0.6
91-120	I	7.4-8.2	7.8±0.5	6.4-7.2	6.8±0.3	5.5-6.5	6.0±0.4	4.3-6.7	5.4±1.0
	II	6.1-6.9	6.5±0.3	5.3-6.3	5.7±0.4	4.7-5.8	5.1±0.5	4.7-5.3	4.9±0.3
	III	7.5-7.8	7.7±0.1	6.2-7.5	6.8±0.5	5.4-6.9	6.0±0.6	5.0-5.6	5.3±0.3
Overall in 120 days (average of three sites)		109.1-118.3	112.6±4.0	107.3-112.4	109.6±1.5	94.5-101.5	97.6±3.4	88.3-93.9	90.9±2.4

* *Average of four baits*

Table 2: Substrates consumed (g) when kept together at site 1

Substrates	Consumption (g) of substrates kept together				
	0-30 days	31-60 days	61-90 days	91-120 days	Overall, in 120days
Paper waste	26.7	20.6	17.0	11.6	75.9
Card board	26.1	19.1	16.7	11.2	73.1
Toilet paper	22.1	15.6	14.7	10.1	62.5
Wood	20.9	11.7	13.9	9.3	55.8
Total	95.8	67.0	62.3	42.2	267.3

The extent of substrate consumption was much higher (upto three times) when all the four substrates were kept together, in comparison to the extent of consumption when individual substrates were kept in isolation (Tables 1 - 4). For example the maximum average substrate consumption in stand-alone baits was only 112.6 g (Table 1) in comparison to the maximum of 338.6 g consumed in multiple baits (Table 4).

The total number of species found in multiple baits, six, was also more than the number of species found in any individual bait (Table 5). These findings indicate that diversity of substrates attracts more species of termites and results in more brisk foraging than monotonous substrates.

Table 3: Substrates consumed (g) when kept together at site 2

Substrates	Consumption (g) of substrates kept together				
	0-30 days	31-60 days	61-90 days	91-120 days	Overall, in 120days
Paper waste	32.2	20.9	22.2	10.3	85.6
Card board	31.9	19.9	20.5	9.7	82.0
Toilet paper	26.1	16.3	18.9	7.9	69.2
Wood	24.2	15.2	17.3	7.3	64.0
Total	114.4	72.4	78.9	35.2	300.9

Table 4: Substrates consumed (g) when kept together at site 3

Substrates	Consumption (g) of substrates kept together				
	0-30 days	31-60 days	61-90 days	91-120 days	Overall, in 120days
Paper waste	40.4	21.4	22.2	11.6	95.6
Card board	40.7	20.3	19.7	11.1	91.8
Toilet paper	34.9	16.8	17.6	9.9	79.2
Wood	32.0	15.4	15.9	8.7	72.0
Total	148	73.9	75.4	41.3	338.6

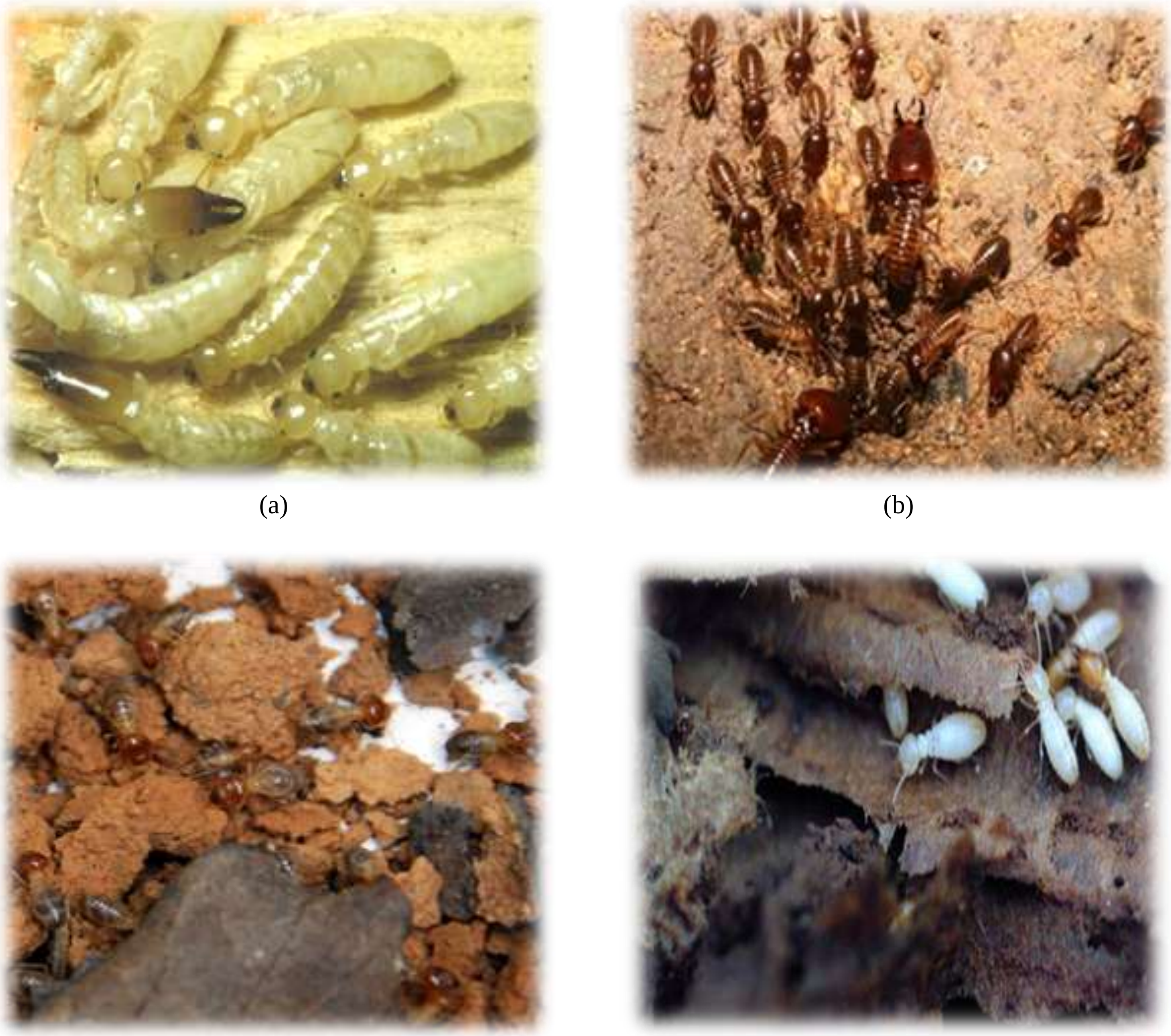
Among the four types of baits waste paper was consumed the most, closely followed by cardboard, toilet paper, and wood in that order. It is difficult to say why toilet paper was not foraged upon to the same extent as was waste paper but the difference is not great either ─ when kept singly, 85.3% of paper waste was consumed in comparison to 76.5% of toilet paper (dry weight basis). When kept along with other baits, 64.9% of the former was consumed in comparison to 55.1% of the latter. Perhaps greater extent of processing and refinement that goes in the making of toilet paper rendered if leaner in nutrients (consequently less appetizing for termites) than paper waste which is principally made up of writing paper.

In a study conducted by Lenz *et al.*, 2011 corrugated cardboard was consumed at the highest rate of *any* of the tested paper types and wood (different types of high quality papers, craft paper, tissue paper, recycled paper, newspaper, pamplets and japanese cedar wood) by both *Coptotermes formanus* and *Reticulitermes speratus.* Taylor *et al.*, (1998) have reported that cardboard blocks were attacked by termites to a greater extent (15%) than toilet paper (2%). It can be generalized that paper and cardboard are among the favourite feeds of the termites.

Upto 79.9 g of a stand-alone bait (waste paper) and upto 148 g of multiple substrates (at site 3) were consumed within the first 30 days. The rate of consumption then fell, and was particularly low during the fourth month. At no site the entire substrate was consumed. This indicates that large reservoir of food attract large number of termites and after the reservoir dwindles termites tend to move on without finishing the low quantities that remain.

Interestingly, even though paper waste was the most consumed of the baits, it attracted only one species ─ *H.obscuriceps.* Toilet paper roll was colonized mostly by *O.anamallensis, O.globicola* and *M.incertoides,* but at times *H.obscuriceps* was also observed. Wood was consumed by *M.convulsionarius, M.incertoides*, and *M.cameroni.* Cardboard attracted three species: *O.anamallensis, H.obscuriceps* and *O.globicola* (Table 3). Irrrespective of the positioning of the baits (individual or in combination), the termite species observed on the baits were same. Bose (1984) has reported that *M.cameroni* is generally found in live and dead wood, and decaying logs etc. In the present study, also, it was found only in wood. The consumed substrates with the tunnels formed by the termites on the different baits is shown in Figure 5.

It is reported (Abe *et al.*, 2000) that species belonging to subfamily Macrotermitinae, where present, have dominant role in the consumption of wood and leaf litter, with consumption rates (weight of litter consumed per unit area) upto 6 times higher than other groups. Dominance of Macrotermitinae can also occur in forests as well as drier ecosystems (Abe *et al.*, 2000). In the study area surveyed by us, also, Macrotermitinae seemed to be dominant, representing 5 out of the 6 species sampled from all the baits.



(a) (b)

(c) (d)

Figure 4: Different species attracted by diffrent baits (a) *O.annamallensis* on toilet paper rolls, (b) *M.convulsionarius* on wood, (c) *H.obscuriceps* on paper waste and cardboard and (d) *M.incertoides* on toilet paper rolls.

Table 5: Species attracted by different baits

Baits	Species it attracted
Toilet paper roll	*Odontotermes anamallensis, Microtermes incertoides, O.globicola, Hypotermes obscuriceps*
Writing paper	*H.obscuriceps*
Cardboard	*O.anamallensis, H.obscuriceps, O.globicola*
Wood	*M.incertoides, Macrotermes convulsionarius, Microcerotermes cameroni*
Combination of the above	*O.anamallensis, O.globicola, M.incertoides, H. obscuriceps, M. convulsionarius, M.cameroni*

(a) (b)

(c) (d)

Figure 5: Termite activity, including tunnel formation, on different baits

Out of three study sites, the consumption rate of the baits was the highest at the third site, followed by second and first sites respectively. The reason may be that the third site was the least anthropogenically disturbed and the most densely vegetated of the three sites.

Summary and conclusion

This study is a follow-up of the study presented in previous chapter on the survey of termite species in the Pondicherry University campus using the transect and the quadrat methods. To know the foraging behaviour of termites and to check whether any species missed out in the previous survey shows up, the present study spanning four months was carried out in which four types of baits ─ unscented toilet paper rolls, wood, paper waste and cardboard ─ were laid in three different sites in two patterns – individually and in combinations. Among the four types of baits, waste paper was the most consumed followed by cardboard, toilet paper, and wood in that order, when kept individually as well as in combinations. Baits containing multiples substrates attracted more species and were consumed to a much greater extent than baits of single substrate type. It was also seen that larger reservoirs of food seemed to attract greater foraging and as the reservoir dwindled the extent of foraging dropped as well. In the end some substrate was left unconsumed in all cases.

With the survey done earlier by using transect-based and quadrat-based sampling, a total of thirteen species were sampled and identified. But, only six species – *H.obscuriceps*, *M.convulsionarius*, *O.anamallensis*, *O.globicola*, *M.incertoides* and

M.cameroni - were attracted by the baits. Hence, it can be concluded that bait method is useful in augmenting direct search methods but does not, otherwise, normally generate as comprehensive a survey as the direct search methods do.

Acknowledgement

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A paper based on this chapter has been
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Chapter 6

Species survey and quantification of richness and diversity of termi-fauna at Auroville, India

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Abstract

In Chapters 4 and 5, we have described results of surveys done, first by quadrats and transects, and then by baits, respectively, in Pondicherry University campus situated at North Eastern Puducherry. More species were revealed by the former than by the latter. In this chapter, survey by quadrats and transects in Auroville located close to Pondicherry is presented. A total of ten species belonging to two families: Termitidae and Rhinotermitidae and eight different genera were identified. *Hypotermes obscuriceps* was the most abundant species, followed by *Macrotermes convulsionarius*. *O.feae* was the rare species.

Key words: Termigradation; Termites; Survey; Indices; India; Puducherry

Introduction

Termites are among the few species of insects which possess the ability to grind down even the kind of hard biowaste which defies composting and vermicompsting. They play an important role in processing ligninous wastes.

As discussed in Chapter 4, there is little *quantitative* information on the richness and diversity of termifauna of India. There does exist a lot of information, of which a good part has been compiled by the Zoological Survey of India, on species available in different regions of India and on ways to control them but much less is available, if any, in the form of *quantified* measures of species richness, diversity, prevalence etc.

Despite a general consensus among ecologists of the importance of termites, considerable knowledge gap exists about the functional roles of different termite taxa and the significance of termite diversity to soil function. Much of the published data on termite species richness and population density is not only location-specific but is difficult to generalize because different studies have used different sampling methods and experimental designs (Kaur *et al.*, 2013). As a part of the efforts to cover the existing knowledge-gap, a systematic survey of termite species in Northeastern Puducherry – which is the area where the authors are located – has been carried out and reported elsewhere (Kaur *et al.*, 2013, 2014a). To extend the survey in Pondicherry region we have carried survey of termite species in Auroville (Figure 1).

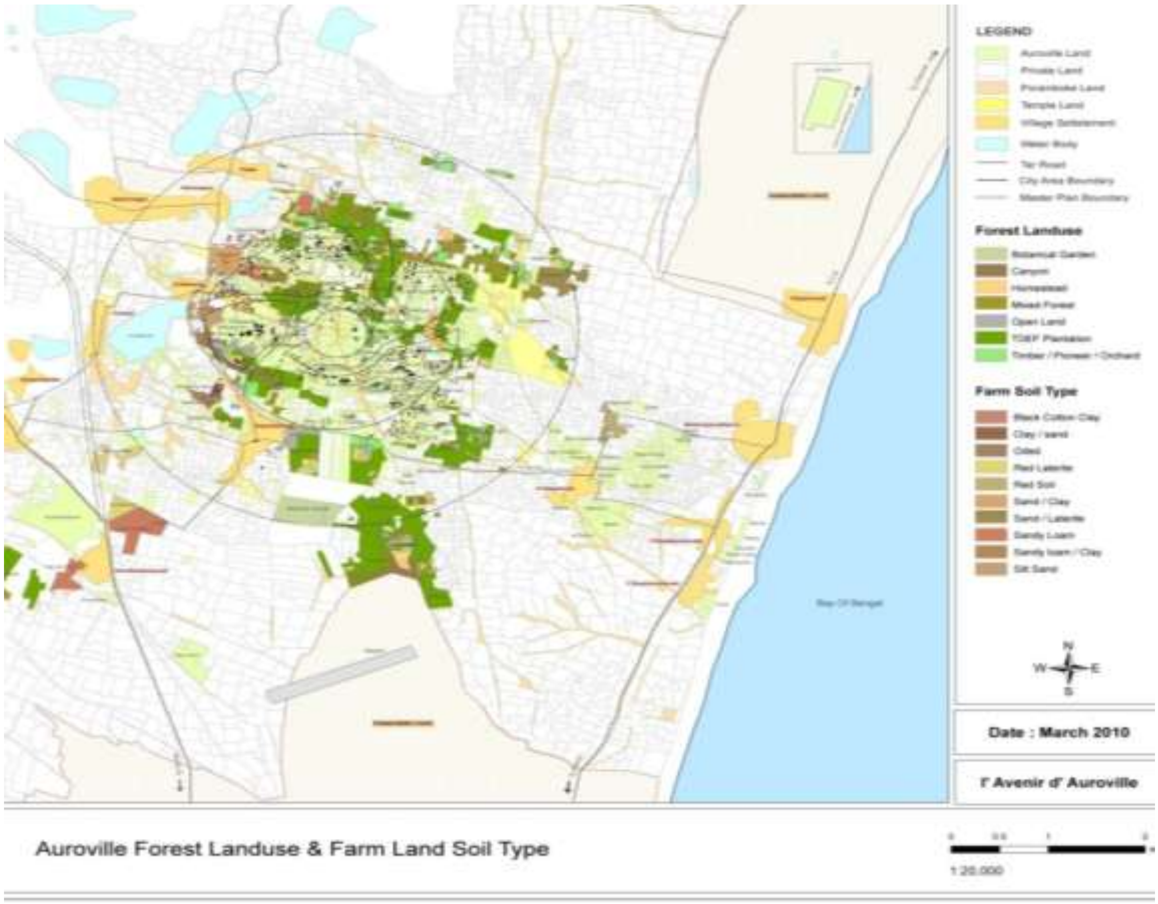

Figure 1: Auroville forest landuse pattern

Materials and Methods

Study area: The study was carried out at four sites in Auroville, which is situated 10 kms north of downtown Puducherry. The core area has a radius of 1.25 km, and is surrounded by a 1.25 km wide green belt. A number of organic farms, dairies, orchards, social forests and wildlife areas are situated in Auroville providing it with a kind of wilderness quality.

Auroville has been organized by its township management into 44 sub-areas (forests). Four of these sub-areas : Aurodam, Gaia, New Lands and Revelation were selected by us for termite survey as they were most representative of the land-use pattern in the region (Figure 2).

The first of the chosen sub-areas, Aurodam, spans 84.6 acres. It consists of cashew and acacia plantations, orchards, etc. The second sub-area is Gaiaand spans 57.7 acres. It is more thickly vegetated than the other three sub-areas chosen by us. The total area of Newlands is 48.7 acres and more than 95% of the area is wooded. The total area of the Revelation is 76 acres.

Methodology: An authentic map of the Auroville area were obtained from the authorities of Auroville. It is to 1:4000 scale for three sub-areas ─ Aurodam, Gaia and Revelation, and 1:3000 scale for Newlands. Three sets of experiments, designed and performed independently of each other were carried out to survey the distribution and prevalence of different species of termites. The experiments were based on transects, quadrats and baits as reported in Kaur *et al.*, 2014b. Each of these has been extensively used in faunal surveys and yields data that can be resolved into indices. The protocol, described by Jones and Eggleton (2000), was adapted from a similar method developed by Eggleton *et al.* (1996). The protocol has been used in many tropical forests around the world (Gathorne-Hardy *et al.*, 2002, Davies *et al.*, 2003). The protocol describes sampling of termites using transects and quadrats.

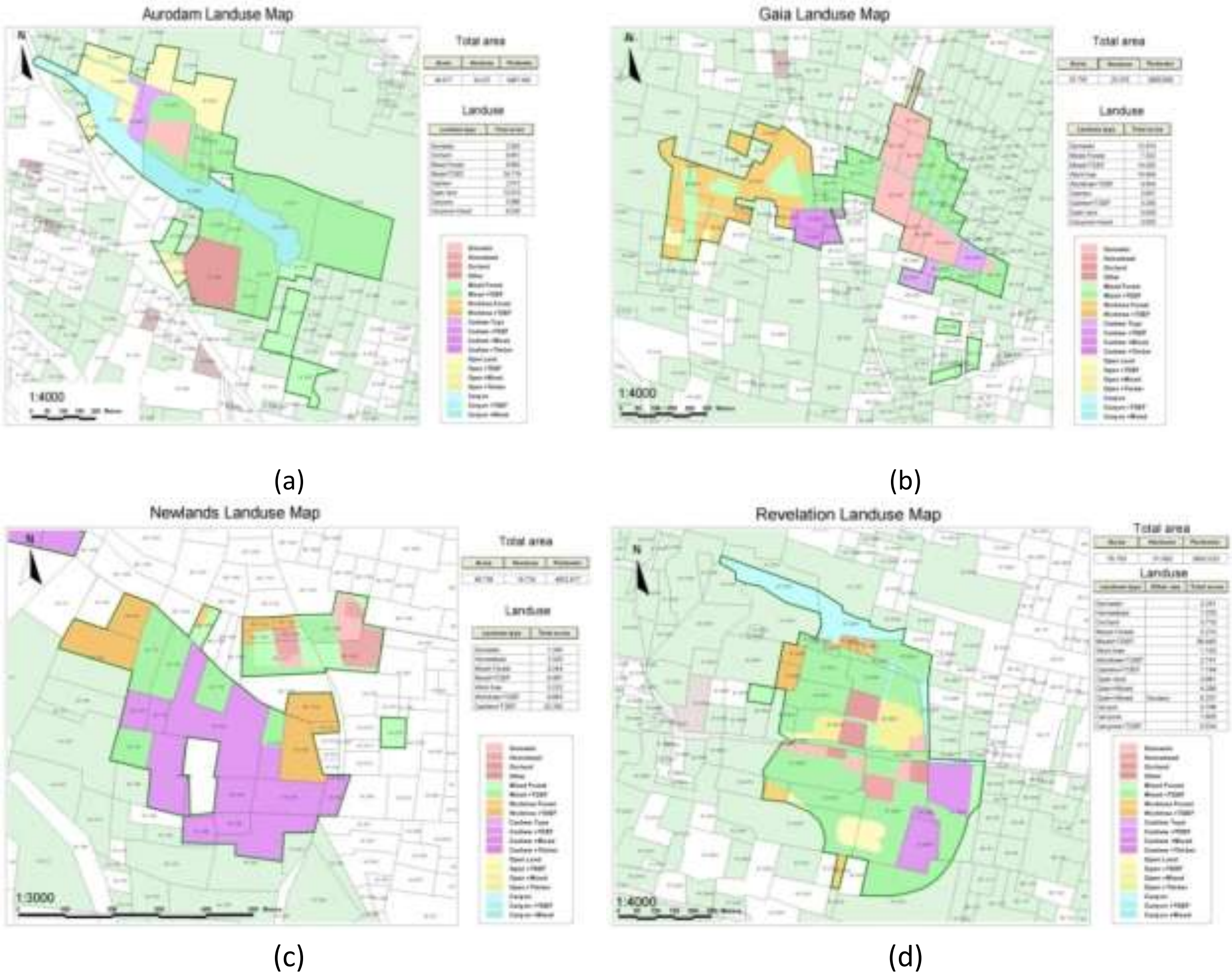

Figure 2: a, b, c and d : Four areas of Auroville forest where survey was conducted

Transect of 100 m long and 2 m wide, was marked and divided into 20 contiguous sections (each 5 m × 2 m) and numbered sequentially. Two trained people sampled each section for 30 minutes (a total of one hour of collecting per section). In each section the following microhabitats were searched for termites: 12 samples of surface soil (each 12 cm × 12 cm, to 10 cm depth); accumulations of litter and humus at the base of trees and between buttress roots; the inside of dead tree stumps, logs, branches, and twigs; the soil within and beneath very rotten logs; all mounds and subterranean nests encountered (checking for inquiline species); arboreal nests, carton runways, and sheeting on vegetation up to a height of 2 m above ground level.

The number of encounters with termites (hits) of a given species within a transect was taken as the relative abundance of that species within that transect. Termites specimens collected for identification were stored in 80 percent isopropyl alcohol. Collected termites were identified by us with the key developed by us by compiling various books (Bose, 1984; Chottani, 1997; Abe *et al.*, 2000).

Results and Discussion

A total of ten species appeared in the samples. They were found to belong to six genera of family Termitidae and one genus of the family Rhinotermitidae (Table 1). The proportion of the identified species based on the number of individuals sampled is shown in Figure 3. *H.obscuriceps* was the most abundant species in all the four sub-areas followed by *M.convulsionarius* and *O.annamallensis. O.feae* was the rare species as was surveyed only from Newlands.

Feeding and nesting habit **-** The substrate preference of the sampled termites, and the feeding groups under which they can be termites are classified in Table 2.

Based on nest type and foraging habit, Abe (1987) has distinguished the termites into single-piece nesters, intermediate nesters, and separate-piece nesters. Wood-feeding termites are single piece nesters. They feed and nest in the same discrete substrate. Intermediate nesters nest in their feeding substrate but also forage out from the colony centre to find other patches of feeding substrate nearby. Again, these are wood-feeding termites. The third group is the separate-piece nesters; they do not nest in their feeding substrate and actively forage for their feeding substrate away from the nest, which does not act as a primary feeding substrate. These have a wide range of feeding substrates.

Another classification proposed by Abe (1987) categorizes the termites based partly on the substrate consumed into wet wood, dry wood, arboreal termites, subterranean termites, and humus-feeding termites.

Based on the site of collection, abdominal colour and feeding biology of the termites, Sleaford *et al.*, (1996) have grouped the termites into four functional groups – soil feeders, soil/wood interface feeders, litter feeders, and wood feeders.

Table 1: Taxa of the termites recorded from Auroville forest

Name of the species	*Family*	*Sub-family*
Hypotermes obscuriceps Wasmann	Termitidae	*Macrotermitinae*
Macrotermes convulsionarius Konig	Termitidae	*Macrotermitinae*
Odontotermes anamallensis Holmgren and Holmgren	Termitidae	*Macrotermitinae*
Odontotermes brunneus	Termitidae	*Macrotermitinae*
Odontotermes redemani Wasmann	Termitidae	*Macrotermitinae*
Odontotermes feae Wasmann	Termitidae	*Macrotermitinae*
Microtermes obesi Holmgren	Termitidae	*Macrotermitinae*
Trinervitermes nigrirostris Mathur and Sen-Sarma	Termitidae	*Nasutitermitinae*
Dicuspiditermes spp.	Termitidae	*Termitinae*
Coptotermes ceylonicus Holmgren	Rhinotermitidae	*Coptotermitinae*

Based on gut content analysis correlated with the morphology and anatomy of worker termites, a quantitative functional classification of termite feeding groups have been given by Donovan *et al.*, (2001) They classified termites into four feeding groups: feeding group I, which comprises wood, litter and grass feeders; feeding group II, comprising wood, litter and grass feeders; feeding group III, which includes very decayed wood or high organic content soil feeders; and feeding group IV, representing low organic content soil feeders ('true soil feeders'). This classification is followed widely and reported by other authors (Jones and Prasetyo, 2002; Davies *et al.,* 2003; Bignell, 2011).

Eggleton and Tayasu (2001) have proposed lifeway classification, which combines Abe's lifetypes classification and Donovan's feeding groups. It comprises of eight groups – six categories within the non-single piece nesters, dry wood and wet wood single-piece nesters. The eight groups are distributed across the two gradients (i) the state of humification of the feeding substrate; and (ii) the degree to which the feeding and nesting substrates overlap.

Termites have been classified into two major feeding groups ─ wood/litter feeders (including fungus-growers) and soil feeders – by Yamada *et al* (2007). Wood/litter feeders are involved in the decomposition of aboveground organic matter (i.e., fine litter as well as small and large woody litter), while soil-feeders contribute to the decomposition of below ground organic matter (i.e., soil organic matter).

Based on the habitat, Capinera (2008) has grouped termites as drywood, dampwood, rotten wood, and subterranean. DeSouza and Cancello (2010) have classified termite species into four feeding groups or functional taxonomic groups, according to the proportion of the humification gradient they feed on. Group I include termites feeding on dead wood and grass. It comprises of lower termites. The other three groups are represented by Termitidae. Group II include termites with a range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus comb and conidia. Soil-wood feeders constitute the group III which includes termites feeding in the organic rich upper layers of the soil, presumably feeding on the soil-wood interface. Group IV are called 'true soil-feeders', ingesting mineral soil to feed on organic matter usually found highly dispersed therein.

Based on the substrates from where the termites were collected, the species sampled in the present study have been matched with the feeding groups reported by different authors (Table 2). All the sampled species are wood/litter feeders having a wide range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus-comb, conidia, etc. They are either separate piece nesters or intermediate nesters. There was no representative of soil-wood feeder which feeds on organic rich upper layer of the soil (Group III and IV of Donovan, 2001).

Species dominance, diversity and evenness – As detailed in chapter 4, there are several studies on termites (Roonwal, 1978; Basu *et* al, 1996; Pardeshi *et al*, 2010; Kumar *et al.*, 2011; Kumar and Thakur, 2010, 2013), but due to lack of use of similar protocol these studies cannot be compared with our studies.

There are other authors who have reported the study on survey in different locations and reported diversity indices (Wood *et al.*, 1982; Akhtar, 2001; Manzoor *et al.*,2011), but these studies cannot be compared with our indices as the samples were collected only from soil cores.

Bama and Ravindran (2011) have studied the termite diversity under different land use regimes of Dindigul district, Tamil Nadu. They have used modified transect protocol and recorded ten species by sampling different land use patterns such as plains, woodlands and hilly areas. Rao *et al.*, (2012) conducted survey to investigate diversity of termite and their damage to living trees of Bhadrachlam forest (1,44,603 ha) in Andhra Pradesh by transect protocol and recorded thirteen species. Varma and Swaran (2007) studied diversity of termites in young eucalypt plantation in tropical forests in Kerala by transect sampling and additionally every month sampling of foraging termites for one year and reported fourteen species (eleven by transect and three by monthly sampling) and among fourteen species surveyed only four were found attacking eucalypt seedlings. But these authors have not reported the diversity indices.

An attempt has been made to compare the species richness and diversity of termites sampled in the present study with that of others who have also followed similar methods of sampling and indices development (Table 3). Hemachandra *et al.*, (2010) examined termite assemblages in patches of undisturbed natural forest and secondary forest spanning 432 ha. In addition, random collections of termites were carried out in both the forests for species determination. They recorded eleven species overall: nine species in the secondary forest (four species by transect sampling, three by random sampling and two by both methods), and two species in the natural forest of which neither was recorded from secondary forest. As a consequence, the Shannon diversity index as computed by them was higher for the secondary forest (1.63) compared to natural forest (0.68).

In the present study, ten species were found which all happen to be wood/litter feeders. The Shannon index of the study area is much higher (H’=1.74─1.82) compared to the natural forest surveyed by Hemachandra *et al.*, (2010). They recorded only soil feeders from natural forest, and attributed the absence of wood feeders there to the natural forest’s altitude and climate. Moreover, they have reported only five dominant species of trees and the litter comprised of small twigs of pencil size and sparse leaf litter in the natural forest. The reason for the presence of only wood/litter feeders in the present study area may be that it has much more diverse tree species and the litter generated is of different types ranging from small to large leaves, small twigs to large barks, shallow patches of litter to thick mulch covering large spans.

Carrijo *et al.*, (2009), surveyed two areas: pasture and natural vegetation of State Park, Goias, Brazil by following the same protocol as in the present study except that their transects were twice as long,. They recorded a total of twenty nine species (seventeen in pasture and twenty one in natural vegetation). The Shannon diversity indices were 2.55 and 2.82 for pasture and natural vegetation respectively. Brazilian savanna is the richest tropical savanna in the world (da Silva and Bates, 2002) and part of the world’s 25 biodiversity hotspots. Hence, as expected, the Shannon diversity index in both vegetations (2.55 and 2.82 at pasture and natural vegetation respectively) are higher than our study area (H’=1.74─1.82).

In the survey conducted by Zeidler *et al.*, (2002) in five farms in the Southern Kuene region, Namibia, a total of ten species was recorded. In each farm they studied a site each of high and low land use intensity. In each area 400 m^2 was surveyed which is twice the area normally used for representative sampling (Jones and Eggleton, 2000). They concluded that termite species assemblages differed between the various forms, as well as across the land-use intensity gradients. The Shannon indices obtained by them ranged from 0─1.46, indicating zero diversity to moderate diversity. The Shannon indices of Auroville forests were higher (H’=1.74─1.82) than compared to study area of Zeidler *et al.*, (2002).

Four different habitats differing in their vegetation and fire history: annually burned savanna, savanna woodland, forest island and gallery forest, in Cote d’Ivoire, West Africa was studied by Dosso *et al.*, (2010). They recorded a total of thirty species. The Simpson index for the areas ranged between 0.80 to 0.90 which indicates generally a low diversity compared to the present study in which the Simpson index value of 0.17 to 0.21 represents very high diversity (Table 3). Among the four habitats studied by Dosso *et al.*, (2010), the forest island was having the highest number of termite species, followed by the gallery forest and the savanna woodland. The forest island and gallery forest has more number of termite species than annually burned savannah as they act as refuge to species that are sensitive to regular fire that occurs in annually burned savannah. Between savanna woodland and annually burned

Table 2: Feeding groups of the termites recorded from Auroville forest

Name of the species	*Foraging/feeding substrate*	*Life type classification of Abe (1987) based on nesting type and foraging habit*	*Feeding group of Donovan et al., (2001)*	*Lifeway classification of Eggleton and Tayasu (2001)*	*Feeding group Yamada (2007)*	*Feeding group of DeSouza and Cancello (2010)*
Hypotermes obscuriceps Wasmann	Mound and leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
Macrotermes convulsionarius Konig	Leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
Odontotermes anamallensis Holmgren and Holmgren	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes brunneus Hagen	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes redemani Wasmann	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes feae Wasmann	Dead wood and leaf litter	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Microtermes obesi Holmgren	Shrubs and forest trees	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Trinervitermes nigrirostris Mathur and Sen-Sarma	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Dicuspiditermes spp.	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Coptotermes ceylonicus Holmgren	Dead wood	Single-piece nesters	I	Sing(I)ww	Wood/litter feeders	I

Feeding groups of Donovan *et al.,* (2001): I= dead wood and grass-feeders, II= Termites with a range of feeding habits including dead wood, grass, leaf litter, and micro-epiphytes, III= feeding in the organic rich upper layers of the soil, IV= true soil-feeders, ingesting apparently mineral soil).(Feeding group of DeSouza and Cancello (2010): I=Wood and grass feeders, II= Litter feeders, III= Soil feeders, IV= Soil feeders) (Lifeway classification of Eggleton and Tayasu (2001): Sing(I)ww= Group I [wood (wet and dry), grass, detritus], lifetype single; Int(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype intermediate; Sep(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype separate; Group III= soil–wood interface, soil feeder;Group IV=soil feeder.Group III and IV are not classified by life types

Table 3: Comparison of the diversity and evenness indices of the present study with other studies

Range and inference	*Auroville forest*				*Kaur et al., (2014)*	*Tenon et al., (2013)*	*Materu et al., (2013)*	*Hemachandra et al., (2010)*	*Dosso et al., (2010)*	*Carrijo et al., (2009)*	*Zeidler et al., (2002)*
	Aurodam	*Gaia forest*	*Newlands*	*Revelation*							
Study area	It consists of cashew and acacia plantations, orchards, etc.	It is more thickly vegetated than the other three sub-areas chosen by us	More than 95% of the area is wooded	More than 90% of the area is covered by canyon, mixed forest, orchard, cashew etc.	A thickly wooded campus (of Pondicherry University) at the East Coast of the Indian Peninsula	Savannas of Northern of Cote d'Ivoire.	In three different area like cropland, forest and grassland in Dar es Salaam, South Africa	Two forest area : natural and secondary forest, Hantane forest range in Sri Lanka	Savanna, Cote d'Ivoire, Africa	Savanna, Brazil	Five farms in Northwestern Namibia
Number of species recorded	Eight	Seven	Nine	Seven	Thirteen	Twenty seven	Sixteen from forests, thirteen from cropland, and seven from grassland.	Eleven	Thirty one	Twenty nine	Six
Span of area covered	34.2 hectares	23.4 hectares	19.7 hectares	31.1 hectares	780 hectares	Not reported	53,000 hectares	432 hectares	Not reported	2,862.3 hectares	Not reported
Simpson's index Range: 0—1 0: Infinite diversity 1: No diversity	0.19 (Rich diversity)	0.17 (Rich diversity)	0.21 (Rich diversity)	0.19 (Rich diversity)	0.34 (High diversity)	0.78 to 0.94 (very low diversity for savanna and plots regularly cultivated during 1 year and gradually increased as regularly cultivated years increased)	—	—	0.80—0.90 (low diversity)	—	—
Shannon index Range: 0—4 Higher value represents greater diversity	1.82	1.78	1.74	1.80	1.45 (moderate diversity)	1.72 to 2.91(v low diversity for savanna and plots regularly	Three areas (in wet and dry season): forest having higher diversity (2.2836 and	1.63 (secondary forest : moderate diversity) 0.68 (natural	—	2.55 (pasture) (high diversity) and 2.82	0 to 1.46 (no diversity to moderate diversity)

Range and inference	Auroville forest				Kaur et al., (2014)	Tenon et al., (2013)	Materu et al., (2013)	Hemachandra et al., (2010)	Dosso et al., (2010)	Carrijo et al., (2009)	Zeidler et al., (2002)
	Aurodam	Gaia forest	Newlands	Revelation							
						cultivated during 1 year and gradually increased as regularly cultivated years increased)	1.8724) followed by cropland (2.0485 and 1.7432), and grassland (1.4854 and 1.2669).	forest : lower diversity)		(natural vegetation) (high diversity)	
Pielou's index Range: 0—1 Higher the value more even the distribution	0.88 (even distribution)	0.92 (even distribution)	0.79 (even distribution)	0.93 (even distribution)	0.57 (moderate eveness in distribution)	—	(in wet and dry season): in cropland, wet-0.73885; dry-0.62872.forest: wet-0.82362;dry-0.67534.Grassl and:wet-0.53573;dry-0.0458.	—	0.27 to 0.46 (low to moderate diversity)	0.93 to 0.94 (even distributio n)	—

savanna, savanna woodland had more number of species as the woodland consisted of savanna patches randomly unburned for five years, whereas annually burned savannah being fuel rich is burned deliberately every year. In our study area, Gaia has highest diversity followed by Aurodam, Revelation and Newlands.

Materu *et al.*, 2013 carried out termite species richness and abundance in an area of about 53,000 ha in Dar-es-Salaam, South Africa, in three different areas: cropland, forest and grassland. The Shannon's index (H') reported by them was highest in the forest in both wet and dry seasons (wet-2.2836; dry-1.8724), followed by cropland (wet-2.0485 and dry-1.7432) and grassland (wet-1.4854; dry-1.2669). In our study, the Shannon index of 1.74-1.82 was almost similar to that reported by Materu *et al.*, (2013) in the forest and cropland surveyed by them during dry season (1.8724).

Tenon *et al.*, (2013) assessed of termite diversity in Savannas of Northern of Cote d'Ivoire. They sampled 27 species obtaining a Shannon index (H') value of 2.88 which is substantially higher than the values obtained in Auroville. Simpson index of 0.94 represent low diversity when compared to Auroville which is very rich in diversity with the index between 0.17 – 0.21.

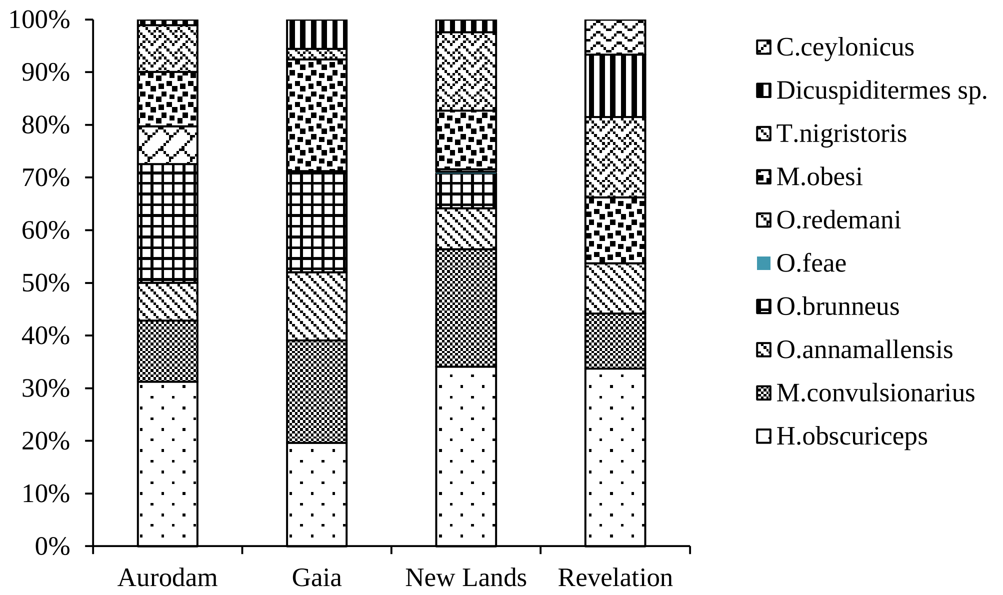

Figure 3: Proportion (number of individuals expressed in %) of the identified termite species in four surveyed forests in Auroville

The Pileou's index reported by Dosso *et al.,* (2010) ranged between 0.27–0.46 representing low to moderate evenness in distribution of species in four different study sites (annually burned savanna, savanna woodland, forest island and gallery forest), whereas in our study, the Pileous index of 0.79 – 0.93 indicate even distribution of species in that respect. Pielou's index reported by Carrijo *et al.,* (2009) are 0.94, 0.93 for pasture and for natural vegetation, respectively, also indicate that the species are evenly distributed. Materu *et al*., (2013) reported Pielou's index value in three different areas in wet and dry season. The forest had high evenness in distribution of species (wet-0.82362; dry-0.67534) compared to cropland (wet- 0.73885; dry- 0.62872), and grassland. In grassland, the distribution of species was moderate in wet season (0.53573) and very low in dry season (0.0458). In our previous study done in Pondicherry University (Kaur *et al.,* 2014), the Pileou's value is 0.57 which indicates moderate evenness in distribution of species. In the present study, Gaia (0.92) and Revelation (0.93) had less variation in species distribution compared to Aurodam (0.88) and Nwlands (0.79).

Sorenson's coefficient of similarity has shown that Gaia and Newlands, Gaia and Revelation, Aurodam and Gaia, and Aurodam and Newlands are similar to each other with value of 0.9, whereas Newlands and Revelation, and Aurodam and Revelation are similar to each other with value of 0.8.

Hence it can be concluded that termite species in the present study areas exhibit less evenness in distribution. The Simpson's index of 0.17 to 0.21 indicates that all these subareas are richly diverse. On the other hand, the Shannon diversity index (1.74-1.82) indicates that there are a few abundant species (*H.obscuriceps, M. convulsionarius*).

Conclusion

A repertoire of locally established termite species was developed using a systematic survey. A total of ten species belonging to two families: Termitidae and Rhinotermitidae and five subfamilies: Macrotermitinae, Amitermitinae, Nasutitermitinae, Termitinae and Coptotermitinae and eight different genus were identified. Out of ten identified species nine belonged to higher termites and one belonged to lower termite. *Hypotermes obscuriceps* was the most abundant species as was surveyed from all the four areas followed by *M.convulsionarius*. *O.feae* was the rare species as was surveyed only from Newlands.

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Chapter 7

An appraisal of bait-based survey of termifauna with references to studies in Auroville, India

Abstract

In Chapters 4 and 5 we have described results of surveys done, first by quadrats and transects, and then by baits, respectively, in Pondicherry University campus situated at North Eastern Puducherry. More species were revelaed by the former than by the latter.

Subsequently we have conducted, as described in Chapter 6, survey by quadrats and transects in Auroville located close to Pondicherry. In the present study, an appraisal of bait-based method has been carried out in the same area. Six different types of baits were used. The baits differed in the way of placement (above or below ground) and moisture (dry or wet). Eleven species belonging to seven genera: *Odontotermes, Hypotermes, Macrotermes, Trinervitermes, Microtermes, Coptotermes* and *Dicuspiditermes* were recorded, whereas by transect and quadrat, ten species belonging to the same seven genera were identified.

Keywords: Termites, bait, foraging, Auroville

Introduction

A systematic survey of termite species in Northeastern Puducherry – which is the area where the authors are located – has been carried out and reported in Chapters 4 and 5. To extend the survey in Pondicherry region we have conducted survey of termite species in Auroville using transects and quadrats which is reported in Chapter 6. The present study reports the survey done in the same area with baits.

Baits attract foraging termites and therefore give the estimate of relative intensity of foraging activity rather than relative population density. It is useful in studying inter and intra specific foraging activity, size of foraging territory, rates of food consumption and estimation of local species richness. Moreover bait method has the potential of bringing to view species which the other two methods might have missed.

Hence, this elaborate study has been done on the feed preference of termites by using different types of baits placed singly and in combination. The study has been done to augment the other systematic biodiversity surveys done as it provides the opportunity to:

a) witness the species which termigrade different types of ligninous biowaste in preference to other termite food, and
b) check whether any species missed out in the previous survey showed up in this experiment.

Materials and method

The study was carried out at four sites in Auroville, which is situated 10 kms north of downtown Puducherry. The core area has a radius of 1.25 km, and is surrounded by a 1.25 km wide green belt. A number of organic farms, dairies, orchards, social forests and wildlife areas are situated in Auroville providing it with a kind of wilderness quality. Auroville has been organized by its township management into 44 sub-areas (forests). Four of these sub-areas: Aurodam, Gaia, Newlands and Revelation were selected by us for termite survey as they were most representative of the land-use pattern in the region.

The first of the chosen sub-areas, Aurodam, spans 84.6 acres. It consists of cashew and acacia plantations, orchards, etc. The second sub-area is Gaia and spans 57.7 acres. It is more thickly vegetated than the other three sub-areas chosen by us. The total area of Newlands is 48.7 acres and more than 95% of the area is wooded. The total area of the Revelation is 76 acres.Six sites in each sub-area, which had brisk termite activity, were selected to keep the baits.

The baits consisted of:

(i) Grass - local species of grass was collected and air dried at room temperature
(ii) Saw dust
(iii) Cow dung pads

(iv) Wood: two stakes installed in contact with one another, as the interface between the stakes tends to encourage rapid colonization by subterranean termites.
(v) Toilet paper roll: single ply, unscented, unbleached rolls.
(vi) Cardboard: rolls of corrugated cardboard.

All the baits were wrapped in aluminium foil and tied with insulation tape to prevent their unrolling and spillage, and also for protection from rain. The wrapping was done in a manner that left easy passages for termites from three directions except, the top.

The baits were placed in four different ways:

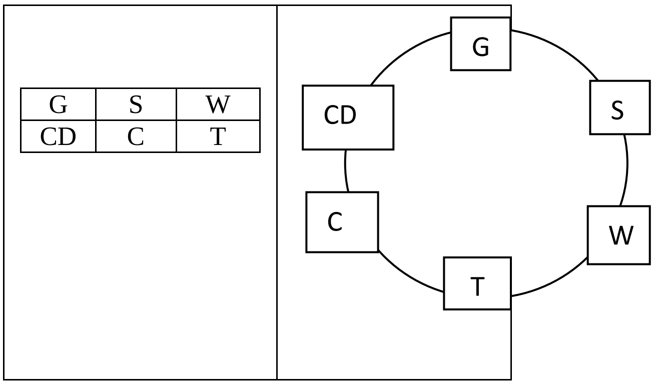
a. In dry form
b. In wetted form
c. On the soil surface
d. Buried in the ground

The first sets of baits were placed above the ground (dry, not moistened with water). The second set of baits were moistened with water and placed above the ground. The third sets of baits were placed 2 cm below the ground and covered with soil. The fourth set of baits were moistened with water, placed below the ground, and covered with soil.

Out of the six sites, in four sites the baits were placed in grids as explained below. A 30m x 30m plot was divided into 36 sub-plots of size 5m x 5m (Figure 1a). In each sub-plot the baits were placed in the centre. In the next site, the baits were placed in rectangular grids (10m x 15m) (Figure 1b) and in circular form in the sixth site where it began with grass pads and ended with cow dung pads as represented in Figure 1c.

G	S	W	T	C	CD
S	W	T	C	CD	G
W	T	C	CD	G	S
T	C	CD	G	S	W
C	CD	G	S	W	T
CD	G	S	W	T	C

(a)



(b) (c)

G-grass; S-saw dust; W-wood; T-toilet paper roll; C-cardboard; CD-cow dung pads

Figure 1. Positioning of baits (a) in the grids of 5m x 5m (b) in rectangular grids(c) circular fashion.

After four months of start up of the study, there was catastrophe due to the cyclone *Thane* (30thDec 2011). The uprooted trees caused difficulty in access to three sub-areas (Gaia, Newlands and Revelation). Hence, the study was continued for another six months only in Aurodam, in which the logs of fallen trees were cleared off.

Results and discussion

Species located

Termite activity on the baits was seen right from the first week. The number of species sampled from the baits in each of the study area given in Table 1. In Aurodam, nine species were found overall. Toilet paper roll, cardboard, wooden stakes and sawdust each attracted four species while cowdung attracted three. In grass, two species were observed. Six species were sampled from baits placed in Gaia, and eight each from Newlands and Revelation (Table 1).

The surveyed termites were placed into feeding groups based on the classifications proposed by Donovan *et al.*, (2001a), Yamada (2007) and desouza and Cancello (2010) as discussed in Kaur *et al.*, (2014). Out of the total of eleven species surveyed using baits, *C.ceylonicus* is a wood feeder, *Dicuspiditermes sp.* is a soil feeder and the rest are litter feeders.

In an earlier study, the authors have surveyed the same four areas using transects and quadrats (Kaur *et al.*, 2014). The findings of that study differ markedly from the present study.

Table 1: Species attracted by different baits

Baits	*Termite species it attracted at different sub-areas*			
	Aurodam	*Gaia*	*Revelation*	*Newlands*
Cowdung	*H.obscuriceps, O.annamallensis* and *M.obesi*	*H.obscuriceps, O.brunneus, O.annamallensis,* and *M.obesi*	*H.obscuriceps, O.brunneus, O.annamallensis,* and *M.obesi*	*H.obscuriceps, O.brunneus O.annamallensis,* and *M.obesi*
Toilet paper roll	*H.obscuriceps, O.redemani, M.convulsionarius* and *M.obesi*	*H.obscuriceps, M.convulsionarius, O.annamallensis* and *M.obesi*	*H.obscuriceps, M.convulsionarius, O.annamallensis,*and *O.redemani*	*H.obscuriceps, M.convulsionarius, O.annamallensis, O.redemani* and *M.obesi*
Cardboard baits	*H.obscuriceps, M.convulsionarius, O.annamallensis* and *M.obesi*	*H.obscuriceps M.convulsionarius, O.annamallensis,* and *M.obesi*	*H.obscuriceps, M.convulsionarius, O.annamallensis* and *M.obesi*	*H.obscuriceps, M.convulsionarius, O.annamallensis* and *M.obesi*
Sawdust	*O.annamallensis, M.convulsionarius, O.horni, Dicuspiditermes sp.*	*M.convulsionarius, O.annamallensis* and *O.brunneus*	*O.annamallensis, O.brunneus* and *O.horni*	*M.convulsionarius, O.annamallensis, O.brunneus* and *O.feae*
Grass	*M.obesi* and *T.nigrirostris*	*M.obesi* and *T.nigrirostris*	*M.obesi* and *T.nigrirostris*	*T.nigrirostris* and *M.obesi*
Wood stakes	*O.annamallensis, O.feae* and *M.obesi*	*O.annamallensis* and *M.obesi*	*O.annamallensis, M.obesi* and *C.ceylonicus*	*O.annamallensis* and *M.obesi*
Combination of the above	*H.obscuriceps, O.annamallensis, M.obesi, O.redemani, and O.feae, M.convulsionarius,* and *T.nigrirostris*	*H.obscuriceps, O.brunneus, O.annamallensis, M.convulsionarius, T.nigrirostris,* and *M.obesi*	*H.obscuriceps, O.brunneus, O.annamallensis, O.redemani, M.convulsionarius, M.obesi, T.nigrirostris,* and *C.ceylonicus*	*H.obscuriceps, O.brunneus, O.redemani, O.annamallensis, O.feae M.convulsionarius, M.obesi* and *T.nigrirostris*

Table 2: Summary of the termites species found in the four sub-areas of Auroville using transects, quadrats and baits

Termite species	Aurodam		Gaia		Newland's		Revelation	
	Transect and Quadrat	Bait	Transect and Quadrat	Bait	Transect and Quadrat	Bait	Transect and Quadrat	Bait
H.obscuriceps	+	+	+	+	+	+	+	+
M.convulsionarius	+	+	+	+	+	+	+	+
O.anamallensis	+	+	+	+	+	+	+	+
D.spp.	+	+	+	–	+	–	+	–
M.obesi	+	+	+	+	+	+	+	+
O.brunneus	+	–	+	+	+	+	–	+
O.redemani	+	+	–	–	+	+	–	+
O.horni	–	+	–	–	–	–	–	–
O.feae	–	+	–	–	+	+	–	–
T.nigrirostris	+	+	+	+	+	+	+	+
C.ceylonicus	–	–	–	–	–	–	+	+
Total number of termite species	8	9	7	6	9	8	7	8

Table 3: Different baits used and number of termite species sampled by other authors

Location of the study area	**Bait used**	**Number of termite species found**	**References**
USA	Toilet paper rolls and wood blocks	Two	La Fage *et al.*, 1976
Mexico	Dungpats	Two	Ettershank *et al.*, 1980
Kenya	Discs of *Commiphors spp*. trees	Seven	Buxton, 1981
Mexico	Toilet paper rolls	One	Schaefer and Whitford, 1981
South Africa	Toilet paper rolls	Eight	Ferrar, 1982
USA	Wooden stakes	One	Su and Scheffrahn, 1986
USA	Toilet paper rolls	Two	Nutting *et al.*, 1987
Australia	Sawdust, toilet paper rolls; timber, fallen logs and branches of eucalyptus, in varying stages of decay	Eleven	Abensperg-Traun , 1993
Brazil	Toilet paper rolls	Forty one	de-Souza, 1993
Mexico	Toilet paper rolls	Two	Nash and Whitford, 1995
USA-Mexico border	Cardboard, Toilet paper rolls, cattle dung, grass, and stalks	Two	Taylor *et al.*, 1998
Malaysia	Toilet paper rolls	One	Sajap, 1999
Australia	Toilet paper rolls, cardboard and wood (differing in placement and moisture status)	Sixteen	Dawes-Gromadzki, 2003a
Australia	Toilet paper rolls	Eleven	Dawes-Gromadzki and Spain, 2003

In Aurodam and Revelation, more number of species were located through baits than were found with the combination of the transect and the quadrat methods. In contrast baits attracted lesser number of species than sampled by the transect and quadrat methods at Gaia and Newlands (Table 2). Five species – *H.obscuriceps*, *M.convulsionarius*, *M.obesi*, *O.annamallensis* and *T.nigrirostris* were found in all the four sub-areas by both the methods.

C.ceylonicus was also sampled by both the methods but only in Revelation.

All the ten species that were located by the combination of the transect and the quadrat methods were also found in baits. *O.horni* was the additional species with baits, that too, only in Aurodam.

The findings of other authors who had sampled termites using baits, with or without other survey methods, are summarized in Table 3. Haverty *et al.*, (1976) compared the findings of the bait-based method with that of the circle quadrats determining abundance of subterranean termites in Arizona desert grassland. They found that *Gnathamitermes perplexus* and *Heterotermes aureus* were attracted by toilet paper rolls, but none of the *Amitermes* species (*A.wheeleri* (Desneux), *A.minimus* Light, *A.emersoni* Light, and *A.silverstrianus* Light), which were found in quadrat based survey, were seen attacking the bait.

In two studies by Dawes-Gromadzki (2005, 2008) many more species were located by direct search sampling than when baits were used but it was also seen that two species of *Heterotermes* were located in the baits but were missed out by the other method.

In another study, which compared the efficacy of bait-based species survey with other survey methods, Zeidler *et al.*, (2004) found that the bait-based method detected 69% of the taxa (thirteen), and the soil-excavating transect and the visual search methods 63% (twelve) each.

From the foraging it may be seen that in some situations bait-based methods have enabled retrieval of larger number of termite species than other survey methods while in some other situations it has been the other way. It is also seen that, at times, bait-based methods are able to retrieve some species missed by the other methods even when the total number of species identified by the former in that study may be lower than that identified by the latter.

Pattern of substrate consumption

The extent of substrate consumption was much higher (upto four times) when all the four substrates were kept together, in comparison to the extent of consumption when individual substrates were kept in isolation (Tables 4a – 8b). For example, in Aurodam, the maximum average substrate consumption in stand-alone baits was 99.4 g (Table 4a) in comparison to 370.4 g - 469.2 g consumed in multiple baits (Table 4b). The total number of species found in multiple baits was also more than the number found in any individual bait. These findings indicate that diversity of substrates attracts more species of termites and results in more brisk foraging than monotonous substrates.

In all the sub-areas, among the six types of baits, cowdung was consumed the most, closely followed by toilet paper, cardboard, sawdust, grass and wood in that order. One-way ANOVA (SPSS software version 16.0) indicates that the difference in substrate consumption among the four sub-areas was statistically significant. Only in the case of wet baits placed below the ground, the difference was not statistically significant in the second and third runs.

Conclusion

This study is a follow-up of the study reported in Chapter 6 on the survey of termite species in Auroville, situated close to Puducherry, India, using the transect and the quadrat methods. To know the foraging behavior of termites and to check whether any species missed out in the previous survey shows up, the present study spanning four months in four sub-areas and ten months in one of the sub-area was carried out in which six types of baits ─ cowdung, toilet paper, cardboard, sawdust, grass and wood ─ were laid in four different sub-areas in three patterns, individually and in combinations. Among the six types of baits, cowdung was consumed the most, closely followed by toilet paper, cardboard, sawdust, grass and wood. With the survey done earlier by using transect-based and quadrat-based sampling, a total of ten species were sampled and identified. In the present work employing baits the same ten species – *H.obscuriceps, O.annamallensis, M.obesi, M.convulsionarius*, *O.brunneus, O.redemani*, *O.feae, T.nigrirostris, Dicuspiditermes sp.,* and *C.ceylonicus* – with an additional species *O.horni*. Though in Aurodam and Revelation, more number of species were located through baits than were found with the combination of the transect and the quadrat methods, it was not so with Gaia and Newlands. Hence bait method is useful in augmenting direct search methods but does not, otherwise, normally generate as comprehensive a survey as the direct search methods do.

Table 4a: Substrates consumed (g) when kept singly at four different sites in Aurodam

Days	Placement of substrate	Substrate consumption (g) when kept singly											
		Cowdung		Toilet paper roll		Cardboard		Saw dust		Grass		Wood	
		Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average± SD
0-30	Below wet	89.2-96.2	94.3±5.2	86.4-96.8	91.6±5.2	85.4-96.2	91.2±5.4	81.0-91.6	86.8±5.4	74.5-87.8	81.2±6.7	71.3-85.2	77.9±7.0
	Above wet	81.9-96.0	88.7±7.1	79.1-94.2	86.2±7.6	81.4-94.3	87.0±6.6	76.5-89.2	82.6±6.4	71.6-85.8	77.2±7.6	66.4-84.5	74.0±9.4
	Below dry	79.2-93.3	85.4±7.2	77.2-91.8	83.7±7.4	76.9-87.5	81.2±5.6	74.6-85.1	79.6±5.3	69.8-80.4	74.1±5.6	62.1-81.1	69.8±10.0
	Above dry	76.1-89.3	81.9±6.8	73.4-86.8	79.5±6.8	72.9-85.4	78.5±6.4	71.0-82.3	76.7±5.6	64.2-76.7	69.4±6.5	59.8-76.5	66.2±9.0
31-60	Below wet	92.2-98.3	94.5±3.3	90.4-96.1	93.2±2.9	87.4-94.0	90.8±3.3	81.6-91.5	86.8±5.0	81.4-90.0	85.7±4.3	78.5-87.0	83.0±4.3
	Above wet	88.6-98.9	93.7±5.2	85.1-94.9	90.2±4.9	84.2-94.1	88.7±5.0	79.7-90.1	85.1±5.2	76.5-85.7	81.2±4.6	75.5-84.0	80.0±4.3
	Below dry	86.4-95.6	90.9±4.6	83.5-93.0	88.3±4.8	81.1-90.3	85.8±4.6	76.4-87.3	81.6±5.5	74.3-84.1	79.3±4.9	73.5-82.3	77.9±4.4
	Above dry	82.4-95.8	89.1±6.7	80.1-89.7	85.0±4.8	77.2-86.3	81.9±4.6	74.5-83.7	79.1±4.6	76.1-82.5	75.9±6.7	67.1-78.7	73.0±5.8
61-90	Below wet	88.7-97.5	93.1±4.4	86.3-95.7	90.9±4.7	88.1-92.6	88.3±4.2	80.2-90.7	84.9±5.3	79.9-88.3	84.1±4.2	75.3-83.5	79.4±4.1
	Above wet	83.2-94.7	89.1±5.8	81.3-92.2	86.7±5.5	81.1-89.8	85.4±4.4	78.4-88.7	83.1±5.2	74.5-84.9	79.2±5.3	73.5-82.3	77.9±4.4
	Below dry	88.3-93.5	88.0±5.7	81.3-89.7	85.4±4.2	78.7-87.9	83.4±4.6	76.9-85.2	80.9±4.2	72.9-81.8	77.3±4.5	69.9-78.3	74.1±4.2
	Above dry	82.9-90.5	86.6±3.8	78.7-87.9	83.3±4.6	73.5-83.7	78.6±5.1	70.9-81.5	76.2±5.3	68.5-77.5	73.1±4.5	63.3-74.7	69.1±5.7
91-120	Below wet	97.6-99.4	98.5±0.9	94.2-98.0	96.5±2.0	91.1-97.0	94.1±3.0	86.0-96.2	91.3±5.1	82.1-91.9	87.1±4.9	79.4-88.9	84.2±4.8
	Above wet	93.7-99.1	96.7±2.8	91.5-97.9	94.5±3.2	86.5-94.7	90.7±4.1	83.1-93.6	88.3±5.3	81.3-89.9	85.5±4.3	78.1-87.1	82.6±4.5
	Below dry	95.0-96.2	95.6±0.6	89.2-96.9	93.1±3.9	84.1-96.6	90.4±6.3	78.0-87.9	83.0±5.0	78.5-87.9	83.3±4.7	76.0-85.8	80.9±4.9
	Above dry	88.2-95.8	91.9±3.8	87.2-94.7	90.9±3.8	81.7-91.5	86.6±4.9	79.9-84.9	82.7±2.5	76.3-85.8	81.1±4.8	71.1-80.8	75.9±4.9
Overall in 160 days (average of three baits)	Below wet	91.9-97.8	94.7±2.7	89.3-97.0	93.1±2.5	88.0-95.0	91.1±2.4	82.2-92.5	87.5±2.7	79.5-89.5	84.5±2.5	76.1-86.2	81.1±3.0
	Above wet	86.9-97.2	92.1±3.8	84.3-94.8	89.4±3.8	83.3-93.2	88.0±2.3	79.4-90.4	84.8±2.6	76.0-86.6	80.8±3.5	73.4-84.5	78.6±3.6
	Below dry	84.9-94.7	90.0±4.4	82.8-92.9	87.6±4.1	80.2-90.6	85.2±3.9	76.5-86.4	81.3±1.4	73.9-83.6	78.5±3.9	70.4-82.2	75.7±4.8
	Above dry	82.4-92.9	87.4±4.2	79.9-89.8	84.7±4.7	76.3-86.7	81.4±3.8	74.1-83.1	78.7±3.0	71.3-80.6	74.9±4.9	65.3-77.7	70.6±4.6

Table 4b: Substrate consumed (g) when kept together at four different sites in Aurodam

Substrate	Substrate consumption (g) when kept together							
	0-30 days		31-60 days		61-90 days		91-120 days	
	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle
Cowdung	79.8	84.1	78.3	82.5	75.9	80.1	74.3	84.6
Toilet paper roll	78.5	82.0	74.6	78.9	72.9	76.5	69.5	79.6
Cardboard	78.0	80.6	74.3	75.9	70.8	71.2	61.0	72.3
Saw dust	76.2	78.3	74.0	74.9	72.6	73.9	58.5	69.3
Grass	70.9	72.7	68.4	71.4	65.7	68.1	55.2	61.6
Wood	67.9	71.5	69.4	70.1	62.3	65.4	51.9	57.5
Total	451.3	469.2	439.0	453.7	420.2	435.2	370.4	424.9

Table 5a: Substrates consumed (g) when kept singly at four different sites in Gaia

Days	Placement of substrate	Cowdung		Toilet paper roll		Cardboard		Saw dust		Grass		Wood	
		Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average ± SD	Range	Average± SD	Range	Average± SD
0-30	Below wet	99.7-120	111.6±10.6	96.3-99.1	97.6±1.4	92.5-98.3	95.2±91.5	87.8-95.3	91.5±3.8	84.5-94.2	89.1±4.9	80.7-89.5	84.8±4.4
	Above wet	95.3-99.6	97.5±2.2	92.1-99.3	95.8±3.6	89.8-96.7	92.6±3.6	87.9-94.1	90.9±3.1	83.1-89.2	85.4±3.3	80.9-88.1	84.2±3.6
	Below dry	89.5-97.2	93.8±3.9	91.6-96.0	93.6±2.2	87.4-94.7	90.5±3.8	82.5-91.5	87.0±4.5	79.5-87.8	83.2±4.2	79.5-85.1	82.5±2.8
	Above dry	88.7-96.6	92.8±4.0	87.2-94.1	90.6±3.5	81.8-90.3	86.0±4.3	80.5-86.1	83.6±2.9	73.4-83.0	78.6±4.8	72.5-84.4	78.6±6.0
31-60	Below wet	95.8-96.5	96.1±0.4	91.3-98.1	94.7±3.4	88.5-97.2	92.6±4.4	84.3-94.2	89.3±5.0	82.3-91.5	86.9±4.6	80.8-89.3	84.7±4.3
	Above wet	89.7-98.9	94.3±4.6	88.0-96.8	92.4±4.4	92.1-97.2	90.7±4.4	82.9-91.3	86.8±4.2	79.1-88.9	83.1±5.1	76.5-87.3	81.9±5.4
	Below dry	88.6-96.2	92.3±3.8	86.2-95.5	90.8±4.7	88.1-93.3	91.3±2.8	80.0-89.1	84.5±4.6	77.0-86.2	81.6±4.6	75.0-84.3	79.6±4.7
	Above dry	84.3-94.5	89.6±5.1	83.9-93.4	88.1±4.8	79.1-89.9	84.1±5.4	77.0-86.4	81.7±4.7	73.3-82.9	78.2±4.8	70.3-79.8	75.1±4.8
61-90	Below wet	91.9-97.3	94.2±2.8	87.2-96.7	91.8±4.8	86.4-94.7	90.4±4.2	82.9-91.3	87.6±4.3	82.9-92.5	87.6±4.8	78.9-87.2	83.0±4.2
	Above wet	87.2-96.7	91.9±4.8	85.1-93.8	89.4±4.4	83.6-91.6	87.6±4.0	80.2-89.9	84.8±4.9	80.2-90.9	84.8±5.5	76.3-85.0	80.6±4.4
	Below dry	85.7-94.5	90.1±4.0	84.1-89.5	87.3±2.8	80.9-89.6	85.3±4.4	78.9-87.2	83.1±4.2	79.1-87.2	83.1±4.1	74.5-83.9	78.9±4.4
	Above dry	84.2-93.1	88.7±4.5	80.9-89.9	85.4±4.5	75.9-86.1	81.0±5.1	74.5-83.3	78.8±4.4	73.5-84.3	78.8±5.4	69.9-78.5	74.2±4.3
91-120	Below wet	96.9-98.3	97.6±0.7	92.0-98.0	95.1±3.0	88.8-97.1	92.9±4.2	85.0-92.5	88.7±3.8	79.1-93.5	86.3±7.2	76.0-87.7	81.9±5.9
	Above wet	92.2-97.6	95.0±2.7	89.2-97.2	93.4±4.0	82.3-93.8	87.9±5.8	81.0-92.8	86.9±5.9	77.8-89.5	83.7±5.9	72.2-87.3	79.8±7.6
	Below dry	88.2-96.1	92.3±4.0	86.5-94.4	90.5±4.0	81.1-90.9	86.0±4.9	77.4-86.8	81.9±4.7	76.1-86.7	81.5±5.3	71.2-80.4	75.8±4.6
	Above dry	82.4-92.5	87.4±5.0	83.5-92.3	88.1±4.4	79.2-87.1	83.3±4.0	73.5-84.6	78.8±5.6	73.5-84.8	79.1±5.7	69.2-78.2	73.8±4.5
Overall in 120 d (average of three baits)	Below wet	96.1-103	99.9±7.9	91.7-96.0	94.4±1.8	89.1-96.8	92.8±2.0	85.0-93.3	89.3±1.6	82.2-92.9	87.5±1.2	79.1-88.4	83.6±1.4
	Above wet	91.1-98.2	94.7±2.3	88.6-96.8	92.8±2.7	87.0-94.8	89.7±2.4	83.0-92.0	87.4±2.6	80.1-89.6	84.3±1.0	76.5-86.9	81.6±1.9
	Below dry	88.0-96.0	92.1±1.5	87.1-94.6	90.6±2.6	84.4-92.1	88.3±3.1	79.7-88.7	84.1±2.2	77.9-86.7	82.4±0.9	75.1-83.4	79.2±2.8
	Above dry	84.9-94.2	89.6±2.3	83.9-92.4	88.1±2.1	79.0-88.4	83.6±2.1	76.4-85.1	80.7±2.4	73.4-83.8	78.7±0.4	70.5-80.2	75.4±2.2

Table 5b: Substrate consumed (g) when kept together at four different sites in Gaia

Substrates	Substrate consumption (g) when kept together							
	0-30 days		31-60 days		61-90 days		91-120 days	
	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle
Cowdung	84.8	86.0	82.9	85.1	79.8	83.2	70.8	81.7
Toilet paper roll	81.2	84.3	79.5	82.9	77.1	80.2	67.8	78.7
Cardboard	79.3	82.5	76.3	77.9	73.0	75.3	60.2	71.5
Saw dust	77.5	80.0	74.1	76.3	72.3	74.9	59.4	65.8
Grass	72.4	73.9	70.9	73.1	68.3	70.4	54.9	60.4
Wood	69.3	72.1	68.2	71.7	66.7	67.9	50.7	58.3
Total	464.5	478.8	451.9	467.0	437.2	451.9	363.8	416.4

Table 6a: Substrates consumed (g) when kept singly at four different sites in Newlands

Days	Placement of substrate	Cowdung		Toilet paper roll		Cardboard		Saw dust		Grass		Wood	
		Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD
0-30	Below wet	96.3-98.2	97.3±1.0	92.7-97.4	94.7±2.4	89.1-96.7	92.5±3.9	80.8-95.5	87.1±7.6	81.5-90.1	85.6±4.3	80.8-89.8	84.2±4.9
	Above wet	87.0-98.1	92.8±5.6	90.4-95.8	92.9±2.7	84.5-92.1	88.0±3.8	79.1-88.0	84.0±4.5	79.8-89.2	84.4±4.7	77.3-86.0	81.6±4.4
	Below dry	84.2-95.9	90.2±5.9	84.6-94.5	89.4±5.0	80.9-90.1	85.4±4.6	79.9-85.8	82.8±3.0	72.3-83.1	77.4±5.4	75.3-83.1	78.8±4.0
	Above dry	82.6-89.9	86.3±3.7	79.1-89.2	84.3±5.1	77.6-86.2	81.8±4.3	73.3-86.5	79.6±6.6	69.9-78.1	73.9±4.1	70.0-78.9	74.0±4.5
31-60	Below wet	92.5-94.1	93.3±0.8	87.3-96.5	92.0±4.6	83.5-92.2	87.7±4.4	79.2-88.0	84.1±4.9	78.7-87.6	83.1±4.3	76.5-85.0	80.9±4.3
	Above wet	85.5-94.1	89.6±4.3	82.5-92.8	87.9±5.2	80.1-89.4	84.8±4.7	77.8-86.5	82.1±4.4	75.1-85.5	79.8±5.3	72.0-82.8	77.4±5.4
	Below dry	82.0-92.9	87.3±5.5	81.5-93.2	87.3±5.9	79.0-88.5	83.5±4.8	74.3-84.5	79.5±5.1	71.0-80.5	75.7±4.8	68.5-76.1	72.6±3.8
	Above dry	81.3-90.5	86.0±4.6	78.2-87.1	82.3±5.0	74.9-84.9	79.4±5.1	72.1-83.3	77.5±5.6	69.3-78.5	73.9±4.6	66.5-75.6	71.0±4.6
61-90	Below wet	86.7-96.3	91.6±4.8	84.6-93.7	89.2±4.6	78.9-89.5	84.2±5.3	76.9-88.0	82.6±5.6	75.5-84.3	79.9±4.4	70.9-79.9	75.4±4.5
	Above wet	81.2-90.8	86.1±4.8	80.4-89.2	84.8±4.4	76.9-85.3	81.1±4.2	75.3-84.9	80.1±4.8	69.9-78.7	74.3±4.4	68.9-77.9	73.4±4.5
	Below dry	80.2-89.9	85.1±4.9	79.2-87.9	83.5±4.4	76.7-85.3	81.1±4.3	72.5-81.6	77.1±4.6	68.9-79.8	74.3±5.5	66.2-75.0	70.7±4.4
	Above dry	78.7-87.9	83.3±4.6	76.9-85.2	81.1±4.2	69.4-79.2	80.5±4.3	69.2-79.5	74.2±5.2	66.1-75.2	70.7±4.6	61.0-69.9	65.4±4.5
91-120	Below wet	88.0-97.7	92.7±4.9	90.2-97.3	93.7±3.6	85.3-96.9	91.2±5.8	82.1-92.1	87.3±5.0	79.2-90.9	85.0±5.9	74.3-85.5	80.0±5.6
	Above wet	85.1-94.8	89.9±4.9	86.0-96.5	91.4±5.3	81.3-91.9	86.7±5.3	81.0-88.9	84.9±4.0	74.1-87.1	80.3±6.5	73.0-83.4	78.0±5.2
	Below dry	82.0-91.8	86.8±4.9	83.1-92.9	88.0±4.9	79.2-89.6	84.4±5.2	76.0-92.8	83.5±8.5	72.4-83.9	78.2±5.8	69.0-78.9	73.8±5.0
	Above dry	79.2-88.6	83.9±4.7	80.2-90.3	85.4±5.1	76.1-86.1	81.2±5.0	71.9-81.9	76.8±5.0	69.0-80.9	75.0±6.0	68.0-75.9	72.0±4.0
Overall in 120 days (average of three baits)	Below wet	90.9-96.6	93.7±2.5	88.7-96.2	92.4±2.4	83.7-92.8	88.9±3.7	79.8-90.9	85.3±2.3	78.7-88.2	83.4±2.6	75.7-85.1	80.1±3.6
	Above wet	84.7-94.5	89.6±2.7	84.8-93.6	89.3±3.6	80.7-89.7	85.2±3.0	78.3-87.1	82.8±2.1	74.7-85.1	79.7±4.1	72.8-82.5	77.6±3.4
	Below dry	82.1-92.6	87.4±2.1	82.1-92.1	87.1±2.5	79.0-88.4	83.6±1.8	75.7-86.2	80.7±3.0	75.2-81.8	76.4±1.7	69.8-78.3	74.0±3.5
	Above dry	80.5-89.2	84.9±1.5	78.6-88.0	83.3±1.9	74.5-84.1	80.7±1.0	71.6-82.8	77.0±2.2	68.6-78.2	73.4±1.9	66.4-75.1	70.6±3.7

Table 6b: Substrate consumed (g) when kept together at four different sites in Newlands

Substrate	Substrate consumption (g) when kept together							
	0-30 days		31-60 days		61-90 days		91-120 days	
	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle
Cowdung	78.0	82.6	76.9	79.5	74.4	77.6	66.8	75.9
Toilet paper roll	76.1	78.9	72.3	76.1	70.3	73.9	60.7	72.7
Cardboard	73.9	75.0	73.1	72.3	69.7	71.9	58.4	60.2
Saw dust	73.5	76.6	72.5	73.1	70.9	71.6	53.7	58.3
Grass	71.0	73.0	66.5	69.0	62.9	65.2	55.2	57.7
Wood	65.1	69.0	65.8	67.3	60.4	64.2	51.0	56.5
Total	437.6	455.1	427.1	437.3	408.6	424.4	345.8	381.5

Table 7a: Substrate consumed (g) when kept singly at four different sites in Revelation

Days	Placement of substrate	Cowdung		Toilet paper roll		Cardboard		Saw dust		Grass		Wood	
		Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD
0-30	Below wet	90.3-97.2	93.8±3.5	88.9-96.0	92.4±3.6	87.0-96.0	91.5±4.5	81.5-91.1	86.0±4.8	79.5-87.4	83.5±5.9	77.5-86.1	81.5±4.3
	Above wet	87.5-96.7	91.9±4.6	85.0-95.5	89.8±5.3	80.0-93.1	86.5±6.6	77.9-86.2	81.9±4.2	77.5-86.2	81.6±4.4	75.5-83.5	79.6±4.0
	Below dry	84.0-93.0	88.5±4.5	83.8-90.4	87.1±3.3	78.4-88.1	83.2±4.9	74.3-85.1	80.0±5.4	71.3-80.4	75.7±4.6	70.4-79.0	74.8±4.3
	Above dry	80.1-91.0	84.9±5.6	77.0-88.1	82.4±5.6	61.5-83.2	73.1±10.9	73.3-82.5	77.9±4.6	67.2-78.0	72.7±5.4	65.8-77.9	71.6±6.1
31-60	Below wet	86.2-95.5	91.0±4.7	85.4-95.0	90.2±4.8	80.1-89.3	84.7±4.6	76.7-86.3	81.5±4.8	74.0-84.0	78.8±5.0	70.1-79.3	74.8±4.6
	Above wet	81.1-90.9	85.9±4.9	80.9-90.0	85.4±4.6	77..3-86.9	82.1±4.8	74.5-84.5	79.4±5.0	70.2-79.3	74.9±4.6	67.6-76.3	72.0±4.4
	Below dry	79.2-88.8	84.0±4.8	77.0-88.6	84.7±5.8	74.1-87.0	80.7±6.5	71.5-83.3	77.6±5.9	65.0-76.9	70.8±6.0	63.5-70.4	67.2±3.5
	Above dry	77.5-88.0	82.9±5.3	75.0-86.5	80.6±5.8	71.1-81.3	76.2±5.1	70.3-79.9	75.1±4.8	64.5-73.6	69.0±4.6	61.4-69.1	65.3±3.9
61-90	Below wet	85.1-94.5	89.9±4.7	82.3-92.0	87.3±4.9	77.9-86.4	82.1±4.3	75.5-84.5	80.3±4.6	72.9-81.4	77.2±4.3	67.5-78.0	72.8±5.3
	Above wet	78.9-88.3	83.6±4.7	78.6-87.5	83.0±4.5	74.7-83.8	79.3±4.6	72.8-81.0	76.9±4.1	66.2-76.5	71.3±5.2	63.9-74.3	69.1±5.2
	Below dry	76.9-85.4	81.2±4.3	76.5-84.1	80.4±3.8	72.5-82.8	77.6±5.2	69.9-78.9	74.4±4.5	65.4-74.9	70.0±4.8	60.2-68.5	64.3±4.2
	Above dry	73.7-82.9	78.3±4.6	73.3-77.9	75.1±2.5	73.5-88.3	80.3±7.5	67.1-77.5	72.3±5.2	62.3-70.8	66.5±4.3	57.5-66.2	61.8±4.4
91-120	Below wet	88.0-97.7	92.7±4.9	86.6-97.9	92.2±5.7	82.2-95.3	88.7±6.6	81.0-88.7	84.9±5.9	79.5-89.9	84.4±5.2	71.2-82.2	76.7±5.5
	Above wet	85.1-94.8	89.9±4.9	84.1-94.5	89.1±5.2	80.2-88.2	84.2±4.0	77.9-87.6	82.7±4.9	78.1-87.1	82.6±4.5	70.2-77.9	74.1±3.9
	Below dry	81.0-92.8	86.8±5.9	81.2-90.9	86.0±4.9	77.3-86.7	82.0±4.7	73.1-82.9	78.0±4.9	77.0-84.8	80.8±3.9	68.4-73.8	71.1±2.7
	Above dry	79.6-87.2	83.6±3.8	77.1-90.1	83.6±6.5	74.4-84.7	79.6±5.2	70.9-78.4	74.6±3.8	71.1-80.8	75.9±4.9	66.2-71.6	68.9±2.7
Overall in 120 days (average of three baits)	Below wet	87.4-96.2	91.9±1.7	85.8-95.2	90.5±2.4	81.8-91.8	86.8±4.2	78.7-87.7	83.2±2.7	76.5-85.7	80.9±3.5	71.6-87.4	76.5±3.7
	Above wet	83.2-92.7	87.2±3.8	82.2-91.9	86.8±3.2	78.1-88.0	83.0±3.1	75.8-84.8	80.2±2.6	73.0-82.3	77.6±5.4	69.3-78.0	73.7±4.4
	Below dry	80.3-90.0	85.1±3.2	79.6-88.5	84.6±3.0	75.6-86.2	80.9±2.4	72.2-82.6	77.5±2.3	69.7-79.3	74.3±5.0	65.6-72.9	69.4±4.6
	Above dry	77.7-87.3	82.4±2.9	75.6-85.7	80.4±3.8	70.1-84.4	77.3±3.3	70.4-79.6	75.0±2.3	66.3-75.8	71.0±4.1	62.7-71.2	66.9±4.3

Table 7b: Substrates consumed (g) when kept together at four different sites in Revelation

Substrate	Substrate consumption (g) when kept together							
	0-30 days		31-60 days		61-90 days		91-120 days	
	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle
Cowdung	85.1	87.8	74.3	76.9	71.9	74.2	65.6	70.9
Toilet paper roll	74.3	75.6	71.4	74.3	67.5	71.7	62.4	67.7
Cardboard	72.1	72.9	68.9	69.7	68.9	66.5	59.3	63.4
Saw dust	71.8	72.7	67.4	67.5	65.5	67.9	57.6	65.8
Grass	66.5	67.9	65.1	67.5	60.7	62.5	59.1	62.5
Wood	63.8	67.5	63.2	64.9	58.3	60.6	55.7	60.3
Total	433.6	444.4	410.3	420.8	392.8	40.34	359.7	390.6

Table 8a: Substrates consumed (g) when kept singly at four different sites in Aurodam

Days	Placement of substrate	Cowdung		Toilet paper roll		Cardboard		Saw dust		Grass		Wood	
		Range	Average± SD	Range	Average± SD	Range	Average± SD	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD
0-30	Below wet	91.1-99.5	95.6±4.2	90.1-97.9	93.8±3.9	84.5-95.7	90±5.6	81.2-88.7	84.8±3.8	76.1-85.8	80.8±4.9	74.0-83.7	78.7±4.9
	Above wet	90.2-97.7	93.9±3.8	85.3-94.9	89.9±4.8	79.1-90.7	84.8±5.8	76.2-84.8	80.1±4.3	73.4-82.8	78.0±4.7	71.0-80.8	75.7±4.9
	Below dry	85.5-95.8	90.6±5.2	82.2-89.8	85.8±3.8	76.3-86.6	81.1±5.2	71.0-80.9	75.9±5.0	69.0-78.9	73.7±5.0	67.6-76.9	72.1±4.7
	Above dry	84.4-93.6	88.9±4.6	77.4-86.9	82.0±4.8	73.0-82.9	77.7±5.0	70.1-77.9	73.9±3.9	67.0-75.9	71.4±4.5	62.4-71.8	67.0±4.7
31-60	Below wet	90.2-97.9	93.9±3.6	87.7-90.2	91.8±4.0	84.5-94.5	89.4±5.0	81.8-91.6	86.5±4.9	79.9-88.6	84.0±4.4	76.4-86.6	81.5±5.1
	Above wet	88.5-95.6	91.9±3.6	86.5-94.1	90.2±3.8	81.8-91.5	86.6±4.9	79.2-89.9	84.4±5.4	76.1-84.9	80.5±4.4	71.2-79.8	75.6±4.3
	Below dry	86.5-94.5	90.2±4.0	83.2-92.8	88.0±4.8	78.7-88.6	83.7±5.0	76.2-85.9	81.1±4.9	71.3-81.8	76.3±5.3	66.4-77.5	71.8±5.6
	Above dry	81.1-91.8	86.3±5.4	79.1-89.6	84.3±5.3	76.1-86.8	81.3±5.4	72.1-80.4	76.3±4.2	69.1-77.8	73.5±4.4	64.1-75.8	69.9±5.9
61-90	Below wet	67.5-76.9	72.1±4.7	64.4-73.4	68.9±4.5	62.0-70.9	66.5±4.5	57.5-68.9	63.2±5.7	56.0-66.9	61.4±5.5	53.0-63.9	58.4±5.5
	Above wet	63.1-74.8	68.9±5.9	59.3-72.8	66.1±6.8	59.1-68.8	63.8±4.9	54.1-65.8	60.0±5.9	51.2-63.8	57.6±6.3	49.6-60.8	55.2±5.6
	Below dry	61.0-68.8	64.8±3.9	57.5-66.9	62.2±4.7	55.5-64.7	59.9±4.8	52.0-60.8	56.4±4.4	49.0-59.9	54.4±5.5	47.4-56.8	52.1±4.7
	Above dry	57.3-66.7	62.0±4.7	53.1-64.7	59.0±5.8	51.0-60.3	55.7±4.7	47.8-56.9	54.0±4.3	47.8-56.9	52.4±4.6	46.0-55.1	50.6±4.6
91-120	Below wet	63.1-72.3	67.8±4.6	61.4-68.8	65.1±3.7	56.2-67.9	62.0±5.9	53.0-65.8	59.4±6.4	51.5-62.5	57.0±5.5	51.8-58.9	55.3±3.6
	Above wet	59.2-68.6	63.8±4.7	55.3-65.9	60.7±5.3	53.2-62.5	57.8±4.8	51.0-60.5	55.8±4.8	46.1-61.9	53.9±7.9	49.0-57.8	53.5±4.4
	Below dry	55.2-64.9	60.1±4.9	51.2-62.9	57.1±5.9	49.2-60.9	55.0±5.5	47.0-57.9	52.5±5.5	44.1-57.9	50.9±6.9	44.0-54.7	49.4±5.4
	Above dry	52.9-61.9	57.1±4.9	50.3-59.3	54.8±4.6	47.6-58.1	52.8±5.3	46.0-54.9	50.4±4.5	43.0-54.5	48.7±5.8	41.5-52.5	47.1±5.5
Overall in 120 days (average of three baits)	Below wet	91.1-99.5	95.6±4.2	64.4-73.4	68.9±4.5	78.9-89.5	84.2±5.3	53.0-65.8	59.4±6.4	82.9-92.5	87.6±4.8	78.9-87.2	83.0±4.2
	Above wet	90.2-97.7	93.9±3.8	59.3-72.8	66.1±6.8	76.9-85.3	81.1±4.8	51.0-60.5	55.8±4.8	80.2-90.9	84.8±5.5	76.3-85.0	80.6±4.4
	Below dry	85.5-95.8	90.6±5.2	57.5-66.9	62.2±4.7	76.7-85.3	81.1±4.3	47.0-57.9	52.5±5.5	79.1-87.2	83.1±4.0	74.5-83.2	78.9±4.4
	Above dry	84.4-93.6	88.9±4.6	53.1-64.7	59.0±5.8	69.4-79.2	74.5±4.9	46.0-54.9	50.4±4.5	73.5-84.3	78.8±5.4	69.9-78.5	74.2±4.3

Table 8b: Substrates consumed (g) when kept together at four different sites in Aurodam

Substrates	Substrate consumption (g) when kept together											
	121-150 days		151-180 days		181-210 days		211-240 days		241-270 days		271-300 days	
	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle	Circle	Rectangle
Cowdung	80.7	88.6	77.7	83.5	50.5	54.1	44.3	49.7	76.5	80.4	76.5	80.4
Toilet paper roll	74.1	79.2	75.6	78.3	47.2	51.2	42.5	46.2	48.9	52.6	73.2	78.8
Cardboard	72.4	76.3	72.6	75.7	45.6	48.4	43.1	45.1	60.2	64.9	69.3	75.4
Saw dust	70.5	72.8	67.8	70.3	41.3	44.2	40.9	43.6	42.6	45.8	66.5	68.3
Grass	65.3	71.7	69.3	74.5	40.3	46.3	40.1	42.5	61.6	66.5	62.1	68.5
Wood	63.1	66.9	64.8	68.7	42.5	45.2	38.6	40.8	62.7	63.9	60.3	62.7
Total	426.1	455.5	427.8	451.0	267.4	289.4	249.6	267.9	352.5	374.1	407.9	434.1

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A paper based on this chapter has been
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Chapter 8

Use of termites with *in-situ* bioreactors in the ecologically benign disposal of the harmful invasive ipomoea (*Ipomoea carnea*)

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Abstract

In this chapter studies on termigradation of the highly ligninous invasive ipomoea (*Ipomoea carnea*) using *in-situ* reactors of capacities ranging from 5 Kg to 100 Kg is reported. More than 50% of the substrate was disposed within 30 days which is a much faster rate than achieved by composting or vermicomposting. Use of trails further speeded up the process as also provided a means of process control. The ecologically benign disposal in this manner prevents the otherwise rotting of the weed in the open (which generates the global warming gases methane and carbon dioxide) while facilitating generation of highly nutritious termite zoomass. Ongoing efforts to expedite the process are also described.

Keywords: *termite, ipomoea, termireactor, ligninous biowaste*

1.0 Introduction

As we have detailed elsewhere (Sankar Ganesh *et al.,* 2008), the amphibious weed Ipomoea (*Ipomoea carnea*) is one of the most productive of macrophytes. It grows profusely in water bodies and on adjoining marshy lands, often jostling out most other plant species. It is known to exert allelopathic effect on some plants and has been shown to possess mammalian toxicity (Makhija *et al*, 2010). Despite spending monies worth billions of dollars across the world to destroy or control this weed, it continues to thrive (Chari and Abbasi, 2003;Schwarz *et al.,* 2003; Ghosh and Singh, 2005; Chari and Abbasi, 2005). Attempts to utilize it have met with more or less equally feeble success. Such attempts haven encompassed a gamut: possible use as livestock feed, building material, paper pulp, source of drugs, fuel etc. (Abbasi and Ramasamy, 1999) – but only very small quantities of the weed is utilizable in one or the other manner. Even such utilization options are region-specific and serve a limited purpose in situations when better options are not available.

Even as huge quantities of ipomoea are generated when ipomoea dies or is mechanically detached from land/water to reduce its infestation, in absence of any means of gainfully disposing it, it is left to rot, generating methane and carbon dioxide which are both global warming gases (GHGs). Of the two, methane is generated whenever anaerobic conditions develop in the heaps of weed masses, which is quite often. As methane has 25 times greater global warming potential than CO_2, the consequences of the rotting of the weed in nature are quite grave. In an endeavour to find possible ways of gainfully utilizing large quantities of ipomoea in an ecologically compatible and inexpensive manner we have explored the option of termigradation. This is based on the premise that if the weed can be ‘termigraded’ it would basically mean converting the weed into termite zoomass and termicast. As has been detailed elsewhere (Abbasi *et al.,* 2007; Gajalakshmi and Abbasi, 2011) termites play a crucial role ─ alongside earthworm and ants ─ in the turn-over and rejuvenation of soils. Hence disposal of ipomoea through termigradation would contribute in two decisive ways in enhancing rejuvenation and agricultural productivity of soils.

We have earlier developed processes for generating vermicast from *Ipomoea* leaves (Sankar Ganesh *et al.,* 2008). But the major parts of the plant that still requires processing is the twigs and the stems as these parts, being highly ligninous, defy not only vermicomposting but composting as well. Hence a process other than composting or vermicomposting is needed if we have to process the whole plants of ipomoea.

Termigradation is a new bioprocess conceived at Centre for Pollution Control and Environmental Engineering (Sankar Ganesh *et al.,* 2007; Abbasi *et* *al.*, 2010). A patent claim has been registered on the basis of the technology that has since been developed (Abbasi and Gajalakshmi, 2012). After extensive proof-of-concept studies, which have all met with success (Gajalakshmi *et al.*, 2014), we have explored utilization of ipomoea by termigradation as detailed in this paper.

2.0 Material*s* and method

Four sets of experiments were conducted with different quantities of ipomoea. All the reactors were charged with its twigs and placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of six reactors with 5 kg feed.

In the second set of experiments, a total of twelve termireactors were operated. All were charged with 20 kg ipomoea. The first six reactors were placed near active termite mounds in the wooded parts of the Pondicherry University campus. To enhance the rate of substrate degradation, by attracting more number of termites to the reactor than coming naturally to the reactor, six of the termireactors were supported by trails of paper waste and saw dust. These trails, 8 in number, were laid alternatively and equidistance from each other going radially outward upto 5 metres from each termireactor in all directions (Figure 1).

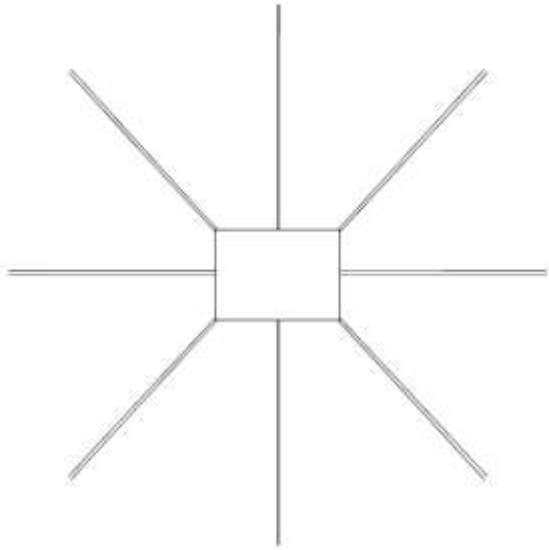

Figure 1: Line diagram of the termireactor with trails used for the studies

In the third set of experiments the termireactors were loaded with 50 Kg of the substrate: triplicates were used with and without trails. Lastly four termireactors scaled to 100 kg feed were explored: two with trails and two without trails. The extent of substrate consumption by termites was quantified once in every ten days in reactors with 5 kg feed and once in fifteen days in all the other reactors. The reactors were observed daily and the species present each time were identified.

All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

3.0 Results and discussion

The results are summarized in Tables 1-4. It is seen that the rate of the 'termigradation' ─ or the rate of consumption of the substrate by termites ─ is the highest during the initial 10-15 days. By the 30th day about half of the feed was termigraded in all reactors without trails and about 70% in reactors with trails. The rate then falls as the quantity of the substrate reduced. In general there is a precipiteous fall in termigradation after about half of the substrate is utilized. This trend is seen to be independent of the initial quantity of the substrate ─ similar trend is seen whether a reactor was started with 5 Kg of substrate (Table 1) or 20-100 Kg (Figure 2). The mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5 (Figure 3). This is very interesting and indicates that those of the termites which scout for food, perhaps generate signals to summon only that much number of foragers at the food source as the source may support for a certain time. Also, as the quantity of the leftover food falls, lesser workers tend to engage with it. This is perhaps done to prevent intra-termites conflicts which may arise if more foragers are attracted to a food source than the number that source can comfortably support. When trails are laid, it perhaps brings in more than one set of scouts to the substrate. This possibly result in more than one school of termites coming to forage and faster and faster termigradation. But the pattern of rate of consumption falling with the substrate quantity is similar to the trend observed in termireactors without trails.

Table 1: Extent of termigradation (%) of *Ipomoea carnea* (5 Kg) at 10-day intervals

Days	**Reactor**						**Termigradation**	
	A	B	C	D	E	F	During each run	Cumulative
0-10	21.8	23.6	20.1	18.4	18.1	18.8	20.1±2.2	20.1±2.2
11-20	14.3	15.0	20.3	17.9	17.5	18.4	17.2±2.2	37.4±1.8
21-30	15.5	15.5	17.3	16.1	15.5	16.6	16.1±0.7	53.5±2.4
31-40	13.2	13.3	11.0	8.5	8.4	8.5	10.5±2.4	63.9±3.7
41-50	8.9	8.4	8.5	8.7	8.8	8.6	8.7±0.2	72.6±3.5
51-60	6.9	6.4	4.0	5.9	6.1	6.0	5.9±1.0	78.5±3.3
61-70	3.7	3.4	4.2	3.7	3.9	3.7	3.8±0.3	82.2±3.3
71-80	3.8	3.2	2.0	3.3	3.4	3.3	3.2±0.6	85.4±3.1
81-90	1.7	1.5	1.6	2.8	3.0	7.4	3.0±2.2	88.4±2.7
91-100	1.2	1.1	1.0	1.5	1.5	0.9	1.2±0.3	89.6±2.5

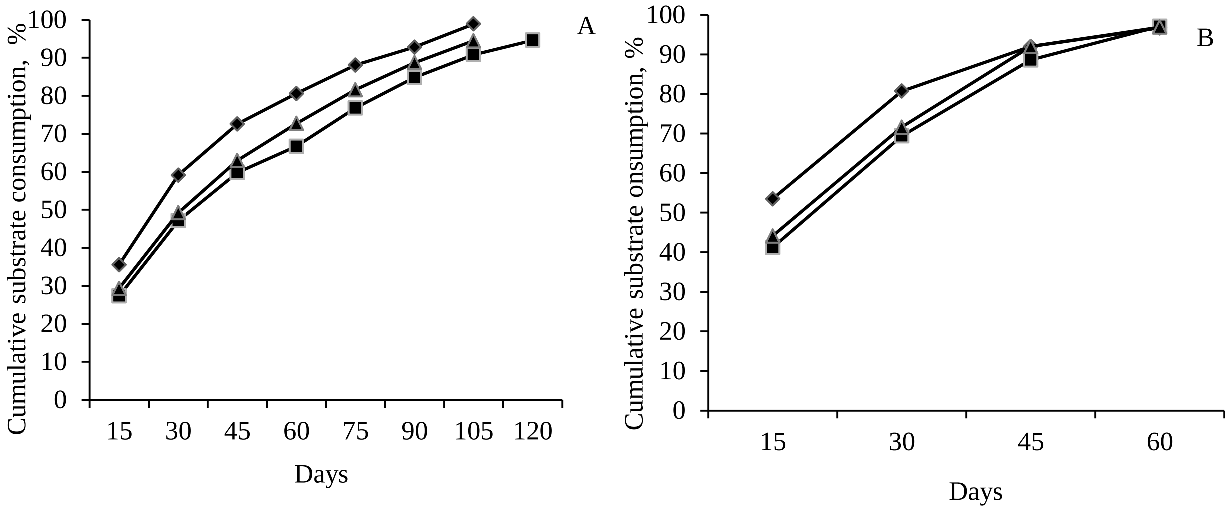

Figure 2: Cumulative of ipomoea consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 20kg Reactor 50 kg Reactor 100 Kg

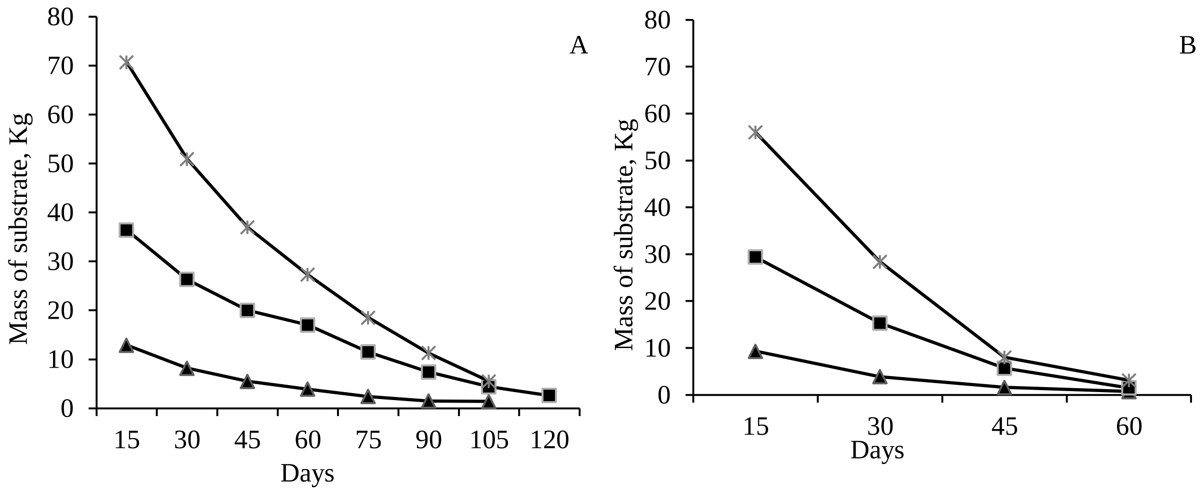

Figure 3: Mass of ipomoea left at different intervals in reactors without (A) and with (B) trails: Reactor 20kg Reactor 50 kg Reactor 100

Table 2: Extent of termigradation (%) of *Ipomoea carnea* (20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails						Termigradation		Reactors supported by trails						Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	C	D	E	F	During each run	Cumulative	A	B	C	D	E	F	During each run	Cumulative	
0-15	37.4	38.2	39.4	33.2	33.6	31.4	35.5±3.2	35.5±3.2	59.3	60.1	60.2	46.6	47.3	47.3	53.5±7.0	53.5±7.0	I 99.5
16-30	25.2	26.9	25.4	21.9	21.4	20.7	23.6±3.0	59.1±5.7	27.3	27.1	27.0	27.4	26.6	27.1	27.1±0.3	80.7±7.2	I 99
31-45	14.5	15.7	16.8	11.8	11.2	10.9	13.5±2.5	72.6±8.2	8.2	8.0	7.6	14.8	14.7	14.8	11.4±3.7	92.0±3.4	D 70
46-60	10.8	11.4	12.0	4.0	4.6	4.9	8.0±3.8	80.6±11.9	-	-	-	7.6	8.2	7.7	7.8±0.3	96.7±0.2	D 80
61-75	6.6	5.2	4.6	9.7	8.4	10.5	7.5±2.4	88.1±9.6	-	-	-	-	-	-	-	-	
76-90	2.9	1.8	1.2	8.1	7.7	6.4	4.7±3.0	92.8±9.6	-	-	-	-	-	-	-	-	
90-105	-	-	-	6.9	6.1	5.3	6.1±0.8	98.9±2.8	-	-	-	-	-	-	-	-	

Table 3: Extent of termigradation (%) of *Ipomoea carnea* (50 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails					Reactors supported by trails					Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor			Termigradation		Reactor			Termigradation		
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	27.4	25.6	28.9	27.3±1.6	27.3±1.6	39.7	40.1	43.8	41.2±2.2	41.2±2.2	I 99.5
16-30	19.7	18.1	22.4	20.1±2.2	47.1±3.8	27.1	27.8	29.7	28.2±1.3	69.4±3.5	I 99.5
31-45	12.6	11.8	13.7	12.7±0.9	59.8±4.8	18.2	18.8	20.5	19.2±1.2	88.6±4.8	I 99.5
46-60	6.9	6.1	7.8	6.9±0.8	66.7±5.7	10.4	10.9	4.2	8.5±3.7	97.1±1.4	I 60
61-75	10.9	9.3	10.1	10.1±0.8	76.8±6.0	-	-	-	-	-	-
76-90	9.1	7.9	7.1	8.0±1.0	84.8±5.6	-	-	-	-	-	-
91-105	6.4	6.1	5.5	6.0±0.4	90.8±5.4	-	-	-	-	-	-
106-120	3.6	4.8	2.9	3.8±0.9	94.6±4.4	-	-	-	-	-	-

(a) (b) (c) (d)

Figure 4 a-c: Ipomoea termireactor showing termite tunnels, **d**: close up of the substrate with the tunnels

In all the reactors supported with trails, > 90% of the feed was consumed within 60 days, whereas the consumption was 80.6, 66.7 and 72.7% in the reactors with 20 kg, 50 kg and 100 kg of feed respectively which were not supported by trails. The enhancement in the termigradation efficiency due to the trails was statistically significant (Tables 1-4) as revealed by the Student's t-test (Microsoft Excel, 2010)**.** This happened till the bulk of the substrate had been consumed in reactors with trails. Thereafter termite activity reduced sharply in these reactors and less substrate was consumed than in the reactors without trails. Termites were seen to feed upon ipomoea by constructing tunnels (Figure 4). After assimilation of the weed, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* was the species present throughout but occasionally *Macrotermes convulsionarius* was observed. Irrespective of the initial feed quantity and whether the reactors were supported with trails or not, ~ 50% of the substrate was consumed in a month's time in all the reactors. This time-span can be considered very quick because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence this is a much less expensive process with much lesser 'footprint'.

4.0 Conclusions

Disposal of amphibious weed ipomoea (*Ipomoea carnea*) was accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 100 Kg. Multiple reactors were operated with and without attaching termite trails to them. The trails constituted lines of paper waste or

Table 4: Extent of termigradation (%) of *Ipomoea carnea* (100 Kg) 15-day intervals

Days	Reactors without trails				Reactors supported by trails				Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor		Termigradation		Reactor		Termigradation		
	A	B	During each run	Cumulative	C	D	During each run	Cumulative	
0-15	29.7	28.9	29.3±0.6	29.3±0.6	42.7	45.4	44.1±1.4	44.1±1.4	I 95
16-30	20.1	19.6	19.9±0.4	49.2±0.9	26.5	28.6	27.6±1.5	71.6±3.3	I 90
31-45	14.2	13.5	13.9±0.5	63.0±1.4	19.8	20.9	20.4±0.8	92.0±4.1	I 95
46-60	10.1	9.3	9.7±0.6	72.7±2.0	6.7	3.2	5.0±2.5	96.9±1.7	D 90
61-75	9.2	8.5	8.9±0.5	81.6±2.5	-	-	-	-	-
76-90	7.5	6.8	7.2±0.5	88.7±3.0	-	-	-	-	-
91-105	6.1	5.5	5.8±0.4	94.5±3.4	-	-	-	-	-

saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

In reactors without trails about half of the initial charge was 'termigraded' in 30 days. The rate was enhanced to >80% when trails were used. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 9

Assimilative disposal of *Eicchornia crassipes* Mart. Solmsby exploiting the lignin-degrading microflora of termites in *in-situ* termireactors

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Abstract

Eicchornia crassipes is one of the most problematic weeds of the world. It colonizes surface water bodies and dramatically impedes flow of lotic systems. It blocks sunlight from reaching under-water biota, seriously jeopardizing their existence. It starves the water of oxygen, often leading to fish kills. Its colonization leads to a drastic reduction in the biodiversity of aquatic habitats and harbouring of disease vectors.

The present chapter reports attempts to develop processes for assimilative disposal of *E.crassipes* — in other words disposal in a way that enables full assimilation of the weed into the environment in an ecologically benign manner.

The weed was fed into the termireactors of 5 to 50 Kg capacity, and was allowed to be acted upon by termites, predominantly *Hypotermes obscuriceps.* The termireactors had been earlier designed by us to facilitate termite action and were placed in a way as to maximize it. Triplicate reactors had closely agreeing termigradation rates. Use of trails further speeded up the process as also provided a means of process control. The termites biodegraded and assimilated the weed, leaving only a small residue of particulates.

Keywords: *Termite,* Eicchornia crassipes*, termireactor, termigradation*

1.0 Introduction

Eicchornia crassipes (Mart. Solm) is one of the most intransigent weeds of the world (Abbasi, 1998). It is among the most prevalent invasives in over 50 countries in five continents (Vilamagna and Murphy, 2010; Yadav and Garg, 2013).It has successfully resisted all attempts of eradicating it by chemical, biological, mechanical, or hybrid means (Abbasi and Ramasamy, 1999). At present these methods succeed only in keeping the weed infestation in check at enormous costs. Wherever *E.crassipes* is not controlled, due to limited resources or other reasons, and which is often the case,it rapidly covers all the water-bodies and surrounding marshy areas in those regions. This leads to enormous harm to biodiversity and water quality in particular, and environmental health in general (Ganguly *et al.,* 2012; Singh and Bishnoi, 2013). At an average annual productivity of 50 dry (ash-free) tonnes per hectare per year, *E.crassipes* is one of the most productive ─ perhaps the most productive ─ plants in the world (Abbasi and Nipaney, 1986; Abbasi and Ramasamy, 1999).

In an endeavour to find a means of assimilating large quantities of *E.crassipes* in an ecologically compatible and inexpensive manner we have explored the possibility of getting the weed biodegraded by termites. The premise is that if the weed can be worked upon by termites ─ a process which we have termed ‘termigradation’ ─ it would basically mean converting the weed into termite zoomass and termicast. As has been detailed elsewhere (Abbasi *et al.,* 2007) termites play a crucial role ─ alongside earthworm and ants ─ in the turn-over and rejuvenation of soils. After extensive proof-of-concept studies, which have all met with success (Gajalakshmi *et al.*, 2014), we have developed a process for termigrading *Ipomoea carnea*, reported in Chapter 8. We have since explored utilization of *E.crassipes* by termigradation as detailed in this chapter.

2.0 Materials and method

Three sets of experiments were conducted with different quantities of *E.crassipes*. All the reactors were charged with whole plants of the weed and were placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of six reactors with 5 kg feed.

In the second set of experiments, six termireactors were each charged with 20 kg of *E.crassipes*. Of these three of the termireactors were supported by trails of paper waste and saw dust. The aim was to enhance the rate of substrate degradation by attracting more number of termites through the trails than coming naturally to the reactor. In each case the trails, 8 in number, were laid alternatively and equidistance from each other going radially outward upto 5 metres from each termireactor in all directions.

In the third set of experiments pilot-scale termireactors of capacity adequate to process 50 Kg of the substrate were employed. Triplicates of these were used with and without trails. The reactors were observed daily and the species present each time were identified. The extent of substrate consumption by termites was quantified once in every fifteen days. All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

3.0 Results and discussion

The results are summarized in Tables 1-3. It is seen that the rate of consumption of the substrate by termites (termigradation) is the highest during the initial 10-15 days. By the 30th day about one-third of the feed was termigraded in all reactors without trails and about 60% in reactors with trails. The rate then fell as the quantity of the substratewas reduced. In general there was a sharp fall in the rate of termigradation after about half of the substrate was utilized. This trend was seen to be independent of the initial quantity of the substrate and similar trend was seen whether a reactor was started with 5 Kg of substrate (Table 1) or 20-50 Kg (Figure 1).

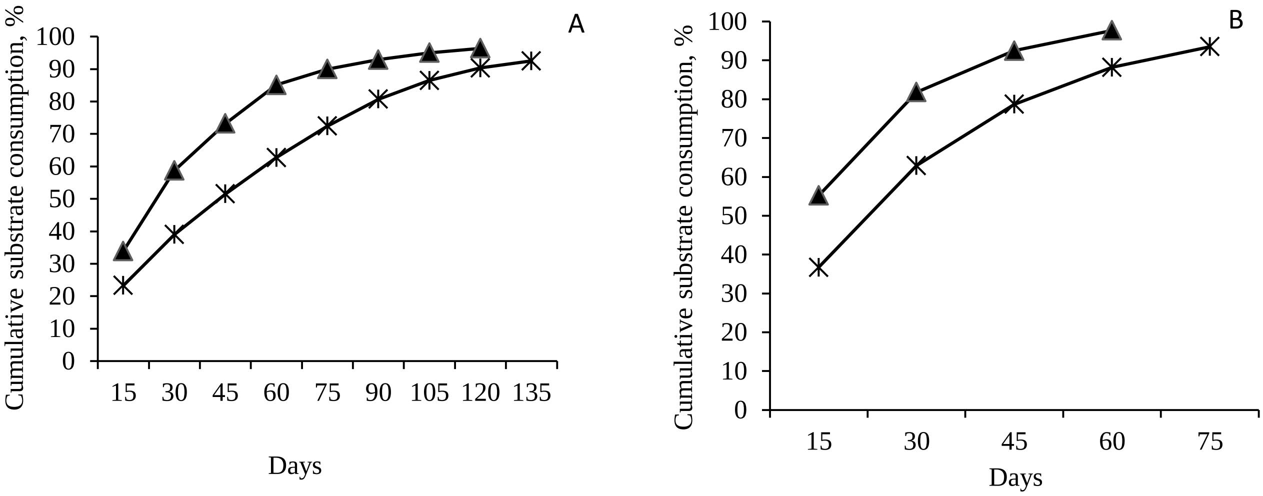

Figure 1: Cumulative of eicchornia consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 20kg Reactor 50 kg

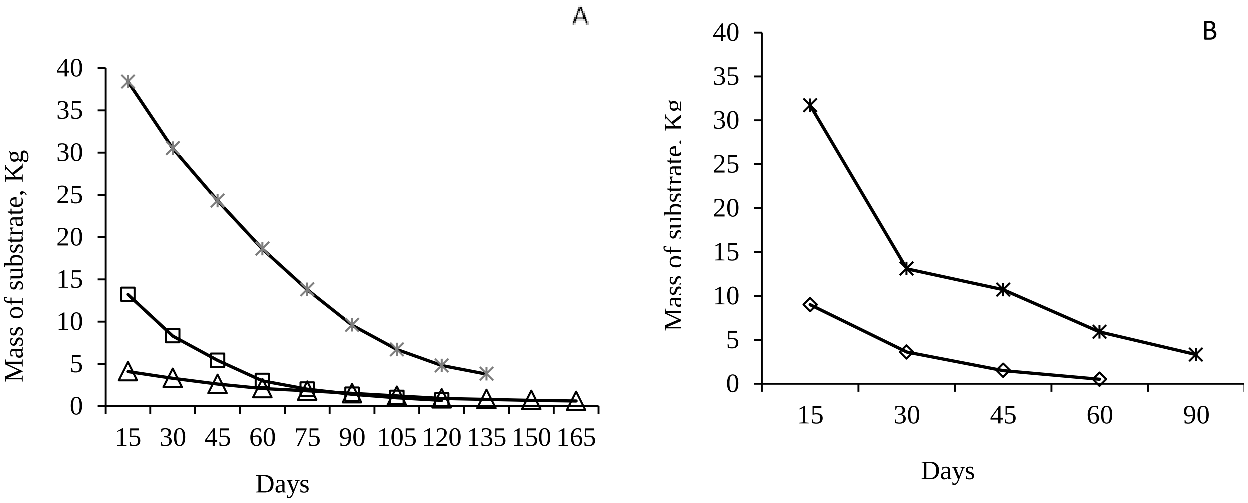

Figure 2: Mass of eicchornia left at different intervals in reactors without (A) and with (B) trails: Reactor 5kg Reactor 20 kg Reactor 50 kg

The mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5 (Figure 2). Apparently those of the termites which scout for food, generate signals to summon only that much number of foragers at the food source as the source may support for a certain time. Also, as the quantity of the leftover food falls, lesser workers tend to engage with it. This is perhaps part of a self-regulating mechanism in termites which prevents intra-termites conflicts that may arise if more foragers are attracted to a food source than the number that source can comfortably support. Laying of trails perhaps facilitates bringing in more than one set of scouts to the substrate. This possibly results in more than one school of termites coming to forage and leads to faster termigradation. But the pattern of rate of consumption falling with the substrate quantity remains similar to the trend observed in termireactors without trails.

Table 1: Extent of termigradation (%) of *Eicchornia crassipes* (5 Kg) at 15-day intervals

Days	Reactor						Termigradation	
	A	B	C	D	E	F	During each run	Cumulative
0-15	16.6	17.7	17.4	19.9	16.0	18.7	17.7±1.4	17.7±0.6
15-30	18.1	18.5	18.9	15.8	15.2	14.9	16.9±1.9	34.6±2.5
31-45	12.2	12.8	12.4	14.5	13.3	13.2	14.3±2.2	47.8±0.9
46-60	10.8	10.3	12.3	7.8	8.5	8.9	9.8±3.1	57.6±3.6
61-75	6.9	7.8	6.2	6.3	7.1	7.8	7.0±0.7	64.6±3.0
76-90	6.7	6.0	7.4	5.6	6.7	6.4	6.5±0.9	71.1±3.8
91-105	6.1	5.3	5.9	5.1	5.6	4.7	5.5±0.4	76.6±3.5
106-120	5.2	4.3	3.9	4.8	5.4	4.3	4.7±0.4	81.3±3.2
121-135	2.8	3.5	2.2	3.2	4.0	3.8	3.3±1.1	84.6±2.3
136-150	1.5	2.5	1.9	2.4	3.1	2.6	2.3±1.3	86.9±1.6
151-165	1.0	1.2	1.4	1.3	1.0	2.1	1.4±1.2	88.3±1.9

There was significant enhancement in the rate of substrate consumption when trails were used (Tables 2 and 3). For example 81.8% consumption occurred in the reactors fed with 20 Kg of *E.crassipes* within a month as compared to 58.7% consumption during the same time spam in reactors without trails. The enhancement was even more striking in larger (50 Kg) reactors: 62.9% consumption was recorded within a month in reactors with trails compared to 39% consumption in the corresponding period in the reactors to which trails had not been attached.

The enhancement in the termigradation efficiency due to the trails was statistically significant (Tables 2-3) as revealed by the Student's t-test (Microsoft Excel, 2010)**.** This happened till the bulk of the substrate had been consumed in reactors with trails. Thereafter termite activity reduced sharply in these reactors and less substrate was consumed than in the reactors without trails. This is consistent with the pattern observed in all the reactors ─ the rate of substrate consumption fell as the quantity of substrate decreased. Termites were seen to make tunnels inside the reactors (Figure 3). After assimilation of the weed, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* was the species present throughout. Irrespective of the initial feed quantity and whether the reactors were supported with trails or not, atleast 35% of the substrate was consumed in a month's time in all the reactors and the rate was dramatically enhanced by the simple expedient of using trails of inexpensive material like waste paper. This process efficiency can be considered very high because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence it is a much more assimilative, non-polluting, and inexpensive process with assimilates carbon in the soil in a manner that is known to enhance agricultural productivity.

Table 2: Extent of termigradation (%) of *Eicchornia crassipes* (20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails			Termigradation		Reactors supported by trails			Termigradation		Increase (I) or decrease (D) In termigradation by use of trails, significant to confidence level
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	33.2	33.9	34.6	33.9±0.7	33.9±0.7	55.1	54.2	56.3	55.2±1.1	55.2±1.1	I 99
16-30	24.2	25.0	25.1	24.8±0.5	58.7±1.2	25.6	26.5	27.8	26.6±1.1	81.8±0.7	I 95
31-45	14.7	14.4	14.5	14.5±0.2	73.2±1.0	10.7	11.0	10.5	10.7±0.3	92.5±0.5	D 99
46-60	12.4	11.8	11.6	11.9±0.4	85.1±0.8	5.4	5.2	4.9	5.2±0.2	97.7±0.3	D 99
61-75	5.1	4.0	5.7	4.9±0.9	90.0±1.3	-	-	-	-	-	-
76-90	3.4	2.4	2.9	2.9±0.6	92.9±1.2	-	-	-	-	-	-
90-105	2.6	2.0	1.7	2.1±0.3	95.0±1.1	-	-	-	-	-	-
106-120	1.4	1.8	1.0	1.4±0.3	96.4±0.8	-	-	-	-	-	-

Table 3: Extent of termigradation (%) of *Eicchornia crassipes* (50 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails					Reactors supported by trails					Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor			Termigradation		Reactor			Termigradation		
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	22.1	23.5	24.2	23.3±1.1	23.3±1.1	36.1	38.5	35.4	36.7±1.6	36.7±1.6	I 99
16-30	14.9	15.8	16.5	15.7±0.8	39.0±1.9	25.9	28.1	24.7	26.2±1.7	62.9±3.4	I 98
31-45	12.6	13.0	11.8	12.5±0.6	51.5±1.6	16.7	12.7	17.9	15.8±2.7	78.7±0.7	D 80
46-60	12.0	10.7	11.1	11.3±0.7	62.7±1.0	9.8	8.3	10.4	9.5±1.9	88.2±0.5	D 90
61-75	11.5	9.6	8.0	9.7±0.8	72.4±0.8	6.4	4.4	5.2	5.3±1.0	93.5±1.0	D 95
76-90	9.2	8.2	7.5	8.3±0.9	80.7±1.6	-	-	-	-	-	-
91-105	5.0	6.1	6.3	5.8±0.7	86.5±1.0	-	-	-	-	-	-
106-120	2.9	4.5	4.0	3.8±0.8	90.3±1.0	-	-	-	-	-	-
121-135	1.8	2.1	2.6	2.2±0.4	92.5±0.9	-	-	-	-	-	-

a b c d

Figure 3 a, b: Eicchornia termireactors with termite tunnels made on the substrate
c: Eicchornia termireactor showing termite tunnels
d: Close up of the substrate with the tunnels

4.0 Conclusion

Disposal of amphibious weed *E.crassipes* was accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 50 Kg. Multiple reactors were operated of which some had trails for leading termite scouts to the reactors. In reactors without trails one-third or more of the initial charge was 'termigraded' in 30 days. The rate was enhanced to >60% when trails were used. The rate of termigradation was independent of the starting substrate quantities and we surmise that the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source. The process was similar to a zero order reaction.

Acknowledgement

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A paper based on this chapter has been
submitted for publication

Chapter 10

Rapid disposal of the weed lantana (*Lantana camara*) in the environment with controlled use of termites

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Abstract
Lantana (*Lantana camara*), a rapid-growing perennial woody shrub, is one of world's most invasive species. Due to its aggressive colonization of landmass, aided by its allelopathic effort, the weed causes great harm to soil health and biodiversity.Due to its prolific growth and wide adaptability it has overrun large areas in the tropics and sub-tropics, and has developed into a serious nuisance. Despite persistent attempts to destroy it by chemical and biological means, it has not been possible to retard its spread, let alone prevent it.

The present paper reports a new process based on controlled use of termites for the disposal of lantana — in other words disposal in a way that enables full assimilation of the weed into the environment in an ecologically benign manner. For it, the process of 'termigradation' (termite-mediated biodegradation), and the associated reactors ('termireactors'), developed recently by us, were utilized.

In the *in-situ* termireactors of upto 50 Kg capacity; more than 50% of lantana waste termigraded within 60 days which is a much faster rate than achieved by composting or vermicomposting. Use of trails further speeded up the process as also provided a means of process control.

Keywords: *Termite*, Lantana camara, *weed*, *termireactor*, *termigradation*

1.0 Introduction

Lantana (*Lantana camara*) belongs to family Verbenaceae of which more common and abundant species include *L.camara*, *L.crenulata*, *L.trifolia* and *L.indica.* Of these *L.camara*, which is commonly referred as lantana is a highly aggressive invader of natural ecosystems (Kumar *et al.,* 2011). Due to its tendency to elbow out other species of plants, and the way it monopolizes the use of soil, water, and nutrients in any area, lantana plays havoc with the area's biodiversity (Holm *et al.,* 1977; Prasad and Jamaluddin, 1986; Saxena, 1991).

In an endeavour to find a means of assimilating large quantities of lantana in an ecologically compatible and inexpensive manner we have explored the possibility of getting the weed biodegraded by termites. The premise is that if the weed can be worked upon by termites ─ a process which we have termed 'termigradation' ─ it would basically mean converting the weed into termite zoomass and termicast. As has been detailed elsewhere (Abbasi *et al.,* 2007) termites play a crucial role ─ alongside earthworm and ants ─ in the turn-over and rejuvenation of soils. After extensive proof-of-concept studies, which have all met with success, we have developed a process of which a patent claim has been registered (Abbasi and Gajalakshmi, 2014). The present chapter describes the use of the process developed by us in the termigradation of lantana.

2.0 Materials and method

Three sets of experiments were conducted with different quantities oflantana. All the reactors were charged with its twigs and placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of six reactors with 5 Kg feed.

In the second set of experiments, a total of sixtermireactors were operated. All were charged with 20 Kg lantana. The first three reactors were placed near active termite mounds in the wooded parts of the Pondicherry University campus. To enhance the rate of substrate degradation, by attracting more number of termites to the reactor than coming naturally to the reactor, three of the termireactors were supported by trails of paper waste and saw dust as detailed in chapters 8 and 9 (Figure 1).

Figure 1: Termireactor with trails placed in field

In the third set of experiments the termireactors were loaded with 50 Kg of the substrate: triplicates were used with and without trails. The extent of substrate consumption by termites was quantified once in every fifteen days in all the other reactors. The reactors were observed daily and the species present each time were identified. .All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

3.0 Results and discussion

The results are summarized in Tables 1-3. It is seen that the rate of the 'termigradation' ─ or the rate of consumption of the substrate by termites ─ is the highest during the initial 10-15 days. By the 60th day, half of feed was termigraded in all reactors without trails and more than 75% in reactors with trails. The rate then fell as the quantity of the substrate was reduced. The rate falls as the quantity of the substrate reduced. In general there is a precipiteous fall in termigradation after about half of the substrate is utilized. This trend is seen to be independent of the initial quantity of the substrate ─ similar trend is seen whether a reactor was started with 5 Kg of substrate (Table 1) or 20-50 (Figure 2). The mass of unconsumed substrate tended to approach zero (Figure 3) within an identical duration of time even when the starting mass differed by a factor of 5 similar to termireactors with the weeds *I.carnea* and *E.crassipes* as discussed in chapters 8 and 9. Supporting the reactors with trails attracted more number of termites than coming naturally to the reactors, hence more substrate consumed when these reactors were with trails. Lantana being processed by the termites is illustrated in Figure 4.

Table 1: Extent of termigradation (%) of *Lantana camara* (5 Kg) at 15-day intervals

Days	Reactor						Termigradation	
	A	B	C	D	E	F	During each run	Cumulative
0-15	13.0	16.7	14.2	15.8	13.5	17.1	15.1±1.7	17.0±0.6
15-30	15.1	14.1	15.7	11.9	14.6	16.0	14.7±1.5	29.8±2.5
31-45	10.2	12.6	10.8	11.5	10.7	13.2	11.5±1.2	41.3±0.9
46-60	10.5	8.5	9.4	8.0	9.9	7.9	9.0±1.1	50.3±3.6
61-75	6.4	8.1	7.4	7.8	7.0	6.6	7.2±0.6	57.5±3.0
76-90	6.2	7.5	6.1	6.7	6.3	5.9	6.5±0.6	64.0±3.8
91-105	5.6	6.1	4.4	3.8	5.6	4.2	5.0±0.9	69.0±3.5
106-120	5.2	4.4	4.0	3.3	5.4	3.8	4.4±0.8	73.4±3.2
121-135	2.3	3.9	3.2	2.9	2.1	1.5	2.7±0.8	76.1±2.3

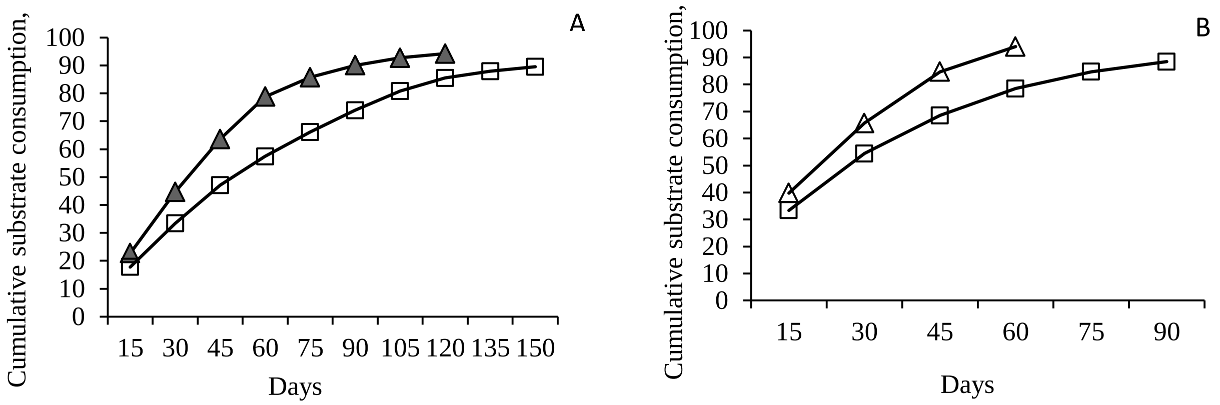


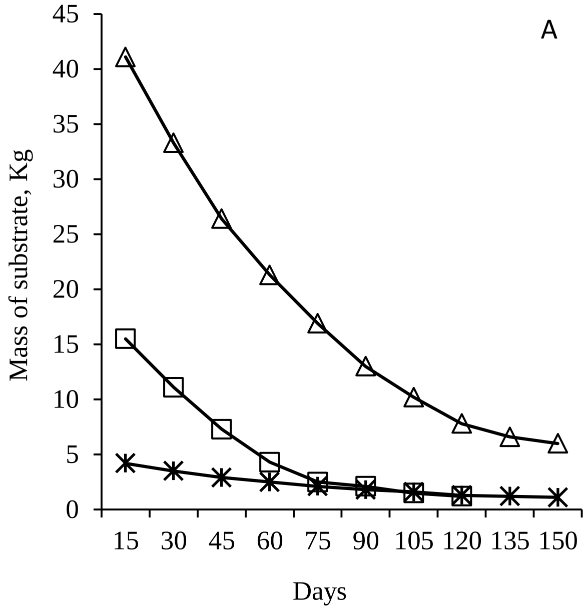
Figure 2: Cumulative of lantana consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 20kg Reactor 50 kg

Table 2: Extent of termigradation (%) of *Lantana camara* (20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails			Termigradation		Reactors supported by trails			Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	22.3	23.1	22.8	22.7±0.4	22.7±0.7	38.8	40.1	40.6	39.8±0.9	39.8±1.1	I 99
16-30	21.5	21.6	22.7	21.9±0.6	44.6±1.2	26.1	25.8	25.7	25.9±0.2	65.7±0.7	I 98
31-45	19.0	19.2	18.6	18.9±0.3	63.6±1.0	18.6	19.4	18.9	19.0±0.4	84.7±0.5	I 60
46-60	14.7	14.5	15.0	14.7±0.3	78.8±0.8	9.7	9.3	8.9	9.3±0.4	94.0±0.3	D 99
61-75	7.7	7.0	6.1	6.9±0.8	85.7±1.3	-	-	-	-	-	-
76-90	4.2	5.1	3.7	4.3±0.7	90.0±1.2	-	-	-	-	-	-
90-105	3.7	2.5	2.0	2.7±0.8	92.7±1.1	-	-	-	-	-	-
106-120	1.1	1.5	1.9	1.5±0.4	94.2±0.8	-	-	-	-	-	-

Table 3: Extent of termigradation (%) of *Lantana camara* (50 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails					Reactors supported by trails					Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor			Termigradation		Reactor			Termigradation		
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	19.9	17.5	16.1	17.8±1.9	17.8±1.9	30.5	33.8	35.9	33.4±2.7	33.4±1.6	I 95
16-30	16.5	16.1	14.2	15.6±1.2	33.4±3.1	20.8	24.0	18.1	21.0±2.9	54.4±3.4	I 90
31-45	14.8	12.9	13.5	13.7±0.9	47.1±3.7	14.8	12.2	15.5	14.2±1.7	68.5±0.7	I 20
46-60	11.5	10.3	9.1	10.3±1.2	57.4±4.9	11.1	8.8	9.9	9.9±1.2	78.5±0.5	D 20
61-75	8.1	9.5	8.5	8.7±0.7	66.1±4.7	7.4	5.3	6.1	6.3±1.1	84.7±1.0	D 80
76-90	7.3	8.2	7.9	7.8±0.4	73.9±4.4	3.7	4.8	2.6	3.7±1.1	88.4±0.4	D 95
91-105	5.2	4.9	7.1	6.9±1.2	80.8±3.5	-	-	-	-	-	-
106-120	3.3	5.8	5.1	4.7±1.3	85.5±2.6	-	-	-	-	-	-
121-135	2.2	1.9	3.0	2.4±0.6	87.9±2.2	-	-	-	-	-	-
136-150	1.5	1.1	1.2	1.6±0.2	89.5±2.3	-	-	-	-	-	-



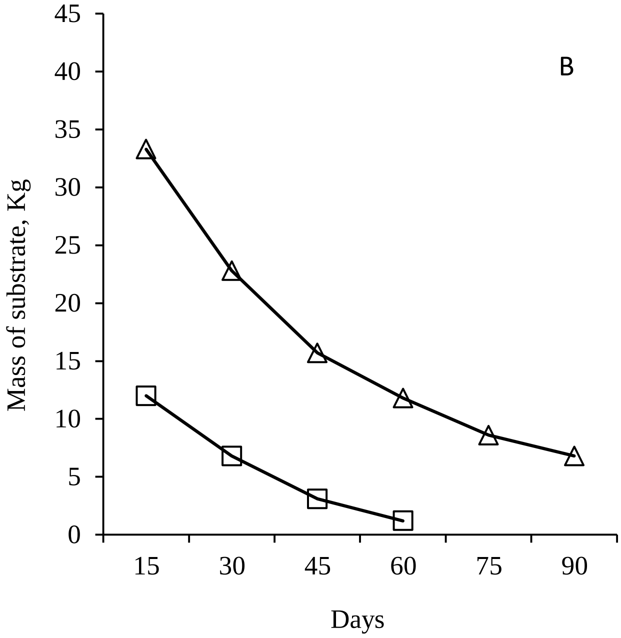


Figure 3: Mass of lantana left at different intervals in reactors without (A) and with (B) trails: Reactor 5 kg Reactor 20 kg Reactor 50 kg

a b c

Figure 4 a: Lantana termireactors with termite tunnels made on the substrate
b: Close up of the substrate with the tunnels,
c: Substrate after removing the tunnels

After assimilation of *L.camara*, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* was the species present.

In all the reactors, > 50% (50.3 % for 5 Kg, 78.8% and 94.0% for 20 Kg and 57.4% and 78.5% for 50 Kg) of the feed was consumed with and without trail within 60 days. This time-span can be considered very quick because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence this is a much less expensive process with much lesser 'footprint'

4.0 Conclusion

Disposal of notorious weed lantana was accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 50 Kg. Multiple reactors were operated with attaching termite trails to them. The trails constituted lines of paper waste or saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

About half of the initial charge was 'termigraded' in 60 days. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 11

Assimilative disposal of sugar industry 'press mud' with controlled use of termites

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Abstract

The sugarcane industries release large quantities of 'press mud', which causes disposal problems.

The present chapter reports attempts to develop a process with which pressmud can be assimilatively disposed — in other words disposed in a way that enables full assimilation of the press mud into the environment in an ecologically benign manner. For termigradation of press mud, *in-situ* termireactors of 5 to 20 Kg capacity were used, in which press mud was allowed to be acted upon by termites, predominantly *Hypotermes obscuriceps.* The termireactors had been earlier designed by us to facilitate termite action. Duplicate reactors had closely agreeing termigradation rates. The termites biodegraded and assimilated the waste, leaving only a small residue of particulates.

Keywords: *termite, press mud, termireactor, termigradation*

1.0 Introduction

India is the second largest producer of the sugar in the world, with an annual output of 25 million tonnes. Among the steps leading to the production of refined sugar is the separation of sugarcane juice from the associated particulates. Upon this separation a solid residue is obtained which is called the press mud. In a typical sugarfactory, the processing of 100 tonnes of cane produces about 3 tonnes of press mud (Verma *et al.*, 2012). Some 8–10 million tonnes of press mud is generated annually.

Usually the pressmud is either disposed off in open fields or given as immature compost to farmers (Gupta *et al.*, 2011) (Table 1). But even as press mud is rich in nitrogen, phosphorous, potassium and other nutrients (Table 2) (Gonzalez *et al*, 2013; Kumar, 2011; Nandy *et al*, 2002), it contains ca 8% wax which can harm the soil quality. Press mud also contains several organic compounds which degrade in the soil to produce foul odours (Rouf *et al*, 2010) (Table 3). As a result, disposal of press mud as being done now is fraught with risks of soil pollution and, as a consequence of it, of water pollution as well (Suthar, 2010; George *et al*, 2010).

Attempts have been made to enhance the fertilizer value of press mud by composting it but it has seen to be a very slow process, taking about 6 months (Table 1).Worse, it still does not remove the foul odor completely (Sen and Chandra, 2007) and has lesser nutritive value than conventional compost (Sangwan *et al*, 2008).

These aspects have posed a major challenge — to find ways to dispose press mud assimilatively; in other words in a manner that it assimilates with the environment without toxifying it.

2.0 Materials and method

Two sets of experiments were conducted with different quantities of press mud. All the reactors were charged with press mud and were placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of four reactors with 5 kg feed and the second set of two termireactors charged with 20kg and were supported by trails of paper waste and saw dust as described in chapter 8.

The extent of substrate consumption by termites was quantified once in every fifteen days in all the other reactors. The reactors were observed daily. and the species present each time were identified.

All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

Table 1: Proposed uses of press mud and problems associated with the use

Composting	To compost press mud, large area of land is required. The investments are high for an industrial composting plant with a production capacity of around 100,000 ton per year. The working conditions of such a facility are also problematic due to air pollution and to hygienic problems.	George *et al.*, 2010
	Decomposition of press mud generates acid leachate and also emits significant amount of greenhouse gases are also emitted.	
	The compost treated in an inadequate way and used as bio-fertilizer can provoke contamination of the sources of water supply, so that its application can represent a danger to public health and a threat to the environment due to exposure to pathogens (Guerra *et al.*, 2003).	
	Conventional composting of press mud takes about six months and also does not remove the foul odor completely. The compost so obtained has less nutritive value and more compactness	Sen and Chandra, 2007
Fertilizer	Press mud directly spread out on the fields can drain off and may contaminate the surface water. This may cause or contribute to eutrophication, because press mud has a high phosphorus and nitrogen content.	George *et al.*, 2010
	Press mud can lead to immobilisation of inorganic nitrogen.	Rasul *et al.*, 2006
	Its constant direct use could cause negative effects like nitrogen immobilization and phytotoxicity.	Negro *et al.*, 1999
	Farmers are reluctant to apply it directly due to its bad odor, transportation cost and fear that its application may lead to crust formation, pH variation and pollution problem. Wax content of press mud (8.15%) affects the soil property by direct application (Thopate*et al.*, 1997) and its high rate of direct application (upto 100 tonnes/acre) leads to soil sickness and water pollution (Bhawalkar and Bhawalkar, 1993).	Sangwan *et al.*, 2008
Biogas generation and use of digested slurry as a fertilizer	Press mud can also be used for biogas production (Conil, 2003; Hermida*et al.*, 2003), but investment costs are high.	George *et al.*, 2010
	Attempts have been made to obtain biogas from press mud but they have not been successful because-a) presence of wax, b) fast acidification (Nunez and Silva, 1983: Sanchez *et al.*, 1996).	Rouf *et al.*, 2010
Burning	On burning, press mud emits toxic gases SO_2 and SO_3, which pollute the environment.	Rouf *et al.*, 2010
Fuel in boiler	Briquettes of press mud when used in boiler as a fuel, it forms clinkers.	Rouf *et al.*, 2010

Table 2: Composition of press mud : minerals

Minerals				*References*
P (%)	K (%)	N (%)	Others (%)	
—	—	1.8	P_2O_5 3.69; K_2O 0.76; Ca 7.80; MgO 0.99; B_2O_3 0.012; Cu 0.005;Fe 0.08; Mn 0.020; Zn 0.017	Cifuentes *et al.*, 2013
—	—	0.56	—	Goud *et al.*, 2013
1.15	0.26	1.7	Ca 2.62; Fe 0.24, Mg 0.21, Zn 0.02, Ni < 0.004	Gonzalez *et al.*, 2013
—	—	0.116	—	Yang *et al.*, 2013
—	0.034	—	—	Gunja *et al.*, 2012
0.87	0.31	1.62	Fe 0.027; Zn 0.010; Cu 0.002	Kumar *et al.*, 2012
—	—	1.63-1.75	—	Saleh-e-In *et al.*, 2012
—	—	2.36	—	Gupta *et al.*, 2011
2.5–3.0	1.0–1.5	0.90-1.25	Ca 11.00; Mg 1.65%;S 0.23; Cu 0.005; Zn 0.0069; Mn 0.0898; Fe 0.2	Dilipkumar, 2011
0.65	0.28	2.05	Ca 2.7; Na 0.18	Radjaram and Saravanane, 2011
2.39	—	2.24	—	Raj and Antil, 2011
0.53	1.72	0.85	—	Kumar *et al.*, 2010
2.4		2.2		George *et al.*, 2010
0.48	1.98	0.82	—	Meena, 2010
—	0.40	—	Ca 2.11; Fe 0.32%; Mg 0.33; Zn 0.01; Ni 0.02	Rouf *et al.*, 2010
0.51	0.83	—	—	Sangwan *et al.*,2008
—	3.52	—	—	Keshavanath *et al.*, 2006
1.23	1.7	—	S 0.39; Mg 0.39; Ca 2.34	Rasul, 2006
—	—	—	SiO 4-10; CaO 1-4; PO 1-3; MgO 0.5-1.5	Partha and Sivasubramanian, 2006
1.10-2.50	0.9	—	Ca 4.3; Mg 0.7; Zn 0.008	Gangavati *et al.*, 2005
1.8	0.39	—	Ca 7.1; Fe 0.08;Mg 0.40	Meunchang *et al.*, 2005
0.71	—	1.20	—	Kuo *et al.*, 2004
—	—	1.10	—	Safi *et al.*, 2004
1.0-2.0	0.5-2.0	1.5-1.7	Calcium (as CaO) 3.2-6; Mg 1-2; S 0.1-0.5	Nandy *et al.*, 2002
1.2	0.71	1.61	Cu 0.0018; Mn 0.0123; Zinc 0.008; Fe 0.0294	Jeyabal and Kuppuswamy, 2001
1.8	0.9	1.9	Ca 4.3; Mg 0.7; S 3.2;Na 0.1; Mn 0.034; Zn 0.008;Cu 0.053	Partha and Krishnan, 2000
—	—	0.4	Phosphate 0.4; Potash 0.02	Mathur *et al.*, 1988

Table 3: Composition of press mud: organics

Variables					***References***
Organic C (%)	Total solids (%)	Volatile solids (%)	C:N ratio	Others (%)	
—	—	80.84 ± 0.13	—	—	Gonzalez *et al.*, 2013
52.16	—	—	—	—	Goud *et al.*, 2013
—	—	—	10.1:1	—	Yang *et al.*, 2013
24.87±5.7					Kumar *et al.*, 2012
20.0–25.0	—	—	—	—	DilipKumar, 2011
33.73	—	—	—	SiO 4–10,CaO 1–4, MgO 0.5–1.5,PO 1–3	Gupta *et al.*, 2011
24.0–29.5	—	—	—	—	Munnoli and Bhosle, 2011
48.8	—	—	24.04:1		Radjaram and Saravanane, 2011
42.3	—	—	19:1	—	Raj and Antil, 2011
—	22.2	77.1	14:1	—	Rouf *et al.*, 2010
44.0 ±1.9	—	—	18.3:1 ± 0.7	—	Sangwan *et al.*, 2008
30-40	—	—	20:1–24:1	—	Nandy *et al.*, 2002
44.0	29.0	—	27:1	—	Jeyabal and Kuppuswamy, 2001
—	—	83.91	—		Sánchez *et al.*, 1996

3.0 Results and discussion

The results are summarized in Tables 4 and 5. Termites were able to feed upon press mud and thus 'assimilate' it. No mortality or lack of vitality was seen in termites who had fed upon press mud. Also, the rate of press mud disposal was high: by the 30th day of termireactor operation, 45.6% of feed was termigraded in the reactors with of 5 Kg capacity and 22.8 % in reactors of 20 Kg capacity. The rate was seen to fall as the quantity of the substrate was reduced. In general there was a precipiteous fall in termigradation after about half of the substrate was utilized. This trend was seen to be independent of the initial quantity of the substrate ─ similar trend was seen whether a reactor was started with 5 Kg of substrate (Table 4) or 20 (Figure 1). In earlier studies on *Ipomoea carnea, Eicchornia crassipes, Lantana camara*, paper waste reported in chapters 9, 10 and 13, we had found that the mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5. But in the case of press mud there was a deviation from this trend. In these reactors, the mass of unconsumed substrate tended to approach zero more quickly when the initial substrate quantity was low. As the substrate quantity at the start of the reactor was raised, it took more number of days for the unconsumed substrate to approach zero (Figure 2). The possible reason is that press mud tends to get compacted with time. This reduces its surface area — thereby proportionally reducing access to termites — as also makes tunnel formation more difficult. Similar trend was observed with two other substrates which also tended to become increasingly compact with time: coir pith and coconut shells as reported in chapters 12 and 14. Greater the termireactor capacity, more strong is the impact of this happening.

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Table 4: Extent of termigradation (%) of pressmud (5 Kg) at 15-day intervals

Days	Reactors				Termigradation	
	A	B	C	D	During each run	Cumulative
0-15	28.3	27.1	26.4	25.1	26.7±1.3	26.7±1.3
15-30	20.4	18.7	17	19.2	18.8±1.4	45.6±2.3
31-45	12.5	13.8	14.6	15.1	14.0±1.1	59.6±1.4
46-60	9.4	10.2	11.6	9.8	10.3±1.0	69.8±0.6
61-75	8.1	7.4	9.0	6.7	7.8±1.0	77.6±1.3
76-90	5.1	6.3	6.8	5.1	5.8±0.9	83.4±1.8
91-105	3.8	4.8	5.1	3.1	4.2±0.9	87.6±2.7
106-120	3	3.4	2.4	2.2	2.8±0.6	90.4±2.9
121-135	2.1	2.7	1.8	1.0	1.9±0.7	90.3±3.4

Table 5: Extent of termigradation (%) of pressmud (20 Kg) 15-day intervals, in the reactors supported by trails

Days	Reactors supported by trails		Termigradation	
	A	B	During each run	Cumulative
0-15	9.2	14.7	11.9±3.9	11.9±3.9
16-30	8.8	12.9	10.9±2.9	22.8±6.8
31-45	8.5	10.7	9.6±1.6	32.4±8.3
46-60	8.1	9.1	8.6±0.7	41.0±9.1
61-75	7.9	6.4	7.2±1.1	48.2±8.0
76-90	6.9	7.7	7.3±0.6	55.5±8.6
90-105	7.6	6.1	6.9±1.1	62.3±7.5
106-120	6.7	5.8	6.3±0.6	68.6±6.9
121-135	6.1	4.6	5.4±1.1	73.9±5.8
136-150	5.8	3.6	4.7±1.6	78.6±4.2
151-165	5.2	3.1	4.2±1.5	82.8±2.8
166-180	4.7	2.7	3.7±1.4	86.5±1.3
181-195	2.4	1.6	2.0±0.6	88.5±0.8
196-210	1.1	0.7	0.9±0.3	89.4±0.5

After assimilation of the press mud, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* was the sole species encountered.

In all the reactors, > 50% (83.4 % for 5 Kg, and 55.5 % for 20 Kg) of the feed was consumed within 90 days (Tables 4 and 5) and (Figure 1). This rate of press mud biodegradation is faster than the time of 6 months needed for press mud composting (Sen and Chandra, 2007). More significantly, whereas periodic supervision for maintaining moisture, turning of substrates, and resultant energy/material inputs, are necessary in composting,these are not required in termigradation. Nor is toxic leachate, which is bane of press mud composting (George *et al.,* 2010), is produced in termigradation. Hence this is a much less expensive process with much lesser ‘footprint’.

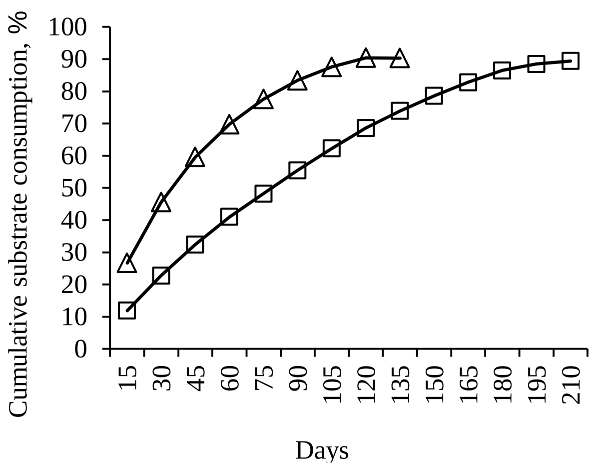

Figure 1: Cumulative of press mud consumption, %, in termireactors of different capacities supported by trails Reactor 5kg Reactor 20 kg

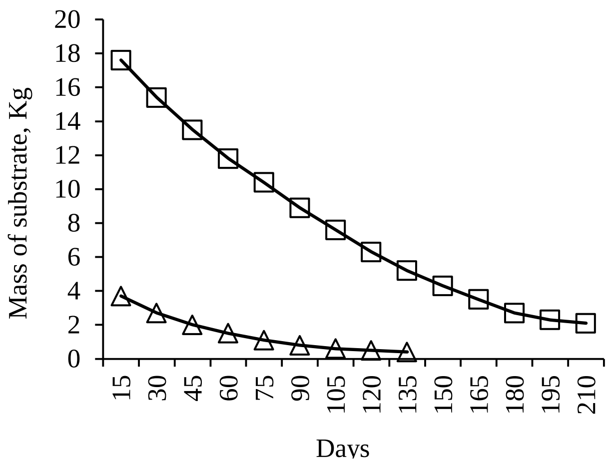

Figure 2: Mass of the press mud left at different intervals in reactors Supported by trails: Reactor 5kg Reactor 20 kg

5.0 Conclusion

Disposal of a major stream of waste arising from sugar industries,press mud, was accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 20 Kg. Multiple reactors were operated with attaching termite trails to them. The trails constituted lines of paper waste or saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

About one- fourth of the initial charge was ‘termigraded’ in 30 days. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 12

A new process based on controlled use of termites in disposing the highly problematic waste ─ coir pith

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Abstract

An estimated 1.5 million tons of coir pith is generated in India, representing about 20% of the global pith output. In absence of any means of gainful utilization, most of this produce is piled up as waste and becomes a source of environmental pollution.

In this chapter, termigradation of coir pith is reported. Coir pith was fed to the termireactors of 5 to 20 Kg capacity, and was allowed to be acted upon by the termite species *Hypotermes obscuriceps.* It enabled processing of coir pith at a much faster rate than is possible with composting or vermicomposting.

Keywords: *termite, coir pith, termireactor, termigradation*

1.0 Introduction

Coir pith is generated when coconut husk is beaten down to separate coir fibres from its pith matrix. An estimated 7.5 million tons of pith (Kamaraj, 1994; Paramanandham *et al.*, 2013) gets released across the world every year, of which a fifth is produced in India.

The pith is high in its lignin as well as moisture content (Tables 1 and 2) (Dan, 1993; Ross *et al.*, 2010; Vinodhini *et al.*, 2005). The former characteristic makes it very slow to biodegrade, precluding its use as a good soil conditioner. The latter characteristic makes it inappropriate for use as fuel (Ross *et al.*, 2010). Attempts have been made to find uses of coir pith as a fertilizer, as a source of gaseous fuels via anaerobic digestion, and used as a substrate for obtaining vermicompost. But none of the options have been attractive enough to enable utilization of substantial quantities coir pith. As a result most of the coir pith is considered a waste and is piled up close to where it is generated (Gopal and Gupta, 2001; Mathew *et al.*,2000). This leads to serious problems of environmental pollution as rainwater falling over coir pith mounds causes leaching of phenols and inorganics which then either percolate underground and pollute groundwater or run off with water to pollute rivers and ponds (Gopal and Gupta, 2001). Moistened mounds of coir pith harbor insects, rodents and other pests (Grimwood, 1975). In summers dried pith poses fire hazard. Attempts to dispose coir pith by setting it on fire have shown that it tends to smoulder due to high ash content. This leads to acid and toxic gaseous emissions for several days.

2.0 Materials and method

Two sets of experiments were conducted with different quantities of coir pith. All the reactors were charged with coir pithand were placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of six reactors with 5 kg feed: two unsupported by trails and four supported by trails of paper waste and saw dust

In the second set of experiments, two termireactors were each charged with 20 kg ofcoir pith. and were supported by trails as described in chapter 8. The aim was to enhance the rate of substrate degradation by attracting more number of termites through the trails than coming naturally to the reactor.

Table 1 : Composition of coir pith : organics

Author and year	*Variables*					
	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Organic C (%)	C:N ratio	Other organics
Kumari *et al.*,2013	29.3	19.1	34.6	–	105:1	Phenol 15.10%
Mythili *et al.*,2013	–	–	–	–	–	Volatile solids69.35 (0.4)
Sheeba *et al.*,2013	–	–	–	–	–	–
Su *et al.*,2013	–	–	–	42.9	–	
Verma *et al.*, 2013	43.4	0.25	45.8	–	–	Pectin and related compounds 3.0%
Tripetchkul *et al.*, 2012	–	–	–	–	66:1±11.3	Organic matter 52.89±9.07%
Reghuvaran and Ravindranath, 2010	–	–	39.6	–	–	–
Vinodhini *et al.*, 2005	–	–	28.25	–	–	–
Ramalingam *et al.*, 2004				–	–	Pentosan-lignin ratio is below 0.5
Kandasamy and Natarajan, 2003	26		30	29	112:1	–
Abad *et al.*, 2002	–	–	35-54	–	75:186	–
Prabhu, and Thomas, 2002	40	–	–	–	100:1	Polyphenol content about 0.1 %
Jeyabal and Kuppuswamy, 2001	–	–	29	30	115:1	–
Pillai and Vasudev, 2001	43.4	0.25	45.84	–	–	Pectin’s and related compound 3 %,
Thomas *et al.*, 1998	22	–	34.73	–	–	Phenol 1.40%, Cellulose : lignin ratio 0.7
Ramesh and Gunathilagaraj, 1996	–	–	–	27.7	120:1	–
Natarajan, 1995	–	–	43	–	–	–
Savithri and Khan, 1994	–	–	–	–	58:1-112:1	–
Dan, 1993	35	–	25.2	–	–	Pentosan 7.5%
Saminathan, 1990	–	–	–	25	–	–
Nagarajan *et al.*, 1986	–	–	–	26.1	–	–
Satyanarayana and Pavithran, 1985	40-45	–	42-44	–	–	–
Joachim, 1930	–	–	0.33	–	–	–
Joachim, 1929	–	–	–	–	–	Pentosan/lignin ratio is 1:0.30

Table 2: Composition of coir pith : minerals

Author and year	*Minerals*			
	P (%)	K (%)	N (%)	Others(%)
Kumari *et al.*,2013	0.04	0.64	–	Fe 0.014,Cu 0.00046, Mn 0.0014, Zn 0.0011
Su *et al.*,2013	–	–	0.3	–
Reghuvaran and Ravindranath, 2010	27.5	0.05	1.3	–
Ramadhas *et al.*, 2008	–	–	1.51	–
Kunchikannan *et al.*,2007	0.21	1.5	0.48	Na 4.3, Mn0.02, Ca 1.40,Cu 0.01,Mg 0.59 and Zn 0.04
Ramadhas *et al.*, 2006	–	–	1.51	–
Kandasamy and Natarajan, 2003	0.01	0.78	0.26	Fe 0.000007, Cu 0.00031, Ca 0.40, Mg 0.36, Mn0.0012, Zn 0.00075
Jeyabal and Kuppuswamy, 2001	0.36	0.29	0.26	Cu 0.0007,Zn 0.0019, Mn 0.002, Fe 0.0127
Thomas *et al.*, 1998	–	–	0.46	–
Ramesh and Gunathilagaraj, 1996	–	0.65	–	–
Nagarajan *et al.*, 1986	0.09	0.84	0.21	–
Joachim, 1930	0.05	0.9	0.9	Ca 0.4

The extent of substrate consumption by termites was quantified once in every fifteen days in all the other reactors. The reactors were observed daily and the species present each time were identified. All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

Table

Table 3: Extent of termigradation (%) of coir pith (5 Kg) at 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails		Termigradation		Reactor supported by trails				Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	During each run	Cumulative	A	B	C	D	During each run	Cumulative	
0-15	25.1	21.7	23.4±2.4	23.4±2.4	32.1	31.5	35.1	31.9	32.7±1.7	32.7±1.7	I 99.5
15-30	19.3	18.2	18.8±0.8	42.2±3.2	19.5	19.8	18.5	20.5	19.6±0.8	52.2±1.0	I 60
31-45	13.3	15.0	14.2±1.2	56.3±2.0	15.9	14.8	15.2	14.0	14.9±0.8	67.3±1.2	I 60
46-60	10.0	12.1	11.1±1.5	67.4±0.5	11.8	11.1	13.1	10.2	11.5±1.2	78.8±2.4	I 20
61-75	6.8	6.8	6.8±0	74.2±0.5	7.9	7.0	7.2	8.0	7.5±0.5	86.3±2.3	I 80
76-90	5.9	5.0	5.5±0.6	79.6±1.3	6.1	6.5	5.9	5.6	6.0±0.4	92.3±2.3	I 60
91-105	3.1	2.2	2.7±0.6	82.3±1.8	2.4	1.8	1.1	2.6	1.9±0.7	94.3±1.9	D 60

Table 4: Extent of termigradation (%) of coir pith (20 Kg) 15-day intervals, in the reactors supported by trails

Days	Reactors supported by trails		Termigradation	
	A	B	During each run	Cumulative
0-15	10.5	14.1	12.3±2.5	12.3±2.5
16-30	9.8	12.9	11.4±2.2	23.7±4.7
31-45	10.3	11.5	10.9±0.8	34.6±5.6
46-60	9.6	10.0	9.8±0.3	44.4±5.9
61-75	9.2	8.8	9.0±0.3	53.4±5.6
76-90	8.7	7.1	7.9±1.1	61.3±4.5
90-105	7.9	6.5	7.2±1.0	68.5±3.5
106-120	7.4	5.2	6.3±1.6	74.8±1.9
121-135	7.1	6.8	6.9±0.2	81.7±1.7
136-150	6.6	3.7	5.2±2.1	86.9±0.4
151-165	5.9	1.9	3.9±2.9	90.8±3.2

3.0 Results and discussion

The results are summarized in Tables 3 and 4. It is seen that the rate of the 'termigradation' ─ or the rate of consumption of the substrate by termites ─ is the highest during the initial 10-15 days. By the 30th day more than half of the feed (52.2%) was termigraded in the reactors supported by trails, in 5kg reactors.

In all the reactors, the rate of feed utilization is seen to fall as the quantity of the substrate is reduced. There is a pronounced drop in the rate of termigradation after about half of the substrate is utilized.This trend is seen to be independent of the initial quantity of the substrate ─ similar trend is seen whether a reactor was started with 5 Kg of substrate (Table 3) or 20 (Figure 1 and 3). The mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5 with the weeds *Ipomoea carnea*, *Eicchornia crassipes*, *Lantana camara*, and used paper and paper cups (reported in chapter 7, 8 and 9. But there was a deviation from this trend in case of termireactors with press mud: In these reactors, the mass of unconsumed substrate tended to approach zero more quickly when the initial substrate quantity was lower. As the substrate quantity at the start of the reactor was raised, it took more number of days for the unconsumed substrate to approach zero (Figure 2 and 4). The possible reason is that press mud tends to get compacted with time. This reduces its surface area — thereby proportionally reducing access to termites — as also makes tunnel formation more difficult. Similar trend was observed with termireactors with press mud reported in chapter 11. Greater the initial quantity of coir pith feed, more strong is the impact of these happenings. After the assimilation of the coir pith, only a small residue of particulates was found in the reactors. *Hypotermesobscuriceps* was the only species encountered in the reactors.

In all the reactors, > 50% (74.2% in reactors unsupported by trails, 86.3 % in reactors supported by trails for 5 Kg, and 53.4 % for 20 Kg) of the feed was consumed within 75 days. In reactors supported with trails, as much as 52.2% of coir pith was consumed within a month. This time-span can be considered very quick because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence this is a much less expensive process with much lesser 'footprint'

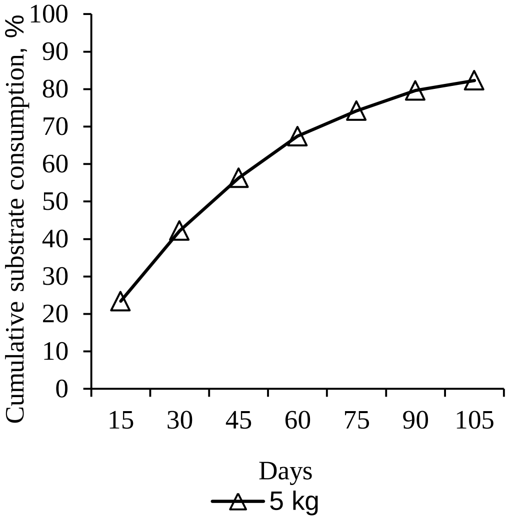

Figure 1: Cumulative of coir pith consumption, %, in termireactors not supported by trails Reactor 5kg

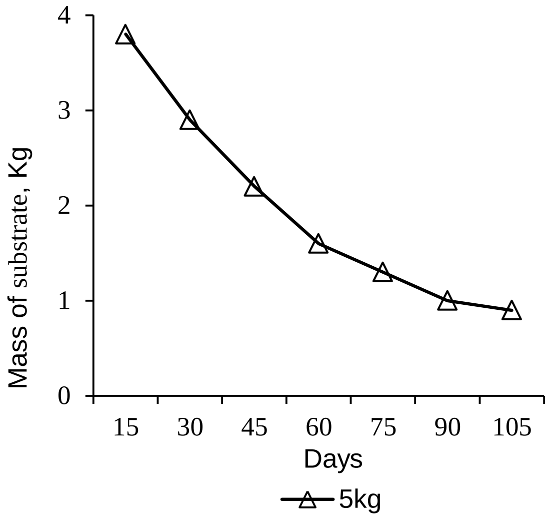

Figure 2: Mass of the coir pith left at different intervals in reactorsnot supported by trails: Reactor 5kg

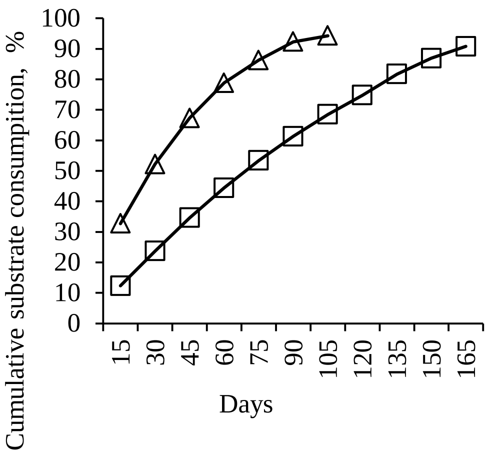

Figure 3: Cumulative of coir pith consumption, %, in termireactors of different capacities supported by trails Reactor 5kg Reactor 20 kg

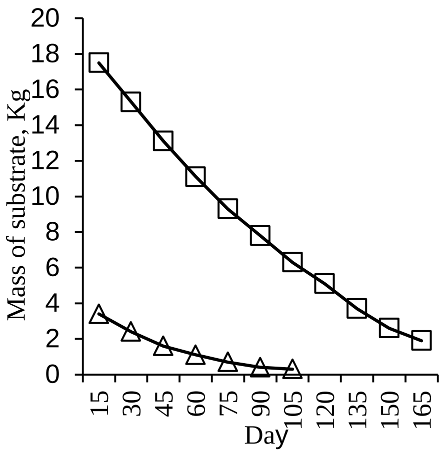

Figure 4: Mass of the coir pith left at different intervals in reactors supported by trails: Reactor 5kg Reactor 20 kg

4.0 Conclusion

Disposal of a major industrial waste, coir pith, which otherwise causes environmental pollution, was accomplished by controlled action of termites. This was accomplished using *in-situ* reactors of capacities ranging from 5 to 20 Kg. Duplicate reactors were operated with attaching termite trails to them. The trails constituted lines of paper waste or saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

In reactors without trails about one-third of the initial charge was 'termigraded' in 30 days. The rate was enhanced to >60% when trails were used. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 13

Controlled use of termites in disposing paper waste

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Abstract
Waste paper and paper cups accounts for 37.8% of municipal solid waste (MSW). Of these about 65% is recycled while the rest 35% poses disposal problems.

The present chapter reports a new process based on controlled use of termites for the disposal of used paper cups and waste paper — in other words disposal in a way that enables full assimilation of the used paper cups and waste paper into the environment in an ecologically benign manner. For it, the process of 'termigradation' (termite-mediated biodegradation), and the associated reactors ('termireactors'), developed recently by us, were utilized.

In the *in-situ* termireactors of upto 20 Kg and 50 Kg capacity, for used paper cups and waste paper respectively; more than 40% of used paper cups and more than 65% of waste paper wastermigraded within 60 days.

Keywords: *termite, paper cups,paper waste, termireactor, termigradation*

1.0 Introduction

It has been estimated that about 65% of all waste paper is recycled (Ikeda *et al.,* 2006). The remaining 35% estimated to be ~ 8 million tonnes annually, poses disposal problems. It is often added to the municipal solid waste (MSW) and sent to landfills. However, because of environmental restrictions, lack of suitable new sites, and concerns about the greenhouse effect, incineration or disposal by landfill may become practically impossible in the near future. It is, therefore, required to develop an efficient way to dispose of such a tremendous amount of waste paper (Filos *et al.,* 2006).

Waste paper is usually recycled into low-grade paper products, such as newsprint, paper towels, toilet paper, and cardboard (Park *et al.,* 2004). Even the conventional waste paper recycling directed towards new paper production may require sorting to avoid unclean waste, pulping, de-inking and bleaching, depending on the intended products. These processes can be costly and demanding in time, water and energy (Berglund and Söderholm, 2003). Expensive processes such as de-inking may produce toxic waste ink sludge containing both ink and various paper fillers. Other uses of waste paper include production of activated carbon (Shimada *et al.,* 2004), but require specialized equipment and large energy expenditure (Baillie *et al.,* 2011).As far paper cups, their recycling is particularly difficult because of presence of paraffin (Singh *et al.,* 2013).
In the present work an attempt has been made to to termigradate paper waste in a manner that it assimilates into the environment without any carbon or ecological footprint.

2.0 Materials and method

Three sets of experiments were conducted with used paper cups. The first set comprised of six reactors with 5 kg of feed and the second set of two termireactors charged with 10 Kg paper cups and were supported by trails of paper waste and saw dust. In the third set of experiments, the termireactors were loaded with 20 Kg of paper cups; triplicates were used with and without trails.

Another three sets of experiments were conducted with paper waste. The first set comprised of six reactors with 5 kg of feed and the second set of two termireactors charged with 20 Kg and were supported by trails. In the third set of experiments the termireactors were loaded with 50 Kg of used paper waste; triplicates were used with and without trails.

All the reactors were were placed near active termite mounds in the wooded parts of the Pondicherry University campus. The extent of substrate consumption by termites was quantified once in every fifteen days in all the reactors. In each case the trails, 8 in number, were laid alternatively and equidistance from each other going radially outward upto 5 metres from each termireactor in all directions. The reactors were observed daily and the species present each time were identified.

All quantities have been reported on 'dry weight basis'; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

3.0 Results and discussion

The results are summarized in Tables 1-6. The rate of the 'termigradation' ─ or the rate of consumption of the substrate by termites ─ was the highest during the initial 10-15 days. By the 60th day of termireactor operation, more than 40% and 65%, used paper cups and paper waste, respectively, were termigraded in all reactors not supported by trails; and more than 65% and 85%, in the reactors supported by trails. The rate was seen to fall as the quantity of the substrate was reduced. In general there was a precipiteous fall in termigradation after about half of the substrate is utilized. This trend was seen to be independent of the initial quantity of the substrate ─ similar trend was seen whether a reactor was started with 5 Kg of substrate (Table 1) or 20-50 (Figures 1 and 3).

Table 1: Extent of termigradation (%) of paper cups (5Kg) at 15-day intervals

Days	Reactor						Termigradation	
	A	B	C	D	E	F	During each run	Cumulative
0-15	8	9.1	9.7	8.6	9.8	8.9	9.0±0.7	9.0±0.7
15-30	12.6	12.9	13.1	11.9	12.1	12.7	12.6±0.5	21.0±0.9
31-45	7.8	8.0	9.5	7.4	8.2	7.9	8.1±0.7	29.7±1.5
46-60	10.7	10.6	11.0	10.1	12.2	9.5	10.7±0.9	40.3±2.1
61-75	5.2	5.6	8.9	8.1	6.8	7.2	6.9±1.4	47.4±2.8
76-90	5.1	5.4	5.6	4.9	5.9	6.3	5.5±0.5	52.8±3.0
91-105	6.3	5.3	4.8	4.5	5.5	4.1	5.1±0.8	57.8±2.9
106-120	3.1	3.2	3.4	3.9	4.4	5.0	3.8±0.8	61.8±2.9
121-135	4.1	4.0	3.9	5.2	3.9	4.7	4.3±0.5	66.1±2.8
136-150	2.5	2.6	2.6	3.2	4.2	5.1	3.4±1.1	69.4±3.2

The mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5 with the weeds *Ipomoea carnea*, *Eicchornia crassipes*, and *Lantana camara* (as discussed in chapter 8, 9 and 10) (Figure 2 and 4). Supporting the reactors with trails attracted more number of termites than coming naturally to the reactors, hence more substrate consumed when these reactors were with trails.

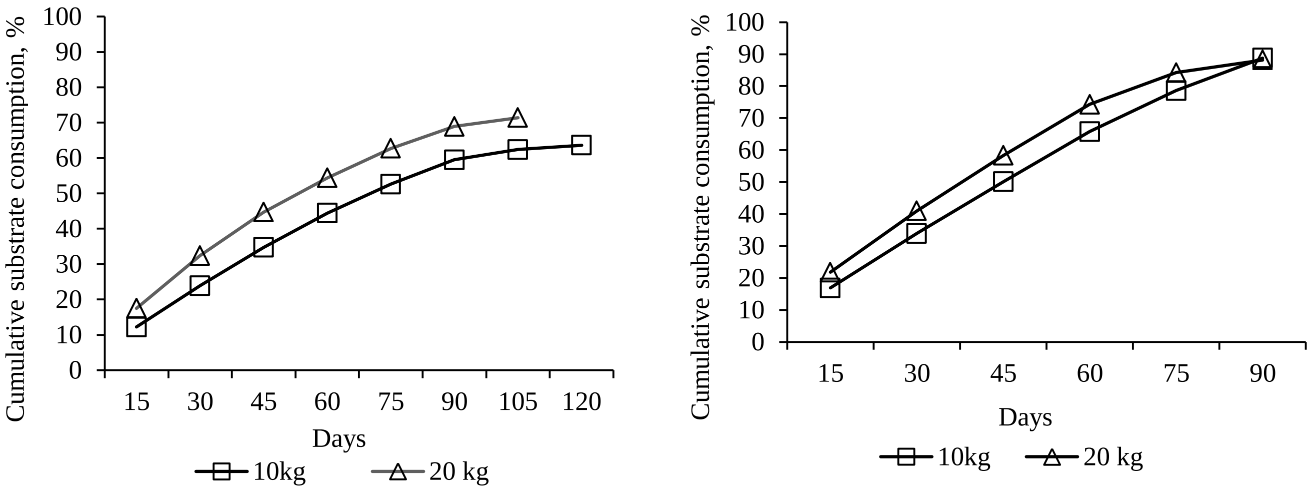


Figure 1: Cumulative of paper cups consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 10kg Reactor 20 kg

Table 2: Extent of termigradation (%) of paper cups (10 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails			Termigradation		Reactors supported by trails			Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	12.4	11.4	12.8	12.2±0.7	12.2±0.7	16.8	17.5	16.6	16.9±0.5	16.9±0.4	I 95
16-30	13	10.8	11.4	11.7±1.1	23.9±1.6	17.5	18	15.4	17.0±1.4	33.9±1.8	I 95
31-45	12.2	9.9	10.3	10.8±1.2	34.7±2.8	16.4	17.2	14.9	16.2±1.2	50.1±2.9	I 95
46-60	11.9	8.8	8.4	9.7±1.9	44.4±4.3	16.2	16.8	14.2	15.7±1.4	65.8±4.3	I 95
61-75	9.5	7.8	7.2	8.2±1.2	52.6±5.4	12.7	13.4	12.2	12.8±0.6	78.6±4.8	I 95
76-90	8.1	6.8	5.9	6.9±1.1	59.5±6.3	10.2	11.8	8.5	10.2±1.7	88.8±6.5	I 90
90-105	3.9	3.0	1.9	2.9±1.0	62.4±0.7	-	-	-	-	-	-
106-120	1.8	1.1	0.7	1.2±0.6	63.6±8.3	-	-	-	-	-	-

Table 3: Extent of termigradation (%) of paper cups(20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails					Reactors supported by trails					Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor			Termigradation		Reactor			Termigradation		
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	16.9	17.4	18.3	17.5±0.7	17.5±0.7	21.4	22.1	21.9	21.8±0.4	21.8±0.4	I 99
16-30	14.4	15.6	14.7	14.9±0.6	32.4±0.9	19.1	20.1	18.4	19.2±0.9	41.0±1.0	I 99
31-45	12.3	13.8	10.8	12.3±1.5	44.7±1.8	17.2	18.7	16.9	17.6±1.0	58.3±2.1	I 99
46-60	9.4	10.0	9.7	9.7±0.3	54.4±2.1	14.6	16.9	15.7	15.7±1.2	74.3±3.0	I 99
61-75	7.7	8.3	9.0	8.3±0.7	62.7±2.2	8.9	9.4	11.4	9.9±1.3	84.2±3.0	I 90
76-90	5.0	6.4	7.1	6.2±1.1	68.9±2.9	4.1	3.2	4.9	4.1±0.9	88.2±2.6	D 90
91-105	1.7	2.5	3.1	2.4±0.7	71.4±3.5	-	-	-	-	-	-

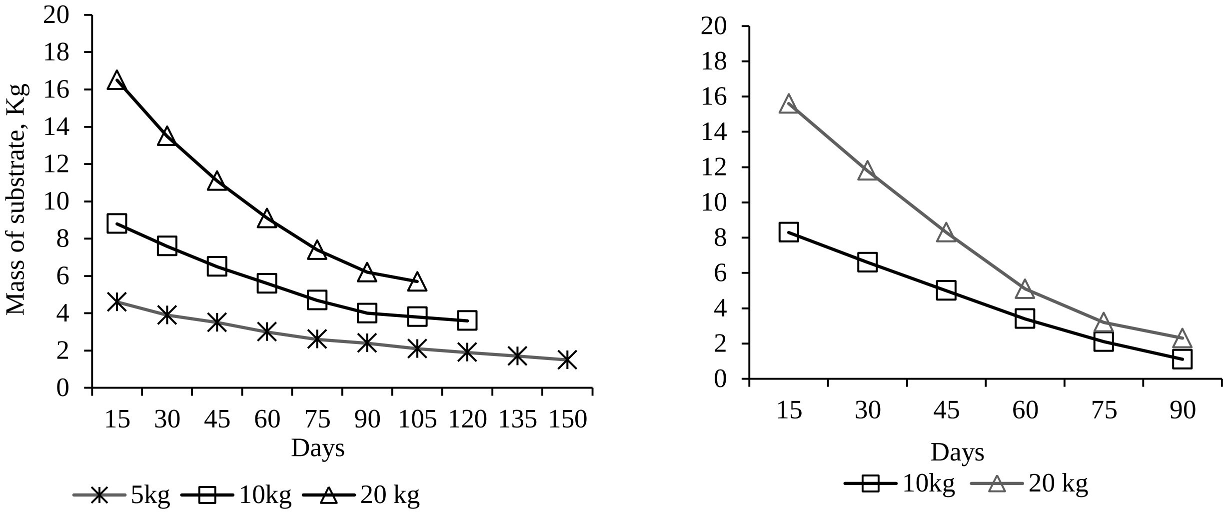


Figure 2: Mass of paper cups left at different intervals in reactors without (A) and with (B) trails : Reactor 5 kg Reactor 10 kg Reactor 20 kg

It can be noted that paper waste was comparatively more termigraded than used paper cups and the possible reason might be due to plastic lining of paper cups. After assimilation of the used paper cups and paper waste, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* and *Odontotermes annamallensis* were the species encountered.

Table 4: Extent of termigradation (%) of Paper waste (5 Kg) at 15-day intervals

Days	Reactor						Termigradation	
	A	B	C	D	E	F	During each run	Cumulative
0-15	24.8	21.5	22.8	23.7	24.3	26.5	23.9±1.7	23.9±1.7
15-30	16.1	17.6	18.2	19.7	17.1	16.6	17.6±1.3	41.5±1.6
31-45	14.2	13.8	13.1	15.6	13.1	14.4	14.0±0.9	55.5±2.3
46-60	12.8	11.7	12.1	11.6	10.8	11.9	11.8±0.7	67.3±2.4
61-75	11.2	10.3	10.8	9.9	9.0	10.4	10.3±0.8	77.6±2.6
76-90	9.6	8.0	9.0	7.1	8.1	9.2	8.5±0.9	86.1±2.9
91-105	6.2	5.6	5.2	5.0	6.9	6.0	5.8±0.7	91.9±2.8
106-120	2.7	4.5	4.0	3.7	4.9	3.9	3.9±0.8	95.9±2.2

In all the reactors, > 50% (52.6% and 78.6% for 10 Kg and 62.7% and 84.2% for 20 Kg) of the used paper cups was consumed with and without trail within 75 days; except in 5 kg reactor where the termigradation was close to 50%. In all the reactors loaded with used paper waste, > 75% (77.6 % for 5 Kg, 89.5% and 97% for 20 Kg and 79.3% and 97.3% for 50 Kg) was consumed with and without trail within 75 days.

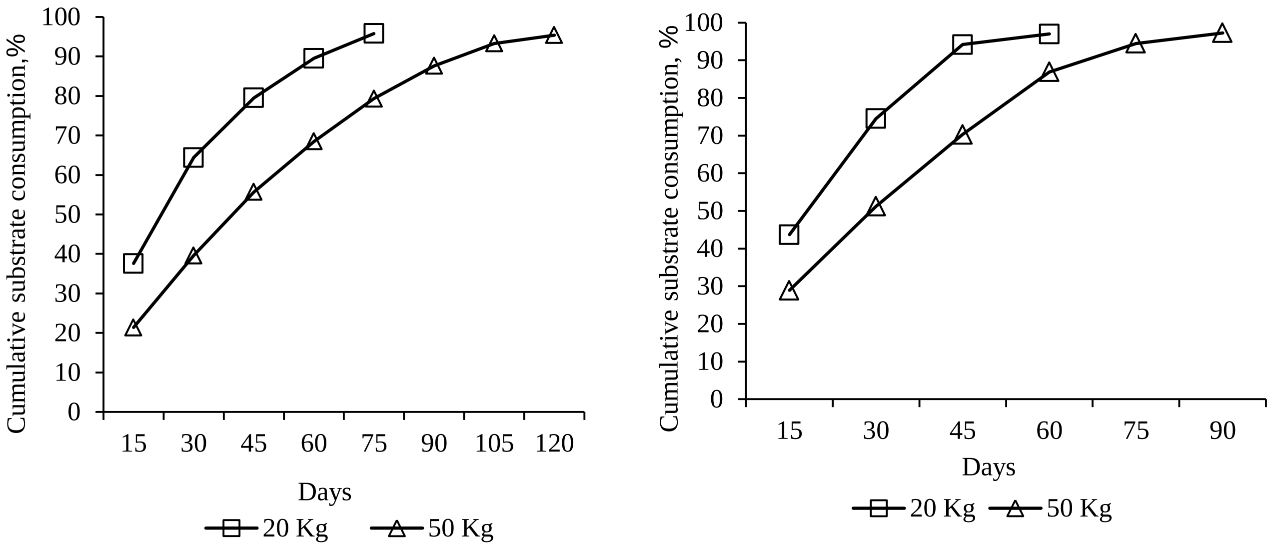


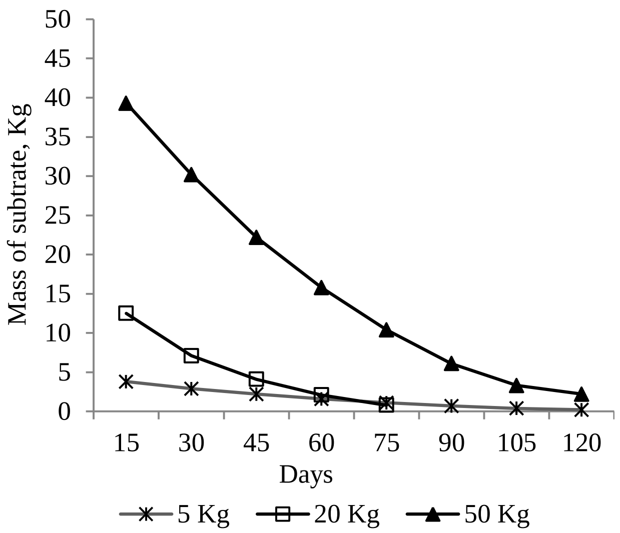
Figure 3: Cumulative of paper waste consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 20kg Reactor 50 kg

Table 5: Extent of termigradation (%) of paper waste (20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails			Termigradation		Reactors supported by trails			Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	39.7	40.8	32.4	37.6±4.6	37.6±4.6	45.9	42.3	43.0	43.7±1.9	43.7±1.9	I 80
16-30	26.8	27.9	25.5	26.7±1.2	64.4±5.7	30.7	32.5	29.1	30.7±1.7	74.5±2.3	I 99
31-45	13.5	15.1	16.8	15.1±1.7	79.5±4.6	18.0	19.2	22.0	19.7±2.1	94.2±0.3	I 99
46-60	9.7	8.1	12.2	10.0±2.1	89.5±2.5	4.1	2.9	1.4	2.8±1.4	97.0±1.6	D 90
61-75	6.5	5.2	7.4	6.4±1.1	95.8±1.4	—	—	—	—	—	—

Table 6: Extent of termigradation (%) of paper waste (50 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails				Reactors supported by trails				Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor		Termigradation		Reactor		Termigradation		
	A	B	During each run	Cumulative	A	B	During each run	Cumulative	
0-15	20.6	22.1	21.4±1.1	21.4±1.1	29.7	28.0	28.9±1.2	28.9±1.2	I 80
16-30	17.6	18.9	18.3±0.9	39.6±1.9	21.4	23.2	22.3±1.3	51.2±0.1	I 95
31-45	15.8	16.4	16.1±0.4	55.7±2.4	18.5	19.8	19.2±0.9	70.3±1.0	I 90
46-60	12.5	13.1	12.8±0.4	68.5±2.8	15.9	17.2	16.6±0.9	86.9±1.9	I 90
61-75	10.2	11.4	10.8±0.8	79.3±3.7	8.8	6.5	7.7±1.6	94.5±0.3	D 60
76-90	9.4	7.5	8.5±1.3	87.6±2.1	3.6	2.0	2.8±1.1	97.3±0.8	D 98
91-105	6.3	5.0	5.7±0.9	93.3±1.2	—	—	—	—	—
106-120	2.8	1.5	2.2±0.9	95.4±0.3	—	—	—	—	—



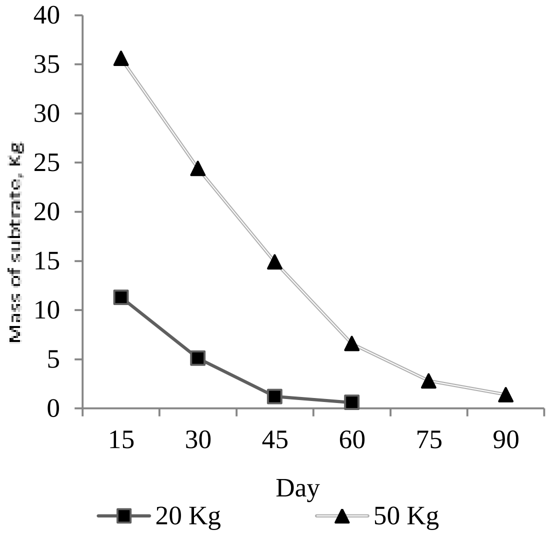


Figure 4: Mass of paper waste left at different intervals in reactors without (A) and with (B) trails: Reactor 5 kg Reactor 20 kg Reactor 50 kg

4.0 Conclusion

Disposal of used paper cups and paper waste was accomplished by controlled action of termites using in-situ reactors of capacities ranging from 5 to 20 Kg, and 5 to 50 Kg, respectively. Multiple reactors were operated with attaching termite trails to them. The trails constituted lines of paper waste or saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

About half of the initial charge was 'termigraded' in 60 days. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 14

Speedy biodegradation of waste coconut shells by the controlled use of termites

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Abstract
Coconut shell is used as a raw material for making activated carbon but a large fraction of the shells that come out from coconut oil industry is not utilized. It poses disposal problem as the shells are very very slow to biodegrade due to the presence of high concentrations of lignocelluloses in them.

The present chapter reports a new process that relies on the controlled use of termites for the disposal of coconut shells in a way that enables full assimilation of the shells into the environment in an ecologically benign manner. It is based on the technique of 'termigradation' (termite-mediated biodegradation), and the associated reactors ('termireactors'), developed recently by us.

In the *in-situ* termireactors of upto 50 Kg capacity; almost 50% (46.6% for 5 Kg; 78.8% and 92.7% in 20 Kg – without and with trails; and 64.4% and 74.5% for 50 Kg – without and with trails) of the feed was consumed within 60 days. Use of trails further speeded up the process as also provided a means of process control.

Keywords: *termite, coconut shells, termireactor, termigradation*

1.0 Introduction

Coconut palm (*Cocos nucifera* L.) is abundantly grown in coastal areas of all tropical countries. Close to 60 million tons of coconut are produced across the world, principally in Indonesia, Philippines and India (FAO, 2013).

The processing of coconut to obtain food products and oil leads to huge quantities of solid waste, mostly in the form of fiber and shell (Pillai *et al.*, 2014). As the shell constitutes ~12% of the weight of the coconut (FAO, 2013), about 7.2 million tons of coconut shell are generated annually in the world.

Coconut shell is very rich in lignocellulosic material and is considered tougher than wood (Chun *et al.*, 2012) (Tables 1 and 2). The shells that can not be put to use find their way in municipal solid waste (MSW). But they defy composting or vermicomposting and persist in the environment for decades due to their very slow rate of biodegradation.

In an endeavour to find means of assimilating large quantities of coconut shells in an ecologically compatible and inexpensive manner we have explored the possibility of getting them biodegraded by termites. The premise is that if the coconut shells can be worked upon by termites ─ a process which we have termed 'termigradation' ─ it would basically mean converting the hard biowaste into termite zoomass and termicast. As has been detailed elsewhere (Abbasi *et al.*, 2007) termites play a crucial role ─ alongside earthworm and ants ─ in the turn-over and rejuvenation of soils. Hence this approach promises to dispose coconut shells in a manner that promotes ecorestoration. After extensive proof-of-concept studies, which have all met with success, we have developed a process of which a patent claim has been registered (Abbasi and Gajalakshmi, 2014). The present paper describes the use of the process in the termigradation of coconut shells.

2.0 Material*s* and method

Three sets of experiments were conducted with different quantities of coconut shells. All the reactors were charged with coconut shells and placed near active termite mounds in the wooded parts of the Pondicherry University campus. The first set comprised of six reactors with 5 kg feed.

In the second set of experiments, a total of six termireactors were operated. All were charged with 20 kg coconut shells.

Table 1: Composition of coconut shells: minerals

Minerals (%)	***Range***	***References***
Nitrogen	0.1-0.69	Raman *et al.*, 2013; Tangsathitkulchari *et al.*, 2013; Tsai *et al.*, 2006; Tsamba *et al.*, 2006; Daud and Ali, 2004; and Olufayo, 1989
Sulphur	0.024-0.69	Raman *et al.*, 2013; Tsai *et al.*, 2006; Tsamba *et al.*, 2006; Daud and Ali, 2004; and Olufayo, 1989
Others		
Na 1.83; Mg 3.17; Al 1.93; Si 1.87; P 3.03; S 1.96; Cl 23.9; K 37.7; Ca 7.97; Ti 0.487; Fe 8.23; Ni 0.24; Cu 0.106; Zn 0.26; Sr 0.562; Jr 0.114; Pb0.118; Br0 0.165; and Mn 0.124		Kumara and Meikap, 2013

Table 2: Composition of coconut shells :organics

Variables (%)	***Range***	***References***
Organic carbon	50.7-63.5	Raman *et al.*, 2013; Tangsathitkulchari *et al.*, 2013; Ouyang *et al.*, 2013; Tsai *et al.*, 2006; Tsamba *et al.*, 2006; and Daud and Ali, 2004
Hydrogen	5.6-6.7	Ouyang *et al.*, 2013; Tsai *et al.*, 2006; Tsamba *et al.*, 2006; Daud and Ali, 2004; and Olufayo,1989
Oxygen	38.7-44.6	Tsamba *et al.*, 2006; Daud and Ali, 2004; and Olufayo,1989
Volatile matter	70.2-83.3	Ouyang *et al.*, 2013; Duan *et al.*, 2012; Yang *et al.*, 2010; Guo *et al.*, 2009; Kumar and Jena, 2006; Tsamba *et al.*, 2006; Daud and Ali, 2004; Gue, 2004; Bhattacharya, 2001
Lignin	30.1-36-5	Child and Ramanathan, 2012; Daud and Ali, 2004; Ogo *et al.*,1995
Cellulose	19.8-53.1	Child and Ramanathan, 2012; Daud and Ali, 2004; Ogo *et al.*,1995
Hemicellulose	68.7	Daud and Ali, 2004
Sulphur	0.17	Tsai *et al.*, 2006
Nitrogen	0.43	Tsai *et al.*, 2006
Others		
Pentosans 29.3; Pentosans in cellulose 20.5; Pentosanincellulosic 38.7		Child and Ramanathan, 2012; Ogo *et al.*,1995

To enhance the rate of substrate degradation, by attracting more number of termites to the reactor than coming naturally to the reactor, three of the termireactors were supported by trails of paper waste and saw dust. These trails, 8 in number, were laid alternatively and equidistance from each other going radially outward upto 5 metres from each termireactor in all directions.

In the third set of experiments, the termireactors were loaded with 50 Kg of the substrate: triplicates were used with and without trails. The extent of substrate consumption by termites was quantified once in every fifteen days in all the reactors. The reactors were observed daily and the species present each time were identified.

All quantities have been reported on ‘dry weight basis’; it is the equivalent of fresh weight of the substrate oven dried at 105˚C to constant weight.

3.0 Results and discussion

The results are summarized in Tables 3-5. It was seen that the rate of the ‘termigradation’ ─ or the rate of consumption of the substrate by termites ─ was the highest during the initial 10-15 days. By the 30th day, about one-third of the feed was termigraded in all reactors without trails and more than 40% in reactors with trails. The rate was seen to fall as the quantity of the substrate was reduced. In general there was a precipiteous fall in termigradation after about half of the substrate was utilized. This trend was seen to be independent of the initial quantity of the substrate ─ similar trend was seen whether a reactor was started with 5 Kg of substrate (Table 3) or 20-50 Kg (Figure 1). In earlier studies on *Ipomoea carnea*, *Eicchornia crassipes*, *Lantana camara*, and paper waste, we had found that the mass of unconsumed substrate tended to approach zero within an identical duration of time even when the starting mass differed by a factor of 5. But in the case of coconut shells there was a deviation from this trend. In these reactors, the mass of unconsumed substrate tended to approach zero more quickly when the initial substrate quantity was low. As the substrate quantity at the start of the reactor was raised, it took more number of days for the unconsumed substrate to approach zero (Figure 2). The possible reason is that large amount of coconut shells makes tunnel formation more difficult. Similar trend was observed with two other substrates which also tended to become increasingly compact with time: coir pith and press mud. Supporting the reactors with trails attracted more number of termites than coming naturally to the reactors, hence more substrate consumed when these reactors were with trails.

After the assimilation of the coconut shells, only a small residue of particulates was found in the reactors. *Hypotermes obscuriceps* and *Microtermes incertoides* were the species encountered in the reactors. The coconut shell being termigraded by the termites is illustrated in Figure 3.

Table 3: Extent of termigradation (%) of coconut shells (5 Kg) at 15-day intervals

Days	Reactor						Termigradation	
	A	B	C	D	E	F	During each run	Cumulative
0-15	14.8	13.1	15.3	13.4	16.2	13.8	14.4±1.2	14.4±1.2
15-30	12.1	13.7	13.2	12.7	14.1	14.3	13.4±0.8	27.8±1.8
31-45	9.9	9.3	10.4	9.5	11.1	9.7	9.9±0.7	37.7±2.1
46-60	8.1	8.5	9.2	8.5	9.9	8.6	8.8±0.6	46.6±2.7
61-75	6.3	5.9	7.4	6.1	8.3	6.2	6.7±0.9	53.2±3.7
76-90	5.2	6.7	5.8	6.7	7.7	6.7	6.5±0.9	59.7±4.1
91-105	3.9	5.1	4.7	5.7	6.4	5.1	5.2±0.9	63.9±2.6
106-120	2.7	5.4	4.0	5.0	5.8	4.8	4.6±1.1	69.5±5.5
121-135	1.9	4.0	3.1	4.0	4.6	3.8	3.6±1.0	73.1±6.2
136-150	1.2	2.1	1.4	2.0	2.8	1.4	1.8±0.6	74.9±6.7

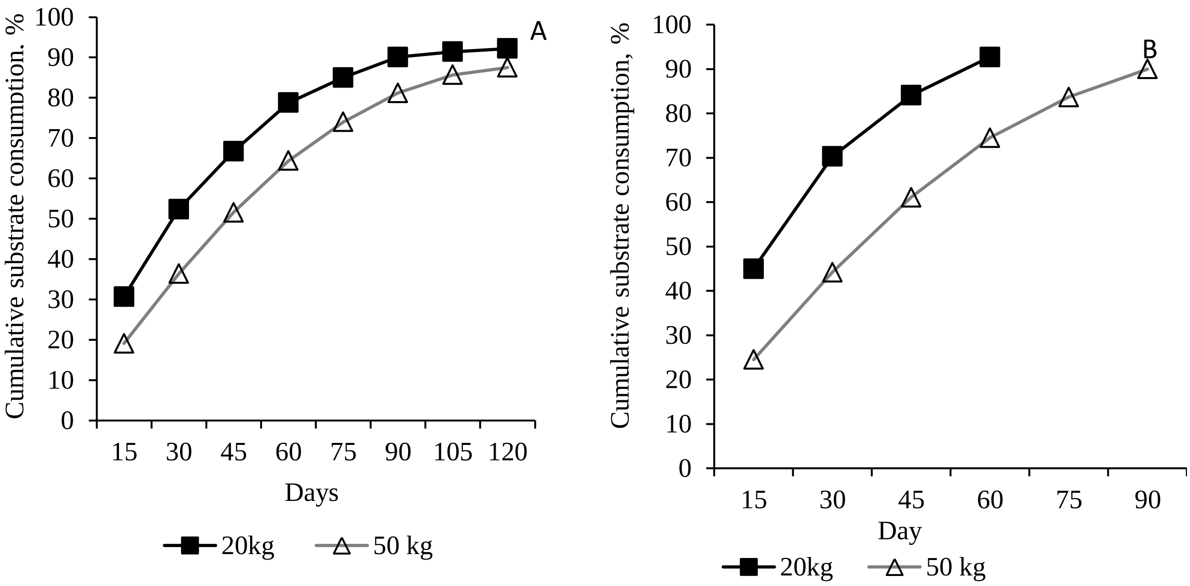

Figure 2: Cumulative of coconut shells consumption, %, in termireactors of different capacities not supported (A) and supported by trails (B): Reactor 20kg Reactor 50 kg

In all the reactors, almost 50% (46.6% for 5 Kg; 78.8% and 92.7% in 20 Kg – without and with trails; and 64.4% and 74.5% for 50 Kg – without and with trails) of the feed was consumed within 60 days. This time-span can be considered very quick because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of

Table 4: Extent of termigradation (%) of coconut shells (20 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails			Termigradation		Reactors supported by trails			Termigradation		Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	29.0	30.6	32.4	30.7±1.4	30.7±1.4	43.2	44.6	47.3	45.0±2.1	45.0±2.1	I 99
16-30	21.4	21.6	22.2	21.7±0.4	52.4±2.1	25.0	26.1	24.7	25.3±0.7	70.3±1.9	I 95
31-45	14.6	14.2	14	14.3±0.3	66.7±1.8	14.2	13.8	13.4	13.8±0.4	84.1±1.5	D 80
46-60	12.4	12.2	11.7	12.0±0.4	78.8±1.5	9.1	8.9	7.7	8.6±0.8	92.7±1.0	D 99
61-75	6.1	5.5	7.2	6.2±0.9	85.0±2.2	-	-	-	-	-	-
76-90	3.3	3.0	2.6	2.9±0.4	90.1±1.8	-	-	-	-	-	-
90-105	2.0	1.7	1.3	1.3±0.4	91.4±1.5	-	-	-	-	-	-
106-120	1.5	1.0	0.8	0.8±0.4	92.2±1.3	-	-	-	-	-	-

Table 5: Extent of termigradation (%) of coconut shells (50 Kg) 15-day intervals, in the reactors without trails and the reactors supported by trails

Days	Reactors without trails					Reactors supported by trails					Increase (I) or decrease (D) in termigradation by use of trails, significant to confidence level
	Reactor			Termigradation		Reactor			Termigradation		
	A	B	C	During each run	Cumulative	A	B	C	During each run	Cumulative	
0-15	19.0	20.5	17.9	19.1±1.1	19.1±1.3	23.1	24.6	25.8	24.5±1.1	24.5±1.4	I 99
16-30	17.2	19.0	15.7	17.3±1.3	36.4±2.9	19.2	18.5	21.4	19.7±1.2	44.2±2.6	I 60
31-45	14.2	16.3	15.1	15.2±0.9	51.6±3.7	16.7	15.6	18.4	16.9±1.2	61.1±3.9	I 60
46-60	12.8	13.7	11.9	12.8±0.7	64.4±4.6	14.2	12.4	13.6	13.4±0.7	74.5±4.2	I 40
61-75	8.1	11.0	9.7	9.6±1.2	74.0±5.6	10.7	8.1	8.8	9.2±1.1	83.7±4.4	D 20
76-90	6.4	8.0	7.2	7.2±0.7	81.2±6.3	8.7	4.2	6.0	6.3±1.8	90.0±5.8	D 20
91-105	4.7	5.2	3.6	4.5±0.7	85.7±6.9	-	-	-	-	-	-
106-120	1.8	2.6	1.0	1.8±0.7	87.5±7.7	-	-	-	-	-	-

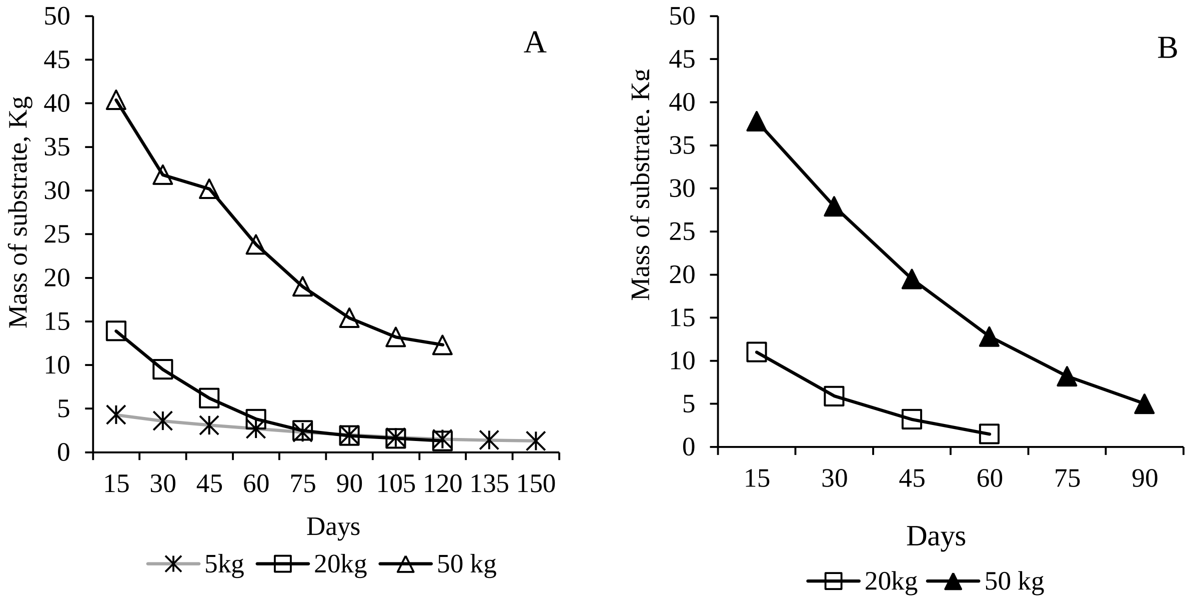

Figure 3: Mass of coconut shells left at different intervals in reactors without (A) and with (B) trails : Reactor 5 kg Reactor 20 kg Reactor 50 kg

a b c d

Figure 4 a, b, c and d: Coconut shell termigraded by the termites

substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence this is a much less expensive process with much lesser 'footprint'.

4.0 Conclusion

Disposal of coconut shells was accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 50 Kg. Multiple reactors were operated with attaching termite trails to them. The trails constituted lines of paper waste or saw dust, drawn in a manner that led termites to the termireactors from eight uniformly spaced directions.

About half of the initial charge was 'termigraded' in 60 days. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for signal for, and summon, the number of foragers in proportion to the quantity of the food source.

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A paper based on this chapter has been
submitted for publication

Chapter 15

Lab studies on trail following behavior of *Hypotermes obscuriceps* towards 2-Phenoxyethanol

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Abstract
The trail following behavior of the termite *Hypotermes obscuriceps* towards trails of 2-Phenoxyethanol was evaluated in the laboratory. *H.obscuriceps* is the most abundant of species found in North-eastern Puducherry, where the authors are located. It is found to assimilate the ligninous waste kept for degradation in the termireactors by the process ─ termigradation ─ developed by us. Termigradation is termite-based biodegradation process and *in-situ* termigradation involves bringing reactors with the substrate to the nature allowing it to be degraded by the termites. In order to increase the number of termites towards the feed, 2-Phenoxyethanol (2-PE) was tested for its potency to be an attractant to the termite species *H.obscuriceps*. All the five concentrations of 2-PE tested in this study ─ 0.1, 0.01, 0.001, 0.0001 and 0.0005% ─ attracted *H.obscuriceps*.

Keywords: 2-Phenoxyethanol, *Hypotermes obscuriceps,* trail, termites, attractant

Introduction

One of the strategies to control termites and other insects has been the use of man-made chemicals to attract the insects in a manner pheromones and other naturally occurring biomolecules do. Once attracted to a spot in this manner the insects can be killed more easily than when they are in dispersed form.

Based on chance observations that termites tended to move down the lines drawn by ball-pen, Becker and Mannesmann (1968) investigated the effectiveness of different ball point ink formulations and nineof the species from 21 genera of 4 families and found that most species tended to follow the trails laid by the ball points or the associated glycols. The response of Rhinotermitidae and Termitidae was more pronounced than that of Kalotermitidae andTermopsidae.

Since then a number of substrates have been found to attract termites to move up the trails formed by then. The gist of all past reports on this subject is presented in Table 1.

In addition to the work reported in Table 1, there are patents registered with ergosterol (Henderson *et al.,* 1999), cholesterol and hydroisoandrosterone (Galis and Strnad, 2000), and 2-naphthalenemethanol (U.S. Pat. No. 5,63,298) as trail-eliciting compounds for termites.

Chen *et al.,* (1998) investigated the constituents of Papermate brand ball-pens and isolated 2-phenoxyethanol (2-PE) from it as a powerful trail-inducing substance. It was thought that the structural similarity of 2-PE to dodecantreinol, the main compound of the trail pheromone of glycol compounds contained in these formulations of *C.formosanus* and *Reticulitermes spp*., may be the reason for its appeal to termites. 2-PE has other favourable attributes ─ it is relatively inexpensive, stable, and does not evaporate too rapidly (Stewart, 1998; LaPorte *et al.,* 2004). The present study is the first report in which the effect of 2-PE trails has been investigated on the termite species *H. obscuriceps.*

Table 1: Non-pheromone chemicals tested so far in making trails that attract termites

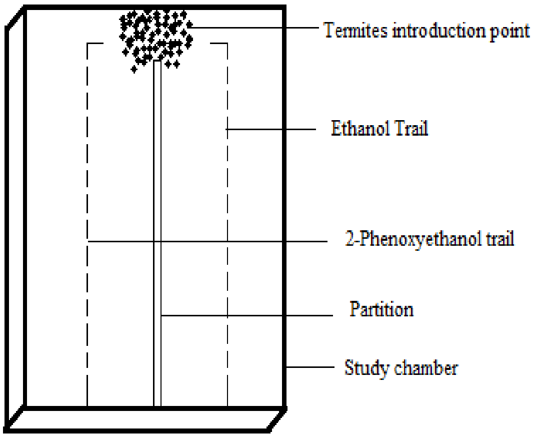
Chemical	Termite genus/species	Concentrations tested	Trail following/attractant	Toxicity	References
Diethyleneglycolmonoethylether, Diethyleneglycolmonobutylether, Ethyleneglycolmonoethylether, Ethyleneglycolmonobutylether, 1,2-propylenglycol-monobutylether, Isomeric 1,2-Propyleneglycol, 1,3-Propylenglycol, Dipropyleneglycol 1,4-Butyleneglycol	Kalotermitidae, Mastotermitidae , Termopsidae, and Termitidae (55 termite species belonging to 21 genera and 4 families)	Not specified	Diethylene glycolmonoethylether and diethyleneglycol butylether were effective for almost all termite spp. except family Kalotermitidae. Isomeric 1,2-Propyleneglycol acted only in very few species. Ethyleneglycolmonoethylether, Ethyleneglycolmonobutylether, 1,2-propylenglycol-monobutylether, Dipropyleneglycol, 1,4-Butyleneglycol were species and group specific.	Not stated	Becker and Mannesmann, 1968
Oil of *Santalumspicatum* fractionated to 10cis-(1) and 10 trans-2,6,10-trimethyldodeca-2,6,10-triene	*Nasutitermes*	Not specified	10cis-(1)-2,6,10-trimethyldodeca-2,6,10-triene more effective than 10 trans-2,6,10-trimethyldodeca-2,6,10-triene	Not stated	Birch *et al.*,1970
(Z)-4-phenyl-3-buten-1-ol derivatives	*Coptotermes, Reticulitermes, Schedorhinotermes*	Not specified	Induced trail forming behaviour in three genera	Not stated	Prestwich *et al*, 1984
Amino acids	*C.formosanus* Shiraki	Not specified	Termites consumed significantly more filter paper treated with D-aspartic acid and L-aspartic acid than paper treated with water. Adding L-proline, L-lysine, L-isoleucine to filter paper significantly increased consumption compared with control filter paper.	Not stated	Chen and Henderson., 1996
Extracts of the brown rot fungus *Gloeophyllum trabeum*	*R.hesperus*	Not specified	The extract assisted worker termites in locating baits.	Not stated	Rust *et al*, 1996
2-phenoxyethanol	*C.formosanus* Shiraki and *Reticulitermes sp.*	Four concentrations of 2-phenoxyethanol (0.23, 0.023, 0.0023 and 0.00023) ug/cm were tested.	In 0.00023 ug/cm limited trail-following activity occurred (≤ 30% of termites followed the trails) compared to 0.23 ug/cm, 0.023 ug/cm, and 0.0023 ug/cm (≥ 60% of termites followed the trails).	Not stated	Chen *et al.*,1998

Chemical	Termite genus/species	Concentrations tested	Trail following/attractant	Toxicity	References
Mixture of sucrose and yeast; urea	*Reticulitermes virginus* and *R.flavipes*	Substrates were drenched with the mixture of sucrose and yeast, or urea	Greater number of termites were recruited to the sucrose and yeast chambers than in water drenched chambers.	Not stated	Waller *et al.*,1999
Synthetic dode-3-en-1-ol	*M.annandalei*	Not specified	Induced both orientation and recruitment behaviour effects	Not stated	Peppuy *et al.*, 2001
Carbon dioxide	*Reticulitermes flavipes, R.tibiais, R.virginicus*	5 – 50 mmol/mol	All the species were attracted to CO_2 in laboratory and field tests	Not stated	Bernklau*et al*, 2005
Napthalene	*C.formosanus* Shiraki	10mg/ml to 0.01mg/ml	Did not elicited trail following behaviour.	Not stated	Cornelius *et al.*, 2005
Summon disks (commercial product)	*C.formosanus* Shiraki	Filter paper disks treated with water extract of summon disks	Consumption of filter paper disks treated with water extract of summon disks was significantly higher than consumption of control filter paper disks.	Not stated	Cornelius and Lax,2005
2-phenoxyethanol	*C.formosanus* Shiraki	Three concentrations of 2-phenoxyethanol - 0.041, 0.082, and 0.164% were tested.	In 0.082% 2-PE treated side, total tunnel network length was significantly more extensive compared with control side for both colony A and B. Even residues of 2-PE on pretreated sand with a concentration of 0.082% had higher tunnel length on 16, 17, 18^{th} day compared to control.	Not stated	Fei *et al.*, 2005a
2-phenoxyethanol	*C.formosanus* Shiraki	Six concentrations (0.00023, 0.0023, 0.023, 0.23, 2.3, 23 µg /cm) plus a control (only ethanol) were tested. Six types of 2-PE gradient trails were created. For "increasing-trail" gradients, they were 0.00023-0.0023-0.023-0.23µg/cm, 0.0023-0.023-0.23 2.3 µg/cm, and 0.023-0.23-2.3-23 µg/cm. For "decreasing-trail" gradients, they were 0.23-0.023-0.0023-0.00023 µg/cm, 2.3-0.23-0.023-0.0023 µg/cm, and 23-2.3-0.23-0.023 µg/cm.	Termites responded 100% to the trail at 0.23 µg /cm. Termites travelled significant distance when initial concentration was 0.0023 µg/cm. 0.23 and 2.3 µg/cm significantly increased termite aggregation compared to the control during 3min and 10 min observational time.	Not stated	Fei *et al.*, 2005b

Chemical	Termite genus/species	Concentrations tested	Trail following/attractant	Toxicity	References
2-phenoxyethanol, acetamiprid, fipronil, and imidacloprid.	*C.formosanus*Shiraki	Two tests were conducted to evaluate the effect of 2-phenoxyethanol as an additive to acetamiprid, fipronil, and imidacloprid on the tunnelling system by the Formosan subterranean termite *Test 1:* In the treated chamber, 0.07% of acetamiprid, fipronil, or imidacloprid and 0.345% of 2-phenoxyethanol were tested. *Test 2:* 0.07% of the insecticide and 0.345% 2-phenoxyethanol were tested by applying 1.0 ml solutions to sand through the two of the four small access holes. In both the tests control was Double distilled water.	Significantly more search tunnels were constructed in the 2-phenoxyethanol treated side compared with the control side on day 1. With the addition of acetamiprid, the total tunnel network length remained significantly higher in the treated side than that of the control side.With imidacloprid and fipronil, the total tunnel network length was greater in the treated side than that in the control side, but the differences were not significant. Termite survival rate in the treated chambers was significantly lower than that in the untreated chamber	Not stated	Fei*et al.*, 2005c
Solvent extracts of intact termite bodies and excised termites	*R.hesperus*	Not specified	Intact termite bodies elicited greater trail-following activity than extracts of excised termites	Not stated	Grace *et al*, 2005
2-phenoxyethanol	*C.formosanus* Shiraki	Four studies were conducted: attraction and toxicity response on different 2-phenoxyethanol, persistence of 2-phenoxyethanol (0.96% upto 13th week), feeding and survivorship in both- choice test and no-choice test.	Consumption of filter paper treated with 0.12% 2-phenoxyethanol was significantly greater compared to the untreated filter paper. It was an attractant but not toxicant at 0.12 and 0.24 per cent, an attractant and toxicant at > 0.48 per cent and the maximum effect was at 0.96 per cent. 2-Phenoxyethanol at 0.96 per cent attracted 90 per cent of the termite workers to the treated filter paper side, killing 85 per cent of the termites within 48 hour. Residues of 2-Phenoxyethanol on pretreated filter paper remained effective in orienting *C.formosanus* Shiraki workers upto 13 weeks.	2-phenoxy ethanol is toxic at ≥0.36%	Ibrahim *et al.*, 2005

Materials and Method

Five concentrations of 2-PE ─ 0.1%, 0.01, 0.001, 0.005 and 0.0005 % ─ were used for the study. The apparatus to study trails of 2-PE consisted of rectangular transparent plastic chambers, 36.5 x 24.5 x 7 cm (Figure 1). Each chamber was divided into two segments by plastic sheets of 32 cm length and 7cm height.



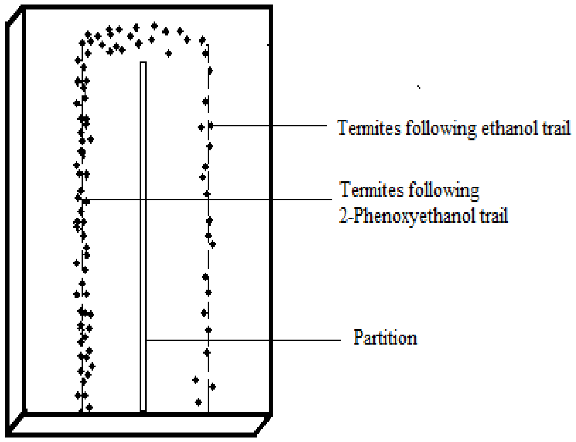


Figure 1: Study chamber (a) Spot where termites are introduced (b) general pattern seen on the 2-Phenoxyethanol and ethanol trails

Termites were collected from three different sites in Pondicherry University campus representing colonies A, B, and C. For each colony three sets of observations were taken, each with different, randomly picked numbers.

In the segments of each chamber, trails of 2-PE and ethanol were marked on either side of divide using micropipettes, as shown in Figure 1. Termites comprising 90 workers and 10 soldiers were released at the spot shown in Figure 1 so that they could follow either of the trails. A set, in triplicate, without 2-PE/ethanol was kept as control to study the behavior of termites. The chambers were covered by black HDPE sheet in order to avoid light and in each run, the trail following behaviour was observed once every 15 minutes till the last of the termites died.

Result and Discussion

The number of termites attracted towards different concentrations of 2-PE and ethanol, and control is given in Tables 2-7. More number of termites were attracted towards 0.1% 2-PE compared to control and other four concentrations of 2-PE (0.01, 0.001, 0.005 and 0.0005%). Paired *t* test shown that difference in the number of termites attracted towards 2-PE in comparison to ethanol is significant at > 99% confidence level in all the experiments. Within the first fifteen minutes of the studies, more than 65%of the termites (on an average) were attracted towards 2-Phenoxyethanol whereas it was never more than 34% in case of ethanol. The number of termites attracted by all concentrations of 2-PE reached a maximum in 15 minutes. Subsequently in the trails bearing 0.1%, 0.01%, 0.001%, 0.005% of 2-PE the number reduced with time; whereas in the trail bearing 0.0005%, the number increased with time.

In first 60 minutes, there was less mortality of termites in chambers which had trails of different concentrations of 2-PE and ethanol than in control. The difference was statistically significant ($p<0.05$). As time passed, the mortality in 2PE/ethanol began to rival and then exceed the mortality in the control chamber. However, for the purpose of setting a trail for the termites, on which a termite will move past in just a few minutes, the absence of toxicity over 60 minute exposure is an indication that 2-PE can serve as an effective as well as safe substance for attracting termites though the substance's trails.

The studies reported by other authors on 2-PE are summarized in Table 8. In the experiments of Chen *et al.,* (1998) with *C.formosanus* and *Reticulitermes sp.,* 0.23, 0.023 and 0.0023 µg/cm of 2-PE elicited trail following behaviour in ≥ 60% of termites. In another study conducted by Fei *et al.,* (2005b) on *C.formosanus* the aggregation behaviour of six different concentrations of 2-PE (0.00023, 0.0023, 0.023, 0.23, 2.3, 23 µg/cm) were explored. Of these 0.23, 2.3, 23 µg/cm of 2-PE were seen to induce a 100% response from the termites.

Fei *et al.,* (2005a) conducted experiments to investigate the effect of three concentrations of 2-PE – 0.041, 0.082 and 0.164% (w/w of sand) – on the

Table 2: Number of termites attracted to 0.1% 2-PE and ethanol, at different timings, from the initial 100 individuals with *H. obscuriceps* : Colony A, B and C

Time	2-PE										Ethanol										Attraction of termites towards 2-Phenoxyethanol, significant to confidence level
	Number of alive termites in each replicate									Mean ±SD	Number of alive termites in each replicate									Mean ±SD	
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9		
After 15 min	90	87	95	92	90	84	89	93	90	90.0±3.2	10	13	5	8	10	16	11	7	10	10.0±3.2	I 99
After 30 min	87	85	92	88	86	81	84	89	84	86.2±3.2	13	15	8	12	14	19	16	11	16	13.8±3.2	I 99
After 45 min	85	85	88	84	83	77	84	83	82	83.4±3.0	15	15	12	16	17	23	16	17	18	16.6±3.0	I 99
After 60 min	83	83	84	84	83	77	79	82	74	81.0±3.5	13	13	12	14	17	23	16	18	18	16.0±3.5	I 99
After 75 min	81	79	79	78	79	73	74	77	69	76.6±3.8	11	12	10	14	15	19	16	18	15	14.4±3.0	I 99
After 90 min	74	76	72	73	72	67	69	74	62	71.0±4.3	8	10	10	14	12	16	13	15	13	12.3±2.6	I 99
After 105 min	69	72	66	66	68	65	61	69	59	66.1±4.1	7	9	8	11	9	12	13	15	13	10.8±2.7	I 99
After 120 min	64	68	63	64	63	61	54	62	53	61.3±4.8	5	7	7	11	9	10	13	15	13	10.0±3.3	I 99
After 135 min	60	65	59	56	60	55	50	57	48	56.7±5.2	4	6	7	11	9	10	11	11	10	8.8±2.5	I 99
After 150 min	56	58	57	53	54	51	45	52	43	52.1±5.2	2	3	5	10	7	10	7	8	8	6.7±2.8	I 99
After 165 min	49	54	52	44	51	48	40	47	38	47.0±5.4	2	3	4	8	7	9	7	8	8	6.2±2.5	I 99
After 180 min	44	49	45	40	46	43	40	43	34	42.7±4.3	0	3	4	6	7	6	7	8	8	5.4±2.7	I 99
After 195 min	40	47	41	37	43	36	40	39	29	39.1±5.0	0	2	4	6	5	6	5	6	5	4.3±2.1	I 99
After 210 min	34	43	36	36	39	31	33	33	24	34.3±5.3	0	1	2	6	4	6	4	6	5	3.8±2.3	I 99
After 225 min	30	38	33	31	32	28	29	29	19	29.9±5.1	0	1	2	4	2	4	4	6	3	2.9±1.8	I 99
After 240 min	22	35	25	27	27	24	23	23	17	24.8±4.9	0	1	2	4	2	3	2	3	3	2.2±1.2	I 99
After 255 min	15	28	21	20	19	19	15	19	14	18.9±4.2	0	0	1	3	2	3	2	2	3	1.8±1.2	I 99
After 270 min	6	24	16	12	16	17	12	17	14	14.9±4.9	0	0	1	0	0	3	2	2	0	0.9±1.2	I 99
After 285 min	2	16	10	8	11	11	8	12	11	9.9±3.8	0	0	0	0	0	0	0	0	0	0	–
After 300 min	0	9	7	5	5	7	6	9	7	6.1±2.7	–	–	–	–	–	–	–	–	–	–	–
After 315 min	0	3	5	1	1	5	5	5	3	3.1±2.0	–	–	–	–	–	–	–	–	–	–	–
After 330 min	0	0	0	0	0	2	3	3	0	0.9±1.4	–	–	–	–	–	–	–	–	–	–	–
After 345 min	0	0	0	0	0	0	3	0	0	0.3±1.0	–	–	–	–	–	–	–	–	–	–	–
After 360 min	0	0	0	0	0	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–

1, 2 and 3 – Triplicates of Colony A of *H.obscuriceps;* 4, 5 and 6 – Triplicates of Colony B of *H.obscuriceps,* and 7, 8 and 9 – Triplicates of Colony C of *H.obscuriceps*

Table 3: Number of termites attracted to 0.01% 2-PE and ethanol, at different timings, from the initial 100 individuals with *H.obscuriceps* : Colony A, B and C

Time	2-PE										Ethanol										Attraction of termites towards 2-Phenoxyethanol, significant to confidence level
	Number of alive termites in each replicate									Mean ±SD	Number of alive termites in each replicate									Mean ±SD	
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9		
After 15 min	85	81	90	83	79	85	92	74	92	84.6±6.1	15	19	10	17	21	15	8	26	8	15.4±6.1	I 99
After 30 min	81	77	86	79	76	81	88	76	88	81.3±4.9	19	23	14	21	24	19	12	24	12	18.7±4.9	I 99
After 45 min	81	76	82	79	76	81	88	79	84	80.7±3.8	19	24	18	21	24	19	12	21	16	19.3±3.8	I 99
After 60 min	81	76	82	75	72	77	79	79	84	78.3±3.7	19	22	18	21	19	19	12	21	14	18.3±3.3	I 99
After 75 min	81	72	78	70	66	71	73	73	78	73.6±4.7	19	19	15	17	17	16	10	17	14	16.0±2.8	I 99
After 90 min	77	69	71	64	63	66	66	68	73	68.6±4.5	15	13	15	14	14	14	10	14	14	13.7±1.5	I 99
After 105 min	71	64	68	61	59	59	58	61	66	63.0±4.5	15	13	12	14	14	13	10	14	11	12.9±1.6	I 99
After 120 min	66	59	63	59	52	55	54	58	64	58.9±4.8	13	13	12	14	14	9	7	14	11	11.9±2.5	I 99
After 135 min	59	52	59	52	47	55	49	52	56	53.4±4.2	10	9	8	10	11	9	5	10	11	9.2±1.9	I 99
After 150 min	59	48	53	48	41	52	43	47	53	49.3±5.5	10	9	8	10	11	9	4	9	10	8.9±2.0	I 99
After 165 min	56	43	50	48	37	47	41	40	44	45.1±5.8	10	9	8	10	11	7	4	9	8	8.4±2.1	I 99
After 180 min	51	40	43	48	29	41	36	36	40	40.4±6.6	6	7	6	7	9	4	4	9	6	6.4±1.8	I 99
After 195 min	47	36	39	43	26	37	32	34	37	36.8±6.1	6	6	6	7	9	4	4	7	6	6.1±1.5	I 99
After 210 min	47	30	34	43	21	37	27	28	36	33.7±8.2	6	6	6	7	7	4	2	6	6	5.6±1.6	I 99
After 225 min	47	23	34	43	17	31	27	24	31	30.8±9.6	4	6	5	4	7	3	2	4	4	4.3±1.5	I 99
After 240 min	41	23	34	36	13	26	27	24	27	27.9±8.2	2	4	2	4	5	3	2	4	4	3.3±1.1	I 99
After 255 min	37	18	28	32	13	24	24	19	20	23.9±7.5	2	4	2	4	5	2	1	4	3	3.0±1.3	I 99
After 270 min	32	18	25	26	13	17	18	18	12	19.9±6.5	0	1	2	1	2	2	1	1	0	1.1±0.8	I 99
After 285 min	24	14	18	21	13	13	13	11	8	15.0±5.0	0	0	0	0	0	0	0	0	0	0	—
After 300 min	17	9	14	15	9	7	6	9	5	10.1±4.2	—	—	—	—	—	—	—	—	—	—	—
After 315 min	11	7	7	8	7	3	2	9	1	6.1±3.4	—	—	—	—	—	—	—	—	—	—	—
After 330 min	6	3	3	3	3	1	0	5	0	2.7±2.1	—	—	—	—	—	—	—	—	—	—	—
After 345 min	2	0	0	1	0	0	0	2	0	0.6±0.9	—	—	—	—	—	—	—	—	—	—	—
After 360 min	2	0	0	0	0	0	0	0	0	0.2±0.7	—	—	—	—	—	—	—	—	—	—	—
After 375 min	0	0	0	0		0	0	0	0	0	—	—	—	—	—	—	—	—	—	—	—

1, 2 and 3 – Triplicates of Colony A of *H.obscuriceps;* 4, 5 and 6 – Triplicates of Colony B of *H.obscuriceps*, and 7, 8 and 9 – Triplicates of Colony C of *H.obscuriceps*

Table 4: Number of termites attracted to 0.001% 2-PE and ethanol, at different timings, from the initial 100 individuals with *H.obscuriceps* : Colony A, B and C

Time	2-PE										Ethanol										Attraction of termites towards 2-Phenoxyethanol, significant to confidence level
	Number of alive termites in each replicate									Mean ±SD	Number of alive termites in each replicate									Mean ±SD	
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9		
After 15 min	73	77	89	86	94	84	76	91	94	84.9±7.9	27	23	11	19	6	16	24	9	6	15.1±7.9	I 99
After 30 min	71	74	84	81	87	81	74	84	91	80.8±6.6	29	26	16	23	13	19	26	16	9	19.2±6.6	I 99
After 45 min	71	71	81	77	84	78	71	79	87	77.7±5.9	29	26	19	23	16	22	29	21	13	22.0±5.5	I 99
After 60 min	67	68	77	77	84	78	71	79	84	76.1±6.3	29	22	23	19	16	22	29	21	13	22.0±5.2	I 99
After 75 min	61	62	77	71	79	74	67	73	79	71.4±6.8	25	16	23	16	13	18	23	18	11	18.4±4.7	I 99
After 90 min	58	58	71	67	74	68	62	69	73	66.7±6.0	19	16	19	16	9	13	19	16	11	15.3±3.6	I 99
After 105 min	54	53	64	63	67	63	56	62	69	61.2±5.7	16	16	16	16	9	9	19	16	8	13.9±4.0	I 99
After 120 min	51	50	60	61	64	56	52	59	65	57.6±5.6	14	16	11	12	9	9	19	16	8	13.1±4.0	I 99
After 135 min	51	50	55	53	58	51	46	53	59	52.9±4.0	14	13	11	10	9	9	13	12	6	11.0±2.5	I 99
After 150 min	45	50	52	49	56	44	41	49	54	48.9±4.9	14	11	11	10	7	9	11	10	6	9.9±2.4	I 99
After 165 min	38	43	48	46	48	40	38	44	50	43.9±4.5	11	7	9	10	4	7	8	10	4	7.8±2.5	I 99
After 180 min	33	39	47	39	42	37	31	37	42	38.6±4.9	11	7	9	7	4	4	8	10	4	7.4±2.8	I 99
After 195 min	30	33	47	34	37	31	27	32	36	34.1±5.7	10	7	9	6	4	4	8	7	4	6.7±2.2	I 99
After 210 min	28	25	47	32	33	27	22	27	33	30.4±7.2	8	5	6	3	4	4	6	5	2	5.1±1.7	I 99
After 225 min	19	21	39	26	30	21	18	19	29	24.7±7.0	8	4	6	3	2	1	6	5	2	4.1±2.3	I 99
After 240 min	15	14	35	22	22	16	13	19	27	20.3±7.1	5	4	4	3	2	1	4	5	2	3.3±1.4	I 99
After 255 min	12	12	29	19	18	11	13	19	22	17.2±5.9	2	4	2	1	2	1	2	2	0	2.0±1.1	I 99
After 270 min	11	9	24	14	15	7	13	16	19	14.2±5.2	0	2	2	0	2	0	0	0	0	0.9±1.0	I 99
After 285 min	11	7	17	8	11	4	9	12	19	10.9±4.7	0	0	0	0	0	0	0	0	0	0	–
After 300 min	11	4	13	6	5	4	6	12	15	8.4±4.3	–	–	–	–	–	–	–	–	–	–	–
After 315 min	11	2	8	6	5	3	3	7	9	6.0±3.0	–	–	–	–	–	–	–	–	–	–	–
After 330 min	7	2	8	5	5	1	3	1	6	4.2±2.6	–	–	–	–	–	–	–	–	–	–	–
After 345 min	5	2	5	5	3	1	3	0	2	2.9±1.8	–	–	–	–	–	–	–	–	–	–	–
After 360 min	2	2	2	1	0	0	0	0	0	0.9±1.0	–	–	–	–	–	–	–	–	–	–	–
After 375 min	0	0	0	0	0	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–

1, 2 and 3 – Triplicates of Colony A of *H.obscuriceps;* 4, 5 and 6 – Triplicates of Colony B of *H.obscuriceps*, and 7, 8 and 9 – Triplicates of Colony C of *H.obscuriceps*

Table 5: Number of termites attracted to 0.005 % 2-PE and ethanol, at different timings, from the initial 100 individuals with *H.obscuriceps* : Colony A, B and C

Time	2-PE										Ethanol										Attraction of termites towards 2-Phenoxyethanol, significant to confidence level
	Number of alive termites in each replicate									Mean	Number of alive termites in each replicate									Mean	
	1	2	3	4	5	6	7	8	9	±SD	1	2	3	4	5	6	7	8	9	±SD	
After 15 min	88	70	82	87	75	76	81	64	66	76.6±8.7	12	30	18	13	25	24	19	36	34	23.4±8.7	I 99
After 30 min	84	72	78	84	72	73	78	62	68	74.6±7.2	16	28	22	16	28	27	22	38	32	25.4±7.2	I 99
After 45 min	81	75	78	81	72	70	77	62	71	74.1±6.1	19	25	22	19	28	30	23	38	29	25.9±6.1	I 99
After 60 min	81	75	73	81	69	70	77	55	71	72.4±7.9	16	25	19	19	21	30	23	38	29	24.4±6.9	I 99
After 75 min	77	69	69	74	65	70	73	50	64	67.9±7.9	12	22	19	15	17	30	19	33	25	21.3±6.9	I 99
After 90 min	71	64	63	68	59	63	67	46	61	62.4±7.2	10	18	14	15	14	24	14	29	21	17.7±6.0	I 99
After 105 min	64	58	58	63	52	58	61	40	55	56.6±7.2	10	18	11	12	11	21	14	26	15	15.3±5.4	I 99
After 120 min	58	55	51	59	44	55	56	37	50	51.7±7.2	10	18	11	10	11	20	11	21	12	13.8±4.5	I 99
After 135 min	53	51	45	56	40	51	49	30	46	46.8±7.9	7	13	11	10	11	16	9	17	8	11.3±3.4	I 99
After 150 min	50	44	41	51	37	45	44	25	41	42.0±7.7	5	10	7	9	9	14	6	14	8	9.1±3.2	I 99
After 165 min	44	39	38	45	32	37	41	21	35	36.9±7.2	3	10	7	7	9	11	6	10	8	7.9±2.5	I 99
After 180 min	40	31	34	41	26	34	38	18	31	32.6±7.2	3	10	5	4	9	8	4	7	6	6.2±2.4	I 99
After 195 min	33	29	27	34	26	29	32	16	27	28.1±5.3	3	8	5	4	7	6	4	7	3	5.2±1.9	I 99
After 210 min	28	25	22	31	22	29	28	13	22	24.4±5.5	3	6	5	4	3	6	4	7	3	4.6±1.5	I 99
After 225 min	26	20	19	29	16	23	23	13	16	20.6±5.2	1	3	2	2	3	6	3	5	3	3.1±1.5	I 99
After 240 min	23	17	19	29	11	19	19	13	16	18.4±5.3	1	3	2	2	3	4	3	2	2	2.4±0.9	I 99
After 255 min	16	13	19	29	11	14	15	9	16	15.8±5.8	1	3	2	2	1	1	3	2	1	1.8±0.8	I 99
After 270 min	15	13	14	21	11	14	15	7	13	13.7±3.7	0	0	0	0	1	1	0	0	1	0.3±0.5	I 99
After 285 min	15	13	10	14	5	14	15	4	9	11.0±4.2	0	0	0	0	0	0	0	0	0	0	–
After 300 min	10	7	10	9	3	11	11	4	9	8.2±2.9	–	–	–	–	–	–	–	–	–	–	–
After 315 min	3	4	8	9	3	7	8	4	9	6.1±2.6	–	–	–	–	–	–	–	–	–	–	–
After 330 min	3	2	5	6	3	7	8	2	5	4.6±2.2	–	–	–	–	–	–	–	–	–	–	–
After 345 min	3	2	1	4	0	7	8	0	1	2.9±2.9	–	–	–	–	–	–	–	–	–	–	–
After 360 min	3	0	1	1	0	2	2		0	1.1±1.1	–	–	–	–	–	–	–	–	–	–	–
After 375 min	0	0	0	0	0	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–

1, 2 and 3 – Triplicates of Colony A of *H.obscuriceps;* 4, 5 and 6 – Triplicates of Colony B of *H.obscuriceps,* and 7, 8 and 9 – Triplicates of Colony C of *H.obscuriceps*

Table 6: Number of termites attracted to 0.0005 % 2-PE and ethanol, at different timings, from the initial 100 individuals with *H.obscuriceps* : Colony A, B and C

Time	2-PE: Number of alive termites in each replicate									2-PE	Ethanol: Number of alive termites in each replicate									Ethanol	Attraction of termites towards 2-Phenoxyethanol, significant to confidence level
	1	2	3	4	5	6	7	8	9	Mean ±SD	1	2	3	4	5	6	7	8	9	Mean ±SD	
After 15 min	65	74	55	62	58	84	70	64	59	65.7±9.1	35	26	45	38	42	16	30	36	41	34.3±9.1	I 99
After 30 min	68	76	59	65	63	81	73	66	63	68.2±7.1	32	24	41	35	37	19	27	34	37	31.8±7.1	I 99
After 45 min	71	79	63	69	67	77	77	69	65	70.8±5.7	29	21	37	31	33	23	23	31	35	29.2±5.7	I 99
After 60 min	71	79	65	69	67	77	77	69	68	71.3±5.0	29	21	35	31	33	21	19	31	32	28.0±6.0	I 99
After 75 min	66	75	65	66	60	71	69	63	68	67.0±4.4	25	18	35	27	29	21	15	27	32	25.4±6.5	I 99
After 90 min	60	70	61	62	54	66	62	58	64	61.9±4.6	22	16	31	24	26	18	12	24	29	22.4±6.2	I 99
After 105 min	56	64	56	56	49	62	56	54	59	56.9±4.4	18	14	27	20	24	18	10	22	27	20.0±5.7	I 99
After 120 min	49	57	52	49	45	59	51	51	53	51.8±4.2	15	13	21	15	24	14	9	22	26	17.7±5.7	I 99
After 135 min	43	53	47	44	42	56	47	45	50	47.4±4.7	11	12	17	12	24	11	9	21	26	15.9±6.3	I 99
After 150 min	38	48	41	40	40	52	44	40	46	43.2±4.6	11	12	15	7	20	11	9	19	26	14.4±6.1	I 99
After 165 min	34	42	36	36	37	47	39	36	41	38.7±4.1	11	12	11	4	17	9	7	16	22	12.1±5.5	I 99
After 180 min	31	35	32	33	33	41	33	33	35	34.0±2.9	9	12	11	4	15	9	4	12	19	10.6±4.8	I 99
After 195 min	31	30	29	31	28	34	26	33	28	30.0±2.5	6	9	11	4	15	9	3	7	17	9.0±4.7	I 99
After 210 min	31	27	25	30	22	26	22	33	25	26.8±3.9	6	7	8	3	10	6	3	5	15	7.0±3.7	I 99
After 225 min	27	23	20	26	19	23	19	30	21	23.1±3.9	4	7	4	2	7	6	3	2	9	4.9±2.5	I 99
After 240 min	24	20	18	23	17	19	17	26	16	20.0±3.5	4	4	1	2	5	5	1	1	5	3.1±1.8	I 99
After 255 min	20	20	14	19	17	14	17	21	16	17.6±2.6	3	2	1	2	2	2	0	0	2	1.6±1.0	I 99
After 270 min	15	20	11	14	17	12	17	15	16	15.2±2.7	0	0	0	0	0	0	0	0	0	0	–
After 285 min	15	15	11	8	14	9	14	15	14	12.8±2.7	–	–	–	–	–	–	–	–	–	–	–
After 300 min	13	12	11	8	10	9	11	12	11	10.8±1.6	–	–	–	–	–	–	–	–	–	–	–
After 315 min	13	12	7	8	10	9	11	8	10	9.8±2.0	–	–	–	–	–	–	–	–	–	–	–
After 330 min	9	7	7	6	7	7	11	3	8	7.2±2.2	–	–	–	–	–	–	–	–	–	–	–
After 345 min	9	7	7	5	5	7	7	1	6	6.0±2.2	–	–	–	–	–	–	–	–	–	–	–
After 360 min	7	5	5	2	4	4	4	0	2	3.7±2.1	–	–	–	–	–	–	–	–	–	–	–
After 375 min	4	4	2	2	4	1	2	0	0	2.4±1.5	–	–	–	–	–	–	–	–	–	–	–
After 390 min	4	4	0	0	2	0	0	0	0	1.4±1.9	–	–	–	–	–	–	–	–	–	–	–
After 405 min	1	0	0	0	0	0	0	0	0	0.3±0.6	–	–	–	–	–	–	–	–	–	–	–
After 420 min	0	0	0	0	0	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–

1, 2 and 3 – Triplicates of Colony A of *H.obscuriceps;* 4, 5 and 6 – Triplicates of Colony B of *H.obscuriceps,* and 7, 8 and 9 – Triplicates of Colony C of *H.obscuriceps*

Table 7: Number of termites, at different timings, from the initial 100 individuals with *H.obscuriceps* : Colony A, B and C in control

Time	Number of alive termites in each replicate			Mean ±SD
	1	2	3	
After 15 min	98	99	97	98.0±1.0
After 30 min	94	99	94	95.7±2.9
After 45 min	91	93	91	91.7±1.2
After 60 min	88	90	85	87.7±2.5
After 75 min	85	88	85	86.0±1.7
After 90 min	82	86	82	83.3±2.3
After 105 min	79	82	78	79.7±2.1
After 120 min	77	80	75	77.3±2.5
After 135 min	74	76	70	73.3±3.1
After 150 min	69	74	70	71.0±2.6
After 165 min	67	70	67	68.0±1.7
After 180 min	64	66	64	64.7±1.2
After 195 min	61	61	59	60.3±1.2
After 210 min	57	55	59	57.0±2.0
After 225 min	53	52	56	53.7±2.1
After 240 min	48	46	50	48.0±2.0
After 255 min	45	40	48	44.3±4.0
After 270 min	43	37	46	42.0±4.6
After 285 min	40	32	41	37.7±4.9
After 300 min	37	26	37	33.3±6.4
After 315 min	35	23	34	30.7±6.7
After 330 min	32	20	29	27.0±6.2
After 345 min	29	18	26	24.3±5.7
After 360 min	26	18	21	21.7±4.0
After 375 min	23	17	18	19.3±3.2
After 390 min	20	15	17	17.3±2.5
After 405 min	17	13	15	15.0±2.0
After 420 min	14	10	12	12.0±2.0
After 450 min	10	8	9	9.0±1.0
After 465 min	6	0	7	4.3±3.8
After 480 min	0	0	4	1.3±2.3
After 495 min	0	0	0	0

Table 8: Comparison of our study with the study reported by other authors

Termite species	Concentrations tested	Trail following/attractant	Toxicity	References
*C.formosanus*Shiraki and *Reticulitermessp.*	Four concentrations of 2-phenoxyethanol (0.23, 0.023, 0.0023 and 0.00023) ug/cm were tested.	In 0.00023 ug/cm limited trail-following activity occurred (≤ 30% of termites followed the trails) compared to 0.23 ug/cm, 0.023 ug/cm, and 0.0023 ug/cm (≥ 60% of termites followed the trails).	Not stated	Chen *et al.*,1998
*C.formosanus*Shiraki	Three concentrations of 2-phenoxyethanol - 0.041, 0.082, and 0.164% were tested.	In 0.082% 2-phenoxyethanol treated side, total tunnel network length was significantly more extensive compared with control side for both colony A and B. Even residues of 2-phenoxyethanol on pretreated sand with a concentration of 0.082% had higher tunnel length on 16, 17, 18^{th} day compared to control.	Not stated	Fei*et al.*, 2005a
*C.formosanus*Shiraki	Six concentrations (0.00023, 0.0023, 0.023, 0.23, 2.3, 23 fig /cm) plus a control (only ethanol) were tested. Six types of 2-phenoxyethanol gradient trails were created. For "increasing-trail" gradients, they were 0.00023-0.0023-0.023-0.23µg/cm, 0.0023-0.023-0.23 2.3 µg/cm, and 0.023-0.23-2.3-23 µg/cm. For "decreasing-trail" gradients, they were 0.23-0.023-0.0023-0.00023 µg/cm, 2.3-0.23-0.023-0.0023 µg/cm, and 23-2.3-0.23-0.023 µg/cm.	Termites responded 100% to the trail at 0.23 µg /cm. Termites travelled significant distance when initial concentration was 0.0023 µg/cm. 0.23 and 2.3 µg/cm significantly increased termite aggregation compared to the control during 3 and 10 min observational time.	Not stated	Fei*et al.*, 2005b
*C.formosanus*Shiraki	Two tests were conducted to evaluate the effect of 2-phenoxyethanol as an additive to acetamiprid, fipronil, and imidacloprid on the tunnelling system by the Formosan subterranean termite *Test 1:* In the treated chamber, 0.07% of acetamiprid, fipronil, or imidacloprid and 0.345% of 2-phenoxyethanol were tested	Significantly more search tunnels were constructed in the 2-phenoxyethanol treated side compared with the control side on day 1. With the addition of acetamiprid, the total tunnel network length remained significantly higher in the treated side than that of the control side.	The addition of 2-phenoxyethanol in any of the three nonrepellent insecticides noted increased the total lengths of tunnel networks compared with the treated controls.	Fei*et al.*, 2005c

Termite species	Concentrations tested	Trail following/attractant	Toxicity	References
	Test 2: 0.07% of the insecticide and 0.345% 2-phenoxyethanol were tested by applying 1.0 ml solutions to sand through the two of the four small access holes. In both the tests control was Double distilled water.	With imidacloprid and fipronil, the total tunnel network length was greater in the treated side than that in the control side, but the differences were not significant. Termite survival rate in the treated chambers was significantly lower than that in the untreated chamber	However, variability was noted among the three insecticides. Only in the test with acetamiprid was the total tunnel network length significantly higher in the treated side than the control side	
*C.formosanus*Shiraki	Four studies were conducted: attraction and toxicity response on different 2-phenoxyethanol, persistence of 2-phenoxyethanol (0.96% upto 13th week), feeding and survivorship in both- choice test and no-choice test.	Consumption of filter paper treated with 0.12% 2-phenoxyethanol was significantly greater compared to the untreated filter paper. It was an attractant but not toxicant at 0.12 and 0.24 per cent, an attractant and toxicant at > 0.48 per cent and the maximum effect was at 0.96 per cent. 2-Phenoxyethanol at 0.96 per cent attracted 90 per cent of the termite workers to the treated filter paper side, killing 85 per cent of the termites within 48 hour. Residues of 2-Phenoxyethanol on pretreated filter paper remained effective in orienting *C.formosanus*Shiraki workers upto 13 weeks.	2-phenoxyethanol is toxic at ≥0.36%	Ibrahim *et al.*, 2005
H.obscuriceps	Five concentrations of 2-PE were tested: 0.1, 0.01, 0.001, 0.0001 and 0.0005% and a control ethanol.	0.1% 2-PE attracted maximum number of termites, followed by 0.01, 0.001, 0.0001 and 0.0005% and then control.	The same trend was also seen in the mortality of the termites with the highest in 0.1% 2-Phenoxyethanol and the least in the control.	Our study

search tunnel formation by *C.formosanus*. At 0.082% 2-PE, the total tunnel network length was significantly more extensive compared with other concentrations of 2-PE and control. In another study conducted by Ibrahim *et al.*, (2005) with 0.012, 0.06, 0.12, 0.24, 0.48. 0.96 and 1.92 % concentrations of 2-PE (w/w of filter paper), it was found that 2-PE was an attractant but not toxicant at 0.12 and 0.24%. In the present study, all the five concentrations of 2-PE (0.1%, 0.01%, 0.001%, 0.005% and 0.0005%) elicited trail forming behaviour on *Hypotermes obscuriceps* without revealing any toxic effect for the first 60 minutes.

Conclusion

In the present study, all the five concentrations of 2-Phenoxyethanol (0.1%, 0.01%, 0.001%, 0.005% and 0.0005%) elicited trail forming behaviour on *H.obscuriceps.* In the first 60 minutes, there was less mortality of termites in chambers which had trails of different concentrations of 2-PE and ethanol than in control. The studies reveal that 2-PE can serve as an effective as well as safe substance for attracting termites though the substance's trails.

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Chapter 16

Summary and conclusion

'Termigradation' as coined by Abbasi (2007) denote termite-based biodegradation processes which have been based on the controlled use of termites. Abbasi, along with Gajalakshmi further conceived two kinds of termite-based reactors ─ *in-situ* and *ex-situ* ─ of which patent claim has been registered (Abbasi and Gajalakshmi, 2012). The former involves bringing termireactors to the nature and the latter involve bringing termites to the confines of a laboratory or a processing unit. *In-situ* termigradation of solid waste appears to have the obvious advantages of a) very low capital and operational cost, and b) simplicity, due to which it can be easily used by lay-persons with minimal training. The present work is one of the attempts to put the above-mentioned ideas into practice.

The thesis has seven parts. Part I comprises of two chapters. Chapters 1 and 2 are the introduction to the studies reported in *Chapters 4 – 14.*

Part II is devoted to surveys of termite species. The first chapter of this part, *Chapter 3,* describes how the sampled termite species were identified. Termite surveys conducted in Pondicherry University and Auroville, are then described in *Chapters 4 – 7*. The aim of surveys was to obtain a repertoire of locally established termite species and also to quantify their richness and relative abundance, to learn which species are relatively better settled in this region. Biotic indices were developed with which the community structures of different areas could be quantitatively compared. A total of thirteen species belonging to two families: Termitidae and Rhinotermitidae and four subfamilies: Macrotermitinae, Amitermitinae, Nasutitermitinae and Coptotermitinae and eight different genera were identified in Pondicherry university campus. Twelve of these are 'higher termites' and one is 'lower termite'. *H.obscuriceps* is the most abundant of all species. The three least abundant species are *M.pakistanicus, O.globicola*, and *E.paradoxalis*.

To learn about the foraging behaviour of the termites and to check whether any species missed out in the previous survey shows up, a bait-based study was carried out as described in *Chapter 5*. Four types of baits ─ unscented toilet paper rolls, wood, paper waste and cardboard ─ were laid in three different sites in two patterns – individually, and in combinations and were observed for 4 months. Of the baits, waste paper was the most consumed followed by cardboard, toilet paper, and wood in that order, whether kept individually or in combinations. Baits containing multiple substrates attracted more species and were consumed to a much greater extent than baits of single substrate type. This survey could locate only six species – *H.obscuriceps, M.convulsionarius, O.anamallensis, O.globicola, M.incertoides* and *M.cameroni* – which were all picked up by the quadrat-transect survey done earlier.

Chapter 6 reports the termite survey done in Auroville, situated near Pondicherry. A total of ten species belonging to two families Termitidae and Rhinotermitidae; five subfamilies, Macrotermitinae, Amitermitinae, Nasutitermitinae, Termitinae and Coptotermitinae; and eight genera were identified. Nine of the species belonged to higher termites and one to the lower termite. *H.obscuriceps* was seen to be the most abundant of all species followed by *M.convulsionarius*. *O.feae* was the least abundance of the species.

The same area was then surveyed by bait method as detailed in *Chapter 7*. This time six types of baits – cowdung, toilet paper, cardboard, sawdust, grass and wood ─ were laid in four different sub-areas in three patterns, individually and in combinations. Cowdung was seen to be consumed the most, followed by toilet paper, cardboard, sawdust, grass and wood. In contrast to the earlier experience, as reported in *Chapter 5*, more species (eleven) were located by the bait method than (ten) were found using quadrat and transect methods in the same area. Out of the eleven species, ten were the same as identified with transects and quadrats while an additional species ─ *O.horni* ─ was located in this survey.

Part III is on the *in-situ* termigradation of three invasive plants: lantana (*Lantana camara*), ipomoea (*Ipomoea carnea*) and water hyacinth (*Eichhornia crassipes*). In case of ipomoea and lantana, the termigradation of twigs was explored as the twigs are

Abbasi, S.A., 2007. Emerging frontier in bioprocess engineering: termigradation. Proceedings of the International Conference on cleaner technologies and environmental management, Pondicherry Engineering College, Puducherry, Jan 4 – 6.

Abbasi, S.A. and Gajalakshmi, S., 2012. A novel process for eco friendly treatment of ligninous biowaste, claim filled with CDAC,GOI, Reference number E-2/12682/2013/DEL.

highly ligneous and cannot be degraded by composting or vermicomposting.

Chapter 8 discusses the disposal of the weed ipomoea (*Ipomoea carnea*) accomplished by controlled action of termites using *in-situ* reactors of capacities ranging from 5 to 100 Kg. The reactors were operated with and without attaching termite trails to them. In reactors without trails about half of the initial charge was termigraded in 30 days. The disposal of amphibious weed *E.crassipes* is reported in *Chapter 9*. In termireactors without trails, one-third or more of the initial charge was termigraded in 30 days, whereas the rate was enhanced to >60% when trails were used. The study on the termigradation of the notorious weed lantana is reported in *Chapter 10*. The reactors were operated similar to that of ipomoea and eichhornia. About half of the initial charge was 'termigraded' in 60 days.

Part IV comprises chapters on the disposal of two industrial wastes. *Chapter 11* is on the study explored to dispose a major stream of waste arising from sugar industries, press mud and *Chapter 12* is on the coir pith. The reactors were operated similar to the other studies reported in *Part* III. In reactors without trails about one-fourth of the initial charge was termigraded' in 30 days. The rate was enhanced to >60% when trails were used.

Part V comprises of the *Chapters 13 and 14* on the termigradation of hard substrates such as coconut shells and near-pure cellulosic substrates like paper cups. It was found that about half of the initial charge of paper waste, paper cups and coconut shells were termigraded in 60 days.

From all the above studies contained in *Part III*, it can be noted that the time-span taken for the assimilation of the substrates by the termigradation process as developed by us can be considered very quick because conventional forms of composting or vermicomposting of biodegradable waste takes much longer. More significantly, whereas periodic supervision for maintaining moisture, turning of substrates (needed in composting), and resultant energy/material inputs, that are necessary in those processes, are not required in termigradation. Hence this is a much less expensive process with much lesser 'footprint'. The process resembled a zero order reaction in the sense that the rate of termigradation appeared independent of the starting substrate quantities; the termite scouts apparently signal for, and summon, the number of foragers in proportion to the quantity of the food source.

Chapter 15 of *Part VI* is devoted to a study on the trail following behavior of the termite *H.obscuriceps* towards trails of 2-Phenoxyethanol (2-PE). *H.obscuriceps* is the most abundant of species found in North-eastern Puducherry and is the one most often found to be working on the subtrates in *in-situ* termireactors. In order to attract greater number of this species towards the termireactors, 2-PE was tested for its potency to be an attractant to *H.obscuriceps* in the laboratory. Five concentrations of 2-PE were tested: 0.1, 0.01, 0.001, 0.0001 and 0.0005% and it was found that at 0.1% 2-PE attracted maximum number of termites, followed by 0.01, 0.001, 0.0001 and 0.0005% and then ethanol.

Part VII comprising of *Chapter 16*, provides the summary and conclusion of the entire study presented in this thesis.