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The Effect of Termite Activity on Soil Profile in a Laboratory Test Tank

Ibrahim G Ali[1*], Berhan M. (Shiday) Ahmed[1], Gary Sheridan[2] and John R. J. French[3]
[1]*(Department of Forest and Ecosystem Science, The University of Melbourne, Richmond, Victoria 3121, Australia)*
[2]*(Department of Forest and Ecosystem Science, The University of Melbourne, Parkville, Victoria 3010, Australia)*
[3]*(Faculty of Science, Health and Education, University of the Sunshine Coast, Maroochydore, Queensland, Australia)*

Abstract: *Termite soil interaction is a multidimensional process, the interphase between the surface and subsurface being the most prominent location that termitaria and other termite structures usually occupy. There is little information on termite foraging behaviour and its impact on soil profile. Foraging activity of termites (Coptotermes frenchi) in a soil profile (300 mm), with layers of top soil, fine sand, coarse sand and gravel, was studied using a test tank in a laboratory to analyse changes in soil profile, termite foraging depth and soil and water transport. Moisture content of soil used for gallery construction was greater than that of the soil in the foraging tank while an average rate of approximately 4 g/day and 1.58 g/day of soil particles and water were transported for gallery construction, respectively. Wood stakes inserted vertically at three different depth levels (0-100, 100-200, 200-300 mm) attracted large number of foraging termites and were covered with subsequently transported soil materials. Visual observations after taking soil profile samples using auger and excavating cross sections of the soil profile confirmed presence of termite activity, soil transport and mixing. However, significant activity did not occur in the time period to result in complete mixing of soil horizons.*
Keywords**:** *Coptotermes, C. frenchi, termite, soil profile, soil horizon, gallery, foraging.*

I. Introduction

Termite soil interaction is a multidimensional process, the interphase between the surface and subsurface being the most prominent location that termitaria and other termite structures usually occupy. This interaction extends vertically from as deep as the unconsolidated parent material in a soil profile or associated water tables, to the tips of landmark giant mound structures that define landscapes in many parts of the world; or where arboreal mounds on top or soil sheetings on tree barks are prominent [1, 2, 3 and 4]. The horizontal dimensions, especially in subterranean and harvester termites, usually overlap with each other and are defined by different climate, soil and vegetation factors. The temporal dimension is determined by the continuity and succession of termite colonies and their activities as well as the longevity of their constructed structures [5, 6 and 7].

In nature termites are associated with root systems of trees and other vegetation. Bio-energetically, they forage around such root systems, and, as primary detrivores, there is no reason for them to forage any deeper beyond the deepest root [J.R.J. French, pers. comm.]. In Australia *Coptotermes* are associated with Eucalypt species where root systems can reach up to 60 m in depth [8]. However, in addition to foraging as far as between 100 – 120 m from the nest using networks of tunnels, as in the case of *C. acinaciformis* [2, J.R.J. French pers. comm.], termites have been reported to forage as deep as 100 m [Lepage, 1974 cited in 9] as manifested in the form of vertical transport of water and soil. *C. acinaciformis* have also been reported to have galleries down to dry reason water tables [1]. Such species ensure the presence of enough water in the nest and maintain it by constructing large foraging galleries that go deep below the ground while using fungus, faecal carton and clay to absorb and retain the moisture [10, 11]. Other species control and use water released from their own and the microbes' metabolism or respiration in the mound and maintain high humidity in the nest [12].

Termites build and maintain nesting, foraging and feeding structures either by excavation and/or construction using soil particles from deeper horizons within the soil profile or on soil, tree or other surfaces [2, 9 and 13]. During their foraging activities they primarily sort out selectively and move large amounts of soil particles above and beyond soil surfaces or within soil profiles significantly changing the composition of the soil or profile [14]. The ranges of particle sizes they can penetrate depend on the mandible and head capsule size of the termite species and colonies foraging the area. They cannot penetrate soils with particles that are too large to pick up in their mouths and carry, or with spaces in between too small to let head capsules pass through [15, 16]. The majority of particles transported are, therefore, fine textured and the process usually leads to weathering of profile with a gradual loss of fine material from lower horizons and its accumulation in upper horizons. The transported particles also contain macro and micro nutrients, including rare earth elements, which are continuously rearranged by the tunneling activity whilst addition of salivary and faeces products adds some organic matter to the packed soil [2, 17].

Soil is a heterogeneous material composed of inorganic and organic matter, water and air spaces. Termites take advantage of this heterogeneity while also using physical guidelines and potential food sources encountered during their foraging as guides [18]. Termite species of *C. frenchi* [19], *R. flavipes* and *R. virginicus* [20] have been reported to spreading networks and maximizing areas explored by quickly following gaps in a sand medium to the most distant points and then start tunneling at the extremities. Termites tunnel extensively along objects they consider as food and, if successful, they use it as a starting point to explore more resources in the area [18]. The overall extent of organic matter distribution in a soil profile is determined by the depth of food source or associated nest tree, stage and rate of decomposition and/or feeding, colony size and rate of foraging or soil transport [2].

Termites ingest soil and organic matter, regurgitate it and use it to plaster and build complex tunneling networks. This along with the associated transport of soil particles might lead to structural or morphological changes of soil horizons including those which might have been stratified along textural gradients or lines [1, 7]. In Lee and Wood [2] several reports have been mentioned that describe differentiation of soil horizons or presence of distinct layers of soil consisting of parent material (weathered bed rock), a stony or gravely layer and a surface layer. The surface layer was reported to consist of uniform finer layers of materials derived from the lower layers by termites over a period of time resulting in thicknesses of 10 - 60 cm.

In some cases distinctive stony layers or stone lines are formed as residual materials in the subsoil after termites have transported soil particles to the top soil. Alternatively burial of stony, former surface, horizons could result in the development of such layers [2, 7 and 21]. The composition (particle size distribution) of a horizontal layer of soil developed as a result of termite activity has been reported to be similar to termite mounds and their surrounding soils than to termite unaffected soils. Well sorted finer sand particles form most of the composition while coarse and medium sand particles proportionately present. Towards deeper layers, however, coarser particles become more and more prominent ultimately resulting in the formation of stony layers. Average increases of coarse sand fraction from 6%, to 13%, 23% and to gravel has been reported from the surface layer to 1m, 2.5m and to 3.5m depth below the surface, respectively [22].

Termite preference for topsoil materials has been reported to occasionally lead to transport of soil particles downwards as has been observed in the backfilling of abandoned tunnels and nest chambers in subsoil conspicuous by their darker colors [23]. It was also reported that homogenization of soil profile can be the result, counteracting any vertical heterogenization associated with the formation of distinct soil horizons by other soil forming processes [23, 24]. The continual transport, erosion and reconstructing of the mounds and nests results in the redistribution of the soil particles [4, 25 and 26]. In mound building termites, the preferential use of finer particles also results in higher content of finer soil texture of the mound material, in fact as much as two to three fold [27], compared to that of surface layer of top soils [28]. This may result in a marked textural variability in areas where mound density is high [29, 30] highlighting profile differentiation [24].

Mound construction by termites is easier to observe and quantify in comparison to mixing although rates of mounding and mixing of a soil generally appear to differ substantially [23]. In the field, abundance, area of coverage, weight and size of termite mounds gives an indication on the amount of soil transported to the surface. For instance estimates of more than 1100 mounds/ha for mounds in tropical Australia, weighing 62 ton/ha of soil and covering 1.7**%** of the sampled area [2], and 2400 ton/ha of soil or equivalent to 20 cm deep layer, for *Macrotermitinae* in Congo, covering 33 % of the surface (Meyer 1960 in [2]) have been reported. Estimates of up to 1300 kg ha-1 yr1 and 180 kg ha-1yr1 were also reported for soil materials accumulated as a result of termite (*Pseudacanthotermes spiniger*) sheetings and termite (*Microtermes*) soil packs in maize stalks, respectively [31]. Termite mound heights of more than 8m have been recorded for *Macrotermes* species in Ethiopia and *Nasutitermes triodiae* in Australia [2]. Moreover, Wood [4] reported that more than 10,000 kg ha-1 could be eroded annually from termite constructions.

Changes in different layers of the soil profile and the depth of these effects have been measured in many different ways. In soil beneath termite mounds vertical dissection of the mound and the underlying soil profile has been used in different studies. Samples taken from such soils in Redlands, Queensland, Australia, showed increases by up to 1.5 times in most chemical properties towards the upper layers of the soil profile closer to the mound base [32]. Although this process disturbs or destroys the termite colony, it provided the opportunity to visually observe or digitally map the pattern of changes in terms of soil composition and formations of tunnel or other structures as well as the extent of depth of soil in the profile. Feeding galleries turn out to be mostly horizontally oriented in not so deep levels while foraging galleries tend to be vertically oriented in order to reach different depth levels to access soil, water and food [33].

However, there is little information on termite foraging behaviors and their impact on artificial test tanks in laboratory consisting of layers of top soil, fine sand, coarse sand and gravel layers. The relationship between termite foraging behavior and particle size distribution in a soil profile was the basic reference in the idea of design and setup of the current experiment. The study was intended to help understand the dynamics of termite foraging activities that result in significant changes in soil profile and in construction of termite structures in nests, mounds, galleries, sheet covers, etc. It would also help increase our understanding of the influence of bioturbation on the vertical distribution of soil particles and organic matter in stratified soil profile in a laboratory apparatus. The main objectives of the experiment, therefore, were:
i- to measure the amount of soil and water transported by termites during gallery construction
ii- to investigate possible foraging depth in a termite test tank; to investigate whether termites forage at lower horizons (gravel and coarse sand layers) in a soil profile to access food source while foraging and feeding in the immediate upper horizons
iii- to observe the extent of change termites foraging along a stratified soil profile cause.

II. Materials And Methods

2.1. Termite

The termite species used for the study was the wood feeding subterranean termite *Coptotermes frenchi* Hill. It is one of the most highly adaptable species widely distributed in Australia. Usually it occurs in subterranean colonies, builds mounds, or nests in living trees, in stumps and root crowns inside the hole. The nests are regularly found at ground level in colder areas or up to 10 m above ground level in warmer areas. It feeds in the nest tree or log while also feeding on adjacent trees using galleries constructed for foraging [34].

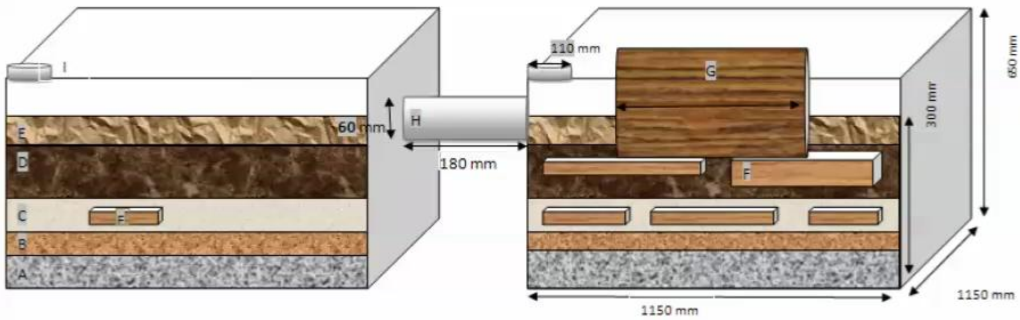
2.2. Experimental apparatus and design

Two rectangular box perspex test tanks (1150 mm X 1150 mm X 650 mm size) were designed at the University of Melbourne, Burnley Campus, for the study by establishing one as a nesting and the other as a foraging platform for termites (Fig 1). They were connected by polyvinyl chloride (PVC) pipe (180 mm long and 60 mm diameter). At the base of the tanks a 50 mm deep coarse gravel layer (6-8 mm size) was laid down to help drain out any excess moisture from the upper layers. Excess water was monitored with the help of a vertically standing PVC pipe (650 mm length and 110 mm diameter) inserted into the tank near a corner. A thin layer (20 mm deep) of coarse sand (Course Washed Sand, Rocla Quarry product) was added on the gravel layer to act as a filter and help prevent the washing away of the finer particles from the upper layers into the gravel layer. A sand layer of 60 mm deep (Fine Washed Sand, Source- Rocla Quarry product) and an organic matter layer, 120 mm deep (Composted pine bark – medium; between 3mm & 6mm particle size; Source- Debco)

Figure 1. External view of termite (*C. frenchi*) test tank (A), top view of foraging tank after the establishment of the soil layers (B) and termite nest on the nesting tank (C).

were then spread over the coarse sand layer. After placing some blocks of dry wood stakes (*Pinus radiata* D. Don) in each layer as food for the foraging termites, water was showered on the surface layer. The soil profile was completed after putting some more organic matter and finally topdressing it with garden soil acquired from the Burnley campus horticultural garden. The tanks were filled with the soil profile until just below the level of the PVC pipe connecting the two tanks (150 mm from the top edge of the tank).

In the nesting tank, a previously active termite nest (*C. frenchi*) in an infested log (600 mm long, 180 mm diameter) was transported and placed on top of the organic matter layer. The colony in the infested log had an estimated population of half a million. But the colony in the tank were suppressed due to the limited foraging space and unfavorable weather conditions and were estimated at around 200,000, the best measure being taken when termites aggregate on stakes and from the population on the feeding tank. All contents of the old tank (the infested log and the soil) were emptied into the nest tank after putting more dry wood stakes (*P. radiata*) as feed for the nesting termites. More organic matter and garden soil were also added to cover the nest and bring it to the level of the tank.



A = Gravel Layer (Granite Gravel) (50 mm deep)
B = Course Washed Sand Layer (20 mm deep)
C = Fine Washed Sand Layer (60 mm deep)
D = Organic Matter Layer (Composted pine bark – medium (between 3mm & 6mm particle size) (120 mm deep)
E = Local Garden Soil Layer (50 mm deep)
F = Wood blocks randomly placed inside the soil layers as feed for termites (Pinus radiata D. Don)
G = Termite nest in a tree log (600 mm long, 180 mm diameter)
H = PVC pipe (with a valve) (180 mm long, 60 mm diameter) connecting the tanks
I = PVC pipe (650 mm long, 110 mm diameter) inserted vertically into the nest tank near corner for checking excess moisture on the basement
F = is also used an indicator of termite foraging depth and moisture movement in the foraging tank

Figure 2. Schematic design of termite foraging and nesting apparatus to study the effects of termite (*Coptotermes frenchi*) foraging along a soil profile in a test tank

Blocks of dry wood stakes (*P. radiata*) were placed at random in the organic matter layer and on top of the gravel, coarse sand and the fine washed sand layers during their establishment in order to act as food sources and attract foraging termites. Termite activity at these layers was analyzed in order to measure the lowest possible foraging depth in a test tank soil profile.

Volume of soil and gravel materials used for the experiment was also calculated to highlight the amount of soil and gravel exposed to termite manipulation (Table 1).

Once established the experimental apparatus was run for two years. However, the particular studies conducted to analyze and measure soil and water transport by taking samples of galleries constructed by foraging termites were conducted for a period of fifteen days. The change in the composition of the different horizons in the soil profile as a result of the termite activities to transport soil particles and access food sources at different layers was analyzed at the end of the experimental period.

Table 1 Volume of materials at different horizons in a soil profile exposed to termite foraging in a test tank

Soil Horizon	Depth (mm)	Height (mm)	Width (mm)	Length (mm)	Volume (m^3)
E (Local Garden Soil)	0	50	1150	1150	0.066
D (Organic Matter Layer)	50	120	1150	1150	0.159
C (Fine Washed Sand Layer)	170	60	1150	1150	0.079
B (Course Washed Sand Layer)	230	20	1150	1150	0.026
A (Gravel Layer)	250	50	1150	1150	0.066
Total	300	300	1150	1150	0.396

2.3. Soil and moisture transport

After all soil layers had been established the soil surface was brought to being level with the valve opening connecting both tanks by adding more topsoil in the nesting and foraging tanks. A piece of 200 mm wet wood was placed inside the valve with its edges extending as far as the nesting and foraging surfaces, so that termites could move easily. Prior to allowing termite entry into the foraging tank by opening the valve, the soil surface in the tank was sprinkled with tap water. A total amount of 40 ml of water over a period of 10 weeks was added (sprinkled) over the soil surface to encourage and maintain continuous termite activity. Termites were allowed to forage on the soil in the foraging tank for two weeks before the first observation was made. Their activities in the foraging tank were monitored and any structure built on the surface and on the walls of the tank above the soil surface level was recorded during each observation.

In order to measure soil and water transport by termites, samples of galleries built by foraging termites were collected from wall surfaces used by the foraging termites of a test tank for fifteen days. The wall surfaces were, therefore, cleared of any galleries built prior in order to collect the fresh ones built. The samples were collected from the entire wall surfaces used as foraging by the termites and were immediately weighed and then oven dried for 24 hr at 105^{o}C. The difference between moist and oven dry gallery soil was taken as the moisture content of the soil, reflecting the termites' moisture carrying capacity. The oven dry soil was considered as the weight of soil particles transported concurrently at that particular period. At the same time samples of soil were also collected from the surface of soil in the foraging tank to reflect the moisture content of soil in the tank for comparison with the gallery soils.

2.4. Foraging depth in soil profiles

Foraging depth in this study was determined using several methods. Wood stakes were (*P. radiata*) placed at the bottom (gravel and coarse sand layer) of the soil profiles to encourage termite foraging. The gravel layer was the deepest layer in the test tank that termites could manage to forage and feed (300 mm depth). The wood stakes were analyzed for termite attack or foraging and feeding to determine if termite could forage to such depths in a soil profile in a test tank.

One method used was randomly cutting a vertical cross section of the soil profile in the foraging tank and visually analyze termite foraging, termite galleries/tunnels and/or changes in the composition of the previously uniform gravel, coarse sand and fine sand layers as a result of termite foraging approximately 40 weeks after establishing the apparatus.

Another alternative method used to measure the depth level termites penetrated in soil profile in the test tank was using wood stakes (*P. radiata*) (20 mm X 40 mm) with lengths of 100 mm, 200 mm and 300 mm inserted vertically into the test tank at random locations. The 100 mm wood stakes were inserted in the top 100 mm layer of the soil to evaluate and determine termite foraging at the top 100 mm. The 200 mm wood stakes were inserted into the 200 mm layer of the soil but prior to the installation the top 100 mm half was covered with black tape so that termite foraging on the lower 100 mm could be analyzed. Finally, 300 mm wood stakes were inserted into the soil profile with black tape covering the upper 200 mm before being installed to analyze termite foraging at the bottom 100 mm of the soil profile. Termite foraging was checked after three weeks for all the wood stakes inserted, by gently pulling them out and carefully removing the soil and termites. As mentioned in the literature, termites follow wood stakes or any other material to forage into other places using them as a guide [18, 20]. Covering the 200 mm and 300 mm wood stakes with black tape reduced the likelihood of termites attacking the wood stakes at the intended level, foraging from above using it as a guide.

2.5. Changes in soil profile

In order to observe changes in the composition of soil profile in a test tank due to the foraging activity of termites, samples of soil profiles were taken at random locations using an auger. Visual observations were made to analyze change of color and composition, presence of galleries, or other termite transported soil particles and organic materials. Foraging depth was also estimated from analyzing these changes at different soil horizons in the soil profile.

III. Results And Discussion

3.1. Foraging and gallery construction

After the establishment of the two test tanks, it took a while for any visible termite activity to be observed on the foraging tank. As mentioned above, moisture was applied on the soil surface of the foraging tank to encourage and maintain termite activity. After about 8 weeks, significant termite activity and gallery construction were observed on the soil surface and on the walls of the foraging tank (Fig 4 A). This involved transfer of substantial amount of soil material from the soil profile to build foraging galleries. Galleries constructed for foraging present termites with a special microenvironment with constant humidity and temperature [35, 36]. During the construction of galleries termites carry both moisture and soil particles mixed with a salivary secretion as reported in similar findings by other studies [19, 37 and 38]. Constructed galleries could easily be identified by their uniform size, color, composition, compactness and slightly raised rounded structures [2]. It was also reported that galleries and other termite constructed structures contain more clay than the original soils they were extracted from [2, 29].

The galleries constructed originated from the opening valve connecting the two tanks which was the point of entry for the termites from the nesting tank (Fig 4 C). It means that the wet wood placed in the valve connecting the two tanks worked as an incentive to attract the foraging termites from the nest to the foraging tank. Branches of galleries were subsequently formed radiating into different directions on or near the surface (Fig 4 B). Two major (primary) galleries were formed from the valve opening along the edges of the test tank while three others were constructed along the central direction of the surface tank eventually branching into networks of subsequent smaller galleries extending outwards. Similar behaviors of termite foraging have been reported by Campora and Grace [39] where termites construct galleries or tunnels in directions that divide their search areas evenly. It would also limit the amount of energy expended to build galleries in searching or accessing food source [40].

Galleries on wall surfaces of the foraging tank were constructed by termites foraging towards the upper edge of the tank. During the initial construction all galleries constructed vertically along the surface or alienated towards the upper edge of tank were considered for observation. After cleaning the walls of the tanks of any previous gallery construction, observations were set for thirteen days to evaluate the number of galleries constructed every day and their heights were marked and measured. The number of days was enough to allow termite galleries to reach the edges of the tank and active

Figure 3. Termite galleries (moist) (A) under construction on the soil and wall surfaces of the foraging test tank, (B) branched on the surface of foraging tank, and (C) originating and branching into different directions for effective foraging.

foraging termites to forage beyond the edges of the tank. Only two of a total nine galleries reached the edge of the tank (approximately 15 mm length), while the rest did not extend longer than 5.2 cm (Fig 5). Termites were observed intensifying their activities on the longest galleries through which they reached and foraged on the edge of the tank trying to go beyond the perimeters. It has been reported that limited energy is available for termite foraging, as well as carrying and transporting soil particles. Construction of many branching galleries might lead to a reduction in foraging efficiency and, thus, termites restrict branching and create long branched galleries [41].

Figure 4. Some of the galleries constructed on the walls of a termite foraging tank considered for estimating soil and water transport

Termites control their branch tunnel length and frequency in order to improve their foraging efficiency according to prevailing conditions [42]. It has been reported that when foraging termites discover new feeding sites, they intensify their foraging activity and systematically advance in that direction, continuously extending the galleries, while slowing down or stopping in other directions, abandoning the galleries [39, 43].

Intensity of gallery systems in terms of number of branching, foraging areas and width of individual galleries reflect species specific characteristics [44]. The diameter of the foraging galleries constructed in this study ranged from 4 to 7 mm while, as mentioned above, the lengths depend on whether termites used a certain gallery to forage as further to other areas on the surface of the foraging tank or as high to the edges of the foraging tank as possible. Wider and thicker galleries were observed in galleries where termites showed intensive activities and reached the upper edge of the test tank. The galleries were later collected and used for the determination of the amount of soil and water transported in that particular period of time.

3.2. Soil and moisture transport

The foraging tank was covered on top with transparent glass in order to stop the movement of termites out of the tank while at the same time to minimize loss of moisture and dryness and maintain constant conditions in the tank for the duration of the experiment as much as possible. So the galleries collected in 13 days of foraging (Appendix 1) were assumed to be constructed continuously and hence were wet or equivalent to newly constructed ones in other experiments [37].

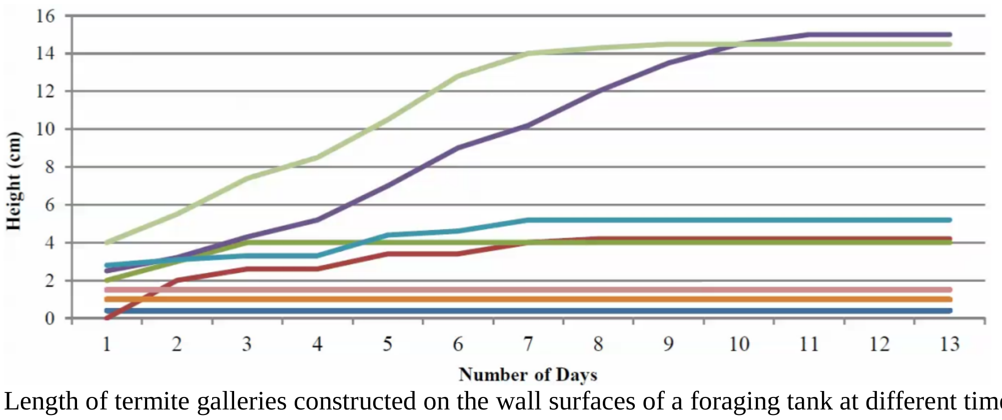


Figure 5. Length of termite galleries constructed on the wall surfaces of a foraging tank at different times (day)

The moisture content of the galleries collected from the wall surface of the foraging tank was 34.41 % (Table 2). It was greater than the moisture content of the soil in the foraging tank which was 17.45 % and 15.5 % for the two samples taken. 20.53 g of water was transported from the soil profile in the tank along with the soil particles transported to construct the foraging galleries. This result confirms the fact that termites transport water and soil from the soil material in the foraging tank to build the galleries on the walls and keep them relatively moist and humid for their foraging [19, 37]. This resulted in the higher moisture content than the soil where they transported the soil and water from [2, 45]. Condensation built up on the walls of a moist container was not considered during the calculation of the moisture content use during termite soil transportation. This might have affected the moisture available for termites. It would be interesting to see the effects of such moisture on termite soil and moisture transportation in the future.

Table 2. Percentage soil moisture content (% MC) of surface soil and galleries constructed on wall surfaces of foraging test tank

Sample	Wet Wt	Dry Wt	Plastic Wt	Al Foil Wt	Net Oven Dry Wt	% MC
Sample 1	50	53.82	3.73	11.25	42.57	**17.45**
Sample 2	50	54.67	3.73	11.25	43.42	**15.15**
Mud Soil	80.2	70.85	22.45	11.18	59.67	**34.41**

Ahmed [37] reported minimum and maximum carrying capacity of termites in an Accelerated Field Simulator (AFS) test of 25 % and 40 % respectively. The results in this experiment fall within this range. The values are also similar to the amount of moisture content that termites prefer when foraging in soils as reported in other literature [37].

The oven dry weight of the total amount of soil transported from the foraging tank and used for the construction of galleries in 15 days was 59.67 g. This means that termites transported soil particles for gallery construction on the wall surface of the tank at an average rate of approximately 4 g/day. In some studies it has been reported that up to 45 % of soil brought to the surface every year by the Senegalese termite of *Macrotermes subhyalinus* was in the form of foraging galleries. These structures are very significant in soil transport and turnover, especially in the field, due to their relatively faster construction and rapid erosion by forces such as rain [7].

Whether analyzed at a laboratory or in the field, Campora and Grace [46] reported that similar basic patterns of foraging are observed by *C. formosanus* although daily fluctuations in foraging activity occur probably linked to temperature changes. It is important to note that generally during the study, more galleries were constructed in the summer when the temperature was conducive and when water was applied. During winter termite activity was minimal, but it was encouraged and maintained by covering the tank and immediate surroundings using dark plastic sheets and using a heater to warm it up. In this experiment the intention was to maintain continuous termite activity throughout the experimental period. No measurements of daily or hourly temperatures were taken. The plastic sheets helped darken the covered area and trap the heat generated within. Yet it is difficult to replicate conditions in the field even in this seemingly big apparatus as differences in daily foraging rate can occur between colonies in the field that are not noticeable in the laboratory [46].

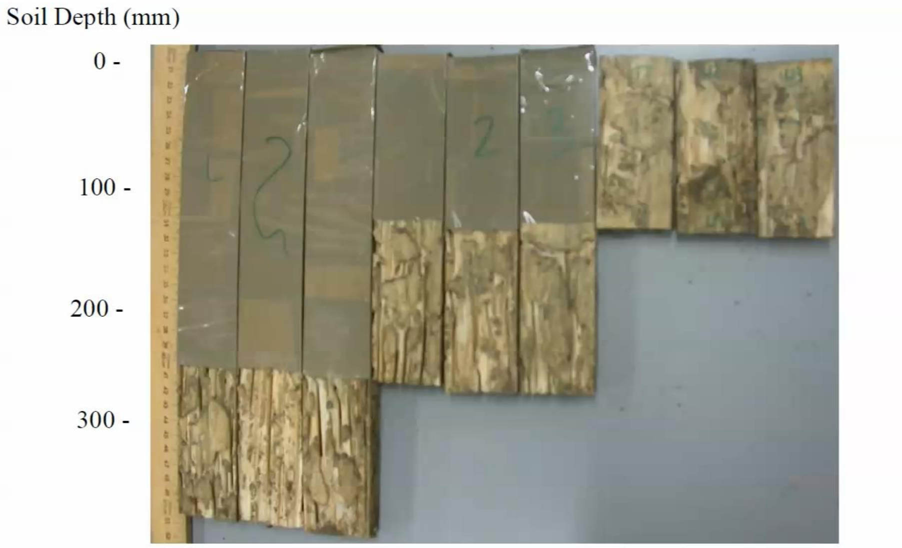


Figure 6. Wood stakes of *Pinus radiata* after exposure to termite attack and foraging for three weeks by burying the lower 100 mm at different depths of a soil profile while covering the rest with plastic tape.

3.3. Foraging depth in soil profiles

In order to determine termite foraging depth in a test tank, nine wood stake samples that were placed randomly in the soil profile were recovered from the sites after three weeks. Soil and termites on the wood stakes were removed carefully thereafter. All the stakes at the different depth levels of the soil profile attracted large number of foraging termites. Fig 6 shows all nine samples after exposure to termite attack at different depths in the soil profile. Termite feeding on the wood stakes was confirmed by the consumption of wood on the surface, causing superficial damage, especially vertically along the grain lines. Apparently, it can be concluded that termites managed to forage at all the depth levels of the soil profile in the test tank and accessed food resources.

Foraging termites were reported to access the food source at the upper soil horizons while at the same time foraging deeper to feed on the other wood blocks concurrently transporting soil particles to the lower layers which were manifested in the change of composition of the previously uniform sandy layer horizons. Similar behavior of concurrent foraging to access sources of food located at different zones has been reported by Arab and Costa-Leonardo [40].

3.4. Soil profile mixing

In order to observe changes in the composition of the soil profile in a test tank due to foraging activity of termites, samples of the soil profile were taken using an auger at random locations. Visual observation in terms of change of color and composition, presence of galleries, or other termite transported soil particles and organic materials were made. In almost all the samples taken for observation (Fig 7) the different stratifications of soil horizons could not be distinctively identified with reference to their original composition. Furthermore, it was assumed that significant amount of termite activity leads to similar changes although soil and water leaching during the soil surface watering could contribute to such changes, although in a lesser extent, due to the length of time the tanks were left for termite activities to flourish. Termites modified the original composition of the soil horizons by simply incorporating materials from the upper horizons into the lower ones through selective sorting process while foraging towards the lower horizons to search and access the wood stakes. Similar assertions were reported in Holt *et al.* [5].

The dark brown colour observed in the lower soil horizons after exposure to termite foraging showed that soil and organic materials were transported and incorporated into the horizons whose composition was uniform (fine sand, coarse sand) in each soil horizon. Voids or tunnels could also be observed in the lower horizons showing abundant termite activity throughout the soil profile in the tank. This confirms the fact that, selective sorting and simple incorporation of soil materials from different horizons would considerably modify the original particle-size distributions [5].

This study was also intended to highlight the significance of termites as biological agents in soil development when the impact of other soil forming processes is reduced to a minimum. The soil tanks were watered weekly or so in order to minimize disturbance of termite activity as well as leaching or any other downward movement of soil particles, while giving enough time for significant termite manipulation of the soil. The fact that this was a closed system gives an idea on the extent termites modify soil systems as well as ideas on the timeframe that they could change a soil system although there are some more factors associated when this kind of research is analyzed from the field.

Figure 7. Changes in color and composition of soil profile samples taken randomly in a termite test tank after exposure to termite foraging.

Usually formosan termites feed heavily on the first located and accessed food before they move to another one [47]. However, during their food search activities they could also forage simultaneously towards more food sources at the same time, as mentioned in the earlier sections. Towards this end, a cross section of the soil profile in the tank was cut to observe changes in the composition and appearance of the soil horizons due to termite activities to access food sources located at the lower horizons. Similar to the samples taken using an auger, changes in color have been observed throughout the soil profile as a result of termite foraging, transport and mixing of soil particles derived from the upper layers as far as the bottom layer.

Termite activity has been observed in the lower layers of coarse sand (250 mm) and gravel (300 mm) layers. This also suggests that termites search and access food sources located deep in the soil profile while at the same feeding on other food sources located and accessed in the upper layers. However, it can also be concluded that significant termite activity did not take place to result in complete mixing of the soil horizons in the soil profile. The original stratifications of the different horizons were relatively still intact or clear lines could be observed in the cross section of the soil profile (Fig 8) in between the different layers of the soil horizons.

Figure 8. Views of a random soil profile cross section cut through a soil profile in a test tank.

IV. Conclusions

This preliminary study confirmed that termite foraging and gallery construction involves transfer of substantial amount of soil material and water from the soil profile. Only a few galleries reached the edge of the foraging tank, achieving maximum height, while the rest did not extend beyond 520 mm. Termites intensified their activities on the longest galleries through which they reached and foraged on the edge of the tank. The diameter of the foraging galleries ranged from 4 to 7 mm while lengths depended on whether termites used a certain gallery to forage as far to other areas on the surface of the foraging tank or as high to the edges of the foraging tank as possible.

Moisture content of galleries collected from the wall surfaces of foraging tank was greater than that of the soil in the foraging tank. They were kept relatively moist and humid for further foraging, maintaining the higher moisture content than the soil they were transported from. The oven dry weight of the total amount of soil transported from the foraging tank and used for the construction of galleries in 15 days was 59.67 g. This means that termites transported soil particles for gallery construction on the wall surface of the tank at an average rate of approximately 4 g/day.

Wood stakes at different depth levels of soil profile in test tank attracted large number of foraging termites and subsequent transported soil materials. Termite feeding on the wood stakes was also confirmed by the consumption of wood on the surface, superficial damage, aligned vertically along grain lines. Termites managed to forage at all depth levels (0 – 300 mm) of the soil profile in the test tank and accessed food resources.

Termites modified the original composition of the soil horizons by simply incorporating materials from the upper horizons into the lower ones through a selective sorting process while foraging towards the lower horizons to search and access the wood stakes placed. Stratifications of soil horizons could not be distinctively identified with reference to their original composition. The dark brown colour observed in the lower soil horizons after exposure to termite foraging showed that soil and organic materials were transported and incorporated into the horizons whose composition was uniform (fine sand, coarse sand) in each soil horizon. Voids or tunnels could also be observed in the lower horizons showing abundant termite activity throughout the soil profile in the tank.

The fact that termite activity was observed in the lower layers of coarse sand (250 mm) and gravel (300 mm) layers may suggest that termites search and access food sources located deep in the soil profile while at the same feeding on other food sources located and accessed in the upper layers. However, it can also be concluded that significant termite activity did not take place to result in complete mixing of the soil horizons in the soil profile. The original stratifications of the different horizons were relatively still intact or clear horizontal lines could be observed in the cross section of the soil profile in between the different layers of the soil horizons.

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Appendix 1. Length (cm) of termite galleries constructed at vertical surfaces of a foraging tank above the surface of a soil profile at different number of days (for 13 days)

Tube Number	Number of Days												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
2	0.00	2.00	2.60	2.60	3.40	3.40	4.00	4.20	4.20	4.20	4.20	4.20	4.20
3	2.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
4	2.50	3.20	4.30	5.20	7.00	9.00	10.20	12.00	13.50	14.50	15.00	15.00	15.00
5	2.80	3.10	3.30	3.30	4.40	4.60	5.20	5.20	5.20	5.20	5.20	5.20	5.20
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
8	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
9	4.00	5.50	7.40	8.50	10.50	12.80	14.00	14.30	14.50	14.50	14.50	14.50	14.50