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RESEARCH ARTICLE - TERMITES

Effect of Termite on Soil pH and Its Application for Termite Control in Zhejiang Province, China

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Abstract

Soil dwelling termites dig nests in the ground that have a significant impact on the soil environment. Activities of termites can result in accumulation of organic matter and enrichment of nutrients and minerals in the soil. Samples from the nest/surrounding soils of two termite species (*Odontotermes formosanus* (Shiraki) and *Reticulitermes flaviceps* (Oshima)) and termite non-invaded soils in the seawall of the Qiantang River, Zhejiang Province, China were collected and analysed for soil pH. The results show that the observed termites prefer an acidic environment and that their activities elevate the pH of termite mound soil compared with surrounding soil. Considering the differences in the distribution areas, termite species, and properties of termite mounds and surrounding soils, this paper also examines the literature concerning the effects of termites on soil pH. After summarizing the pH of the termite survival soil environment, the feasibility of termite control by modifying the soil pH is addressed. Finally, some topics for future research are discussed.

Introduction

Termites are considered to be an important asset in the soil ecosystem; their activities alter the soil pH, organic carbon content, water content and void ratio (Lee & Wood, 1971; Nutting et al., 1987; de Bruyn & Conacher, 1990; Asawalam et al., 1999; Sarcinelli et al., 2009). However, termites have become a serious menace to both plants and structures. Housing constructions, dams and reservoirs, and agricultural fields are vulnerable to termite attack (Su & Scheffrahn, 1998; Verma et al., 2009; Tian et al., 2009). Termites have caused an annual economic loss of over 1000 million dollars and 250-300 million dollars in the USA and China, respectively (Verma et al., 2009). Effective methods have been taken to control termites, including physical, chemical, biological and bait technologies (Su & Scheffrahn, 1998; Su, 2002). Termite control using saline soil is a novel technology that was recently developed in China. It has been applied in Safety Assurance of 1000 Reservoirs Projects in Zhejiang Province (Chen, 2002; Chen et al., 2011). However, this method fails to supply complete knowledge of the underlying mechanism.

Odontotermes formosanus (Shiraki) and *Reticulitermes flaviceps* (Oshima) are two dominant termite species that destroy earthen seawall of the Qiantang River, Zhejiang Province, China. Published studies presenting effect of termites on soil properties are numerous (reviews by de Bruyn & Conacher, 1990; Robert, 2007; Neupane, 2015). However, little information is available in the literature on the quantitative description of *Odontotermes formosanus* (Shiraki) and *Reticulitermes flaviceps* (Oshima) affect soil pH. The objectives of the present study were therefore to (1) evaluate the influence of soil pH resulting from activities of the observed termites, and (2) probe the feasibility of termite control using saline soil in terms of soil pH modification.

Materials and Methods

Methods

To achieve the study objectives, we (1) surveyed the termite nest at the study site, (2) collected samples from the termite nest/surrounding soils and termite non-invaded soils, (3) measured the soil pH in the laboratory, and (4) compared the results with the literature concerning the effects of termites on soil pH.

Study field

The study was conducted in the region of the seawall of Qiantang River, Zhejiang Province, China (Fig1), where the climate is subtropical and humid. This area has an average annual rainfall of approximately 1200 mm and an average annual daily temperature of approximately 16 °C. In 2000, inspectors first discovered and verified a termite infestation in the ancient seawall. The nest materials of two termite species, *Odontotermes formosanus* (Shiraki) and *Reticulitermes flaviceps* (Oshima), and their surrounding soils were collected and analyzed in terms of pH in the present work.

Soil sampling and pH analysis

Soil sampling at two main types of seawall is sketched in Fig 1b (Stone seawall) and Fig 1c (Slope seawall). The termite nests were excavated, and soil sampling was carried out at different positions, ranging from top to the bottom of the nest, and then pooled into a single sample. The adjacent surrounding soil without termite activity was also sampled within 2 m of the central of the nest. The pH determinations were carried out in a 1 : 2.5 soil to water mixture using a pH-meter (Ministry of Agriculture of the People's Republic of China, 2007).

Statistical analyses

Statistical Product and Service Solutions (SPSS, 2007) was used for statistical test. Paired sample *t*-test was used to determine significant differences between pHs of the nest material and the surrounding soils.

Results

pH of the termite nest/surrounding soils

The material of seawall filling soil is mainly composed of silty clay. Most termite infestations are caused by *Odontotermes formosanus* (Shiraki) and *Reticulitermes flaviceps* (Oshima). The pH of the nest materials were higher than that of the surrounding soils ($P< 0.05$) (Tables 1, 2). In general, the nest materials of *Reticulitermes flaviceps* (Oshima) have been found to have higher pH values than the nest materials of *Odontotermes formosanus* (Shiraki).

pH of the termite non-invaded soils

No termites were detected in the following areas (Fig 1): (1) a seawall constructed of saline soil after the 1960s, such as in Hezhuang; (2) a seawall reinforced using saline soil, such as in Laoyanchang, which was collected from an intertidal zone; (3) a seawall that had been showered by an inflow of seawater due to a storm surge, such as in Dushan. The salinity

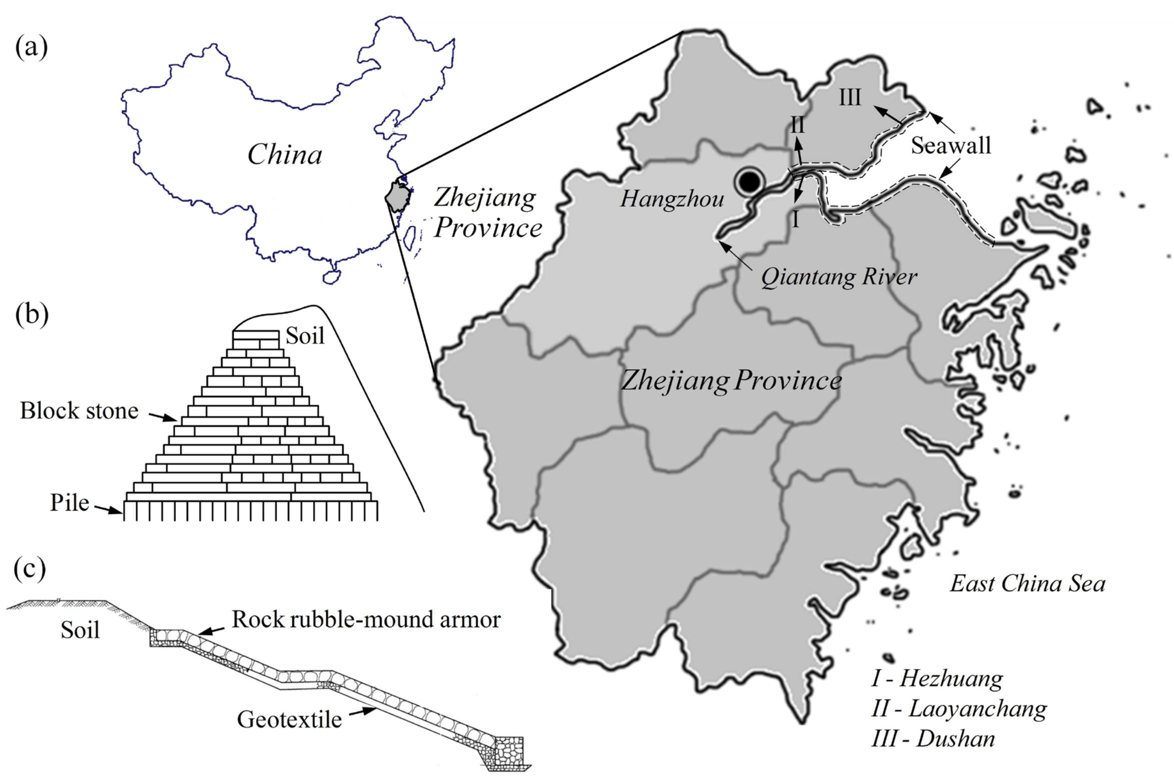

Fig 1. Study site. (a) Location of the Qiantang River in China; (b) Stone seawall; (c) Slope seawall.

Table 1. pH of termites nest materials and the surrounding soils.

Specie	Sampling site	TN	SS	TN-SS	T-Value	n
Odontotermes formosanus (Shiraki)	Stone seawall	6.52 (±0.36) [6.07–7.19]	6.10 (±0.16) [5.85 –6.47]	0.43	3.25*	10
	Slope seawall	6.44 (±0.29) [6.03 –7.08]	6.06 (±0.19) [5.81 –6.42]	0.38	3.04*	10
Reticulitermes flaviceps (Oshima)	Stone seawall	6.95 (±0.43) [6.44 –7.69]	6.18 (±0.26) [5.74 –6.68]	0.78	3.95*	10
	Slope seawall	6.86 (±0.39) [6.53 –7.74]	6.14 (±0.30) [5.71 –6.76]	0.71	3.60*	10

TN: Termite nest, SS: Surrounding soil.* Significant at the 5% level (P ≤ 0.05). Values are mean (±SD) [minimum–maximum]. SD: Standard deviation.

of the seawater is approximately 1%.The results for the pH of the termite non-invaded soils are presented in table 2.The pH values of the termite non-invaded soils ranged from 8.12 to 8.94, which was far higher than the values of the termite nest/surrounding soils.

Discussion

Considering the differences in the distribution areas, termite species, and properties of termite mounds and surrounding soils, we also summarized pH test studies in the peer-reviewed, scientific literature and found 117 results published in 51 papers (Table 3). Statistically, most termites nested in acidic and weakly alkaline soils, with surrounding soils pH values between 3.5 and 8.7 (Fig 2a). Of 117 sets of data, 84% showed surrounding soils pH values lower than 7, with an average of 5.7. pH values from 4.5 to 5.5 demonstrated the highest frequency band in surrounding soils, covering 38%. Thus, the results supported a preference of most termites for an acidic soil environment. The pH values of termite mounds within this range (Fig 2b), however, had a higher average value (6.2). The frequency distribution of pH value differences (D-Value) between termite mounds and surrounding soils are presented in Fig 3. Among the data, 76% showed increases in pH caused by the activities of termites. A pH value difference ranging from 0 to 0.5 demonstrated the highest frequency band statistically, covering 48%.

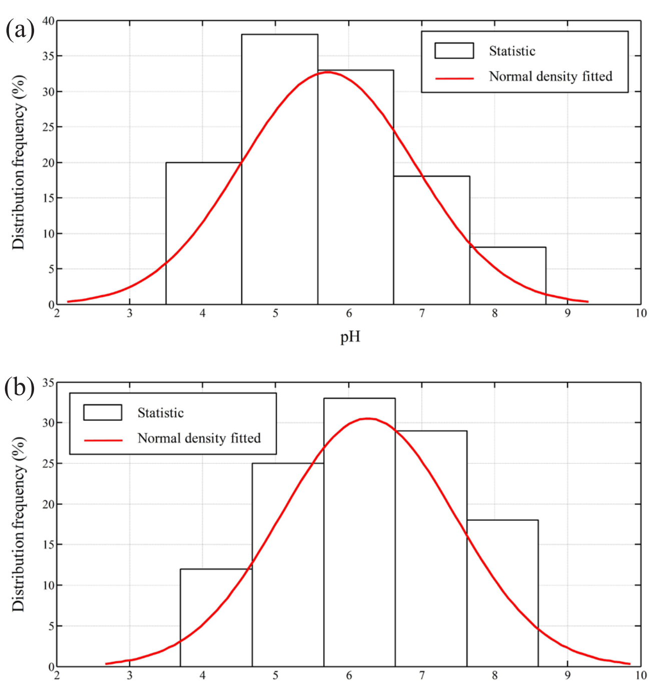

Fig 2. pH frequency distributions of surrounding soils and termite mounds. (a) Surrounding soils; (b) Termite mounds.

Consistent with previous literature analysis, termite nest material and surrounding soils are considered to be slightly acidic in the seawall of Qiantang River. In the termite non-invaded areas, the pH of the seawall filling had a higher value. Therefore, an increase in soil pH might lead to termite inactivation. In practice, irrigating with seawater on the inside slope (Fig 4a), covering a saline soil mixture on the slope (Fig 4b) or filling the saline soil in the seawall (Fig 4c) could reduce termite infestation. In China, a method to increase the pH of dike fillings with saline soils is shown in Fig 5.

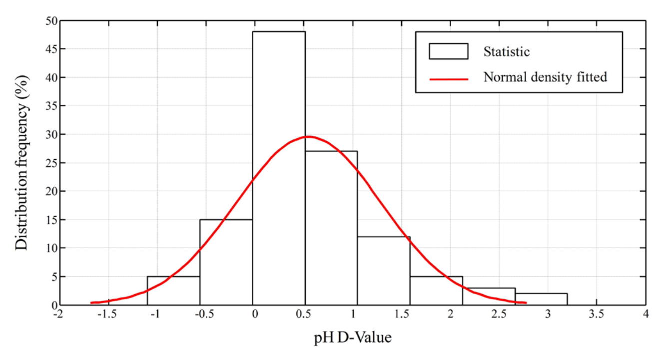

Fig 3. Frequency distribution of pH difference-values (D-Value) between termite mounds and surrounding soils.

In this method, a well with a diameter of 0.5 m is created though the seepage line of the dike (Fig 5b) and then backfilled with salt-mixed soils at a salt/soil ratio of 0.08% (Fig 5c). This method is easy to setup and perform, and the effectiveness of the termite control period can reach 20 years (Chen, 2002).

Nevertheless, negative effects may be incurred from the addition of saline soil as a termite control measure. The physical properties of the mixed soil would change compared with the original soil. An appropriate amount of salt had no obvious effect on the soil permeability. However, the coefficient of water-soluble salts of the soil clearly increased. In addition, the soil shear strength and compression modulus would decrease with the rise in soil salinity (Chen et al., 2015). Furthermore, termites are not the only organisms living in the environment, so all other organisms would be affected by the saline soil.

Table 2. pH of the termite non-invaded soils (n=10).

Sampling site	pH
Stone seawall	8.46 (±0.19) [8.28 –8.94]
Slope seawall	8.51 (±0.25) [8.12 –8.85]

Values are mean (±SD) [minimum – maximum]. SD: Standard deviation.

Conclusions

The present study provides evidence that the activities of *Odontotermes formosanus* (Shiraki) and *Reticulitermes flaviceps* (Oshima) significantly influence the soil pH and that a soil pH increase may lead to termite inactivation. Further research should include the following topics: (1) During development, termite nests undergo many processes; therefore, the variability of the soil pH during different periods must be considered; (2) different species of termites have different preferences regarding selection of a nest soil environment, and the progress of related studies is still in its infancy; (3) the maneuverability, effectiveness and durability of termite control by using saline soil need to be better understood.

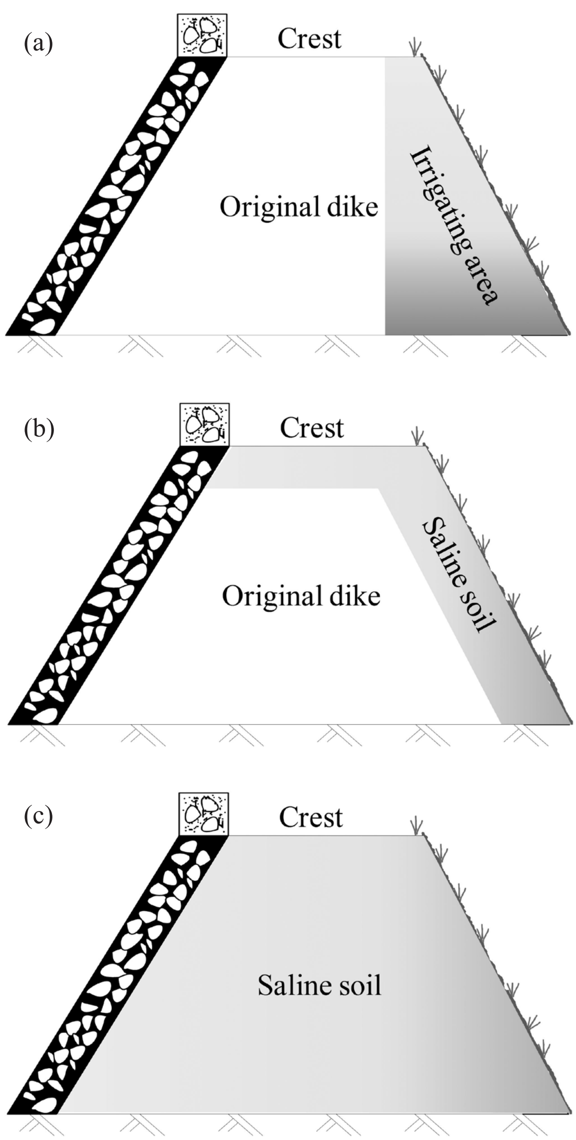

Fig 4. Methods for increasing the soil pH of seawall. (a) Seawater irrigation; (b) Saline soil covering; (c) Saline soil filling.

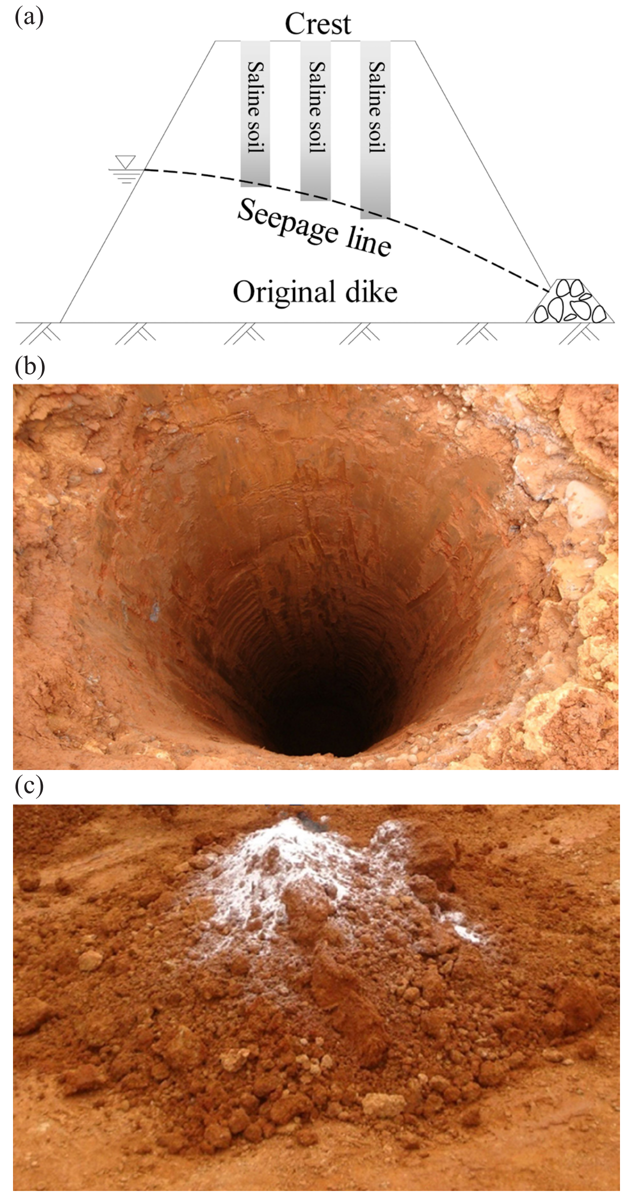

Fig 5. Site operation of termite control with saline soil. (a) Sketch diagram; (b) Dig wells; (c) Backfill with salt mixed soils.

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Authors contribution

Y Li and LH Chen contributed to the conception of the study and manuscript preparation; Y Li and DZ Pan performed the data analyses and wrote the manuscript; ZY Dong and CH Pan helped perform the analysis with constructive discussions.

Table 3. Summary for the pHs of termite mounds (TM) and surrounding soils (SS) from literature.

Location	Reference	Species	Soil pH*		
			TM	SS	DV
Kenya	Robinson, 1958	*Odontotermes badius* (Haviland)	5.89	5.52	0.37
	Arshad, 1982	*Macrotermes michaelseni* (Sjöst)	5.6	5.1	0.5
	Bagine, 1984	*Odontotermes* sp.	7.9	8.6	-0.7
	Arshad et al., 1988	*Macrotermes michaelseni*	7.1	6.0	1.1
		Macrotermes michaelseni	6.1	5.7	0.4
		Macrotermes herus	7.2	5.5	1.7
		Macrotermes herus	7.9	6.1	1.8
		Macrotermes herus	5.8	5.5	0.3
Zimbabwe	Watson, 1962	sp.	7.91(±0.85)	6.16(±0.55)	1.75
	Watson, 1969	*Odontotermes badius* (Haviland)	5.7	4.4	1.3
		sp.	7.2	4.9	2.3
	Watson, 1972	*Macrotermes natalensis* (Haviland)	5.8	4.3	1.5
	Watson, 1977	*Macrotermes falciger* (Gerstäcker)	7.4	5.0	2.4
	Muvengwi et al., 2013	*Macrotermes*.sp.	7.5(±0.1)	5.8(±0.2)	1.7
Nigeria	Nye, 1955	*Macrotermes nigeriensis* (Sjöst)	6.83(±0.39)	6.60(±0.17)	0.23
		Macrotermes nigeriensis (Sjöst)	6.83(±0.31)	5.88(±0.69)	0.95
	Malaka, 1977	*Amitermes evuncifer*	4.6	4.2	0.4
		Cubitermes sp.	4.7	4.4	0.3
		Macrotermes bellicosus	4.5	4.7	-0.2
		Trinervitermes geminatus	5.1	4.7	0.4
	Wood et al., 1983	*Cubitermes ocularus* (Silvestri)	5.9(±0.12)	6.0(±0.11)	-0.1
		Cubitermes severus (Silvestri)	6.0(±0.07)	5.3(±0.03)	0.7
	Akamigbo, 1984	*Nasutitermes* sp.	5.3	4.9	0.4
	Anderson & Wood, 1984	*Cubitermes severus*	6.0	5.3	0.7
		Procubitermes aburiensis	5.5	4.9	0.6
	Ezenwa, 1985	*Macrotermes bellicosus*	6.3	5.8	0.5
		Trinervitermes geminatus	6.3	5.7	0.6
	Asawalam et al., 1999	*Nasutitermes* sp.	5.1	4.2	0.9
	Abe &Wakatsuki, 2010	*Macrotermes bellicosus*	6.8(±1.3)	5.8(±0.6)	1.0
		Macrotermes bellicosus	5.8(±0.2)	6.2(±0.9)	-0.4
		Macrotermes bellicosus	7.2(±0.4)	6.3(±0.4)	0.9
	Afolabi et al., 2014	*Macrotermes bellicosus*	6.72	6.62	0.1
		Trinervitermes geminatus	6.33	6.33	0.0
	Ehigiator et al., 2015	sp.	5.9	4.9	1.0
		sp.	5.8	4.8	1.0
		sp.	6.1	4.9	1.2
		sp.	6.1	4.7	1.4
		sp.	6.2	5.1	1.1
Congo	Garnier-Sillam & Harry, 1995	*Noditermes lamanianus*	4.8(±0.2)	4.1(±0.3)	0.7
		Cubitermes fungifaber	4.8(±0.3)	4.1(±0.3)	0.7
		Thoracotermes rnacrothorax	4.5(±0.3)	4.1(±0.3)	0.4
		Crenetermes albotarsalis	3.7(±0.1)	4.1(±0.3)	-0.4
	Mujinya et al., 2010	*Macrotermes* sp.	6.4(±1.39)	5.0(±0.01)	1.4
	Mujinya et al., 2011	*Macrotermes* sp.	8.0	4.8	3.2
		Macrotermes sp.	8.6	6.0	2.6
	Erens et al., 2015	*Macrotermes falciger*	8.11(±0.1)	5.21(±0.16)	2.9

Table 3. Summary for the pHs of termite mounds (TM) and surrounding soils (SS) from literature. (Continuation)

Location	Reference	Species	Soil pH*		
			TM	SS	DV
Uganda	Okwakol, 1987	*Cubitermes testaceus* (Williams)	5.5(±0.3)	4.7(±0.1)	0.8
Tanzania	Mahaney et al., 1999	sp.	7.51	5.56	1.95
		sp.	7.12	5.59	1.53
	Ketch et al., 2001	*Macrotermes* sp.	6.4	5.4	1.0
		Macrotermes sp.	6.2	5.0	1.2
		Macrotermes sp.	6.1	5.3	0.8
		Macrotermes sp.	4.7	4.4	0.3
Cameroon	Donovan et al., 2001	*Cubitermes fungifaber*	4.26	4.08	0.18
		Cubitermes fungifaber	5.02	4.51	0.51
		Cubitermes fungifaber	5.77	5.52	0.25
		Cubitermes fungifaber	5.73	5.86	-0.13
		Cubitermes fungifaber	6.03	6.29	-0.26
Guinea	Jouquet et al., 2004	*Macrotermes bellicosus*	5.38(±0.12)	4.92(±0.13)	0.46
Gabon	Roose-Amsaleg et al., 2004	*Cubitermes* sp.	5.3(±0.5)	4.9(±0.2)	0.4
	Roose-Amsaleg et al., 2005	*Cubitermes* sp.	5.41(±0.37)	4.64(±0.34)	0.77
Côte d'Ivoire	Jouquet et al., 2005	*Ancistrotermes cavithorax* (Sjöstedt)	6.64(±0.2)	6.53(±0.32)	0.11
		Ancistrotermes cavithorax (Sjöstedt)	7.06(±0.64)	6.82(±0.3)	0.24
		Odontotermes nrpauperans (Silvestri)	6.92(±0.39)	6.82(±0.3)	0.1
Burkina Faso	Brossard et al., 2007	*Trinervitermes geminatus*	6.7(±0.5)	6.6(±0.6)	0.1
		Trinervitermes trinervius	6.9(±0.7)	6.4(±0.3)	0.5
Ethiopia	Debelo & Degaga, 2014	*Macroterme.* sp.	8.00	7.03	0.97
		Macrotermes sp.	8.23	7.46	0.77
South Africa	Gosling et al., 2012	*Trinervitermes* sp.	6.02	5.83	0.19
		Macrotermes sp.	6.95	5.83	1.12
		Odontotermes sp.	6.51	5.83	0.68
Venezuela	Salick et al., 1983	sp.	3.9	3.9	0.0
		sp.	4.3	3.5	0.8
	López-Hernández & Febre, 1984	*Cubitermes* sp.	6.7	5.7	1.0
		Macrotermesbellicosus	6.1	5.8	0.3
		Trinervitermes geminatus	7.3	6.5	0.8
	López-Hernández, 2001	*Nasutitermes ephratae*	5.6	4.8	0.8
USA	Nutting et al., 1987	*Gnathamitermes perplexus* (Banks)	7.6	6.8	0.8
		Heterotermes aureus (Synder)	7.9	6.8	1.1
Brazil	Fageria & Baligar, 2004	sp.	5.7	5.4	0.3
	Kaschuk et al., 2006	sp.	4.83(±0.31)	4.55(±0.07)	0.28
		sp.	4.27(±0.15)	4.10(±0.01)	0.17
		sp.	5.07(±0.21)	5.23(±0.22)	-0.16
		sp.	4.73(±0.43)	4.48(±0.08)	0.25
		sp.	4.80(±0.33)	4.68(±0.03)	0.12
	Ackerman et al., 2007	sp.	4.3	4.4	-0.1
	Sarcinelli et al., 2009	sp.	4.23	3.89	0.34
		sp.	4.99	3.98	1.01
		sp.	4.96	4.19	0.77
		sp.	5.26	4.78	0.48

Table 3. Summary for the pHs of termite mounds (TM) and surrounding soils (SS) from literature. (Continuation)

Location	Reference	Species	Soil pH*		
			TM	SS	DV
Australia	Park et al., 1994	*Drepanotermes tamminensis* (Hill)	5.18(±0.06)	5.31(±0.09)	-0.13
		Drepanotermes tamminensis (Hill)	4.67(±0.04)	5.61(±0.08)	-0.94
	Lee & Wood, 1971	*Amitermes hurensis*	5.5	6.6	-1.1
		Drepanotermes rubriceps	5.5	6.4	-0.9
		Nasutitermes exitiosus	4.3	4.9	-0.6
		Nasutitermes triodiae	6.2	5.8	0.4
	Okello-Oloya et al., 1985	*Amitermes* sp.	6.4	5.0	1.4
India	Samra et al., 1979	*Odontotermes wallonensis*	7.0	7.4	-0.4
	Gupta et al., 1981	*Odontotermes gurdaspurensis*	8.5	8.7	-0.2
		Odontotermes gurdaspurensis	8.4	8.5	-0.1
	Rao et al., 2013	*Odontotermes obesus*	7.43(±0.07)	6.67(±0.20)	0.76
	Jouquet et al., 2016	*Odontotermes obesus*	6.03(±0.07)	6.23(±0.13)	-0.2
		Odontotermes obesus	6.55(±0.11)	6.46(±0.15)	0.09
Iran	Gholami & Riazi, 2012	sp.	7.94	7.71	0.23
Pakistan	Sheikh & Kayani, 1982	*Odontotermes lokanandi* Chatterjee & Thakur	7.6(±0.1)	7.4(±0.1)	0.2
		Odontotermes obesus (Rambur)	7.9(±0.1)	7.7(±0.1)	0.2
		Amitermes belli (Desneux)	7.5(±0.0)	7.5(±0.0)	0.0
		Anacanthotermes macrocephalus (Desneux)	7.8(±0.1)	7.6(±0.1)	0.2
		Anacanthotermes vagans(Hagen)	7.8(±0.1)	7.9(±0.1)	-0.1
		Coptotermes heimi (Wasmann)	7.2(±0.0)	7.2(±0.0)	0.0
		Heterotermes indicola (Wasmann)	6.9(±0.0)	6.9(±0.0)	0.0
		Microtermes mycophagus (Desneux)	7.9(±0.1)	7.6(±0.1)	0.3
		Microtermes obesi Holmgren	7.7(±0.0)	7.8(±0.0)	-0.1
		Microtermes unicolor Snyder	7.4(±0.1)	7.3(±0.1)	0.1
		Microcerotermes heimi Wasmann	8.1(±0.0)	8.1(±0.0)	0.0
		Microcerotermes sakesarensis Ahmad	7.6(±0.0)	7.6(±0.1)	0.0
		Odontotermes gurdaspurensis Holmgren & Holmgren	7.2(±0.0)	7.2(±0.1)	0.0

* Values are mean (±SD), SD: Standard deviation, sp.: species unknown.
TM: Termite mound, SS: Surrounding soil, DV: pH difference valuebetween TM and SS.

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