Original Article

Effectiveness of disodium octaborate tetrahydrate (Timbor®) in controlling subterranean termite attack and decay of house sill plates

Kunio Tsunoda・J. Kenneth Grace・Anthony Byrne・Paul I. Morris

K. Tsunoda (correspondence person)
Wood Research Institute, Kyoto University Uji, Kyoto 611-011 Japan
Tel. +81-774-38-3661; Fax +81-774-38-3664
e-mail: tsunoda@termite.kuwri.kyoto-u.ac.jp

J. K. Grace
University of Hawaii at Manoa, College of Tropical Agriculture & Human Resources
3050 Maile Way, Honolulu, Hawaii, USA.

A. Byrne・P. I. Morris
Forintek Canada Corp. 2665 East Mall, Vancouver, British Columbia, Canada

Key words: Subterranean termites, Disodium octaborate tetrahydrate, House sill plate (dodai), Termite resistance

Abstract

This study determined the field performance of simulated house sill plates (dodai) subjected to termite attack and decay. Hem-fir dodai were pressure-treated to two retentions of disodium octaborate tetrahydrate (Tim-bor®) targeted at 2%(w/w) and 3%(w/w) boric acid equivalent, both shell- and through-treatment. These were installed in a protected above-ground field test in Kagoshima, Japan simulating the house sill plate used in conventional Japanese housing construction. Chromated copper arsenate treated hem-fir was used as the reference material, and locally used hinoki (*Chamaecyparis obtusa* Endl.) dodai were also installed in the test. The test site supports active subterranean termites, *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* (Kolbe). Samples were inspected annually and rated for both termite and decay damage.

After 5 years untreated hem-fir controls and hinoki were most heavily attacked by termites and the incipient decay sign was noticed on some untreated controls, while exceptionally only two samples of the treated materials sustained traces of termite attack. All preservatives of the current study, therefore, protected the sill plates. Based on comparisons with end-matched samples installed in a test site in Hawaii, where attack of controls appears to be up to 10 times faster, the data suggest these treatments would provide long-term protection of sill plates from termite and decay attack.

Keywords: Subterranean termites, disodium octaborate tetrahydrate, house sill plate (dodai), termite resistance.

1. **Introduction**

As reviewed elsewhere, boron compounds have been widely used in the world as wood preservatives since the 1940's[1)], because of their high toxicity to both wood-attacking insects and wood-decaying fungi[2-5)]. However, leachability of the borates such as disodium octaborate tetrahydrate (DOT) in running water is the most disadvantageous characteristics[6)]. The use of borates is therefore limited to the preservative treatment of wood under protected and above-ground situations (including coated end-use). Therefore, house framing is the principle use of borate-treated wood. Framing in termite regions has been protected for decades by formulations containing both organic termiticides and fungicides, but one by one these have been withdrawn from the market as a result of environmental pressures. Attention has therefore turned to the potential of borates to prevent termite damage[5,7,8)]. In addition, preservatives containing heavy metal elements are coming under increasing attack from segments of society and it is possible that water-soluble borates may substitute fro some of those preservatives where the high fixation in not a requirement[9)].

Japanese standard laboratory tests showed that termites can attack wood treated with higher borate loadings than can decay fungi when unweathered small wood specimens were exposed to a monoculture of the decay fungi of *Fomitopsis palustris* (Berk. et Curt.) Gilbn. & Ryv. and *Trametes versicolor* (L.: Fr.) Pilát or to the Formosan subterranean termite, *Coptotermes formosanus* Shiraki 1[10,11)]. The latest results indicated that a retention level of 0.5% BAE appeared to be high enough to control both decay fungi and to protect solid wood and wood-based composites from *C. formosanus*[12)]. In contrast, weathered wood specimens were easily decayed even at a retention of over 10%BAE because the residual borate amount became undetectable after weathering cycles as expected from its high leachability[11)].

Several field test methods have been proposed to simulate unprotected above-ground conditions where decay and relatively slight termite attack may occur [13-20)]. These test conditions are not suitable for evaluating the efficacy of preservatives under protected above-ground conditions. More recently, in Australia and The United States, decay and termite resistance of wood and wood-based composites have been tested under conditions that simulate protected above-ground use in the field. Australian results demonstrated that 0.5-1.3%BAE was needed to protect wood from *Coptotermes acinaciformis* (Froggatt)[21-23] whereas *C. formosanus* seemed more tolerant to the borate treatment in the United States where a miniature house trial estimated a threshold value of 2.1%BAE[24]. Unfortunately, none of these studies addressed the loss of borates from treated wood during exposure in the field.

The first phase of the current investigation, therefore, verified the test method and has been reported elsewhere[25,26]. The second or main phase, reported here, was a larger scale simulation field test in Kagoshima, Japan. The current paper deals with the updated results in Kagoshima and a brief comparison with those in Hawaii where the end-matched samples were also installed in the same way.

2. Materials and methods

2.1 Wood treatment

Unseasoned hem-fir dodai (10.5 cm x 10.5 cm x 350 cm long heartwood with >40% moisture content) were obtained and separated into the two component species, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and amabilis fir (*Abies amabilis* (Dougl.) Forbes). Species were confirmed by examination under a light microscope. Pieces 130m long, without large knots or checks, were end-sealed with epoxy resin, weighed, and treated using combinations of a full-cell pressure process together with diffusion at Forintek Canada Corp.'s laboratory in Vancouver BC[27]. A two-hour press time was used for amabilis fir and a six-hour press time for western hemlock at an impregnation pressure of 1035 kPa. Samples were treated either with DOT or DOT plus didecyldimethylammonium chloride (DDAC) or with chromated copper arsenate (CCA) in water solutions. Pre-test, end-sealed samples from each original dodai were pressure treated with water alone and, based on the weight uptake, the required preservative concentrations were calculated to enable target retentions to be met.

The preservative uptake for each 130 cm piece was determined based on its post-treatment weight. A 5.0 cm slice, cut from the mid-point of each piece, was used to determine the preservative penetration and the retention by chemical analysis. To reveal the penetration in the borate-treated wood, a two part curcumin reagent was sprayed onto the sample28). For the borate-treated pieces the resulting twin ca.65cm samples were end-sealed again and sorted into groups with similar borate retentions and penetrations. The objective was to produce both shell- and through-treated cross sections at target levels of 2% BAE (Boric Acid Equivalent) or 3% BAE, (low and high levels respectively). The selected shell-treated samples were stickered for air-drying immediately after treatment and placed in covered outdoor storage. To obtain the through-treatments, selected samples were stored wet by wrapping them in polyethylene sheets. Storage was for a diffusion period of 3-56 days to reach full penetration, the longer time being required for the western hemlock. During this process, the oversized samples were monitored by periodically cutting a 5.0 cm slice from one end of the samples and checking preservative penetration with curcumin. The samples were end-sealed and placed in storage until full penetration had occurred. At that time they were stickered for air drying. When a moisture content of about 20% was achieved, the samples were trimmed to 400mm length, one twin sample destined for each of two field test sites (Hawaii and Japan) for a replication of 10 per treatment per site.

For comparison to the borate-treated dodai, incised hem-fir samples were treated to a target of 4kg/m^3 CCA. The freshly cut ends on all treated samples were treated by brushing with two coats of a field cut preservative (10% DOT in water or 2% copper naphthenate solution in light petroleum solvent).

The treatments evaluated in the current study included Treatment 1: 2%BAE shell, Treatment 2: 3%BAE shell, Treatment 3: 2%BAE through, Treatment 4: 3%BAE through, Treatment 5: 2%BAE + DDAC shell, Treatment 6: CCA 4 kg/m^3, Treatment 7: untreated hem-fir (mean air-dried density of western hemlock and amabilis fir at installation were 644 and 624 kg/m^3, respectively) and Treatment 8: untreated hinoki (commercial product containing both sapwood and heartwood portions with mean air-dried density of 627 kg/m^3 at installation). Ten replicates of each treatment were tested.

2.2 Field test sites

The test site is located in the national pine forest growing on sandy soil in Kagoshima Prefecture on the island of Kyushu, Japan, close to the East China Sea, and has been maintained by Wood Research Institute of Kyoto University for more than 20 years. Ten test installations (PVC boxes) each containing 8 samples were set up in the test which contains active colonies of *C. formosanus* and *Reticulitermes speratus* (Kolbe). The mean annual temperature is approximately 18°C and precipitation 2,240 mm(29). The temperature has a distinct summer maximum temperature (mean daily temperature for July of 28°C) which results in high termite activity during the summer but more limited activity during the winter (mean for January of 7°C).

2.3 Test installation and inspection

Installation followed the test method previously reported[25, 26]. Each sample was placed on a concrete building block 19 cm high. Untreated pine sapwood stakes were driven down in the hollows of the block (0.5-1.0 cm apart from the sample bottom face) to encourage termites to come from the infested soil directly to the test samples placed on top of the blocks (Fig. 1). Sample sets on blocks were covered with a PVC inverted five-sided box (90 x 50 x 45 cm). The eight samples per box included one replicate of each borate treatment plus one untreated western hemlock or amabilis fir sample. Also included in each box was one hinoki (*Chamaecyparis obtusa* Endl.) that represented locally available alternative termite-resistant wood products. A data logger for recording temperature and relative humidity was installed in one of the test boxes in December, 1997, and the data was downloaded a year later.

The dodai samples were installed in December 1995 and inspected annually around the anniversary of the test installation. Samples were gently removed from the concrete blocks and inspected visually and by probing the underside of the sill plates where the termites had contacted the wood. The samples were rated on the American Wood Preservers' Association scale of 10-0 with the ratings shown in Table 1. During inspections, decay was also recorded on a similar 10-0 scale. Following inspection samples were replaced in the same location.

The presence or absence of termite activity was noted during the inspections. Feeder stakes were replaced as necessary to encourage continuous exposure of the samples to termites. At the 1998 inspection, a moisture meter [Kett Kagaku Kenkyosho, HM520(MOCO-2)] was used to determine the moisture contents of the samples.

3. Results and discussion

3.1 Borate retention

Table 2 gives the mean analyzed retention and the retention ranges for test materials. Despite samples being selected carefully, there was a large amount of variation in chemical retention. This is attributable to the naturally high variability of wood as a substrate.

3.2 Progress in termite attack

Table 3 shows the progression of termite attack over 5 years. Untreated hem-fir controls and hinoki reference materials showed gradually increasing termite damage reaching a mean rating around 6 after 5 years. In contrast, all DOT-treated samples (2% BAE shell and through and 3% BAE shell and through treatments) were free from termite attack and decay, while one replicate each of 2% BAE with DDAC and CCA reference preservative, were very slightly attacked with a rating of 9 in the second and the fourth year exposure period, respectively. Since then, however, no progress in damage was noticed. Thus, mean ratings of the treated materials stayed at 9.9 or higher even after five years exposure. Despite the presence of two termite species, damage was attributed mainly to *C. formosanus*.

Termites appeared to sporadically attack all of the treatments being tested. Attack appeared to be irrespective of whether the level of borate treatment was high or low and shell or through treatment or whether the treated wood was western hemlock or amabilis fir. The performance of borate-treated wood appears to rely on the fact that borates are not a termite repellent (low repellency) and that after feeding on wood which acts as slow-acting stomach poison, termites are able to restrict further colony feeding on the treated wood (feeding deterrence/avoidance) 30). This might account for the exceptional termite attack on two treated samples (see Table 3, one each of treatment 5 and 6).

3.3 Conditions inside the PVC box and decay occurrence

The relative humidity and temperature inside the boxes respectively remained over 10% and 1℃ higher than those of the ambient air (Table 4)29). The calculated equilibrium moisture content for the year averaged 19% (Table 4). However, it was apparent that condensation formed on the lids of the boxes and dripped onto the samples, probably because of overnight fluctuation in relative humidity reaching 100%31). This might create a leaching hazard for the borate-treated samples over the long term, although no detrimental effects are apparent at this stage. The moist conditions led to stain and mould growth on some samples together with slight decay on untreated hem-fir. Actual moisture content measurements conducted on December 18, 1998 suggested that moisture contents were high enough after three years exposure in at least surface zones of the dodai samples, for decay fungi to grow since mean moisture contents on the top and the bottom faces were 39 and 42 %, respectively. For most samples, the bottoms were generally wetter than the tops.

Unexpectedly, no sign of decay was observed for the first 4 years [32), though incipient decay was finally found on some untreated hem-fir and hinoki controls in the 5th year. The moisture contents were equivalent to those of the wood components in the crawlspace of the old post and beam Japanese homes[33). A few samples were as high as 60-70% (note: the meter is not accurate at those levels) and this is probably attributable to dripping of condensation and water uptake through the soil linking test samples and pine feeder stakes.

3.4 Comparison of sites

The data from the Hawaii test is reported in details elsewhere, but it is useful to compare the results from the two sites. Table 5 gives the mean and ranges of termite ratings after four years at the two test sites. Although termite attack varied among boxes[32,34,35) , clearly the Hawaii site showed rapid and consistent attack of both treated and untreated wood.

The heavier attack in Hawaii can be partially attributed to the warm temperatures year round and to the high activity levels of a voracious termite[34,35). Since previous studies on the temperature response of *C. formosanus* demonstrated that optimum temperature ranges are from 20 to 35℃[36,37), termite activity would be suppressed for 6 months from November through April in Kagoshima because monthly mean temperature during the period is lower than 20℃[29). In addition, Yamano who worked on the effect of temperature on the wood consumption rates of *C. formosanus* when termites were maintained at constant temperature under laboratory conditions, concluded that the highest rate was recorded at 35℃, which was more than double of the rate at 25℃ and more than 4 times of the rate at 20℃[38). This leads us to consider that the period with temperatures over 20℃ is an important factor to regulate the activity of *C. formosanus*, and accounts for the seasonability in wood consumption and severity in attack on the wood samples. Field studies with the termite species appeared to support this temperature preference in wood consumption, and indicated that the highest wood consumption took place during the period with high temperatures over 30℃ in Louisiana[39].

4. Conclusions

1) The test method proved to be an effective above-ground method of testing preservative-treated wood against subterranean termites and decay fungi under non-leaching but humid conditions.

2)While CCA- and borate-treated lumber were all susceptible to slight damage as a result of surface grazing by subterranean termites, both preservatives at the levels tested here effectively protected sill plates for at least 5 years.

3) Although termite attack started from sapwood before attack occurred in heartwood and the incipient decay sign of surface softening was limited in the sapwood, the naturally durable wood hinoki appeared to be more susceptible to termite and decay attack than the preservative-treated wood and not significantly more durable than the untreated hem-fir.

4) The Hawaiian test site appears to be up to 10 times faster than the Kagoshima site in achieving failure of controls.

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Table 1. Termite attack rating system

AWPA rating	Description
10	Sound. Surface grazing (nibbling) is permitted, but such cosmetic damage must be noted in the report.
9	Trace of attack. For example, surface erosion up to 5 mm deep, or up to two termite penetrations of up to 10 mm deep.
7	Moderate attack. For example, surface erosion over 5 mm, penetrations over 10 mm deep or ramifying tunnels present.
4	Heavy attack. For example, extensive tunneling of up to 50–75% of the cross-section.
0	Failed due to termite attack.

Notes: Adapted from AWPA Standard E7-93. The same rating system was applied to decay assessment.

Table 2. Analyzed preservative retentions in test material

Treatment	Penetration	Preservative retention	
		Mean	Range
Hem-fir			
Untreated		0	0-0
Borate 2%BAE*	Shell	2.9	1.1-5.4
Borate 3%BAE*	Shell	3.4	1.3-5.0
Borate 2%BAE*	Through	1.6	1.1-2.6
Borate 3%BAE*	Through	3.0	1.7-5.1
Borate 2%BAE + DDAC*	Shell	1.5	0.5-2.0
CCA (oxide) 4 kg/m^3*	Shell	4.5	2.8-5.1
Untreated hinoki		0	0-0

*: Target retention

Table 3. Progress in termite and decay ratings for 5-year exposure (1995-2000)

	Treatment			
	5:2%BAE + DDAC shell	6: CCA 4 kg/m^3	7: Untreated hem-fir	8: Untreated hinoki
Box 1	10-10-10-10-10	10-10-10-10-10	09-07-07-07-07	09-07-07-07-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10
Box 2	10-10-10-10-10	10-10-10-10-10	10-07-07-07-07	07-04-04-04-04
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-10
Box 3	10-10-10-10-10	10-10-10-09-09	07-07-07-07-07	09-07-07-07-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-10
Box 4	10-10-10-10-10	10-10-10-10-10	09-07-04-04-04	09-07-07-07-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-10
Box 5	10-10-10-10-10	10-10-10-10-10	09-07-07-07-07	09-07-07-07-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-10
Box 6	10-10-10-10-10	10-10-10-10-10	09-07-07-07-04	09-07-07-07-04
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-09
Box 7	10-10-10-10-10	10-10-10-10-10	09-07-07-07-04	10-09-09-09-09
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-10
Box 8	10-09-09-09-09	10-10-10-10-10	09-07-07-07-07	10-10-10-09-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10
Box 9	10-10-10-10-10	10-10-10-10-10	10-10-09-07-04	10-10-09-07-07
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-09	10-10-10-10-09
Box 10	10-10-10-10-10	10-10-10-10-10	10-10-10-10-07	10-10-04-04-04
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10	10-10-10-10-10
Mean	10-9.9-9.9-9.9-9.9	10-10-10-9.9-9.9	9.1-7.6-7.2-7.0-5.8	9.2-7.8-7.1-6.8-6.3
	10-10-10-10-10	10-10-10-10-10	10-10-10-10-9.3	10-10-10-10-9.8

Notes: Treatments 1-4 are omitted from the table because of no attack (*i.e.* ratings are all 10-10-10-10-10).
Figures on the upper and lower lines in each box are for termite and decay rating, respectively.

Table 4. Temperature and relative humidity inside the test PVC box

Month	Inside the PVC box		Kagoshima city [29)]		Calculated equilibrium moisture contents of wood in the PVC box
	Temperature (℃)	Relative humidity (%)	Temperature (℃)	Relative humidity (%)	
January	8.4	86	7.2	71	18.9
February	8.2	87	8.3	70	19.3
March	12.9	85	11.4	69	18.3
April	15.0	84	16.4	73	17.8
May	21.6	83	20.1	74	17.1
June	25.7	88	23.4	79	19.2
July	29.3	88	27.4	78	18.9
August	29.8	87	27.9	77	18.4
September	27.2	86	25.1	76	18.1
October	21.7	87	20.0	71	18.9
November	16.6	91	14.5	72	21.3
December	8.2	87	9.2	72	19.3
Yearly mean	18.7	87	17.6	72	18.9

Table 5. Comparison of termite damage between Kagoshima and Hawaii sites after 4 years

Treatment	Penetration	Ratings for termite damage			
		Kagoshima[30)]		Hawaii[33)]	
		Mean	Range	Mean	Range
Hem-fir					
Untreated		7.0	10-4	0	0-0
Borate 2%BAE*	Shell	10	10-10	9.2	10-7
Borate 3%BAE*	Shell	10	10-10	9.7	10-9
Borate 2%BAE*	Through	10	10-10	9.8	10-9
Borate 3%BAE*	Through	10	10-10	9.7	10-9
Borate 2%BAE* + DDAC	Shell	9.9	10-9	9.3	10-7
CCA (oxide) 4 kg/m^3 *	Shell	9.9	10-9	9.5	10-7
Reference material					
ACZA** 4 kg/m^3 * Douglas fir	Shell	--	--	10	10-10
Untreated hinoki		6.8	9-4	--	--

*: Target retention, **: Ammoniacal copper zinc arsenate, --: Not tested.

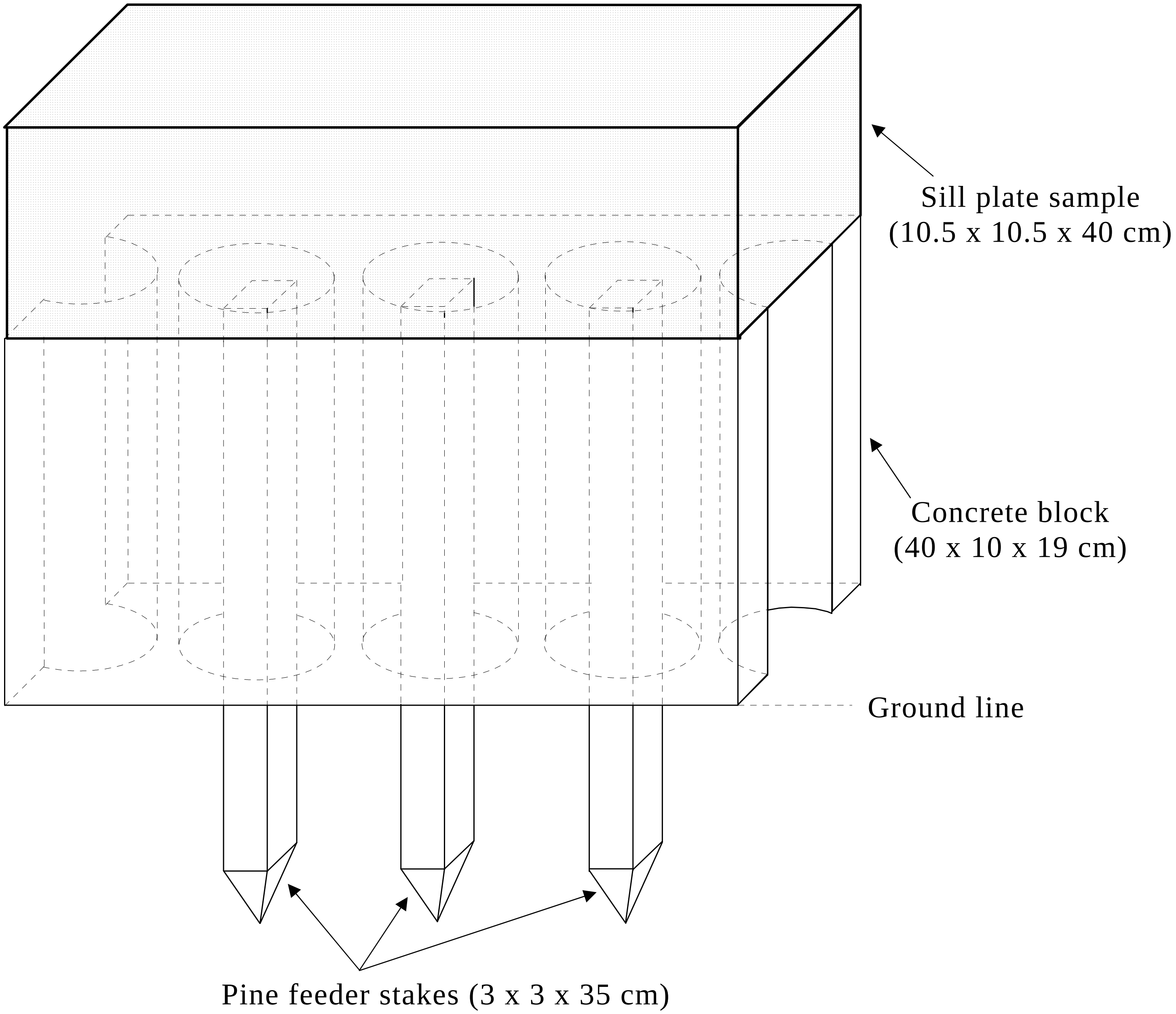

Fig. 1 Setup of a sill plate on the concrete block