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DEPARTMENT OF SCIENCE

MINISTRY OF ECONOMIC AFFAIRS.

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TOA LABANUKROM Ph. D., Director General

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Some Results of Termite Activity in Thailand Soils[1]

BY

Robert L. Pendleton

Of the Departmenl of Agriculture, Bangkok, Thailand.

Illustrated with photographs by the author.

INTRODUCTION.

Much has been published about the destructiveness of termites. It should be of interest, therefore, to know that in many parts of Thailand these ubiquitous insects are of considerable benefit to the farmers (6). The millions of mounds which termites have built and strive to maintain furnish the farmers of this Kingdom with small plots of modified soil which when utilized properly are especially useful for production of cotton, tobacco, chillies, vegetables, and mulberry leaves.

CALCIUM CARBONATE CONCRETIONS IN TERMITE MOUNDS.

In 1935, in the course of a survey of the soils and agricultural problems of an area on the lower eastern slopes of the Chiengmai Valley I noticed for the first time the occurrence of spots of small "gravels" which appeared strikingly like small "kankar," the calcium carbonate concretions with which I had been familiar in Northern Indian soils. I also noted some conspicuous blank spots in the tobacco fields, and these had similar "gravels" (Fig. 9). Observation and inquiry soon revealed the fact that the spots where these "gravels" were to be found and the blanks in the tobacco were just those spots where large termite mounds had previously stood before being levelled

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[1] Grateful acknowledgement is made of the assistance so generously given by many members of the staff of the Department of Agriculture in the collection of samples and data presented herein, and for permission to publish this paper.

Thanks are due to M. R. Chaktong Tongyai, entomologist of this Department for assistance in preparing this paper.

off. Samples of the "gravels," analysed subsequently, proved conclusively that they were calcium carbonate concretions.[2]

At first it seemed impossible that these concretions could be $CaCO_3$, for the soils in the localities where they were noted are a fine sandy white lixivium, a laterite soil with an incipient to well developed laterite horizon at about 1 m. or a little more below the surface. As is shown in Table 3, the normal soils of the localities where termite heaps have been sampled are moderately to strongly acid. Such profiles indicate that these soils have been very thoroughly leached of plant nutrient substances. Now since there are no known deposits of calcium carbonate within many kilometres of the locality, the only possible source of this $CaCO_3$ seemed to be the food of the termites. which comes from the plant remains within a radius of some tens of metres from the mound. The soils where these termite concretions were first noted are rather typical of vast areas in Thailand where the weathering and normal erosional processes acting upon sandstones and other sedimentary rocks have reduced the topography to a peneplain (Figs. 7, 11). Such soils are "suffering from too little erosion" (7).

Subsequently I learned[3] of an even more accentuated type of $CaCO_3$ accumulation, where a solid mass of impure limestone has developed in the base of certain termite mounds in East Africa. The substance of his observations has since been published (5). Observations on the chemical and physical characteristics of termite mound soils of Java have been recorded by Den Doop (2) and of East Africa by Griffith (3).

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[2] Since the Department of Agriculture does not have a chemical laboratory the analyses of the soils and concretions reported in this paper have all been made under the supervision of Nai Sangar Sharasuvana, Chief of the Division of Agricultural Science, Department of Science, Ministry of Economic Affairs.

[3] Through private correspondence with Mr. G. Milne, soil chemist of the East African Agricultural Research Station, Amani.

NATURE AND DISTRIBUTION OF TERMITE MOUNDS.

Termites of many types and of many scores of species occur generally in equatorial and sub-tropical regions. Colonies of some sorts build large conspicuous conical mounds of earth above the land surface (Figs. 1, 2, 12), while others make only small termitaria of organic materials above ground, and still another important group constructs their colonies entirely below the field surface.[4]

In this paper we will consider only the most conspicuous type of earth-built termite mounds found in Thailand. This type is a large, conspicuous, hard rain-proof mound usually of clay loam texture, often more than 2 metres high, and 5 or 6 metres in diameter at the base. It is interesting to note that the termite mounds which stand on light sandy soils as at Haadyai (หาดใหญ่) and Maecho (แม่โจ้), are so firmly and compactly fashioned that even after 2 or 3 days continuous rain the mound does not become wet inside; even in the rainy season it is very difficult to dig into such mounds. By contrast, on certain relatively very limited areas of soils much heavier in texture, as at Klong Maplap, Sukotai Province, (สถานีคลองมะพลับ อำเภอสวรรคโลก จังหวัดสุโขทัย) termite mounds will at times become wet inside after 2 or 3 inches of rainfall, and even in the dry season are much easier to dig into and break down. The cavities in these mounds are usually all above field level, and are nearly filled with the "fungus gardens" a honeycombed mass of organic material on which the termites grow some of their food. Two groups of termites, the black, and the large white are both believed to build mounds of this sort. This type of mound is not only important as an agricultural soil (Figs. 4–7) but it is in the base of and below such mounds that the calcareous earth and the $CaCO_3$ concretions have developed. In parts of Thailand where sandy laterite soils predominate, the much more clayey soil from the termite heaps is sometimes used for binding gravel in road surfacing.

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[4] And to our sorrow some of us know another type of termite which ruins books on our library shelves, but does not appear to construct any nests or covered passages at all.

Except in the low, flat, deeply flooded plains this large type of mound occurs very generally in Thailand. The mounds are distributed surprisingly uniformly over the land, often roughly about one per acre (Figs. 2, 3). Unless intentionally deforested by man, the heaps are occupied by a dense growth of trees and brush of sorts which do not grow well, if at all, on the padi or sandy forest land about them, probably because the country soil is often quite acid as well as being poorly drained during the rainy season (June to October). The fall of leaves and twigs from the trees on the mounds, undoubtedly helps to fertilize the padi land in which they stand. In poor sandy white lixivium laterite soils which normally carry an open stand of slow-growing forest trees (Fig 11), the mounds are often common, though seldom nearly as abundant as on more fertile, heavier, less leached padi soil.

Agricultural Importance of Termite Mounds.

Since the mounds are made of heavier textured material than the usual surface soil, the termites must bring up this earth from some depth below the surface. It is in this heavier textured and more fertile material that such upland crops as native cotton, tobacco (Figs. 4, 7), mulberry (Fig. 6), beans, pineapples, sugar cane, and chillies (*Capsicum*) (Fig. 5) grow excellently, while on the flat normal soils of the locality such crops will grow only very poorly if at all unless well manured. Where these mounds are scattered here and there through the forest the farmers frequently clear them of the brush and trees during the dry season, and with the onset of the rains plant and fence these scattered mounds (Fig. 7). When there is no other " upland " soil convenient, i. e. land suitable for other crops than padi, the mounds in paddy land are also often cleared and planted (Fig. 4). As in all other parts of Thailand, even on the poor sandy soils the staple crop is also padi, tho on such light soils it can only be raised on lower lying portions where enough rain water accumulates and can be held by low field dikes or ridges long enough on the land to enable the padi crop to grow and mature.

Along the edges of many of the new highways in Thailand termite mounds have been cut thru and a portion moved away (Figs. 10, 11). In the course of our reconnaissance soil and agricultural surveys we have collected soil samples from several such mounds. Chemical and physical analyses of a number of those samples are presented below.

The samples from ten different termite mounds, and their associated normal soils reported upon in this paper were collected in many different parts of Thailand, over a region 1,400 kms. (870 miles) long from north south, and 600 kms (370 miles) wide from east and to west. Analyses have not yet been completed of four additional sets of samples from termite mounds and their associated normal soils.

Sampling Termite Mounds and Preparation of Samples.

Samples were collected only from such recently excavated or opened mounds that apparently representative samples could be collected approximately along the vertical center line and at the center of the base. Even in seemingly fresh cuts the surface of the cut was dug away before sampling, so that any contamination of the samples might be eliminated. Figure 10 illustrates the method of sampling. Fungus gardens or the immediate smoothed walls of cavities which had contained the fungus gardens were avoided in the sampling.

Samples were dried in canvas sacks in the shade, and shipped in the same sacks to headquarters. Each sample was divided, and approximately a half sent to the laboratory of the Department of Science for the chemical and physical determinations. The other half of each sample has been stored in a large glass jar in our soil museum.

In the laboratory, in preparation for analyses, the samples are ground rather too vigorously, and as much as possible is passed thru the 1 mm. sieve. With this treatment given every sample, there is no doubt that what remains and is weighed as "gravel and concretion" is definitely hard and rocklike.[5]

In making these analyses the Department of Science followed its methods as set out in its mimeographed "Methods and Procedure of Soil Chemical Analysis." In most repects these follow British practices.

PHYSICAL ANALYSES.

The mechanical analyses (Table 1) were made by the pipet method, treating the 10 gram samples of air dry soil with hydrogen peroxide, to remove the organic matter, followed by treatment with HCl, to give 150—200 ml. N/5 HCl after decomposing the carbonates. Flocculation was by means of 4 cc. of N NaOH. Except for 2 of the samples reported upon in this paper the loss on solution varied between 0.3% and 1.%. Sample 761-T lost 1.3% and sample 652 2.5%. Results of physical comparisons have been reported on the basis of air dry soil.

MOISTURE RELATIONSHIPS OF THE SOIL.

Comparisons of the moisture equivalents of normal and termite mound soils would doubtless have been the most interesting, but the lack of a suitable centrifuge precluded obtaining these. In the absence of such data there are presented certain "single-value" data obtained by the use of the Keen-Raczkowski "box" experiment (4), and the sticky point and rolling-out limit following Bodman and Perry (1).[6]

As might be expected, there are bigger differences between the normal soil and the termite mound soil in those localities where the normal soils such as Nos 98, 91, and 257 are very light in texture and thoroly leached. Younger, less thoroly weathered soils, such as

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[5] Some of my laterite samples, to be reported upon elsewhere, were completely broken up by this treatment and were analysed as "fine earth"!

[6] These determinations were made by M. Cero, of the Department of Science.

Nos. 488 & 489, 553 & 554 show less differences between the normal soil and samples from the termite mounds. Obviously the soil of termite mounds is particularly important in those regions where the normal soil is thoroly leached, low in plant food, and light in texture. The higher fertility and consequently the agricultural importance of the mounds is due to the higher plant nutrient content, the higher pH, the better moisture relationships and because the upper portions of the mounds are above the water level on the padi land.

In general it may be said that the termite mound soils usually have a higher air dry moisture content, and their pore space is usually higher, and when sieved samples are subjected to the Keen-Raczkowski test the termite mound soils usually absorb more water; and their volume expansion is usually greater. The sticky point, the rolling out limit, and the non-plastic range vary with the soil type and the particular horizon, and no striking differences between normal and termite soils are apparent. As a whole the sticky point and rolling out limits of termite mound soils are higher, especially in the sandy types.

Chemical Analyses.

Percentages are expressed on the water-free basis. It should be noted that carbon has been determined by collecting in standardized iodine solution the fumes from the Kjeldahl digestion and titrating with standard sodium thiosulfate solution. Some years ago the laboratory discontinued the strong acid digestion, in place of which fusion of the sample is done. Hence of the analyses reported here all but No. 69 have been by the carbonate fusion method. The base exchange determinations have been made by the Schollenberger normal ammonium acetate method. The pH determinations have been made on the dried samples, using the quinhydrone electrode whenever possible. During the time this was sent overseas for repair the colorimetric method had to be substituted.

TABLE 1.

LOCATIONS AND MECHANICAL ANALYSES OF NORMAL AND TERMITE MOUND SOILS.

Locations and depths of Sampling	Gravel & concs.	Coarse sand	Fine sand	Silt	Clay	Loss on ignit.
	%	%	%	%	%	%
(แม่โจ้ จังหวัดเชียงใหม่)						
Maecho, Chiengmai Province, termite mound.						
69-1 2 m above field level ..	—	11.9	35.7	13.9	30.-	5.8
69-2 1 ,, ,, ,, ,, ..	--	14.2	32.7	14.1	29.7	5.8
66-3 ½ ,, ,, ,, ,, ..	33.-	8.2	20.8	6.9	21.1	4.5
Normal soil near above mound						
98-1 Depth 0-11 cm ..	—	13.6	45.6	26.4	12.3	1.6
98-2 ,, 11-33 ,, ..	—	17.7	43.5	23.9	14.4	1.3
98-3 ,, 33-59 ,, ..	—	16.9	46.9	22.9	12.2	1.1
98-4 ,, 59-100 ,, ..	29.-	10.8	30.6	13.5	15.4	1.4
Maecho, Chiengmai Province samples across levelled mound in tobacco field.						
116-1 0-25 cm good tobacco ..	—	24.9	56.2	10.8	6.9	1.4
116-2 do ,, poor ,, ..	3.6	12.3	43.8	13.5	22.7	2.9
116-3 ,, ,, no ,, ..	41.3	7.3	21.7	9.-	14.2	.6
116-4 ,, ,, poor ,, ..	8.4	10.1	46.3	12.1	17.3	2.4
116-5 ,, ,, good ,, ..	—	18.6	57.6	12.4	8.8	1.7
Normal soil adjoining the tobacco field (cf Fig. 9)						
91-1 Depth 0-14 cm ..	—	11.9	61.3	14.9	9.3	2.6
91-2 ,, 15-25 ,, ..	—	14.4	64.5	11.9	8.1	1.1
91-3 ,, 25-52 ,, ..	—	9.-	66.6	12.6	11.-	1.4
91-4 ,, 52-100 ,, ..	—	16.7	64.7	7.5	10.5	1.4

TABLE 1. (*Cont'd*)

LOCATIONS AND MECHANICAL ANALYSES OF NORMAL AND TERMITE MOUND SOILS.

Locations and depths of Sampling	Gravel & concs.	Coarse sand	Fine sand	Silt	Clay	Loss on ignit.
	%	%	%	%	%	%
(จังหวัดยะลา)						
Satain, Yala Province, termite mound (cf Fig. 10)						
256-1 Depth 0-20 cm ..	—	32.9	30.6	11.7	20.5	3.4
256-2 „ 90-110 „ ..	—	28.9	28.1	15.4	21.8	3.9
256-3 „ 110-205 „ ..	—	23.8	26.-	14.9	29.4	4.2
Normal soil, 20 meters distant.						
257-1 Depth 0-15 cm ..	—	44.-	30.6	10.3	12.2	2.7
257-2 „ 35-50 „ ..	—	40.6	26.-	10.1	17.1	2.2
(จังหวัดพัทลุง)						
Phathalung Province, 12 km west of railway. Termite Mound base.						
347-X 1.5 m from top ..	—	13.7	18.9	22.-	35.7	6.3
Normal padi field soil few meters distant.						
347-1 0-15 cm	—	8.8	20.1	32.-	30.6	7.3
(ตำบลบ้านบึง อำเภอท่ามะกา จังหวัดกาญจนบุรี)						
Ban Böng, Thamaka township, Kanchanaburi Province, Poor tobacco on levelled mound.						
488-1 Depth 0-20 cm ..	—	7.3	34.5	27.9	19.1	5.7
488-2 „ 30-45 „ ..	—	6.9	39.-	23.7	22.7	6.2
Normal soil with good tobacco, 10 meters distant from above (cf Fig. 8)						
489-1 Depth 0-25 cm ..	—	7.7	37.7	24.9	21.9	7.9
489-2 „ 30-50 „ ..	—	6.4	35.4	26.6	23.5	5.2

TABLE 1. (*Cont'd*)

LOCATIONS AND MECHANICAL ANALYSES OF NORMAL AND TERMITE MOUND SOILS.

Locations and depths of Sampling	Gravel & concs.	Coarse sand	Fine sand	Silt	Clay	Loss on ignit.
	%	%	%	%	%	%
(อำเภอเกาะคา จังหวัดลำปาง)						
Gaw Kha, Lampang Province; recently cleared and partially levelled termite mound.						
554-1 Depth 0-15 cm ..	—	20.4	35.8	13.7	24.8	5.2
554-2 „ 20-40 „ ..	—	18.-	29.2	12.6	31.2	6.6
554-3 „ 50-70 „ ..	—	18.3	28.8	13.9	29.6	6.8
554-4 „ 80-105 „ ..	—	18.5	26.0	13.7	32.3	1.2
Normal soil, 15 meters distant.						
553-1 Depth 0-20 cm ..	—	21.7	42.-	20.2	14.4	2.9
553-2 „ 20-55 „ ..	—	23.7	36.2	20.6	18.-	2.9
553-3 „ 70-95 „ ..	11.1	11.6	21.3	11.2	36.5	5.3
(ตำบลนายม จังหวัดเพ็ชรบูรณ์)						
Nayom, Phetchabun Province. Termite mound cut by highway. (cf Fig. 11)						
652-T 1/3 m below field level ..	—	7.5	19.8	25.6	26.6	5.7
Normal forest soil few meters from above mound.						
652-1 Depth 0-18 cm ..	33.8	8.9	21.-	16.1	13.9	4.1
652-2 „ 18-45 „ ..	51.4	2.9	6.4	7.8	25.-	3.9

TABLE 1. *(Cont'd)*

LOCATIONS AND MECHANICAL ANALYSES OF NORMAL AND TERMITE MOUND SOILS.

Locations and depth of Sampling	Gravel & concs.	Coarse sand	Find sand	Silt	Clay	Loss on Ignit.
	%	%	%	%	%	%
(อำเภอเดชอุดม จังหวัดอุบลราชธานี)						
Detudom township, Ubon Province. Termite mound 1.3 m high cut by road.						
691–1 1 m below top of mound ..	—	.72	65.7	6.–	17.8	3.1
Padi field in forest on similar soil type, 2 km distant.						
690–1 Depth 0–15 cm ..	—	2.4	86.8	8.2	.45	.8
690–2 „ 20–50 „ ..	—	2.6	77.5	16.4	2.8	.5
(ตำบลบ้านปิน อำเภอพะเยา จังหวัดเชียงราย)						
Ban Pin, Payao township, Chiengrai Province. Termite mound in forest.						
758–T .5 m below soil level ..	—	4.1	13.1	34.8	36.5	5.9
Normal forest soil.						
758–1 Depth 0–20 cm ..	—	1.4	17.3	42.4	28.1	7.–
758–2 „ 20–+ „ ..	—	2.–	18.6	43.5	27.7	5.4
(จังหวัดน่าน)						
Nan Province. Termite mound on old terrace along river.						
761–T Slightly above field level ..	—	4.3	23.5	24.7	36.4	5.2
Normal field soil 50 m distant.						
761–1 Depth 0–20 cm ..	—	5.5	43.1	29.–	18.6	3.6
761–2 „ 20–50 „ ..	—	10.1	45.9	25.3	15.8	2.4

TABLE 2.

Results of Some "Single - Value" Measurements of Termite Mound and Normal Soils.

Sample No.	Keen-Raczkowski "Box Experiment" Moisture Air Dry	App. sp. Grav.	Water absorbed	Pore space.	Real spec. Grav.	Vol. expansion	Sticky Point	Rolling Out Limit	Non-Plastic Range
	%		%	%		%	%	%	%
69–1	3.–	1.47	39.–	50.1	2.15	7.3	25.7	17.8	7.9
69–2	2.9	1.36	39.4	47.4	2.31	7.8	25.3	17.1	8.2
69–3	3.2	1.22	48.7	57.6	2.32	7.9	27.5	21.7	5.8
98–1	.66	1.65	33.8	34.3	2.05	—	13.4	9.6	3.8
98–2	.65	1.69	30.2	36.5	2.58	2.6	12.9	9.–	3.9
98–3	.68	1.81	28.9	36.–	2.74	1.9	12.–	9.1	2.9
98–4	.92	1.68	25.9	40.9	2.71	3.6	14.–	10.1	3.9
116–1	.45	1.72	21.2	34.4	2.49	5.3	13.6	8.7	4.9
116–2	1.73	1.52	32.3	43.2	2.39	10.8	18.3	13.7	4.6
116–3	2.20	1.38	39.6	49.–	2.48	10.8	24.4	19.2	5.2
116–4	1.40	1.68	36.7	40.9	2.60	8.2	16.1	10.8	5.3
116–5	.59	1.73	22.2	35.9	2.52	6.2	14.2	8.8	7.4
91–1	.84	1.63	26.4	40.8	2.61	4.5	16.7	9.9	6.8
91–2	.40	1.78	20.9	35.3	2.63	4.2	14.8	7.2	7.6
91–3	.23	1.69	23.8	38.5	2.59	5.1	14.9	8.7	6.2
91–4	4.68	1.83	27.5	37.9	2.76	6.2	nd	7.6	nd
256–1	2.0	1.52	30.–	42.7	2.57	1.88	17.2	11.4	5.8
256–2	2.5	1.45	33.4	43.7	2.42	5.12	18.7	10.8	7.9
256–3	3.5	1.38	40.1	47.9	2.35	9.97	26.4	18.8	7.6
257–1	1.4	1.53	26.8	39.2	2.47	1.38	14.3	7.8	6.5
257–2	1.5	1.56	27.–	39.2	2.47	2.96	23.9	10.1	13.8
347–X	3.6	1.45	No	rise	of	water	25.3	17.2	8.1
347–1	2.5	1.27	43.1	50.6	2.48	3.4	31.1	22.4	8.7
488–1	3.6	1.38	42.2	50.6	2.43	12.–	25.9	19.7	6.2
488–2	3.5	1.38	41.6	47.8	2.28	13.9	25.2	18.3	6.9
489–1	2.8	1.39	40.6	49.1	2.43	10.6	23.–	17.9	5.1
489–2	2.9	1.38	40.2	49.8	2.52	6.9	22.9	16.6	6.3

TABLE 2. (*Cont'd*)

Results of some "Single—Value" Measurements of Termite Mound and Normal Soils.

Sample No.	Keen-Raczkowski "Box Experiment" Moisture Air Dry	App. sp. Grav.	Water absorbed	Pore space	Real spec. Grav.	Vol. expansion	Sticky Point	Rolling Out Limit	Non-Plastic Range
	%		%	%		%	%	%	%
554–1	4.2	1.54	37.7	47.3	2.55	12.5	18.5	13.3	5.2
554–2	4.9	1.58	39.1	49.6	2.72	12.6	20.4	14.2	6.2
554–3	4.9	1.48	40.3	48.–	2.45	13.8	21.1	13.9	7.2
554–4	5.1	1.53	40.7	49.9	2.61	13.9	20.7	14.7	6.0
553–1	1.7	1.56	27.1	40.–	2.51	2.1	13.9	7.5	6.4
553–2	2.2	1.55	29.–	40.9	2.45	5.3	14.3	8.3	6.0
553–3	5.3	1.53	38.4	48.1	2.54	12.6	23.7	17.2	6.5
652–T	6.9	1.51	47.3	53.0	2.49	22.2	32.3	18.–	14.3
652–1	3.5	1.40	39.7	48.2	2.41	9.2	25.8	15.6	10.2
652–2	7.2	1.51	52.6	56.2	2.58	28.–	43.6	22.8	20.8
691–T	2.1	1.54	33.2	46.4	2.55	5.2	nd	nd	nd
690–1	.4	1.66	23.8	36.8	2.47	6.1	19.6	12.–	7.6
690–2	.2	1.78	21.7	33.6	2.65	5.7	nd	nd	nd
758–T	3.5	1.46	38.3	50.8	2.73	5.2	27.–	19.5	7.5
758–1	2.9	1.24	48.2	54.6	2.54	5.4	30.9	19.4	11.5
758–2	2.5	1.31	40.8	51.–	2.52	2.9	26.9	15.6	11.3
761–T	3.9	1.42	40.4	50.5	2.57	8.5	25.3	18.7	6.6
761–1	1.4	1.47	32.4	46.2	2.66	1.6	16.2	9.3	6.9
761–2	1.–	1.56	26.8	40.4	2.54	2.1	11.8	7.2	4.6

TABLE 3.

Comparison of Chemical Analyses of Termite Mound and Normal Soils.

	C.	N.	Insol Res.	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5	1% citric soluble		Carbonates as $CaCO_3$	pH
										K_2O	P_2O_5		
	%	%	%	%	%	%	%	%	%	%	%	%	
69 Termite Mound													
[1] 69–1	1.1	.12	83.9	.60	6.–	1.–	.4	.3	.06	.09	.02	—	6.8
[1] 69–2	2.2	.11	83.4	.5	6.–	1.3	.4	.3	.07	.1	.03	—	6.9
[1] 69–3	1.0	.06	75.1	.7	5.7	6.–	.6	.3	.05	.04	.01	—	7.0
						Fusion							
			SiO_2										
98 Normal soil													
98–1	.4	.04	94.4	.5	3.–	.2	.5	.2	.03	.01	.004	—	5.3
98–2	.3	.02	93.2	.9	4.3	.2	.6	.3	.03	.01	.001	—	4.5
98–3	.2	.02	94.4	1.5	3.1	.3	.4	.2	.02	.01	.001	—	4.3
98–4	.2	.02	91.3	.7	4.–	.2	1.–	.3	.03	.004	.001	—	4.3
116 Levelled Termite Mound													
116–1	.44	.06	89.8	.9	1.7	.4	.3	.3	.03	.02	.008	—	7.7
116–2	.41	.07	89.6	1.9	5.–	.9	.4	.7	.02	.01	.003	—	7.6
116–3	.33	.06	82.3	1.9	5.4	4.9	.4	.8	.02	.01	.004	4.	7.8
116–4	.33	.05	94.7	1.–	2.1	.9	.4	.5	.02	.01	.003	—	7.8
116–5	.63	.06	96.5	.9	2.7	.6	.4	.4	.02	.01	.004	—	7.6

[1] Strong Acid Digestion

TABLE 3. *(Contd.)*

COMPARISON OF CHEMICAL ANALYSES OF TERMITE MOUND AND NORMAL SOILS

	C.	N.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5	1% citric soluble		Carbonates as $CaCO_3$	pH
										K_2O	P_2O_5		
	%	%	%	%	%	%	%	%	%	%	%	%	
Normal soil													
91-1	.9	.07	93.4	.8	2.2	.4	.3	.11	.11	.004	.014	—	4.9
91-2	.2	.03	96.2	.7	1.8	.4	.2	.10	.06	.003	.005	—	4.7
91-3	.2	.04	93.3	1.1	3.4	.4	.3	.18	.07	.008	.003	—	4.5
91-4	.1	?	93.4	1.2	3.2	.3	.3	.14	.09	.008	.006	—	4.4
Termite Mound													
256-1	1.22	.12	80.1	1.7	12.-	.08	.76	.72	.03	.01	.003	—	4.1
256-2	.96	.12	79.1	1.8	12.1	.27	.50	.73	.03	.01	.004	—	5.8
256-3	.84	.11	78.9	1.9	14.-	.30	.65	.70	.03	.01	.003	—	6.7
Normal field soil													
257-1	1.46	.12	87.9	.8	7.3	.09	.58	.41	.02	.004	tr	—	4.2
257-2	.38	.06	84.2	1.4	11.7	.06	.42	.52	.02	.002	tr	—	4.3
Termite Mound													
347-X	1.11	.13	70.7	.7	19.8	2.-	.6	.15	.22	.01	.02	2.1	8.5
Normal soil													
347-1	1.27	.14	69.3	.9	22.2	.3	.3	2.3	.2	.01	.001	—	5.5

TABLE 3. (*Contd.*)

COMPARISON OF CHEMICAL ANALYSES OF TERMITE MOUND AND NORMAL SOILS.

	C	N	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5	1% citric soluble		Carbonates as $CaCO_3$	pH
										K_2O	P_2O_5		
	%	%	%	%	%	%	%	%	%	%	%	%	
Termite Mound													
488–1	1.4	.11	69.7	3.7	15.2	2.9	1.3	2.6	.14	.03	.044	3.9	8.4
488–2	1.–	.13	72.1	3.7	15.5	1.2	1.2	3.0	.11	.02	.023	—	8.5
Normal soil													
489–1	1.4	.13	73.9	3.2	13.1	.64	1.1	3.–	.14	.014	.047	.43	8.2
489–2	1.3	.10	70.4	3.3	14.1	.51	1.1	2.9	.11	.011	.011	—	7.3
Top of partly levelled old termite mound													
554–1	.39	.12	78.5	3.1	10.3	.83	—	.37	.032	nd	nd	nd	6.5
554–2	.49	.08	72.6	3.4	11.9	2.9	—	.21	.048	nd	nd	nd	7.3
554–3	.38	.07	73.6	4.2	13.5	2.9	.92	.40	.023	nd	nd	nd	6.4
554–4	.33	.06	72.9	3.9	12.8	2.9	1.3	.18	.04	nd	nd	4.7	8.2
Normal soil													
553–1	.79	.09	87.9	2.1	6.9	.2	.5	.46	.02	nd	nd	—	5.2
553–2	.43	.06	86.1	2.5	8.1	.3	—	.56	.01	nd	nd	—	5.1
553–3	1.26	.06	71.–	4.7	17.5	.4	1.–	.85	.01	nd	nd	—	4.6
Termite Mound													
652–T	.63	.069	65.5	7.5	12.9	5.13	1.04	.23	tr	nd	nd	6.9	8.2
Normal forest soil													
652–1	1.85	.14	76.4	7.5	9.7	.38	.59	.14	.045	nd	nd	—	5.4
652–2	.89	.096	63.6	8.8	20.2	.49	.76	.25	.022	nd	nd	—	4.9

TABLE 3. (*Contd.*)

COMPARISON OF CHEMICAL ANALYSES OF TERMITE MOUND AND NORMAL SOILS.

	C	N	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5	1% citric soluble K_2O	1% citric soluble P_2O_5	Carbonates as $CaCO_3$	pH
	%	%	%	%	%	%	%	%	%	%	%	%	
691-Termite Mound													
691–1	.57	.068	85.1	2.–	7.5	1.7	.92	.27	.022	nd	nd	3.38	8.2
Padi land													
690–1	.33	.024	98.7	.43	.96	.16	.22	.13	tr	nd	nd	—	5.2
690–2	.25	.02	98.4	.5	1.–	.24	.26	tr	tr	nd	nd	—	5.2
758 Termite Mound													
758–T	.57	.088	69.6	5.8	14.4	1.18	1.99	1.58	.06	nd	nd	2.0	8.1
Normal forest soil													
758–1	1.86	.18	77.4	4.1	9.4	.27	.96	.83	.12	nd	nd	—	5.8
758–2	.79	.12	77.8	4.6	10.7	.26	.96	1.–	.1	nd	nd	—	5.1
761 Termite Mound													
761–T	.55	.066	78.8	2.4	11.8	1.5	1.–	.73	.068	nd	nd	2.75	8.4
Normal field soil													
761–1	.88	.1	88.9	1.4	5.7	.25	.84	.68	.023	nd	nd	—	5.–
761–2	1.2	.12	90.4	1.5	4.4	.18	—	.44	.017	nd	nd	—	5.–

TABLE 4.

Analyses of Concretions from Termite Mounds and from Normal Soils.

	SiO_2 %	Fe_2O_3 %	Al_3O_3 %	CaO %	MgO %	K_2O %	P_2O_5 %	TiO_2 %
69–3 Termite Mound	53.2	2.–	4.–	19.3	6.9	.4	.2	.4
98–4 Normal, lateritic soil	93.8	3.–	1.8	.6	nd	nd	nd	nd
116–2 Termite Mound	66.6	1.8	5.–	10.1	2.6	nd	nd	.2
116–3 ,, ,,	64.2	.7	6.3	13.2	2.5	nd	nd	.3
116–4 ,, ,,	48.1	1.3	7.6	17.9	nd	nd	nd	.3
553–3 Normal, lateritic soil	50.–	27.3	13.2	.25	2.4	nd	nd	.22
652–1 Normal, lateritic soil	62.6	19.1	8.8	2.7	2.4	nd	nd	.42
652–2 —do.—	36.1	24.9	26.8	2.4	3.4	nd	nd	1.1

TABLE 5.

EXCHANGEABLE BASES IN SOME TERMITE MOUND AND NORMAL SOILS.

	m. e. per 100 grams water free soil				
	Ca	Mg	Na	K	Total
98–4 Normal, lateritic	1.0	1.6	.4	.1	3.1
116–1 Levelled Termite Mound ..	nd	nd	nd	nd	nd
116–2 ,, ,, ,, ..	8.5	4.8	.2	.5	14.–
116–3 ,, ,, ,, ..	26.2	5.2	.1	1.1	32.6
116–4 ,, ,, ,, ..	11.7	3.0	.3	.3	15.3
116–5 ,, ,, ,, ..	nd	nd	nd	nd	nd
488–1 Levelled Termite Mound ..	45.8	7.3	.35	1.1	54.6
488–2 ,, ,, ,, ..	29.0	3.9	.18	.72	33.8
489–1 Normal tobacco soil ..	17.0	3.4	.13	.88	21.4
489–2 ,, ,, ,, ..	10.9	3.1	.11	.41	14.5
652–T Termite Mound	29.7	18.6	3.8	.53	52.6
652–1 Normal soil	10.1	6.1	.35	.26	16.8
652–2 ,, ,, ...	16.3	8.7	.32	.32	25.6
691–1 Termite Mound base ..	15.9	8.8	4.5	.56	29.8
690–1 Normal padi soil	.95	1.8	1.4	.11	4.3
690–2 ,, ,, ,, ...	.93	3.2	.33	.07	4.5
758–T Termite Mound base ..	20.6	7.1	.27	.32	28.3
758–1 Normal forest soil ..	6.5	4.6	.35	.15	11.6
758–2 ,, ,, ,, ..	2.9	5.–	.21	.13	8.2
761–T Termite Mound base ..	19.5	15.9	.39	.48	36.3
761–1 Normal padi soil	1.6	1.8	.25	.08	3.7
761–2 ,, ,, ,, ...	.73	1.9	.2	.09	2.9

Average of Normal Soils	16.–
,, ,, Termite Mound soils	33.03

It is evident from the analytical data (Table 3) that there is a wide variation in the percentage of $CaCO_3$ in the samples reported upon in this paper. Without exception there is a distinctly larger quantity of total Ca in the fine earth of the samples from the termite mounds than in the fine earth of the normal soils near by. Similar trends are shown by the much higher pH of the samples from mounds, than of the associated normal soils. Samples from the base of the mounds are practically always at least neutral, and usually distinctly basic. In those termite mound samples of which exchangeable bases have been determined, the total quantities are almost double the average of the normal soils reported.

The two samples from termite mounds which do contain lime concretions have 33 and 41% of them in the total weight of sample. And of these concretions roughly 35 and 18% respectively are $CaCO_3$ (Table 4). Both of these mounds stood upon soils with unusually high percentages of quartz sand and silt; this explains the large proportions of SiO_2 found in these concretions—at least much of it was doubtless mechanically enclosed. On the other hand, the only type of concretions which were found in the associated normal soils are two samples with the "iron concretion" type, with the familiar smooth, brown limonite surface. The analyses of all the 10 termite mound samples as yet available for comparison show that only 20% of the mounds have calcium carbonate concretions, yet from the number of times I have seen similar calcium carbonate concretions at and scattered about the sites of broken down termite mounds there seems to be little doubt that the development of concretions under termite mounds in Thailand is much more common than the data on the ten samples here reported upon would indicate. Presumably the most important factor determining the presence of concretions is the age of the mound and relative continuity of its occupancy by a termite colony or succession of colonies.

How Does the Calcium Carbonate Accumulate?

Even during the rainy season these mounds are extremely hard, and difficult to dig into, even with a heavy pick. And under the normal conditions they must certainly be rain-proof. In fact, the main purposes of the mounds appear to be to protect the fungus gardens of the colony from injury by heavy rains or flood water, and to maintain favorable humidity for the colony throughout the long dry season. If rain water did penetrate the mounds, the $CaCO_3$ would not accumulate; yet without the presence of considerable moisture the $CaCO_3$ could hardly accumulate and form concretions.

Professor Light[7] states that very little is known about the age of termite mounds. He believes there is no mechanism for the replacement of the primary pair in the colony, hence there is no reason to believe that the colony can continue to live for the many hundreds of years which would seem to be necessary to bring about the accumulation of the $CaCO_3$ in these mounds under the conditions which have been observed here in Thailand. Light does add that some work was done in French Indo-China which led to the belief that there was replacement of queens, at least in such large colonies. But whatever may be the usual length of life of a termite colony dependent upon a single primary pair, Tongyai[8] notes that after the death of an occupying colony, the mound may be occupied by a new swarming pair. Hence there is no reason to suppose that reoccupation could not take place repeatedly.

Den Doop (2) may be correct that in western Java the mounds serve as chimneys for the evaporation of water, and so make possible the accumulation of $CaCO_3$. Here in Thailand the termite mounds which are built on certain more clayey soils do show surface cracks during the long dry serson. During this season such cracks and mechanical damage to the mounds are not repaired by the termites, probably because the soil is so dry they cannot manipulate it. Such

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[7] Dr. S. F. Light, Professor of Zoology, University of California, in a private communication, dated May 15, 1941.

[8] M.R. Chaktong Tongyai, Entomologist, Dept. of Agriculture Thailand, in a private communication. He states that frequently after completely exterminating the termites in these large mounds, by the use of white arsenic or Paris green, it is not long before the mound is reoccupied.

cracks, together with the tunnels and cavities in the mounds, would allow at least a certain amount of evaporation up thru the mound from the base. With the onset of the rains, in May or early June, the termites rapidly repair their mounds and at times enlarge them. Trees and shrubs, too, growing on the mounds certainly transpire much water. On the other hand, the most marked accumulations of calcium carbonate concretions occur underneath the mounds which are much harder and which do not crack, and which stand on the very poor sandy soils.

Whatever may be the manner in which the calcium carbonate has accumulated, there does not appear to be any other source than the vegetation of the locality, from which this $CaCO_3$ cold come. Nor do there seems to by any conceivable processes which could explain the accumulation of the Ca compounds from the plant remains of the surrounding land without there also accumulating more or less equivalent proportions of the other elements commonly associated in the plant tissues which are the food of the termites. Milne's guesses (5) as well as our own as to what the possible mechanism or process may be, seem too fantastic to repeat here. And Professor Light agrees that all attempts to explain the accumulation of calcium carbonate seem ridiculous. He continues: "I am forced to believe that this material must be brought up from lower strata which are not taken into consideration in statements with regard to absence of limestone and low pH of the soil. Certainly there is no reason to think that termites have any mechanism for concentrating mineral materials of any sort. Some of them do, of course, pass soil through their bodies and it is well known that the mound material has been altered. In the Philippines it is sometimes used in tennis courts, and Fuller speaks of its being used in similar situations in South Africa." We have not yet demonstrated by excavation what the composition of the deeper materials are under termite mounds, but it seems improbable that there is any $CaCO_3$ at all within reach of termite activity.

DESTRUCTION OF MOUNDS SELDOM ADVISABLE.

Tho many times a farmer will somewhat partially level off the top of termite mounds the better to plant crops on them, the average farmer in Thailand is adverse to completely destroying or levelling them off. Since the mounds serve as soils for special crops to supplement the inadequacies of the country soils in the several principal regions, it is just as well that this feeling persists. Moreover, because except in rare localities even plows are not employed for any uses other than preparing the soil for planting lowland padi, while tractors and heavy farm machinery are extremely seldom used in Thailand, there is not the need in this country for having fields quite clear and unobstructed by any termite mounds or other obstacles.

When mounds are broken down and the earth spread around tho former site, the productivity of the land remains very irregular (Figs. 8, 9). Other fertility relationships seem to prevail in the Klong Maplap region, Sukotai province (คลองมะพลับ จังหวัดสุโขทัย), tho satisfactory comparisons are not yet possible, for analyses of samples of termite heap and normal soils from this region have not yet been completed. In this region, on the relatively fertile brown silt loam to silty clay loam soils, it has been found that tobacco planted on completely levelled down termite mounds grows distinctly better than that planted on the normal field soils of the locality. This is more surprising in view of the fact that cassava (*Manihot utilissima*), which requires a fertile soil, in this locality did not thrive at all on sites of similarly levelled mounds.

If the complete clearing and levelling of the land for agricultural use is justified, not only should the mounds be broken down, but the earth should be spread over a large radius, and the site of the mound should be excavated to at least ½ meter depth and the excavated earth spread well over the field. Then the hole should be filled with surface soil taken from some distance from the site of the mound. Thereafter the entire field should be well and deeply plowed, to insure the mixing of the termite mound soil with the normal soil.

Summary and Conclusions.

In Thailand large termite mounds are abundant over much of the country. The natural vegetation on these mounds is usually quite different from that on the land on which the mounds stand. The differences are particularly striking where the regional soil is a poor sandy laterite soil.

Agriculturally the mounds are important, for farmers frequently clear off the natural vegetation and plant the termite mounds to "upland" (as contrasted to padi) crops which the farmers need and which will not thrive on the usual soils of the locality. If the mounds are dug down to make a more permanent planting site, this should be done gradually, thru a period of years.

Especially in the light sandy lateritic soil regions the soil material of which the mounds have been constructed is much heavier than the surface soil of the locality; the reaction is neutral or basic. while the soils about the mound are often quite acid. The principal chemical difference is that in the base of the mounds there are considerable accumulations of calcium carbonate.

Even tho great age of the mounds be postulated, there is no known method by which the termites can bring about the differential accumulation of calcium carbonate; on the other hand there is no known soil developmental process which could account for the chemical and physical soil differences shown by the data presented in this paper.

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Bangkok—November 1941.

Fig. 1. Shrubs and trees on a big termite mound. On a slightly elevated sandy strip in a flat, grassy plain. Soil Samples 241-1, 2 were collected in this plain. Near Tapad railway station, Songkla province, (สถานีตาแปด จังหวัดสงขลา) Southern Thailand. June 1936. RLP Foto 631—4.

Fig. 2. Many shrubs and trees on termite mounds scattered over padi land. Padi harvest in progress. Along the railway km 228 north of Bangkok. Near Ban Ma Gawk station (สถานี บ้านมะกอก); 23 kms south of Paknampo, Nakorn Sawan province (จังหวัด นครสวรรค์), Central Thailand. December 1935. RLP Foto 557—4.

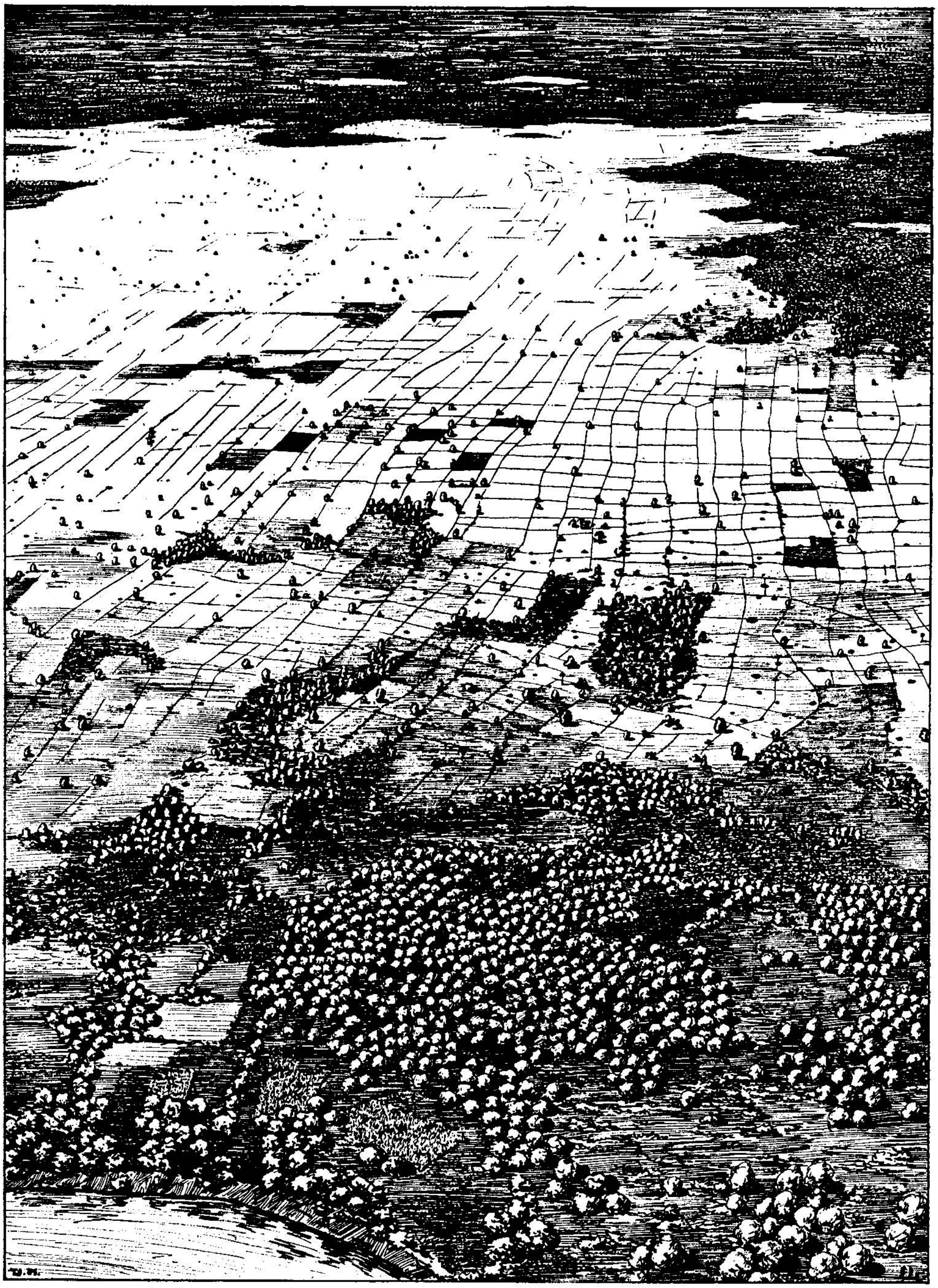


Fig. 3. The lighter colored fields in the middle distance are padi lands; the dark trees and isolated masses of shrubs stand on termite mounds. It will be noted that there are almost no mounds in the lower land, far from the river. The dark masses in the far distance are forests which are swampy in the rainy season. In the foreground, on the higher land near the river bank, are grown bananas, sugar cane, some native cotton and other "upland" crops which are rotated with the forest cover crop. Utaradit province, (จัดหวัดอุตตรดิถต์) northern central Thailand. December [illegible]

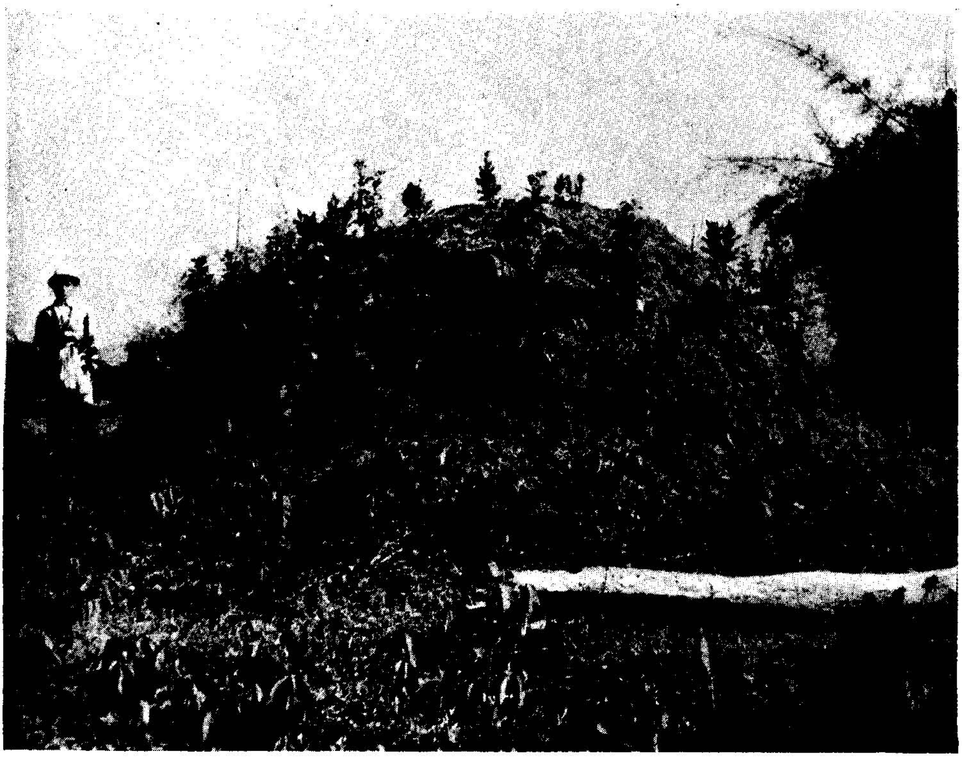


Fig. 4. Cleared termite mound planted to tobacco. Rice is raised on the surrounding land. จังหวัด เลย Loei valley, north-eastern Thailand. February 1938. RLP Foto 972—8.

Fig. 5. Chillies (*Capsicum*) are growing on the small termite mound in the right foreground, while on the sandy soil of the clearing (caiñgin) all about the mound, a crop of peanuts is growing. Soil samples 601-1, 2 represent this sandy soil. South of Raheng, Tak province, (จังหวัด ตาก) Northern Thailand. November 1937. RLP Foto 870—5.

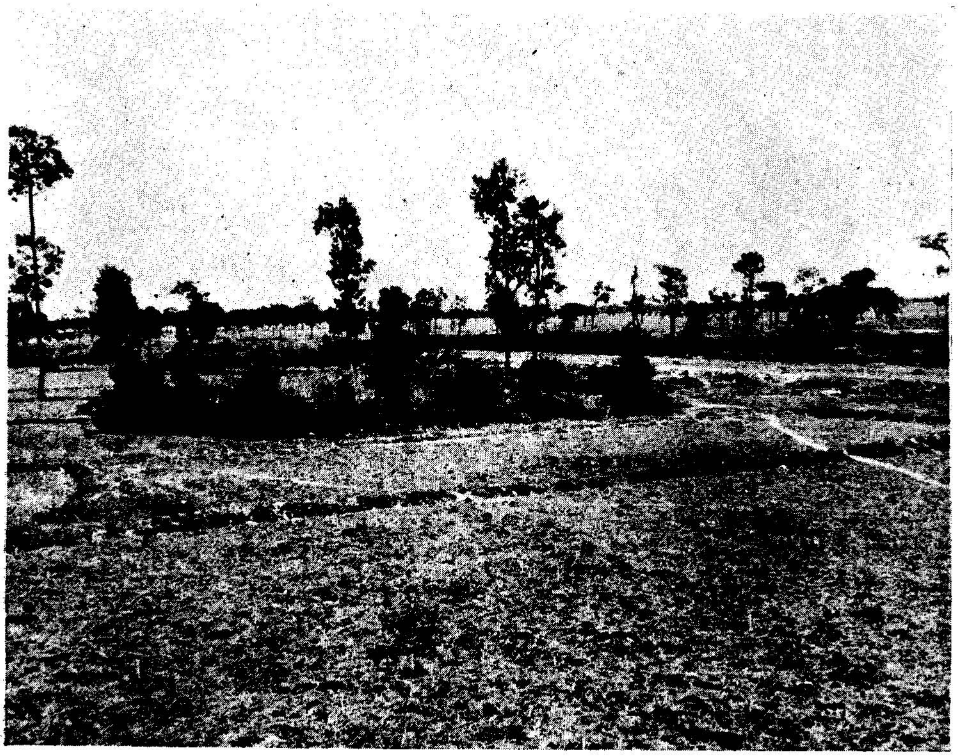


Fig. 6. Mulberry bushes thriving on the circular plot of fertile clay loam resulting from a partially levelled off termite heap. Bushes and a log fence keep cattle out. Providing the rains are adequate the light fine sandy loam of the diked fields (padis) round about does produce a modest crop of rice annually in the rainy season, but the soil is quite too poor for other crops. Yasodhorn township, Ubon province (อำเภอ ยะโสธร จังหวัด อุบลราชธานี), Norther-eastern Thailand. March 1936. RLP Foto 594—9.

Fig. 7. Native tobacco growing vigorously without any manure on a small termite mound which has not been dug down. Unless the poor sandy soil of this locality is heavily manured it will not produce any tobacco at all. Payakapumipisai township, Mahasarakam province, (อำเภอ พยัคฆภูมิพิไสย จังหวัดมหาสารคาม) north-eastern Thailand. March 1940. RLP Foto 1221—9.

Fig. 8. Poor tobacco on a termite mound dug down flat under occidental compulsion. In the distance are the flue-curing barns of the Experiment Station of the British American Tobacco Company. The wiser Chinese tobacco growers of this locality only very gradually work down the mounds, in the course of years and plant on the slopes. Soil samples 488-1, 2 are from this poor spot; while samples 489-1, 2 represent the productive soil where the man stands. Ban Böng, Thamaka township, Kanchanaburi province, (ตำบลบ้านบึ่ง อำเภอท่ามะกา จังหวัด กาญจนบุรี) western Thailand. February 1937. RLP Foto 789—5.

Fig. 9. Tobacco does not grow at all where termite mounds previously stood on this light fine sandy loam. Samples 116-1, 2, 3, 4, 5 collected across this spot. Northern Thailand Agricultural Experiment Station, Maecho, Chiengmai valley (สถานี ทดลองกสิกรรม แม่โจ้ จังหวัดเชียงใหม่). January 1936. RLP Foto 559—5.

Fig. 10. Collecting samples 256-1, 2, 3 from a termite mound near ตำบลสะเตง Satain, Yala province (จังหวัด ยะลา), Southern Thailand. Sample 257 is from the low flat scrub land behind the men. July 1936. RLP Foto 637—1.

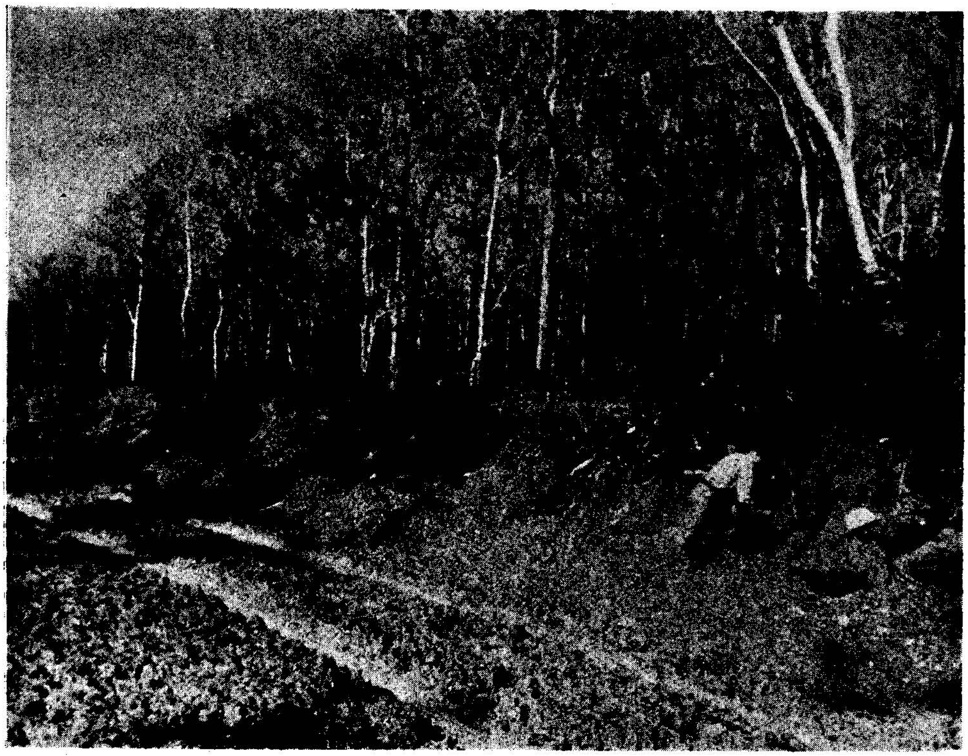
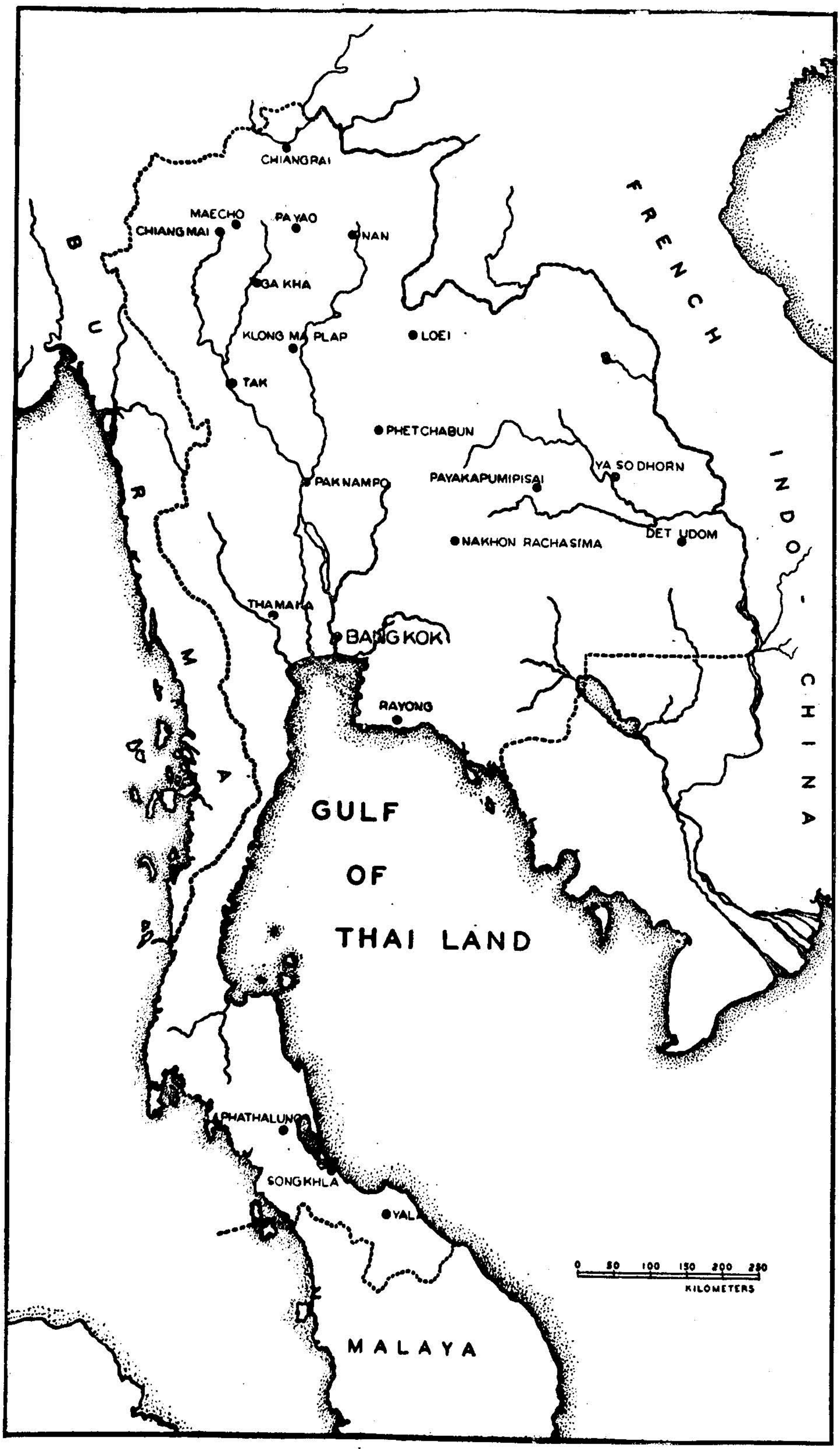


Fig. 11. Collecting sample 652-T from the deeper portion of a termite mound which had been cut thru in the course of grading this new road. The whitish lixivium soil profile with iron concretions and the *teng-rang* forest (samples 652-1, 2) indicate that the soil is lateritic. Phetchabun province (จังหวัด เพ็ชรบูรณ์), eastern central Thailand. February 1938. RLP Foto No. 948—7.

Fig. 12. In a flat country the author frequently uses big termite mounds as vantage points from which to photograph and take notes of the soils and land use conditions of the locality. This termite mound of clay is in a region of light sandy laterite soils, with the laterite horizon at about a meter below field level. Rayong province, (จังหวัด ระยอง) south-eastern Thailand. November 1936. RLP Foto 723—4.



Map Showing Locations of Places Mentioned.