The Effects of Herbicides in South Vietnam

PART B: WORKING PAPERS

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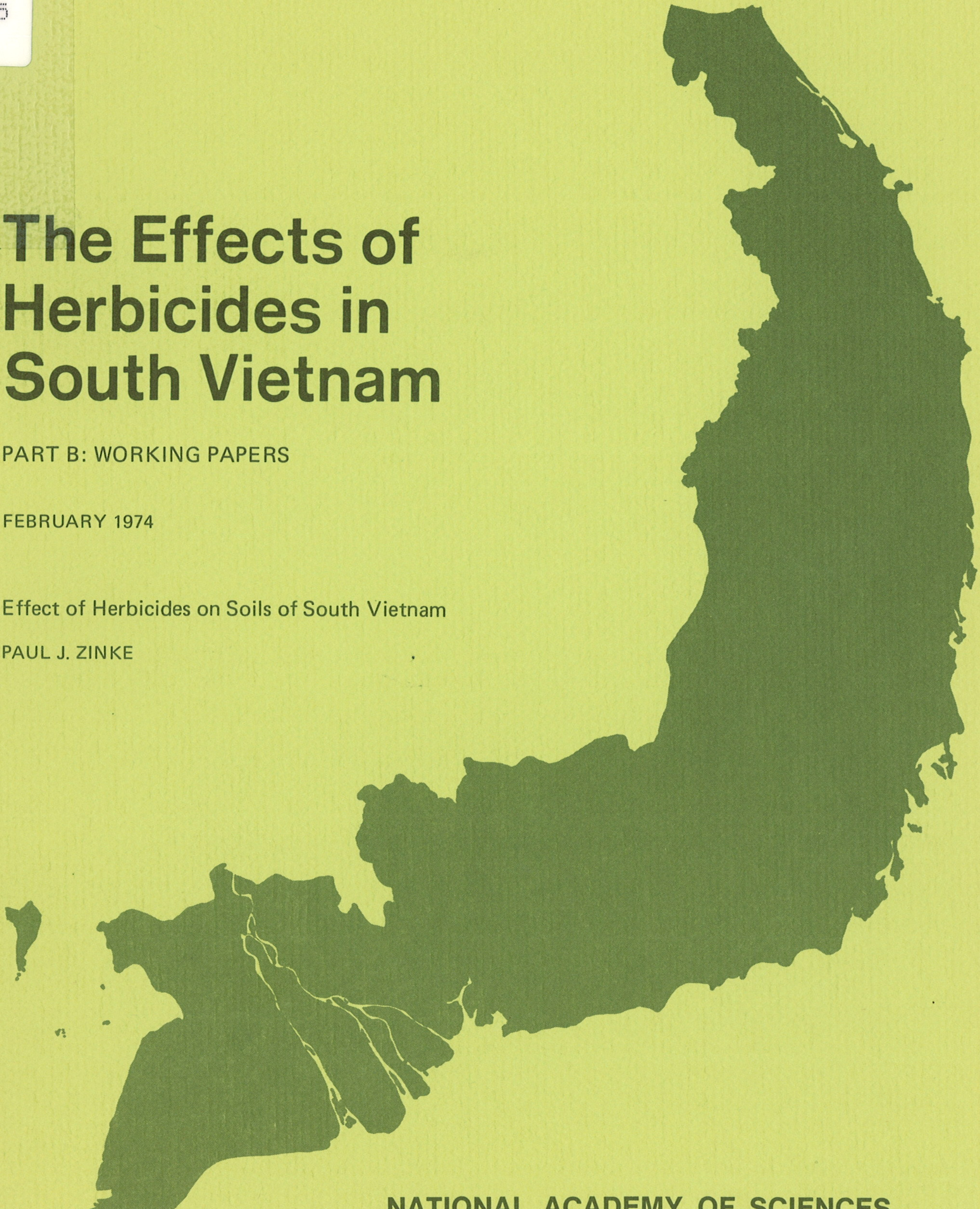

NATIONAL ACADEMY OF SCIENCES

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Effect of Herbicides on Soils of South Vietnam

PAUL J. ZINKE[a]

This report concerns the effect of defoliation of vegetation in South Vietnam (SVN) on soil properties, exclusive of the actual herbicide content. Concern has been expressed that defoliation in SVN for military objectives may have caused deleterious changes in the associated soil or in the chemical and physical processes of these soils. Some of the hypotheses that have been expressed are: (1) soil fertility may have been adversely affected, (2) irreversible harmful changes that are peculiar to soils in tropical areas may have occurred, and (3) there may have been soil erosion with consequent permanent soil loss. These are all legitimate concerns when one considers the effect of herbicides and defoliation in a broader context than that of military objectives.

The purpose of this report is to document the possible changes that may occur to soil through defoliation of the vegetation growing on the soil, and to evaluate the relative seriousness of these changes. The data presented are the results of three field visits made to various areas in SVN by soil investigators for the purpose of observing firsthand the effects of defoliation on soils. Soil samples were obtained during these visits and subjected to various physical and chemical measurements, which were then used to test hypotheses about the effects of defoliation on soil properties.

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The literature concerning processes in subtropical and tropical soils was reviewed with the objective of appraising the possible effects of defoliation on soil processes, particularly those that may be deleterious. Several man-years of effort by laboratory technicians in analyzing soils and reviewing literature were involved.

SCOPE OF THE SOILS INVESTIGATION WORK

Field Investigation

The objective of evaluating the effect of defoliation on soil properties and processes implies a relationship between soil properties and vegetation. The soils study was divided between effects on soils of mangrove forests and those of upland forests, the two main groups of vegetation types affected by defoliation. Soil investigation sites were located in various places in SVN and Thailand. These locations and their characteristics are presented in Table I.

In SVN there were difficulties in getting to ground locations typical of defoliated areas because of lack of military security. For this reason there are few field site locations in defoliated upland forest areas. However, comparable areas were selected in Thailand, where it was much easier to obtain large numbers of soil samples and related vegetation samples for analysis.

Methods Used at Field Sites

Since each area represents a soil with a range of properties, and since any soil area will have variation in a soil property such as relative acidity (soil reaction or pH), it was necessary to take a number of samples

Table I.

Location and characteristics of field investigation sites for soil studies - Upland forests

Site No.	Location[a]	No. Soil Samples	Type of Vegetation	Type of Soil	History
374	Ban Pa Pae, T.	10	Closed forest	Red yellow podzolic	Village reserve forest
381-387	Sekerat, T.	72	Closed forest	Latosol & laterite	Old growth forest
388,389,390	Tak, T.	24	Open forest	Regosol	Second growth forest
391	Near Chieng Dao, T.	10	Open forest	Alluvial soil	*Dipterocarpus alatus*
392,393,394	Chieng Dao watershed Exp. Station, T.	30	Open forest	Gray brown podzolic	*Hoppea-shorea*
395,396	Doi Suthep, T.	20	Closed forest	Red yellow podzolic	*Quercus*, *castanopsis*
396A	Doi Suthep, Km 10, T.	10	Open forest	Podzolic lithosol	*Dipterocarpus tuberculatus*
397-402	Lampang, T.	50	Open forest	Regosol-alluvium	
420	Dong Xoi, RVN	14	Closed forest	Gray brown podzolic	Mixed dipterocarp
421	Pranburi, T.	20	Closed forest	Reddish brown podzolic	Second growth forest
422	Pranburi, T.	20	Closed forest	Latosol & laterite	Old growth forest
424	Sekerat, T.	24	Closed forest		
434	Lampang, T. Mae Moh Teak farm		Closed forest	Gray podzolic	Secondary succession to bamboo
		304[b]			

[a] RVN - Republic of Vietnam
T - Thailand

[b] 4,228 soils analyses on 304 samples

to examine the soil variability. At least for surface soils, multiple samples were taken at each soil sampling location wherever possible in both defoliated and undefoliated areas. It will be difficult to establish any real effect of a treatment such as defoliation on a particular soil property if it is not an effect that will show significant changes in data measuring that property.

Soil properties characteristically vary with depth, and where possible samples were obtained to represent such variation.

Because the vegetation of tropical forests may contain a large proportion of the soil fertility elements on a site, an area representative of upland forest, bamboo succession, and mangrove forest was investigated to evaluate vegetation storage of fertility elements.

Thus, an examination was made of surface variability of soil, variation with depth of the soil, and the weight (biomass) and fertility element storage of the vegetation on a known area.

RESULTS OF SOIL STUDIES

Soil Fertility Properties: Upland Forest Area

The upland forest area sampled in SVN was located at Dong-Xoai, and represented a forest that had not been defoliated. The adjacent defoliated areas were not accessible because of military action; however, a defoliated region in Thailand was sampled. The background fertility storage in forest-soil situations typical of SVN was sampled in Sekerat Forest south of Nakhon Ratchesima, and in a transect across Thailand from Sekerat to Doi Chiengdao north of Chiangmai. The results of this work will be discussed, first in terms of the fertility storage of the typical forest-soil types, the known effect of defoliation at a site where there was a good comparison between soil under defoliated and nondefoliated vegetation, and then a development of possible effects that could result from a return of all leaves to the soil surface. The areas sampled represented Closed forest and Open forest as referred to by Rollet (1962?). The locations in the upland forest are described in Table I, and represent 304 soil samples at 29 locations in SVN and Thailand.

Range of Fertility in Upland Forest Soils

The fertility elements investigated in the soil included carbon, nitrogen, calcium, magnesium, potassium, sodium, and manganese as exchangeable cations, and water-soluble phosphorus. In addition, the pH of the soil was analyzed, as well as the capacity of the soil to exchange fertility elements (cation exchange capacity or C.E.C.). These data have been calculated as total storage of the element in the top 5 cm (2.5 in.), and the storage of elements in the total soil profile to a depth of 1 m (see Tables II, III, IV, and V).

The data indicate that the surface soils associated with the Closed forest are more fertile in some respects than those of the Open forest. There is more organic matter (represented by carbon content), more nitrogen, and a greater C.E.C. Soils associated with the Open forest tended to have more calcium and magnesium stored in them, but were lower in potassium storage. These values are all expressed in gram equivalent (g eq) weights of the elements concerned. In general, the denser the forest, the less

Table II.

Soil properties representing fertility storage, and factors relevant to it in surface layers of Closed forest (Foret Dense) soils of Southeast Asia analyzed in defoliation studies. Soils analyses in top 5 cm, (2") of soil reported as Carbon (C) and Nitrogen (N) in grams per square meter of soil surface per centimeter depth increment; and Cation Exchange Capacity (CEC), and Exchangeable Bases, Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Manganese (Mn), as equivalents per square meter of soil surface per centimeter depth increment.

Site No.	C	N	C/N	pH	Bulk Density	CEC	Ca	Mg	K	Na	Mn
381	517	36	14	3.6	1.0	1.48	.18	.09	.04	.01	.02
382[a]	387	35	11	4.9	1.1	1.38	.89	.27	.09	.01	.13
383	298	23	13	3.7	1.0	1.08	.07	.08	.03	.00	.00
384	369	30	12	3.8	1.0	1.28	.13	.10	.04	.00	.01
385	253	20	13	4.0	1.1	0.72	.11	.06	.02	.00	.02
386	335	28	12	4.0	1.2	0.96	.11	.08	.04	.01	.03
387[a]	162	15	11	3.7	1.1	1.01	.71	.39	.19	.02	.10
395	345	25	14	4.5	0.7	1.25	.04	.03	.03	.01	.00
396	452	23	20	4.3	0.5	0.92	.01	.02	.03	.00	.00
420[b]	293	22	13	4.0	0.9	1.01	.02	.04	.02	.01	.02
421[b]	148	13	11	6.0	1.3	0.80	.55	.15	.04	.00	.03
422[b]	170	15	11	6.9	1.1	0.73	.50	.18	.04	.00	.03
424[b]	232	19	12	3.7	1.0	0.89	.04	.06	.02	.01	.01
434[b]	405	22	18	5.6	1.3	1.54	.61	.30	.02	.00	.03
MEAN	287	23	13	4.5	1.0	1.08	.28	.13	.05	.005	.030

[a] 382, and 387 were influenced by termites.
[b] data represent means of multiple surface samples, 420--10; 421--20; 422--20; 424--24; and 434-- 5 samples.

Table III.

Soil properties representing fertility storage and factors relevant to it in surface layers of Open forest (Foret claire) soils of Southeast Asia analyzed in defoliation studies. Soils analyses in top 5 cm (2") of soil, reported as Carbon (C), and Nitrogen (N) in grams per square meter of soil surface per centimeter of depth increment; and Cation Exchange Capacity (CEC), and exchangeable bases, Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Manganese (Mn), as equivalents per square meter of soil surface per centimeter depth increment.

Site No.	C	N	C/N	pH	Bulk Density	CEC	Ca	Mg	K	Na	Mn
388	462	12	38	7.6	1.2	0.39	3.1	.54	.13	.00	.06
389	179	11	16	7.2	1.2	0.78	1.0	.11	.02	.00	.01
390	154	5	31	7.3	1.1	1.01	1.06	.12	.02	.03	.01
391	162	3	50	5.9	1.0	0.92	.50	.26	.04	.00	.02
392	263	14	18	6.2	0.9	0.99	0.44	.16	.04	.01	.02
393	240	14	17	5.6	1.1	0.95	0.22	.09	.04	.01	.02
394	193	12	16	5.6	1.0	0.92	0.34	.20	.08	.00	.03
396A	212	13	16	5.8	1.1	0.83	0.22	0.25	.04	.00	.01
396A[a]	87	7	13	4.7	1.1	0.43	.08	.04	.01	.00	.02
397	95	7	13	6.4	1.1	0.50	.24	.16	.00	.00	.01
398	163	12	14	6.2	1.1	1.40	.84	.28	.02	.00	.00
398[a]	168	11	16	6.1	1.1	1.37	.81	.31	.02	.00	.01
399	221	11	20	5.9	1.2	0.89	.46	.27	.02	.00	.02
399[a]	202	9	22	5.1	1.1	0.69	.31	.20	.02	.00	.03
400	191	8	23	5.7	1.0	0.78	.32	.23	.02	.00	.01
400[a]	148	7	20	6.4	1.1	0.69	.57	.15	.03	.02	.01
401	122	8	16	5.1	1.1	0.52	.23	.10	.03	.00	.03
401[a]	141	8	18	6.1	1.1	0.71	.45	.22	.02	.00	.01
402	122	5	24	6.1	1.3	0.71	.42	.19	.03	.01	.02
402[a]	161	10	16	5.8	1.3	0.85	.31	.24	.02	.02	.02
MEAN	184	9.4	21	6.1	1.1	0.82	.60	.21	.03	.005	.02

[a] sampled in opening between trees.

Table IV.

Soil properties representing fertility storage and factors relevant to it in top meter of Closed forest soils in Southeast Asia analyzed in defoliation studies. Storage amounts are summation of individual profile depth increment storage calculations based on original laboratory analyses and factor of depth, density, and stone content for each horizon. Carbon (C) as kilograms per square meter of soil surface to one meter depth, Nitrogen (N) as grams per square meter, Cation exchange capacity (CEC) as equivalents per square meter to a depth of a meter, and exchangeable cations as equivalents per square meter, Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Manganese (Mn).

Closed Forest (Forêt Dense)

Site No.	C	N	C/N	CEC	Ca	Mg	K	Na	Mn
381	8.3	606	14	43.2	1.5	1.9	1.0	0.4	0.3
382[a]	10.6	995	11	61.9	12.9	10.3	3.3	0.4	2.2
383	8.2	685	12	58.2	1.1	2.5	2.2	0.4	0.1
384	7.4	661	11	44.6	1.4	0.9	1.0	0.3	0.1
385	5.0	447	11	32.6	1.4	0.9	0.4	0.2	0.3
386	7.0	658	11	44.2	1.2	1.7	0.7	0.4	0.4
387[a]	28.0	2203	13	138.8	43.3	13.0	4.5	0.4	3.4
395	9.0	642	14	43.8	0.4	0.4	0.8	0.3	0.1
396	14.7	870	17	63.9	0.6	0.4	1.3	1.5	0.2
MEAN	10.9	862	13	59.0	7.0	3.6	2.1	0.5	0.8
MEAN (without termite influenced soils)	8.5	652	13	47.2	1.1	1.2	1.0	0.5	0.2

[a]Soil influenced by termites; 387 being a profile through a live mound; 382 an old mound.

Table V.

Soil properties representing fertility storage and factors relevant to it in top meter of open forest soils in Southeast Asia analyzed in defoliation studies. Storage amounts are summation of individual profile depth increment storage calculations based on original laboratory analyses related to field quantities by factors of depth, bulk density, and stone content applied to the analysis for each horizon. Carbon (C) as kilograms per square meter of soil surface to one-meter depth, Nitrogen (N), as grams per square meter, Cation exchange capacity (CEC) as equivalents per square meter to a depth of a meter, and exchangeable cations as equivalents per square meter, Calcium (CA), Magnesium (Mg), Potassium (K), Sodium (Na), and Manganese (Mn).

Open Forest (Forêt Claire)

Site No.	C	N	C/N	CEC	Ca	Mg	K	Na	Mn
388	6.4	278	23	32.3	53.4	10.3	1.4	0.1	0.4
389	3.0	268	11	28.6	22.8	3.3	0.5	0.6	0.2
390	4.7	250	19	47.1	38.0	4.8	0.2	0.6	0.1
391	6.1	456	13	60.9	21.4	12.7	1.6	0.1	1.0
392	4.8	391	12	52.8	3.9	3.1	1.3	0.4	0.7
393	6.2	443	14	58.0	2.0	1.0	1.4	1.4	1.3
394	4.2	329	13	51.1	2.6	2.4	2.2	1.2	1.0
396A	4.0	326	12	34.6	1.3	4.7	2.2	0.7	0.4
397	2.0	226	9	35.2	3.0	5.6	3.4	0.5	0.1
398	5.6	550	10	149.4	32.4	35.2	2.0	0.6	0.4
399	2.9	281	10	44.4	9.0	9.2	1.8	0.3	0.4
400	4.4	407	11	50.4	16.4	11.5	3.8	2.2	0.8
401	2.9	215	14	35.6	11.8	6.4	1.4	0.5	0.5
402	3.4	253	13	33.9	5.5	4.0	1.2	1.8	0.9
MEAN	4.3	334	13	51.0	16.0	8.2	1.7	0.8	0.6

calcium, magnesium, and potassium were stored in the soil. The forest removes these stored elements from the soil, presumably retaining them in the vegetation.

The storage of fertility elements in the soils to a depth of 1 m may give a better indication of overall fertility of the site. At most of the sampling sites the entire soil profile was sampled in the upland forest areas, and these data (Table IV and V) also indicate that there is more storage of carbon and nitrogen in the Closed forest soils than in those of the Open forest. Again, they indicate much more calcium and magnesium and much less potassium in the Open than in the Closed forest areas. The following averages exemplify this:

Forest type	Elemental storage in forest soil[a]							
	C	N	C/N	C.E.C.	Ca	Mg	K	Mn.
Closed	10.9	862	13	59.0	7.0	3.6	2.1	0.8
Open	4.3	334	13	51.0	16.0	8.2	1.7	0.6

[a]C and N as g/m^2 to a depth of 1 m; C.E.C., Ca, Mg, and K as eq/m^2 to a depth of 1 m.

The higher the storage of nutrient elements, or the greater the C.E.C. in the soil, the better should be the buffering of defoliation effects or any other impact on a forest. Thus, in general, the soil of the Closed forest should be less affected by defoliation than that of the Open forest.

Storage in Forest vs. Soil

A considerable amount of the fertility of a tropical forest site may be stored in the vegetation, relative to the soil. Since a major effect of defoliation is to eliminate the aboveground storage elements from a site, it is important to evaluate to what extent this occurrence may affect storage. An example of the fertility storage that may be expected in Closed forests typical of SVN is presented in Table VI. These data were taken from work by Zinke et al. (1970). They indicate that considerable weight of various elements are stored in the forest. This is well-known to local inhabitants, who burn these forests to fertilize the soil in their practice of swidden cultivation. It is of interest to note that the old forest at Ban Pa-Pae has 1217 lb/acre of nitrogen, 172 lb/acre of phosphorus, and 1371 lb/acre of potassium.

Presumably, the effect of defoliating a forest stand would be to return the fertility stored in the leaf weight to the soil. There it would be stored and subsequently used by plants, or possibly lost by leaching through runoff and seepage of rainwater. In this regard, it is of interest to compare the fertility storage in the forest as it stands to the corresponding storage in the soil. Such data indicate that there is a considerable proportion of the site fertility (soil + vegetation) stored in the vegetation of the Closed forest (see Table VII). Approximately 6 to 14 percent of the site's nitrogen resides in the vegetation, with an estimated 1 to 6 percent being in the foliage. The foliage may also contain from 5 to more than 20 percent of the potassium on the site. Thus, defoliation may be affecting relatively large proportions of some elements on the site as in the case of potassium and presumably phosphorus, and relatively lower proportions of other elements such as nitrogen. Defoliation may be a serious interruption of shifting cultivation fallow cycles, since these take advantage of the nutrient storage in the forest fallow.

Table VI.

Biomass and Fertility Storage Data for two typical Closed Forest Stands

Location	Ban Pa Pae			Sakerat		
Vegetation Component	Foliage	Wood[a]	Total	Foliage	Wood[a]	Total
Vegetation Wt. g/m^2	3869	34823	38692	607	20,000	20,607
Nitrogen g/m^2	62	75	137	10	43	52
Phosphorus g/m^2	5.4	13.9	19.3	0.8	8.	8.8
Potassium g/m^2	50	104	154	8	60	68
Gram equivs/m^2	[1.3]	[2.6]	[3.9]	[0.2]	[1.5]	[1.7]
Calcium g/m^2	23	174	197	4	100	104
Gram equivs/m^2	[1.1]	[8.7]	[9.8]	[0.2]	[5.0]	[5.2]
Magnesium g/m^2	12	17	29	2	10	12
Gram equivs/m^2	[1.0]	[1.4]	[2.4]	[0.2]	[0.8]	[1.0]
Total Ca + Mg + K	[3.4]	[12.7]	[16.1]	[0.6]	[7.3]	[7.9]
Proportion Ca + Mg + K	21%	79%	100%	8%	92%	100%

[a] Branches and stems.

The following percentage elemental compositions were assumed for fertility elements based upon analyses run on the foliage and woody components of the forests at each location:

Element	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Foliage	1.6	0.14	1.3	0.6	0.3
Wood	0.2	0.04	0.3	0.5	0.05

Table VII.

Comparative Storage of Nitrogen and Potassium in the Vegetation and Soil of a Closed Forest (All as grams per m^2)[a]

	Nitrogen	Potassium
Vegetation Leaves	62 - 10	50 - 8
Wood	75 - 43	104 - 60
Total	137 - 53	154 - 68
Soil (to depth of 1 meter)	867	82
Total Site Storage	1004 - 919	236 - 150
Proportion of Fertility (Storage in trees)	13.6% - 5.7%	65.2% - 45.3%
Proportion of Fertility (Storage in foliage)	6.2% - 1.0%	21.2% - 5.3%

[a]Multiply by 8.9 for pounds per acre; or for very rough estimate by 10.

Fate of Elements Returned to the Soil

The soil serves as a storage medium for the forest, carrying over fertility storage from generation to generation of vegetation. The soil is more or less efficient in holding elements in storage against the leaching effects of rainfall, or against losses to the atmosphere of some elements such as nitrogen. Exchangeable cations such as calcium, magnesium, and potassium will be stored on the C.E.C. of the soil.

The forest soil can be considered to be an ion exchange medium on the landscape. The vegetation contains elements such as calcium, magnesium, and potassium that return to this medium. The measure of this capacity, the C.E.C., has been transferred from the usual laboratory value (mg eq/100 g of soil) to the field value of g eq of capacity/m^2 of soil to a depth of 1 m. These values, presented in Tables IV and V, indicate that for the Closed forest sites investigated there were 59 g eq of exchange capacity to a depth of 1 m, and less in the Open forest. In comparison, commercial cation exchangers used in water softening and rehabilitation have capacities ranging from 4 to 50 g eq/ft^3, or 43 to 538 eq/m^3 (Fair and Geyer 1954).

The disposition of fertility cations entering the soil from vegetation additions as a result of defoliation would depend upon the soil capacity to absorb them on the cation exchange storage capacity. Also, whether any particular one--such as potassium--would be absorbed depends upon the relative proportion of it to the other elements (i.e., calcium or magnesium) present in the added foliage or on the soil exchange complex. The following summarized cation quantities expressed in g eq/m^2 of soil surface are characteristic of the Closed forest:

	C.E.C.	Calcium	Magnesium	Potassium
Vegetation				
Foliage		1.1-0.2	1.0-0.2	1.3-0.2
Wood		8.7-5.0	1.4-0.8	2.6-1.5
Total		9.8-5.2	2.4-1.0	3.9-1.7
Soil (average)	59.0	7.0	3.6	2.1

Thus, if the foliage is removed from the trees and placed on the soil, eventually from 3.4 to 0.6 g eq of cations will be entering soil with a capacity of 59.0 g eq. This capacity is only partially saturated with 12.7 eq of calcium + magnesium + potassium (sodium being nil in these soils). The 12.7 eq represent only 22 percent of the cation storage capacity of this average Closed forest soil; the remainder is occupied by either hydrogen or aluminum ions. Presumably there is sufficient storage capacity on the exchange complex to add the 3.4 to 0.6 eq of exchangeable cations that will result from weathering of the foliage dropped from the defoliated forest. However, there is a risk of losing the potassium if the level of calcium and magnesium is too high in the incoming soil solution, or if the hydrogen and aluminum contents or the exchange complex are too high. Thus, the addition of elements to the soil from foliage drop represents an increase of fertility to the soil if the storage capacity is adequate to hold these elements against subsequent leaching.

Fertility Balance of Secondary Succession with Bamboo

Secondary succession to bamboo may occur as a special case in the Closed forest. A site was found in such a forest area north of Lampang in Thailand where bamboo had taken over a previous forest. It was located on the Mae Moh teak plantation, on a gray-brown podzolic soil. A 10-year-old growth of bamboo was cut from a 20 by 20 m plot and the vegetation components weighed and expressed as weight/m^2. Representative samples of this vegetation were analyzed for the various fertility elements (see Table VIII).

These data indicate a much lower vegetation weight and correspondingly lower fertility storage in the bamboo. The fertility elements are distributed so that a large proportion of them are in the underground root portions of the plants. This would indicate that the bamboo maintains lower fertility storage on the site, and maintains it in a form that would be difficult to return to the soil unless an effective way of killing the roots is developed. Thus, to the extent that defoliation may bring a succession to bamboo, the amount and availability of fertility on the site may be decreased.

An Evaluation of a Defoliated Upland Forest Area

There have been few opportunities to properly sample soils in defoliated vs. nondefoliated areas during the past few years. The chances of ambush in the forest during wartime are high, since these areas serve as refuge for illegal hostile groups. However, several types of studies were carried out. One attempted to establish the number of samples actually required to determine the true soil fertility values of an area, and to establish what significant change--if any--was brought about by a disturbance such as defoliation.

The number of soil samples needed to deal with the variability of the surface soil properties was investigated at Dong Xoai in Phuoc-Long Province, SVN. Surface soil samples to a depth of 5 cm were taken on a transect in relatively undisturbed forest. Nine sites were sampled for assessment of soil

Table VIII.

Fertility balance of Vegetation and Soil in a Closed Forest situation currently occupied by bamboo, at Mae Moh Teak Plantation, Lampang, Thailand. (Based upon a 20 meter x 20 meter plot).

Vegetation Component	Foliage	Stems Living	Stems Dead	Roots	Total
Weight of Vegetation grams per square meter	129	940	480	1442	2991
Fertility Elements					
Nitrogen	2.4	3.5	1.5	9.6	17.2
Phosphorus	0.2	0.4	0.1	1.4	2.1
Potassium g/m^2	0.7	2.7	1.2	5.5	10.1
$eq/m^2 \times 10^3$	[18.41]	[69.72]	[30.45]	[140.86]	
Calcium g/m^2	0.5	0.3	0.2	0.5	1.5
$eq/m^2 \times 10^3$	[24.33]	[16.42]	[10.06]	[25.18]	
Magnesium g/m^2	0.5	0.6	0.2	1.8	3.1
$eq/m^2 \times 10^3$	[39.25]	[46.38]	[19.74]	[144.67]	
Total K + Ca + Mg (eq/m^2)	0.082	0.133	.060	0.311	0.586
Proportion %	14%	23%	10%	53%	100%

density and various fertility elements and their variability. The data, analyzed statistically in Table IX, indicate that to characterize the real mean value of the quantity being measured in the soil to a confidence level of 90 ± 10 percent, one would need only 1 sample for pH, 6 for bulk density, 11 for percent total nitrogen, 25 for percent carbon, 34 for exchangeable potassium, 47 for magnesium, 50 for manganese, and 434 for phosphorus. Thus, to be certain that the true value of a soil property is measured--particularly for comparison with the same soil property under defoliated conditions--large numbers of soil samples must be gathered in an unbiased way. Without such samples and analyses, any statement about changes in soil properties as a result of varying forest conditions is merely an opinion subject to the bias of the observer.

An evaluation of the effect of a defoliation treatment on the fertility of a Closed forest soil was made at Pran Buri, Thailand. In this area, test applications had been made of defoliants of various types and amounts on a series of nearly 100 test plots. The test plots were on a terrace area having red-yellow podzolic soils. Two areas were found where a suitable comparison between an area treated with herbicide and an untreated area could be made. The defoliation treatment in 1964 was made with 9.1 lb of Agent Orange and 1/2 lb of picloram per acre. In 1971, 20 samples were selected at 10-m intervals in a transect through the treated area. A plot adjacent to this area, which had not been treated with herbicides, was selected as a comparison area. In this area, 20 soil samples were gathered on a similar transect.

The statistical analysis of the data for 20 surface soils from the

Table 9

VARIABILITY IN SOIL SAMPLE 422VN VIET NAM SOILS-NONDEFOLIATED DATE: 22 JAN 74

PRAN BURI TEST PLOTS - THAILAND

HOR. NO.	CODE	DEPTH (CM) TOP	BOT	BULK DEN.	PCT. >2 MM	PH	PCT. C	PCT. N	P PPM	......EXCHANGEABLE BASES, MEQ/100 GRAMS...... C.E.C.	CA++	MG++	K+	NA+	MN++	....PERCENT.... SAND	SILT	CLAY
1		0.	7.0	1.07	0.	7.0	2.16	.140	.916	7.44	3.91	2.11	.54	.03	.29	-0.	-0.	-0.
2		0.	7.0	1.13	0.	6.8	1.35	.125	1.254	5.71	2.98	1.67	.36	.03	.29	-0.	-0.	-0.
3		0.	7.0	1.14	0.	6.7	1.38	.123	.978	5.76	2.87	1.63	.34	.03	.23	-0.	-0.	-0.
4		0.	7.0	1.01	1.26	6.3	1.82	.152	.728	6.63	2.99	1.43	.37	.01	.37	-0.	-0.	-0.
5		0.	7.0	.98	0.	6.7	2.06	.164	2.224	7.39	2.60	3.52	.51	.02	.12	-0.	-0.	-0.
6		0.	7.0	1.28	0.	6.2	.96	.097	.464	5.60	2.14	1.66	.34	.02	.08	-0.	-0.	-0.
7		0.	7.0	1.04	0.	7.0	1.98	.165	1.182	8.01	5.33	2.00	.39	.02	.12	-0.	-0.	-0.
8		0.	7.0	.87	0.	6.3	1.91	.180	1.369	7.76	3.82	1.86	.28	.01	.16	-0.	-0.	-0.
9		0.	7.0	1.21	0.	6.6	1.16	.116	.552	6.66	3.49	2.14	.32	.01	.12	-0.	-0.	-0.
10		0.	7.0	1.11	1.80	6.9	1.50	.140	1.066	6.66	3.61	2.00	.38	.01	.13	-0.	-0.	-0.
11		0.	7.0	1.30	0.	7.1	1.14	.086	.350	4.35	3.37	.87	.31	0.	.09	-0.	-0.	-0.
12		0.	7.0	1.34	0.	7.2	1.05	.111	.326	6.94	4.95	1.18	.45	0.	.11	-0.	-0.	-0.
13		0.	7.0	1.26	0.	7.9	1.32	.119	.527	6.24	8.33	1.16	.37	0.	.09	-0.	-0.	-0.
14		0.	7.0	1.39	0.	7.6	1.44	.103	.325	5.91	5.31	1.11	.29	0.	.08	-0.	-0.	-0.
15		0.	7.0	1.14	0.	7.8	1.43	.152	.313	6.49	7.08	1.17	.41	0.	.36	-0.	-0.	-0.
16		0.	7.0	1.24	0.	7.9	1.40	.089	.464	5.67	6.62	1.26	.26	.01	.32	-0.	-0.	-0.
17		0.	7.0	.97	0.	6.7	1.28	.135	1.984	6.09	4.14	1.44	.33	.01	.43	-0.	-0.	-0.
18		0.	7.0	1.17	0.	6.5	1.28	.120	1.481	5.84	4.02	1.25	.27	.02	.48	-0.	-0.	-0.
19		0.	7.0	1.05	1.00	7.2	2.46	.166	1.989	8.27	6.17	1.82	.35	.01	.46	-0.	-0.	-0.
20		0.	7.0	1.16	0.	6.5	1.40	.118	1.274	6.29	3.25	1.76	.35	.01	.49	-0.	-0.	-0.

Table 9 cont'd.

VARIABILITY IN SOIL SAMPLE 422VN VIET NAM SOILS-NONDEFOLIATED DATE: 22 JAN 74

					CONFIDENCE LIMITS				SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT					
				COEFF	..(90 PERCENT)..		..(95 PERCENT)..		(90 PCT. CONF.)...			(95 PCT. CONF.)...		
	N	MEAN	STD.DEV	VAR.					TOL: 1	5	10	1	5	10
BULK DENS.	20	1.143	.135	11.8	1.091	1.195	1.080	1.206	417	17	4	611	24	6
PCT. >2MM.	20	.203	.513	252.8	.005	.401	-.037	.443	99999	7641	1910	99999	11197	2799
PH	20	6.945	.526	7.6	6.742	7.148	6.699	7.191	171	7	2	251	10	3
PCT. C	20	1.524	.404	26.5	1.368	1.680	1.335	1.713	2096	84	21	3071	123	31
PCT. N	20	.130	.027	20.7	.120	.140	.117	.143	1284	51	13	1881	75	19
PO4 (PPM)	20	3.030	1.844	60.8	2.317	3.743	2.167	3.893	11069	443	111	16220	649	162
C.E.C.	20	6.485	.954	14.7	6.117	6.854	6.039	6.932	647	26	6	948	38	9
CALCIUM	20	4.349	1.654	38.0	3.710	4.988	3.575	5.123	4322	173	43	6333	253	63
MAGNESIUM	20	1.652	.575	34.8	1.430	1.874	1.383	1.921	3618	145	36	5302	212	53
POTASSIUM	20	.361	.073	20.3	.333	.389	.327	.395	1236	49	12	1811	72	18
SODIUM	20	.012	.010	81.6	.009	.016	.008	.017	19888	796	199	29143	1166	291
MANGANESE	20	.241	.149	61.9	.183	.299	.171	.311	11437	457	114	16759	670	168

Table 9 cont'd.

VARIABILITY IN SOIL SAMPLE 422VN VIET NAM SOILS-NONDEFOLIATED DATE: 22 JAN 74

	N	MEAN	STD.DEV	COEFF VAR.	...... CONFIDENCE LIMITS ....(90 PERCENT)..		..(95 PERCENT)..		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.)... TOL: 1	5	10	(95 PCT. CONF.)... 1	5	10
C DENSITY G/SQ.M/CM	20	170.362	34.049	20.0	157.198	183.526	154.427	186.298	1194	48	12	1750	70	17
N DENSITY G/SQ.M/CM	20	14.535	1.761	12.1	13.854	15.216	13.711	15.359	439	18	4	643	26	6
PO4 DENS. MG/SQ.M/CM	20	32.814	17.693	53.9	25.973	39.654	24.533	41.094	8692	348	87	12736	509	127
CEC DENS. EQ/SQ.M/CM	20	.732	.091	12.5	.697	.768	.690	.775	466	19	5	683	27	7
CA DENS. EQ/SQ.M/CM	20	.501	.217	43.3	.417	.585	.399	.603	5616	225	56	8230	329	82
MG DENS. EQ/SQ.M/CM	20	.184	.053	28.7	.164	.205	.160	.209	2462	98	25	3608	144	36
K DENS. EQ/SQ.M/CM	20	.041	.009	20.8	.038	.044	.037	.045	1291	52	13	1892	76	19
NA DENS. EQ/SQ.M/CM	20	.001	.001	83.5	.001	.002	.001	.002	20820	833	208	30509	1220	305
MN DENS. EQ/SQ.M/CM	20	.027	.016	60.5	.021	.033	.019	.034	10931	437	109	16019	641	160

defoliated vs. the nondefoliated area is presented in Table X. In the table of average values, the means for the defoliated area are generally lower to a significant degree (at 5 percent level or less) for pH, and lower for percent carbon, percent nitrogen, phosphorus (parts per million), magnesium (mg eq/100 g of soil). They were higher to a significant degree only for sodium (mg eq/100 g of soil), and to a very significant degree for bulk density. When the fertility elements are compared in a volume of field soil instead of on a weight basis, the elements that are significantly lower 7 years after defoliation are nitrogen (g/m^2/cm depth) and phosphorus (mg PO_4^{-2}/m^2/cm depth). The nitrogen was less by 1.4 g/m^2 to a depth of 1 cm; that is, by 10 percent from the control, or approximately 7.0 g to the depth of the sample (62 lb/acre to a depth of 2 in.). If this difference is maintained to a 1-ft depth, the nitrogen loss due to defoliation could be up to 375 lb/acre of soil. The possible loss of phosphorus from this study is also severe in that soil samples from the control area indicate 32.8 mg available water-soluble phosphorus as PO_4^{-2} or 10.7 g as phosphorus ($\frac{P}{PO_4^{-2}}$ = 0.3263); whereas in the defoliated area the phosphorus content was 15.9 g as PO_4^{-2} or 5.2 g as phosphorus, a loss of 50 percent of the available phosphorus in the top layer of the soil. This is a loss of 27.5 g to the depth sampled, or approximately 80 lb/acre. Thus, if this comparison is valid, there is a severe loss in the nitrogen and the phosphorus contents of the defoliated area in this study. The soil pH became more acid to a significant extent.

Table 10

VARIABILITY IN SOIL SAMPLE 424 TL SEKERAT DRY EVERGREEN FOREST DATE: 22 JAN 74

CLOSED FOREST VARIABILITY STUDY

HOR. NO.	CODE	DEPTH (CM) TOP	BOT	BULK DEN.	PCT. >2 MM	PH	PCT. C	PCT. N	P PPM	C.E.C.	CA++	MG++	K+	NA+	MN++	SAND	SILT	CLAY
										......EXCHANGEABLE BASES, MEQ/100 GRAMS......						....PERCENT....		
A1		0.	5.0	1.07	.30	3.7	3.12	.234	.525	9.81	.87	1.25	.45	.05	.13	-0.	-0.	-0.
A2		0.	5.0	.94	.48	4.1	3.02	.233	.568	10.24	1.82	1.51	.34	.03	.39	-0.	-0.	-0.
A3		0.	5.0	1.01	.19	3.7	2.68	.183	.440	9.16	.61	.62	.39	.07	.06	-0.	-0.	-0.
A4		0.	5.0	1.08	.29	3.7	1.56	.162	.412	7.25	.50	.27	.26	.05	.06	-0.	-0.	-0.
B1		0.	5.0	.80	.48	3.8	2.62	.220	.185	9.69	.29	.48	.22	.12	.05	-0.	-0.	-0.
B2		0.	5.0	1.03	.99	3.6	3.04	.233	.511	10.44	.23	.71	.39	.07	.03	-0.	-0.	-0.
B3		0.	5.0	1.03	1.49	3.6	2.65	.171	.582	9.08	.24	.54	.32	.06	.01	-0.	-0.	-0.
B4		0.	5.0	.96	.40	3.8	1.98	.183	.497	7.20	.28	.56	.26	.08	.06	-0.	-0.	-0.
C1		0.	5.0	.99	.97	3.6	1.92	.186	1.008	6.54	.27	.50	.26	.08	.04	-0.	-0.	-0.
C2		0.	5.0	1.11	1.15	3.6	2.00	.171	.540	7.81	.27	.43	.20	.16	.10	-0.	-0.	-0.
C3		0.	5.0	.91	.63	3.5	2.62	.202	.852	9.24	.28	.48	.22	.13	.04	-0.	-0.	-0.
C4		0.	5.0	1.04	.43	3.7	2.98	.204	.412	9.41	.21	.42	.21	.12	.02	-0.	-0.	-0.
D1		0.	5.0	1.05	1.34	3.7	2.13	.166	.341	8.23	.19	.38	.18	.14	.06	-0.	-0.	-0.
D2		0.	5.0	1.03	.43	3.9	1.62	.170	.199	7.74	.17	.27	.18	.11	.11	-0.	-0.	-0.
D3		0.	5.0	1.10	.70	3.8	1.58	.144	.199	7.89	.19	.32	.14	.05	.19	-0.	-0.	-0.
D4		0.	5.0	1.02	.37	3.7	1.92	.175	.483	9.02	.30	.44	.23	.03	.08	-0.	-0.	-0.
E1		0.	5.0	1.08	1.77	3.6	1.48	.154	1.136	7.02	.26	.64	.37	.04	.09	-0.	-0.	-0.
E2		0.	5.0	.94	.47	3.5	3.52	.213	.838	13.30	.36	.58	.24	.04	.03	-0.	-0.	-0.
E3		0.	5.0	1.00	.32	3.7	2.40	.182	.554	8.58	.68	.37	.17	.07	.09	-0.	-0.	-0.
E4		0.	5.0	1.03	.56	3.6	1.70	.183	.554	8.04	.25	.48	.19	.12	.05	-0.	-0.	-0.
F1		0.	5.0	1.04	1.78	3.8	2.20	.187	.497	8.95	.25	.65	.23	.13	.22	-0.	-0.	-0.
F2		0.	5.0	1.03	.99	3.8	2.53	.220	.341	9.70	.28	.49	.16	.16	.12	-0.	-0.	-0.
F3		0.	5.0	.96	1.12	3.8	2.02	.210	.426	9.62	.74	.51	.22	.04	.13	-0.	-0.	-0.
F4		0.	5.0	1.05	.91	3.8	2.42	.210	.483	9.91	.70	.73	.18	.01	.11	-0.	-0.	-0.

Table 10 cont'd.

VARIABILITY IN SOIL SAMPLE 424 TL SEKERAT DRY EVERGREEN FOREST DATE: 22 JAN 74

	N	MEAN	STD.DEV	COEFF VAR.	CONFIDENCE LIMITS (90 PERCENT)		CONFIDENCE LIMITS (95 PERCENT)		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.) TOL: 1	5	10	(95 PCT. CONF.) 1	5	10
BULK DENS.	24	1.012	.068	6.8	.989	1.036	.984	1.041	134	5	1	196	8	2
PCT. >2MM.	24	.773	.472	61.1	.608	.939	.574	.973	10960	438	110	15970	639	160
PH	24	3.712	.133	3.6	3.666	3.759	3.656	3.769	38	2	1	55	2	1
PCT. C	24	2.321	.567	24.4	2.123	2.520	2.082	2.561	1751	70	18	2552	102	26
PCT. N	24	.191	.026	13.5	.182	.201	.181	.202	537	21	5	782	31	8
PO4 (PPM)	24	1.608	.718	44.7	1.356	1.859	1.304	1.911	5865	235	59	8546	342	85
C.E.C.	24	8.911	1.433	16.1	8.410	9.412	8.306	9.516	759	30	8	1106	44	11
CALCIUM	24	.427	.358	84.0	.301	.552	.275	.578	20736	829	207	30215	1209	302
MAGNESIUM	24	.568	.282	49.6	.469	.666	.449	.687	7219	289	72	10519	421	105
POTASSIUM	24	.250	.083	33.3	.221	.280	.215	.286	3249	130	32	4734	189	47
SODIUM	24	.082	.044	54.2	.066	.097	.063	.100	8644	346	86	12595	504	126
MANGANESE	24	.095	.081	85.9	.066	.123	.060	.129	21673	867	217	31581	1263	316

Table 10 cont'd.

VARIABILITY IN SOIL SAMPLE 424 TL   SEKERAT DRY EVERGREEN FOREST   DATE: 22 JAN 74

	N	MEAN	STD.DEV	COEFF VAR.	...... CONFIDENCE LIMITS ....(90 PERCENT)..		..(95 PERCENT)..		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.)... TOL: 1	5	10	(95 PCT. CONF.)... 1	5	10
C DENSITY G/SQ.M/CM	24	231.832	53.831	23.2	212.998	250.666	209.098	254.567	1584	63	16	2308	92	23
N DENSITY G/SQ.M/CM	24	19.158	2.364	12.3	18.331	19.985	18.159	20.156	447	18	4	652	26	7
PO4 DENS. MG/SQ.M/CM	24	16.132	7.177	44.5	13.621	18.643	13.101	19.163	5815	233	58	8474	339	85
CEC DENS. EQ/SQ.M/CM	24	.892	.131	14.7	.846	.938	.836	.947	637	25	6	928	37	9
CA DENS. EQ/SQ.M/CM	24	.042	.034	80.6	.030	.054	.028	.057	19094	764	191	27823	1113	278
MG DENS. EQ/SQ.M/CM	24	.057	.028	49.0	.047	.067	.045	.069	7057	282	71	10283	411	103
K DENS. EQ/SQ.M/CM	24	.025	.009	35.0	.022	.028	.021	.029	3597	144	36	5241	210	52
NA DENS. EQ/SQ.M/CM	24	.008	.005	55.3	.007	.010	.006	.010	8982	359	90	13088	524	131
MN DENS. EQ/SQ.M/CM	24	.010	.008	83.2	.007	.012	.006	.013	20336	813	203	29632	1185	296

Soil Fertility Properties: Mangrove Forest Areas

The mangrove forest areas in SVN are mainly in the south tip of the country at the Ca-Mau Peninsula, in the Rung-Sat between Saigon and Vung-Tau, and along the east coast near Cam-Ranh Bay. Soils studies were conducted mainly in the Rung-Sat area, north of Vung-Tau, and in the Nam-Can area of the Ca-Mau Peninsula. The soil samples taken in the Rung-Sat area were from defoliated and now barren areas, those in the Vung-Tau area were from second growth mangrove and a clearing, and those in the Nam-Can area were from both defoliated and nondefoliated mangrove forest. In addition, the mangrove forest was sampled at Khlung, near Chantaburi in southeastern Thailand--for comparison as an area that had not been disturbed by defoliation. Total fertility storage in the mangrove forest--in both vegetation and soil--was determined at Vung-Tau and Chantaburi.

The extent of soil sampling in mangrove forests is indicated in Table XI. A total of 162 soil samples was obtained in mangrove forests, and nearly 2000 different analyses were made of these samples to determine the various fertility elements and physical factors involved in storage of fertility. Most of the mangrove soils were in silts deposited by the Mekong and the Saigon Rivers, with some peaty deposits in basins in this delta material. The Florida samples were included for comparison.

Range of Fertility of Mangrove Soils

The analyses of surface mangrove soils are presented in Table XII. These data are the mean values of analyses of from five to 24 replicate samples taken in transects and grid patterns at each site to avoid sampling

Table XI.

Location and Characteristics of field investigation sites for soil studies -- Mangroves.

Site No.	Location[a]	No. of Soil Samples	Type of Soil	History
416	Rung Sat, RVN	4	Alluvial-silt	Defoliated
417	Nam Can, RVN	5	Alluvial-peaty muck	Defoliated - Agent Orange
418	Nam Can, RVN	5	Alluvial-silt	Defoliated - Agent Orange
419	Nam Can, RVN	5	Alluvial-silt	Forest plantation-non-defoliated (Ca Mau Forest)
425	Near Chantaburi, T	7	Peat	
426	Vung Tau, RVN	24		Forest managed - non-defoliated for wood and charcoal
427	Vung Tau, RVN	24		
428	Vung Tau, RVN	9	Sandy silt	Second growth mangrove forest - crab mounds
429A	Vung Tau biomass, RVN	7	Silt to sandy	Second growth mangrove forest
429B	Plots	7	Silt	
429C		7		
429	Rung Sat, RVN	14		Defoliated - <u>Acrostichum</u> fern invasion
430	Rung Sat, RVN, inland transect	6	Alluvial-silt	Defoliated -- considerable wood harvest and utilization by local residents and refugees.
431	Rung Sat, RVN, shore transect	6	" "	
432	Rung Sat, RVN, second landing	6	" "	
433	Rung Sat, RVN, third landing	10	" "	
433	Marcos Island, Fla.	8	Peat	Avicennia
434	Marcos Island, Fla.	8	"	Rhizophora
		162		

[a]RVN - Republic of Vietnam; T - Thailand; Fla. - Florida. (1,782 soils analyses on 162 samples.)

Table XII.

Soil properties representing fertility storage and factors relevant to it in surface layers of Mangrove forest soils in Southeast Asia, as analyzed in the defoliation studies. Soils analyses in the top 5 cm (2") of soil, reported as Carbon (C), and Nitrogen (N) in grams per square meter of soil surface per centimeter of depth increment; and Cation Exchange Capacity (CEC), and exchangeable bases, Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Manganese (Mn), as equivalents per square meter of soil surface per centimeter depth increment. These are means based upon numbers of samples indicated at each site (n).

Site No.	n	C	N	C/N	pH	Bulk Density	CEC	Ca	Mg	K	Na	Mn
417	5	236	14	18	5.62	0.54	1.50	0.40	0.86	0.14	1.50	0.01
418	5	210	15	14	6.32	0.98	2.29	0.56	1.13	0.16	2.09	0.03
419	5	173	15	12	7.18	0.94	2.27	0.51	1.28	0.21	2.64	0.05
425	5	737	20	37	6.20	0.31	1.90	0.02	1.34	0.10	2.25	0.00
426	24	278	13	21	3.76	0.96	1.34	0.42	1.15	0.10	1.92	0.00
427	24	264	12	22	4.08	0.78	1.19	0.36	0.92	0.07	1.47	0.00
428	9	266	12	22	3.09	1.10	1.20	0.30	0.81	0.06	1.57	0.00
429	14	166	13	13	6.70	0.66	1.94	0.39	1.11	0.12	1.06	0.00
430	6	336	19	18	6.18	0.83	2.20	0.54	1.45	0.15	2.32	0.00
431	6	438	22	20	5.90	0.68	2.27	0.52	1.46	0.14	2.40	0.00
432	6	464	21	22	5.82	0.57	2.41	0.63	1.75	0.14	2.70	0.00
433	10	429	17	25	5.49	0.34	1.97	0.55	1.47	0.10	2.36	0.00
MEAN		333	16	20	5.47	0.76	1.87	0.40	1.23	0.12	2.02	0.007
MEANS for Comparison												
Closed Forest		287	23	13	4.49	1.0	1.08	0.28	0.13	0.05	0.00	0.03
Open Forest		184	9	21	6.08	1.1	0.76	0.60	0.21	0.03	0.00	0.02

bias. At the Vung-Tau site a special sampling of crab mound sites was conducted to evaluate their effects on soil properties.

The average results of all of the mangrove areas indicate some of the special characteristics of these soils in contrast to those of the upland forests. They are moderately acid soils with the average pH of 5.47 being less acid than the Closed forests, but more so than the upland forest soil. They have more organic matter (carbon) with less nitrogen storage than upland forest soils, and a resulting higher carbon/nitrogen content. The exchange capacity in surface mangrove forest soils is much higher than upland forest soils, and on this exchange capacity are retained higher quantities of exchangeable cations. Mangrove soils contain particularly high amounts of magnesium and sodium, which are derived from the seawater that frequently inundates the regions at high tide.

The variability and the number of samples needed to assess soil fertility properties in a mangrove forest soil were determined at several locations. An example of the sample numbers needed is shown for the soil collected in an area treated with Agent Orange near Nam-Can. The most variable element--phosphorus--could be determined to within $\pm$ 10 percent of the true mean within 90 percent confidence limits, while less than 10 samples would be needed for the exchange capacity and the exchangeable cations calcium, magnesium, potassium, sodium, or manganese. At most of the sampling sites where security allowed only a quick landing, five or six samples in a line transect were obtained. At secure sites such as Vung-Tau, 24 samples were obtained that compared a completely cleared mangrove forest with uncut mangrove forest.

The apparent effect of defoliation on mangrove forest soils is shown by a comparison between the soils in an area defoliated with Agent Orange north of Nam-Can, and an adjacent unsprayed area. These data, taken two years after spraying, indicate that denuding the area with herbicides resulted in an increase in carbon, a slight increase in nitrogen and carbon/nitrogen ratio, a large increase in phosphorus, slight drops in magnesium, potassium, sodium, and manganese, and an increase in calcium. Bulk density increased slightly in the defoliated area. The pH became considerably more acid. These data are presented in Table XIII.

A test plot was established about 20 km north of Vung-Tau in a second growth mangrove forest. A large area of the forest was cut and the soil made bare in a simulation of defoliation. A comparison was made between the fertility properties of 24 barren soil samples and 24 soil samples from the adjacent uncut mangrove forest. The statistical comparison of these data in Table XIV indicates that there is a significant increase in bulk density, and significant increases in magnesium, potassium, sodium, and manganese in the soils that were denuded by removal of vegetation six months prior to sampling. Thus, practices other than defoliation may lead to changes in the mangrove forest soil with time.

Storage in the Entire Mangrove Forest Vegetation and Soil

The total storage of fertility elements in the vegetation and soil of the mangrove forest was determined at the plot site 20 km north of Vung-Tau and at the site near Chantaburi, in order to estimate the proportion of the fertility storage on a site that might be affected by removing the mangrove. The data for the Vung-Tau site presented in Table XIV indicate that a consider-

Table XIII.

Comparison between soil properties in a defoliated vs. non-defoliated mangrove area near Nam Can. Surface 5 cm of soil. (Means based upon 5 samples in each.)

Site No.	418	419
Treatment	Agent Orange	Original Mangrove *Rhizophora apiculata*
Carbon g/m^2	210	173
Nitrogen g/m^2	15.3	14.8
C/N	14	12
Phosphorus as PO_4 = mg/m^2	7.7	5.9
Cation exchange Capacity eq/m^2	2.1	2.1
Calcium equiv./m^2	0.56	0.51
Magnesium equiv./m^2	1.13	1.28
Potassium equiv./m^2	0.16	0.21
Sodium equiv./m^2	2.09	2.64
Manganese equiv./m^2	0.03	0.05
pH	6.32	7.18
Bulk Density	0.98	0.94

Table 14

VARIABILITY IN SOIL SAMPLE 428 VN   VUNGTAU MANGROVE - CRABMOUNDS   DATE: 22 JAN 74

LARGE MOUNDS IN MANGROVE CLEARCUT PLOT

HOR. NO.	CODE	DEPTH (CM) TOP	BOT	BULK DEN.	PCT. >2 MM	PH	PCT. C	PCT. N	P PPM	......EXCHANGEABLE BASES, MEQ/100 GRAMS...... C.E.C.	CA++	MG++	K+	NA+	MN++	....PERCENT.... SAND	SILT	CLAY
1		0.	5.0	1.05	2.32	2.6	2.60	.142	.210	14.89	3.66	10.29	.40	15.01	.03	-0.	-0.	-0.
2		0.	5.0	1.09	1.57	3.0	2.96	.137	.152	12.81	1.08	5.32	.23	12.18	0.	-0.	-0.	-0.
3		0.	5.0	1.19	.51	3.6	1.86	.090	0.	7.93	2.61	6.31	.48	9.65	0.	-0.	-0.	-0.
4		0.	5.0	1.31	.15	3.4	1.08	.065	.257	5.10	.84	4.15	.38	8.97	0.	-0.	-0.	-0.
5		0.	5.0	.81	0.	3.7	4.55	.203	.082	16.77	6.29	14.07	1.16	22.62	0.	-0.	-0.	-0.
6		0.	5.0	1.17	.54	3.1	2.08	.098	.175	6.82	1.16	3.25	.63	8.10	.03	-0.	-0.	-0.
7		0.	5.0	.93	1.16	2.8	3.07	.108	.304	15.12	4.03	11.78	.66	21.38	.03	-0.	-0.	-0.
8		0.	5.0	1.14	.53	2.5	2.16	.105	.327	15.19	2.77	8.00	.75	19.98	0.	-0.	-0.	-0.
9		0.	5.0	1.12	1.65	2.7	3.14	.103	.572	12.54	5.48	7.42	.38	12.97	.05	-0.	-0.	-0.
10		0.	5.0	1.19	.43	3.5	2.80	.134	.035	13.50	3.18	9.96	1.08	19.77	0.	-0.	-0.	-0.

	N	MEAN	STD.DEV	COEFF VAR.	...... CONFIDENCE LIMITS ....(90 PERCENT)..		..(95 PERCENT)..		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.)... TOL: 1	5	10	(95 PCT. CONF.)... 1	5	10
BULK DENS.	10	1.100	.143	13.0	1.017	1.183	.998	1.202	564	23	6	859	34	9
PCT. >2MM.	10	.886	.753	85.0	.449	1.323	.347	1.425	24280	971	243	36975	1479	370
PH	10	3.090	.438	14.2	2.836	3.344	2.776	3.404	676	27	7	1029	41	10
PCT. C	10	2.630	.931	35.4	2.090	3.170	1.964	3.296	4209	168	42	6409	256	64
PCT. N	10	.118	.038	32.0	.097	.140	.091	.146	3430	137	34	5224	209	52
PO4 (PPM)	10	.648	.513	79.1	.351	.945	.282	1.015	21006	840	210	31989	1280	320
C.E.C.	10	12.067	4.016	33.3	9.739	14.395	9.194	14.940	3722	149	37	5668	227	57
CALCIUM	10	3.110	1.836	59.0	2.046	4.174	1.797	4.423	11705	468	117	17825	713	178
MAGNESIUM	10	8.055	3.463	43.0	6.048	10.062	5.578	10.532	6211	248	62	9459	378	95
POTASSIUM	10	.615	.309	50.2	.436	.794	.394	.836	8457	338	85	12879	515	129
SODIUM	10	15.063	5.487	36.4	11.883	18.243	11.138	18.988	4458	178	45	6789	272	68
MANGANESE	10	.014	.019	135.5	.003	.025	.000	.028	61712	2468	617	93979	3759	940

Table 14 cont'd.

VARIABILITY IN SOIL SAMPLE 428 VN   VUNGTAU MANGROVE - CRABMOUNDS   DATE: 22 JAN 74

	N	MEAN	STD.DEV	COEFF VAR.	...... CONFIDENCE LIMITS ..(90 PERCENT)..		..(95 PERCENT)..		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.)... TOL: 1	5	10	(95 PCT. CONF.)... 1	5	10
C DENSITY G/SQ.M/CM	10	276.109	68.146	24.7	236.609	315.610	227.364	324.855	2047	82	20	3117	125	31
N DENSITY G/SQ.M/CM	10	12.532	2.686	21.4	10.976	14.089	10.611	14.454	1543	62	15	2350	94	24
PO4 DENS. MG/SQ.M/CM	10	7.072	5.729	81.0	3.751	10.392	2.974	11.170	22048	882	220	33576	1343	336
CEC DENS. EQ/SQ.M/CM	10	1.275	.354	27.7	1.070	1.480	1.022	1.528	2582	103	26	3932	157	39
CA DENS. EQ/SQ.M/CM	10	.322	.165	51.3	.226	.418	.204	.440	8837	353	88	13457	538	135
MG DENS. EQ/SQ.M/CM	10	.842	.279	33.1	.681	1.004	.643	1.041	3677	147	37	5600	224	56
K DENS. EQ/SQ.M/CM	10	.066	.030	46.4	.048	.083	.044	.087	7245	290	72	11034	441	110
NA DENS. EQ/SQ.M/CM	10	1.594	.486	30.5	1.312	1.875	1.246	1.941	3121	125	31	4753	190	48
MN DENS. EQ/SQ.M/CM	10	.001	.002	137.8	.000	.003	.000	.003	63781	2551	638	97130	3885	971

Table 14 cont'd.

VARIABILITY IN SOIL SAMPLE 428AVN VUNGTAU BIOMASS NO.1 DATE: 22 JAN 74

	N	MEAN	STD.DEV	COEFF VAR.	CONFIDENCE LIMITS ..(90 PERCENT)..		..(95 PERCENT)..		SAMPLE SIZE TO ESTIMATE MEAN +OR- TOL PCT (90 PCT. CONF.)... TOL: 1	5	10	(95 PCT. CONF.)... 1	5	10
C DENSITY G/SQ.M/CM	5	465.780	155.505	33.4	317.512	614.048	272.726	658.834	5066	203	51	8589	344	86
N DENSITY G/SQ.M/CM	5	19.894	8.321	41.8	11.961	27.828	9.564	30.224	7952	318	80	13481	539	135
CEC DENS. EQ/SQ.M/CM	5	2.022	.907	44.9	1.157	2.887	.896	3.148	9151	366	92	15515	621	155
CA DENS. EQ/SQ.M/CM	5	.564	.268	47.5	.309	.819	.232	.896	10240	410	102	17361	694	174
MG DENS. EQ/SQ.M/CM	5	1.537	.760	49.4	.813	2.261	.594	2.480	11102	444	111	18822	753	188
K DENS. EQ/SQ.M/CM	5	.173	.085	49.1	.092	.254	.068	.278	10941	438	109	18548	742	185
NA DENS. EQ/SQ.M/CM	5	3.135	1.845	58.9	1.376	4.894	.844	5.426	15748	630	157	26699	1068	267
MN DENS. EQ/SQ.M/CM	5	.001	.001	52.6	.001	.002	.001	.002	12598	504	126	21358	854	214

able portion of the nitrogen and the potassium is in the foliage relative to the woody portion of the plant. Around 4 g/m^2 are in the foliage of the mangrove forest: approximately 36 lb/acre.

Fertility Status of Soils in the Defoliated Areas of Mangrove Forest

Six sites in the Rung-Sat where mangroves had been defoliated were visited and soil samples collected. It was noted that at each of these sites there had been an almost complete salvage of wood and in many cases even the roots had been dug out of the ground for fuel. The soil properties in the Rung-Sat have been influenced by this complete harvest of the mangrove wood as well as by defoliation.

The data in Table XII for sites 430, 431, 432, and 433 represent soils from such areas in the Rung-Sat. A comparison of these sites with areas 427 and 428 (nondefoliated mangrove forest near Vung-Tau) shows nearly twice as much carbon and nitrogen in the Rung-Sat soils. Also, the Rung-Sat soils have a greater C.E.C. and a larger amount of calcium and potassium on the exchange complex. One can conclude, on the basis of this data, that the defoliated areas visited in the Rung-Sat have fertility levels that are considerably higher than the nondefoliated mangrove forest soils at Vung-Tau.

SUMMARY AND CONCLUSIONS TO SOILS REPORT

1. This study was designed to evaluate the possible effect of forest defoliation in SVN on soil properties associated with fertility.

2. Soils were collected from sites in the upland forest and in mangrove forest areas to determine the range of fertility storage in the soils of these ecosystems.

3. More than 300 soil samples were obtained from upland forest areas of the type that have been subjected to defoliation, some in actual situations comparing defoliated with nondefoliated areas.

4. More than 150 soil samples were obtained from mangrove forest areas of the type that have been subjected to defoliation, some in actual situations comparing defoliated with nondefoliated areas.

5. The soil samples were analyzed for the major fertility elements: nitrogen, phosphorus, calcium, magnesium, potassium, and carbon (for organic matter). Over 6000 analyses have been made of these soils from Southeast Asia. These analyses have been converted from the laboratory values to the actual field storage amounts, taking into account soil density, depth, and stoniness.

6. At selected sites the aboveground vegetation of the forest was sampled for its weight and fertility element contents (nitrogen, phosphorus, calcium, magnesium, potassium, iron, manganese, and zinc). This sampling was carried out on sites where the measurements could be applied to a known area of soil in which the fertility storage was known.

7. Seven intensive vegetation sampling sites were located in mangrove forests, and three in upland forests.

8. The data indicate that the Closed forest soils tend to be more fertile and have a greater capacity to store fertility elements than the Open forest soils.

9. The Closed forest soil should have a greater capacity to buffer changes that might be associated with defoliation.

10. An assessment of two typical sites in the Closed forest shows

storage of fertility elements in the forest vegetation relative to the forest soil is highest for potassium and phosphorus, and lower for nitrogen. In the case of some fertility elements, a relatively high proportion of the total stored fertility on the site (soil + vegetation) is contained in the foliage: more than 20 percent of the total stored potassium and 1 percent of the total stored nitrogen may be found there.

11. A critical aspect of the effect of defoliation on the fertility of the site and of the soil in particular is the disposition of the fertility elements contained in the foliage dropped to the soil, and this has been evaluated in the report.

12. Soils typical of the Closed forest have a moderate to low capacity (55 g eq in 1 m^2 of soil to a depth of 1 m) of C.E.C. This exchange capacity is only partially saturated (to about 23 percent) with such elements as calcium, magnesium, and potassium.

13. The total of the calcium, magnesium, and potassium in the foliage ranges from 6 percent (3.4 g eq/m^2 to 0.6 eq) to 1 percent of the capacity of the soil to retain such cations.

14. The most critical cation element as far as the possibility of loss due to defoliation is potassium, which may be displaced from the soil cation exchange column if any of the other cations are in excess. Since up to 20 percent of the potassium on the site may be in the foliage, a primary is that loss of potassium does not occur due to defoliation and subsequent leaching processes.

15. Secondary succession cover of bamboo maintains much less fertility storage of all elements in its vegetation weight: the largest proportion is in

the roots. Hence, the fertility stored in bamboo would be difficult to release if it were part of a swidden cultivation system. Presumably, a site that has changed to bamboo is one that will be lower in stored fertility.

16. The variability of surface soils in forested areas of SVN was tested by taking multiple samples and subjecting the analytical results to statistical analysis. Minimum numbers of samples were required for less variable soil properties such as pH and bulk density, but in the case of more variable soil properties such as available phosphorus, as many as 434 sampling sites would be required to determine the true value of phosphorus to within ± 10 percent of a 90 percent confidence level.

17. Opinions and conclusions concerning effects of any disturbance (such as defoliation) of the forest soil fertility, unless based upon adequate numbers of samples taken in a random (unbiased) manner, are to be considered as doubtful conclusions subject to the biases of the observer. This pertains to the results of this study as well.

18. In a comparison made between a defoliated plot and a nondefoliated plot 7 years after defoliation, significant changes in fertility elements were noted in nitrogen and available phosphorus in the surface soil layer. In the situation studied, the phosphorus content was reduced by nearly one-half (by nearly 80 lb/acre in the top 2 in. of soil). Nitrogen content was reduced by 10 percent in the defoliated area; a loss of 62 lb/acre to a depth of 2 in. The soil became more acid, dropping from pH 7.0 to 6.0. There was less carbon in the defoliated area, but the difference was not significant. There were no significant differences in the defoliated vs. undefoliated

areas in exchange capacity or in exchangeable calcium, magnesium, or potassium. However, exchangeable sodium was significantly higher in the defoliated area than in the nondefoliated one.

19. Soils were sampled for fertility analysis in mangrove forests at 15 sites, with a total of 162 samples obtained. These indicated that mangrove soils generally had high carbon contents and moderate nitrogen storage amounts with high carbon/nitrogen ratios. The exchangeable cation capacities of the mangrove soils were higher than the upland forest soils, and this was oversaturated with sodium and magnesium as is to be expected due to flooding by seawater.

REFERENCES

Fair, G.M. and J. Geyer. 1954. Water supply and waste water disposal. John Wiley & Sons, Inc., New York. 973 pp.

Rollet, B. 1962? Memorandum on the vegetation of Vietnam south of parallel 17 north. (Defense Mapping Agency Topographic Center translation from French, Washington, D.C., 1972). 48 pp.

Zinke, P.J., S. Sabhasri, and P. Kunstadter. January 19, 1970. Soil fertility aspects of the Lua forest fallow system of shifting cultivation. Chiang Mai, Thailand. Published in Proceedings International Seminar on Economic Development in Northern Thailand. p. 253-278.