PRNC-119
BIOLOGY AND MEDICINE(TID-4500)

PUERTO RICO NUCLEAR CENTER

THE RAIN FOREST PROJECT
ANNUAL REPORT

Jerry R. Kline, Carl F. Jordan, George E. Drewry

June 1, 1968

OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT
NO. AT (40-1)-1833 FOR U. S. ATOMIC ENERGY COMMISSION

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TERRESTRIAL ECOLOGY PROGRAM I
THE RAIN FOREST PROJECT

Jerry R. Kline, Ph.D. Head

ABSTRACT

The Rain Forest Project is a series of studies on one small area of montane rain forest 1500 feet up the side of El Yunque mountain in eastern Puerto Rico. It has three objectives: 1) to study the effects of gamma radiation on the tropical ecosystem; 2) to study mineral cycling and dispersion in the system; 3) and to study the basic biological functions of this ecosystem such as respiration, transpiration, and photosynthesis to better understand phenomena related to the first two objectives. The project is in its fifth year. A section of the forest was irradiated and many follow-up studies have been completed. (For details of the radiation experiment see PRNC-82, Annual Report 1965). Present effort is being directed to long term studies on recovery and succession of vegetation in the irradiated area, and to detailed investigations of mineral cycling and distribution in the tropical ecosystem. Studies are carried out at both the PRNC Rio Piedras Laboratories and at the El Verde field laboratory.

This year's report contains sections on recovery of the irradiated area, light measurements in the forest, water and nutrient cycling in the forest and radionuclide behaviour in certain animals. An appendix lists papers which have been published or have been submitted. The report is assembled from subsections which contain preliminary summaries of subprojects. Each subproject is a convenient work unit which may or may not be sufficient unto itself, in providing explanations for processes taking place in the rain forest. The subsections are signed by the investigator who prepared them and who took the greatest initiative in carrying out the work. Final summaries are prepared by combining subsections in appropriate ways under the co-authorship of various project scientists.

Figure 1. Irradiated area, Nov. 1966. Pipes and cement platform in center supported source.

Figure 2. Irradiated area, Feb. 1968. Thick growth of Cecropia peltata blocks view of source location.

RADIATION RECOVERY*

C.F. Jordan

The objective of these studies is to determine how the radiation damaged area recovers, and to compare this recovery with recovery of another area in the forest that was mechanically stripped of leaves. Total biomass, number of individual plants, and species diversity were determined in 1966 and 1967 by measuring every plant within a 676 m^2 grid that surrounds the radiation source location. Data was broken down into several categories; new vegetation (started from seed after radiation ceased), sprouts, old vegetation (plants existing prior to radiation), and vegetation occurring on the two soil types within the irradiated area. Biomass data was determined by digging up 150 small trees, 35 sprouts and 10 m^2 of grass in another area, measuring them, getting their dry weight, correlating weight with diameter, and applying these correlations to plants in the irradiated area. Correlation coefficients and other statistics are given in Table 1.

Radiation recovery was compared to recovery from mechanical stripping by leaf area index measurements. Table 2 shows that while quantity of new vegetation in the irradiated area has been increasing, quantity in the stripped area began to decline in the summer of 1967. The decrease in new vegetation in the stripped area coincides with an increase in the stripped canopy (old vegetation). Dieback of the irradiated canopy apparently has ceased.

Species diversity and number of individuals increased by about a half, between 1966 and 1967 (Table 3). Biomass more than tripled in this one year (Table 4). Biomass of important species and groups of species in 1966 is given in Table 5.

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*Continuing effort

Table 1

Biomass correlation statistics

A Correlations

Y = Biomass in grams of dry weight

X = Basal diameter in $\frac{1}{128}$ of an inch

N = Number of samples on which regression was based

Tree-shaped species (less than 2 inches diameter)

$Y = .0289x^2 - .2525x - 13.4557$ ($N = 150$)

Sprouts

$Y = .0203x^2 + .7657x - 24.40$ ($N = 35$)

Phytolacca

$Y = .0376x^2 - 2.4276x + 28.1843$ ($N = 13$)

Grasses and Sedges

$Y = 426.$ (% coverage of one m^2) ($N = 10$)

Desmodium

$Y = 615.$ (% coverage of one m^2) ($N = 10$)

B Fitting all tree species to one correlation

Slope and Y intercept of the regression and log of biomass on log of basal diameter for *Drypetes glauca* was tested against slope and Y intercept for *Piper aduncum* by analysis of covariance to test for differences in these two species, both of which have a tree-like shape, that is, a single stem. An "F" test indicated no difference in slope nor in Y intercept. Therefore one correlation was used for all tree-like species.

Continued Table 1

C Determining best correlation

Determined from 10 samples of *Piper aduncum*

X	Y	Correlation coefficient
diameter	weight	.97
height	weight	.94
diameter	height	.93
height (adjusted for dia.-wt. correlation)	weight	.24

Little, if anything, is gained by height measurement, after weight measurement is made.

D Reliability of regression

The 95% limit of confidence around the regression line generated by the log of data derived from 10 samples of *Piper aduncum* at 5 values of X, is:

Diameter (X) ($\frac{1}{128}$ S of an inch)	Dry Weight (Y) (grams)	±	(a=.95)
20	1.2		3.0
50	20.4		2.7
70	56.9		2.7
100	168.5		2.8
200	1395.0		3.0

Table 2

Leaf area indexes of new and old vegetation in the irradiated and mechanically stripped areas

	Leaf Area Index			
	Aug. 1966	Feb. 1967	Aug. 1967	Feb. 1968
Irradiated area, new vegetation	.96	1.64	2.90	3.26
Stripped area, new vegetation	1.51	1.65	1.63	1.45
Irradiated area, old vegetation	2.20	2.10	2.21	2.25
Stripped area, old vegetation	2.53	2.73	2.82	3.02

Table 3

Summary of species and individuals in various categories, in the irradiated area, in 1966 and 1967.

	No. of species	No. of individuals
1966		
Well drained soil ($386m^2$)		
New vegetation	67	2,577
Sprouts	29	469
Old vegetation	47	537
Poorly drained soil ($290m^2$)		
New vegetation	60	1,202
Sprouts	22	174
Old vegetation	38	287
Total, 1966	97*	5,246
1967		
Well drained soil		
New vegetation	99	4,111
Sprouts	43	647
Old vegetation	36	275
Poorly drained soil		
New vegetation	98	3,268
Sprouts	25	258
Old vegetation	24	112
Total, 1967	121*	8,671

*Several species occur in several groups. Therefore, total number of species for entire area does not equal the sum of the individual groups.

Table 4

Biomass of new plants and sprouts in the irradiated area in 1966 and 1967

	Total gms. in area (dry weight)	G/m^2 (dry weight)
1966		
Well drained soil ($386m^2$)		
New vegetation	95,388	247
Sprouts	26,678	69
Poorly drained soil ($290m^2$)		
New vegetation	36,691	126
Sprouts	4,899	16
Total, 1966	163,656	242*
1967		
Well drained soil		
New vegetation	323,256	837
Sprouts	47,727	123
Poorly drained soil		
New vegetation	139,893	482
Sprouts	8,744	30
Total, 1967	519,620	768*

*This is the average biomass/m^2 for total area.

Figs. 1 and 2 show the change in the irradiated area in 16 months due to growth of new vegetation. Table 6, which shows numbers of individuals for every species, is a reference list for future studies.

Both the mechanically stripped area and the irradiated area are recovering, but in different ways. The stripped area is recovering by regrowth of the old canopy, while in the irradiated area, recovery is mainly by growth of new vegetation. Rates of increase of species diversity and number of individuals are very high in the irradiated area at the present time. Species diversity is now higher than the species diversity of the mature forest. Within the next few years, diversity and number of individuals should start a downward trend toward the levels of the mature forest. Standing biomass will of course continue to increase from year to year, but it will be very interesting to see at what stage the forest will have the highest rate of biomass production.

Table 5

Biomass of important species and groups of species of new vegetation in the irradiated area in 1966.

Species or group	Grams, dry weight	Percent, total biomass
Phytolacca icosandra	11,406	6.9%
Desmodium procumbens	4,110	2.5%
Psychotria berteriana	25,779	15.7%
Palicourea riparia	13,033	7.9%
Cecropia peltata	15,497	9.4%
Tabebuia heterophylla	5,967	3.6%
Didymopanax morototoni	12,559	7.6%
Grasses and sedges	32,804	20.0%
Sprouts	31,577	19.2%
Other herbs	745	.4%
Other trees	10,199	6.2%

Table 6

Number of individuals of each species in $676m^2$ surrounding the radiation source in 1966 and 1967. Species are grouped according to whether vegetation originated before or after radiation, whether the individuals are sprouts, soil type on which individuals occur, and year of sampling. An asterisk indicates a grass-like plant, and numbers in "individuals" column for these species indicate number of quadrats in which species was found.

Vascular plants, originating after radiation from seed, in the radiation area in the fall of 1966, on the soil showing oxidized conditions.

Species	Individuals
Psychotria berteriana D.C.	509
Palicourea riparia Benth. & Hook.	254
Cecropia peltata L.	214
Didymopanax morototoni (Aubl.) Dcne. & Pl.	191
Icnanthus pallens (Sw.) Munro; Benth.	183*
Casearia bicolor Urban.	150
Alchornea latifolia Sw.	132
Linociera domingenis (Lam.) Knobl.	112
Miconia racemosa (Aubl.) Dc.	108
Tabebuia pallida Miers.	98
Securidaca virgata Sw.	86
Rajania cordata L.	58
Byrsonima coriacea (Sw.) Dc.	44
Phytolacca icosandra L.	43
Alchorneopsis portoricensis Urban.	41
Miconia tetrandra (Sw.) D. Don.	37
Paspalum conjugatum Berg.	34*
Drypetes glauca Vahl.	31
Nepsera aquatica (Aubl.) Naud.	29
Miconia prasina (Sw.) Dc.	23
Dacryodes excelsa Vahl.	19
Desmodium procumbens (Mill.) Hitcha.	16*
Solanum rugosum Dunal.	15
Casearia arborea (L.C. Rich.) Urban.	14
Inga vera Willd.	13
Croton poecilanthus Urban.	10
Clidemia strigillosa (Sw.) Dc.	10
Spermacoce confusa Rendle.	10
Heteropteris laurifolia (L.) Juss.	7
Ocotea leucoxylon (Sw.) Mez.	7
Sapium laurocerasus Desf.	6

Continued Table 6

Sloanea berteriana Choisy	2
Ocotea moschata (Pavon) Mez.	2
Smilax coriacea Spreng.	2
Solanum torvum Sw.	2
Epidendrum nocturnum Jacq.	2
Ipomea repanda Jacq.	2
Neorudolphia volubilis (Willd.) Britton.	2
Tetragastris balsamifera (Sw.) Kuntze.	2
Guettarda laevis Urban.	1
Matayba domingensis (Dc.) Radlk.	1
Ocotea portoricensis Mez.	1
Hedychium coronarium Koenig	1
Peperomia rotundifolia (L.) H.B.K.	1
Euterpe globosa Gaertn.	1
Casearia sylvestris Sw.	1
Piper aduncum L.	1
Ficus sintenisii Warb.	1
Cyrilla racemiflora L.	1
Piper amalago L.	1
Piper treleaseanum Britton & Wilson	1
Citrus spp.	1
Cordia sulcata Dc.	1
Panicum boliviense Hack.	1*
Polypodum spp.	1
Guatteria caribaea Urb.	1
Eugenia stahlii (Kiaersk) Krug & Urban.	5
Marcgravia rectiflora Tr. & Pl.	4
Henrietella fascicularis (Sw.) C. Wright	4
Guarea ramiflora Vent.	4
Cordia borinquensis Urban.	4
Manilkara bidentata (A.Dc.) Cher.	3
Inga fagifolia (L.) Willd.	3
Meliosma herberti Rolfe.	3
Elephantopus mollis L.	3
Rourea glabra Griseb.	3

Continued Table 6

Sprouts, originating after radiation, in the radiation area in the fall of 1966, on the soil showing oxidized conditions.

Species	Individuals
Sloanea berteriana Choisy.	175
Palicourea riparia Benth. & Hook.	33
Rourea glabra Griseb.	28
Dacryodes excelsa Vahl.	28
Matayba domingensis (Dc.) Radlk.	22
Drypetes glauca Vahl.	18
Eugenia stahlii (Kiaersk) Krug & Urban.	17
Manilkara bidentata (A.Dc.) Cher.	16
Hirtella rugosa Pers.	16
Inga fagifolia (L.) Willd.	14
Ocotea moschata (Pavon) Mez.	12
Guettarda laevis Urban.	12
Miconia prasina (Sw.) Dc.	10
Croton poecilanthus Urban.	10
Meliosma herberti Rolfe.	9
Ormosia krugii Urban	8
Tetragastris balsamifera (Sw.) Kuntze	7
Micropholis garcinifolia Pierre.	6
Marcgravia rectiflora Tr. & Pl.	6
Byrsonima coriacea (Sw.) Dc.	4
Heteropteris laurifolia L. Juss.	4
Poliocarpus calinoides (Eichl.) Gilg.	2
Psychotria berteriana Dc.	2
Ardisia glauciflora Urban.	2
Myrcia splendens (Sw.) Dc.	2
Rajania cordata L.	1
Miconia racemosa (Aubl.) Dc.	1
Ocotea portoricensis Mez.	1
Ixora ferrea (Jacq.) Benth.	1

Continued Table 6

Vascular plants, at least partly living, originating before radiation, growing in the radiation area in the fall of 1966, on the soil showing oxidized conditions.

Species	Individuals
Sloanea berteriana Choisy	115
Rourea glabra Griseb.	84
Eugenia stahlii (Kiaersk) Krug & Urban	51
Dacryodes excelsa Vahl.	30
Palicourea riparia Benth. & Hook.	28
Manilkara bidentata (A.Dc.) Cher.	27
Tetragastris balsamifera (Sw.) Kuntze	26
Heteropteris laurifolia (L.) Juss.	20
Inga fagifolia (L.) Willd.	20
Drypetes glauca Vahl.	14
Myrcia leptoclada Dc.	14
Meliosma herberti Rolfe.	12
Matayba domingensis (Dc.) Radlk.	8
Casearia arborea (L.C. Rich.) Urban.	8
Hirtella rugosa Pers.	7
Euterpe globosa Gaertn.	7
Micropholis garciniaefolia Pierre.	6
Miconia prasina (Sw.) Dc.	5
Guettarda laevis Urban.	4
Ormosia krugii Urban.	4
Ixora ferrea (Jacq.) Benth.	4
Ocotea leucoxylon (Sw.) Mez.	4
Miconia tetrandra (Sw.) D. Don.	4
Ocotea moschata (Pavon) Mez.	3
Linociera domingenis (Lam.) Knobl.	3
Cordia borinquensis Urban.	3
Alchornea latifolia Sw.	3
Cecropia peltata L.	2
Byrsonima coriacea (Sw.) Dc.	2
Homalium racemosum Jacq.	2
Casearia sylvestris Sw.	1
Smilax coriacea Spreng.	1
Casearia guianensis (Aubl.) Urban.	1
Alchorneopsis portoricensis Urban.	1
Didymopanax morototoni (Aubl.) Dcne. & Pl.	1
Buchenavia capitata (Vahl.) Eichl.	1
Tabebuia pallida Miers.	1
Ocotea floribunda (Sw.) Mez.	1
Daphnopsis philippiana Krug. & Urban.	1

Continued Table 6

Ardisia glauciflora Urban	1
Myrcia deflexa (Poir.) Dc.	1
Ocotea portoricensis Mez.	1
Schlegelia brachyantha Urban.	1
Guarea ramiflora Vent.	1
Unknown species	1
Cordia sulcata Dc.	1

Vascular plants, originating after radiation from seed, in the radiation area in the fall of 1966, on the soil showing reduced conditions.

Species	Individuals
Palicourea riparia Benth. & Hook.	203
Tabebuia pallida Miers.	199
Icnanthus pallens (Sw.) Munro; Benth.	133*
Securidaca vilgata Sw.	91
Psychotria berteriana Dc.	79
Didymopanax morototoni (Aubl.) Dcne. & Pl.	63
Cecropia peltata L.	56
Alchornea latifolia Sw.	48
Croton poecilanthus Urban.	35
Drypetes glauca Vahl.	26
Desmodium procumbens (Mill.) Hitchc.	26*
Linociera domingensis (Lam.) Knobl.	23
Miconia tetrandra (Sw.) D. Don.	20
Inga vera Willd.	17
Miconia racemosa (Aubl.) Dc.	17
Dacryodes excelsa Vahl.	13
Rajania cordata L.	13
Panicum bolivense Hack.	12*
Scleria spp.	8*
Eugenia stahlii (Kiaersk) Krug & Urban.	7
Inga fagifolia (L.) Willd.	7
Casearia bicolor Urban.	7
Byrsonima coriacea (Sw.) Dc.	6
Paspalum conjugatum Berg.	6*
Miconia tetrandra (Sw.) D. Don.	6
Nepsera aquatica (Aubl.) Navd.	5
Miconia prasina (Sw.) Dc.	5
Rourea glabra Griseb.	4

Continued Table 6

Casearia arborea (L.C. Rich.) Urban	4
Matayba domingensis Dc. Radlk.	4
Neorudolphia volubilis (Willd.) Britton	4
Psychotria brachiata Sw.	4
Alchorneopsis portoricensis Urban	3
Heteropteris laurifolia L. (Juss.)	3
Ixora ferrea (Jacq.) Benth.	3
Smilax coriacea Spreng.	3
Phytolacca icosandra L.	3
Piper hispidum Sw.	3
Cissampelos pareira L.	3
Sauragesia erecta L.	3
Sloanea berteriana Choisy.	2
Marcgravia rectiflora Tr. & Pl.	2
Piper treleaseanum Britton & Wilson	2
Trichilia pallida Sw.	2
Henrietella fascicularis (Sw.) C. Wright.	2
Solanum rugosum Dunal.	2
Guarea ramiflora Vent.	2
Cayaponia americana (Lam.) Cogn.	2
Euterpe globosa Gaertm.	2
Tournefortia hirsutissima L.	1
Coccolobis pirifolia Desf.	1
Calycogonium squamulosum Cogn.	1
Ocotea leucoxylon (Sw.) Mez.	1
Guettarda laevis Urban.	1
Dendropanax arboreum (L.) Dcne. & P.	1
Mikania fragilis Urban.	1
Guettarda caribaea Urban.	1
Philodendron lingulatum (L.) C. Koch.	1
Cordia borinquensis Urban	1
Casearia sylvestris Sw.	1

Continued Table 6

Sprouts, originating after radiation, in the radiation area in the fall of 1966, on the soil showing reduced conditions.

Species	Individuals
Croton poecilanthus Urban.	48
Palicourea riparia Benth. & Hook	17
Marcgravia rectiflora Tr. & Pl.	17
Rourea glabra Griseb.	4
Sloanea berteriana Choisy.	9
Drypetes glauca Vahl.	9
Heteropteris laurifolia (L.) Juss.	9
Casearia sylvestris Sw.	8
Inga vera Willd.	6
Eugenia stahlii (Kiaersk) Krug. & Urban.	6
Byrsonima coriacea (Sw.) Dc.	5
Ixora ferrea (Jacq.) Benth.	5
Manilkara bidentata (A.Dc.) Cher.	4
Casearia arborea (L.C. Rich.) Urban.	4
Piper amalago L.	3
Miconia tetrandra (Sw.) D. Don.	3
Ocotea portoricensis Mez.	3
Inga fagifolia (L.) Willd.	2
Calycogonium squamulosum Cogn.	2
Cordia borinquensis Urban.	1
Matayba domingensis (Dc.) Radlk.	1
Miconia prasina (Sw.) Dc.	1

Continued Table 6

Vascular plants, at least partly living, originating before radiation, growing in the radiation area in the fall of 1966, on the soil showing reduced conditions.

Species	Individuals
Palicourea riparia Benth. & Hook	42
Rourea glabra Griseb.	41
Heteropteris laurifolia L. Juss.	38
Eugenia stahlii (Kiaersk) Krug. & Urban	18
Euterpe globosa Gaertn.	18
Drypetes glauca Vahl.	14
Inga fagifolia (L.) Willd.	10
Guarea ramiflora Vent.	10
Manilkara bidentata (A. Dc.) Cher.	9
Cordia borinquensis Urban	8
Sloanea berteriana Choisy	8
Miconia tetrandra (Sw.) D. Don.	7
Dacryodes excelsa Vahl.	6
Ixora ferrea (Jacq.) Benth.	5
Tabebuia pallida Miers.	5
Ocotea portoricensis Mez.	4
Calcogonium squamulosum Cogn.	4
Alchornea latifolia Sw.	4
Matayba domingensis (Dc.) Radlk.	4
Casearia sylvestris Sw.	3
Marcgravia rectiflora Tr. & Pl.	3
Tetragastris balsamifera (Sw.) Kuntze.	3
Homalium racemosum Jacq.	3
Miconia prasina (Sw.) Dc.	2
Micropholis garcinifolia Pierre.	2
Hirtella rugosa Pers.	2
Croton poecilanthus Urban.	2
Cecropia peltata L.	2
Inga vera Willd.	2
Casearia arborea (L.C. Rich.) Urban	1
Cyrilla racemiflora L.	1
Piper amaloago L.	1
Myrcia splendens (Sw.) Dc.	1
Ormosia krugii Urban	1
Cassipourea alba Griseb.	1
Myrcia deflexa (Poin) Dc.	1
Pisonia subcordata Sw.	1
Dennstaedtia adiantoides (H. & B.) Moore	1

Continued Table 6

Vascular plants, originating after radiation from seed, in the radiation area in the fall of 1967, on the soil showing oxidized conditions.

Species	Individuals
Psychotria berteriana Dc.	643
Didymopanax morototoni (Aubl.) Dcne. & Pl.	323
Icnanthus pallens (Sw.) Munro; Benth.	321*
Palicourea riparia Benth. & Hook.	277
Tabebuia pallida Miers.	272
Linociera domingenis (Lam.) Knobl.	271
Miconia sintensii Cogn.	263
Securidaca virgata Sw.	126
Casearia bicolor Urban.	126
Casearia arborea (L.C. Rich.) Urban.	97
Miconia prasina (Sw.) Dc.	97
Cecropia peltata L.	95
Pospalum conjugatum Berg.	91*
Desmodium procumbens (Mill.) Hitchu.	69*
Rourea glabra Griseb.	61
Byrsonima coriacea (Sw.) Dc.	58
Alchornea latifolia Sw.	57
Mikania fragilis Urban.	56
Dryopteris deltoidea (Sw.) Kuntze.	53
Euterpe globosa Gaertn.	50
Alchorneopsis portoricensis Urban.	49
Matayba domingensis (Dc.) Radlk.	49
Drypetes glauca Vahl.	44
Dacryodes excelsa Vahl.	39
Nepsera aquatica (Aubl.) Naud.	31
Miconia tetrandra (Sw.)	30
Guarea trichilioides L.	29
Cyathea arborea (L.) J.E. Smith	26
Guarea ramiflora Vent.	21
Eugenia stahlii (Kiaersk) Krug. & Urban.	19
Manilkara bidentata (A.Dc.) Cher.	19
Sloanea berteriana Choisy.	19
Heterotrichum cymosum (Wendl.) Urban.	18
Nephrolepis rivularis (Vahl.) Mett.	17
Solanum rugosum Dunal.	16
Ocotea leucoxylon (Sw.) Mez.	15
Alsophila borinqueña Maxon.	15
Inga vera Willd.	13

Continued Table 6

Heteropteris laurifolia (L.) Juss.	13
Hirtella rugosa Pers.	13
Tetragastris balsamifera (Sw.) Kuntze	13
Piper aduncum L.	12
Ipomoea repanda Jacq.	11
Commelina sp.	9
Panicum boliviense Hack.	8*
Homalium racemosum Jacq.	8
Ocotea moschata (Pavon.) Mez.	8
Phytolacca icosandra L.	7
Dioscorea polygonoides H.&B.; Willd.	7
Guettarda laevis Urban.	7
Sapium laurocerasus Desf.	6
Clusia gundlachii Stahl.	6
Marcgravia rectiflora Tr. & Pl.	5
Elephantopis mollis L.	5
Cordia borinquensis Urban.	5
Doliocarpus calinoides (Eichl.) Gilg.	5
Henrietella fascicularis (Sw.) Sauville.	5
Cyrilla racemiflora L.	4
Borreira ocimoides (Burm. f.) Dc.	4
Myrcia splendens (Sw.) Dc.	4
Piper treleaseanum Britton & Wilson.	4
Cordia sulcata Dc.	4
Daphnopsis philippiana Krug. & Urban.	4
Rajania cordata L.	3
Casearia sylvestris Sw.	3
Solanum torvum Sw.	3
Ocotea portoricensis Mez.	3
Desmodium sp.	3*
Solanum sp.	3
Inga fagifolia (L.) Willd.	2
Spermacoce tenuior L.	2
Hedychium coronarium Koenig.	2
Roystonea borinqueña Cook.	2
Ormosia krugii Urban.	2
Micropholis garcinifolia Pierre.	2
Meliosma herbertii Rolfe.	2
Miconia racemosa (Aubl.) Dc.	2
Paullinia pinnata L.	2
Heliconia bihai L.	2
Paspalum sp.	2*
Smilax coriacea Spreng.	1

Continued Table 6

Sauvagesia erecta L.	1
Ixora ferrea Jacq; Benth.	1
Piper amalago L.	1
Eupatorium odoratum L.	1
Ficus laevigata Vahl.	1
Mikania cordifolia (L.F.) Willd.	1
Clidemia strigillosa (Sw.) Dc.	1
Polypodium sp.	1
Cayaponia americana (Lam.) Cogn.	1
Ficus trigonata L.	1
Eugenia jambos L.	1
Guatteria caribea Urban.	1
Cestrum macrophyllum Vent.	1
Unknown species	1
Myrcia leptoclada Dc.	1
Comocladia glabra (Schultes) Spreng.	1
Spigelia anthelmia L.	1
Scleria sp.	1*

Sprouts, originating after radiation, in the radiation area in the fall of 1967, on the soil showing oxidized conditions.

Species	Individuals
Sloanea berteriana Choisy.	163
Palicourea riparia Benth. & Hook.	122
Psychotria berteriana Dc.	72
Rourea glabra Griseb.	61
Matayba domingensis (Dc.) Radlk.	22
Miconia sintenisii Cogn.	20
Eugenia stahlii (Kiaersk) Krug. & Urban.	15
Croton poecilanthus Urban.	14
Dacryodes excelsa Vahl.	14
Myrcia leptoclada Dc.	13
Inga fagifolia (L.) Willd.	12
Meliosma herbertii Rolfe.	9
Ormosia krugii Urban.	9
Ocotea moschata (Pavon.) Mez.	9
Heteropteris laurifolia (L.) Juss.	8
Miconia prasina (Sw.) Dc.	7
Casearia arborea (L.C. Rich.) Urban.	6
Marcgravia rectiflora Tr. & Pl.	6

Continued Table 6

Tetragastris balsamifera (Sw.) Kuntze.	5
Tabebuia pallida Miers.	4
Mikania fragilis Urban.	4
Cordia borinquensis Urban.	4
Trichilia pallida Sw.	4
Alchorneopsis portoricensis Urban.	4
Drypetes glauca Vahl.	3
Manilkara bidentata (A.Dc.) Cher.	3
Piper aduncum L.	3
Didymopanax morototoni (Aubl.) Dcne. & Pl.	3
Cecropia peltata L.	3
Byrsonima coriacea (Sw.) Dc.	3
Solanum rugosum Dunal.	2
Linociera domingenis (Lam.) Knobl.	2
Myrcia splendens (Sw.) Dc.	2
Casearia bicolor Urban.	2
Hirtella rugosa Pers.	2
Alchornea latifolia Sw.	2
Ocotea portoricensis Mez.	2
Micropholis garcinifolia Pierre.	2
Ardesia glauciflora Urban.	2
Cyathea arborea (L.) J.E. Smith	1
Dioscorea polygonoides H.&B.; Willd.	1
Schlegelia brachyantha Urban.	1
Inga vera Willd.	1

Vascular plants, at least partly living, originating before radiation, growing in the radiation area in the fall of 1967, on the soil showing oxidized conditions.

Species	Indidivuals
Sloanea berteriana Choisy	76
Eugenia stahlii (Kiaersk) Krug. & Urban.	32
Rourea glabra Griseb.	27
Palicourea riparia L.	21
Manilkara bidentata (A.Dc.) Cher.	15
Heteropteris laurifolia (L.) Juss.	14
Inga fagifolia (L.) Willd.	12
Dacryodes excelsa Vahl.	8
Euterpe globosa Gaertn.	6
Guettarda laevis Urban.	5
Tetragastris balsamifera (Sw.) Kuntze	5
Myrcia leptoclada Dc.	5
Matayba domingensis (Dc.) Radlk.	4

Continued Table 6

Ormosia krugii Urban.	4
Hirtella rugosa Pers.	4
Micropholis garcinifolia Pierre.	4
Miconia tetrandra Sw.	3
Ixora ferrea Jacq. Benth.	3
Drypetes glauca Vahl.	3
Cordia borinquensis Urban.	3
Meliosma herbertii Rolfe.	3
Linociera domingenis (Lam.) Knobl.	2
Byrsonima coriacea (Sw.) Dc.	2
Daphnopsis philippiana Krug. & Urban.	2
Cordia sulcata Dc.	1
Miconia prasina (Sw.) Dc.	1
Homalium racemosum Jacq.	1
Ocotea moschata (Pavon.) Mesz.	1
Casearia arborea	1
Tabebuia pallida Miers.	1
Didymopanax morototoni (Aubl.) Dcne. & Pl.	1
Cecropia peltata L.	1
Cyrilla racemiflora L.	1
Ocotea leucoxylon (Sw.) Mez.	1
Marcgravia rectiflora Tr. & Pl.	1
Croton poecilanthus Urban.	1

Vascular plants, originating after radiation from seed, in the radiation area in the fall of 1967, on the soil showing reduced conditions.

Species	Individuals
Tabebuia pallida Miers.	884
Palicourea riparia Benth. & Hook.	383
Icnanthus pallens (Sw.) Munro; Benth.	234*
Securidaca virgata Sw.	198
Miconia sintenisii Cogn.	126
Psychotria berteriana Dc.	122
Didymopanax morototoni (Aubl.) Dcne. & Pl.	108
Desmodium procumbens (Mill.) Hitchu.	106*
Cecropia peltata L.	80
Croton poecilanthus Urban.	72
Mikania fragilis Urban.	67
Paspalum conjugatum Berg.	58*
Linociera domingenis (Lam.) Knobl.	55

Continued Table 6

Drypetes glauca Vahl.	51
Nepsera aquatica (Aubl.) Naud.	49
Miconia prasina (Sw.) Dc.	44
Inga vera Willd.	35
Alchorneopsis portoricensis Urban.	35
Alchornea latifolia Sw.	32
Panicum boliviense Hack.	30*
Casearia bicolor Urban.	27
Cyrilla racemiflora L.	22
Guarea trichilioides L.	21
Euterpe globosa Gaertn.	20
Dacryodes excelsa Vahl.	19
Marcgravia rectiflora Tr. & Pl.	19
Eugenia stahlii (Kiaersk) Krug. & Urban.	17
Rourea glabra Griseb.	17
Piper aduncum L.	17
Dryopteris deltoidea (Sw.) Kuntze.	16
Phytolacca icosandra L.	16
Byrsonima coriacea (Sw.) Dc.	16
Matayba domingensis (Dc.) Radlk.	15
Guettarda laevis Urban	14
Axonopus compessus (Sw.) Beauv.*	13
Ocotea leucoxylon (Sw.) Mez.	12
Casearia arborea (L.C. Rich.) Urban.	11
Smilax coriacea Spreng.	11
Homalium racemosum Jacq.	10
Scleria canescens Boeckl.	10*
Rajania cordata L.	10
Sauvagesia erecta L.	9
Miconia tetrandra Sw.	9
Heteropteris laurifolia (L.) Juss.	8
Psychotria brachiata Sw.	7
Cyathea arborea (L.) J.E. Smith.	7
Borreria ocimoides (Burm. F.) Dc.	7
Ixora ferrea Jacq.; Benth.	7
Casearia arborea (L.C. Rich.) Urban.	5
Elephantopis mollis L.	5
Clusia gundlachii Stahl.	5
Sapium laurocerasus Desf.	5
Inga fagifolia (L.) Willd.	5
Heterotrichum cymosum (Wendl.) Urban.	5
Trichilia pallida Sw.	4
Pothomorphe umbellata Kunth.	4

Continued Table 6

Dryopteris deltoidea (Sw.) Kuntze.	4
Cordia borinquensis Urban.	4
Alsophila borinqueña Maxon.	4
Casearia sylvestris Sw.	4
Solanum rugosum Dunal.	3
Hedychium coronarium Koenig.	3
Neorudolphia volubilis (Willd.) Britton.	3
Piper amalago L.	3
Dioscorea polygonoides H. & B.; Willd.	3
Sloanea berteriana Choisy.	3
Ficus laevigata Vahl.	2
Bidens pilosa L.	2
Eupatorium odoratum L.	2
Fuirena squarrosa Michx.	2
Piper treleaseanum Britton & Wilson.	2
Manilkara bidentata (A. Dc.) Cher.	2
Spermacoce tenvior L.	2
Nephrolepis rivularis (Vahl.) Mett.	2
Solanum torvum Sw.	1
Mikania cordifolia (L.F.) Willd.	1
Clidemia strigillosa (Sw.) Dc.	1
Ocotea moschata	1
Odontosoria sp.	1
Unknown grass	1*
Polypodium chnoodes Spreng.	1
Unknown species	1
Myrcia splendens (Sw.) Dc.	1
Unknown species	1
Philodendron lingulatum (L.) C. Koch.	1
Desmodium sp.	1*
Roystonea borinqueña Cook.	1
Ocotea floribunda (Sw.) Mez.	1
Guarea ramiflora Vent.	1
Solanum sp.	1
Gonzalagunia hirsuta (Jacq.) Schum.	1
Adiantum petiolatum Desv.	1
Cissampelos pareira L.	1
Myrcia splendens (Sw.) Dc.	1
Ocotea portoricensis Mez.	1
Cayaponia americana (Lam.) Cogn.	1
Polypodium sp.	1
Ficus trigonata L.	1

Continued Table 6

Sprouts, originating after radiation, in the radiation area in the fall of 1967, on the soil showing reduced conditions.

Species	Individuals
Palicourea riparia Benth. & Hook.	72
Croton poecilanthus Urban.	64
Heteropteris laurifolia (L.) Juss.	19
Rourea glabra Griseb.	17
Tabebuia pallida Miers.	10
Inga fagifolia (L.) Willd.	9
Casearia sylvestris Sw.	9
Eugenia stahlii (Kiaersk) Krug. & Urban	8
Drypetes glauca Vahl.	6
Casearia arborea (L.C. Rich.) Urban.	5
Matayba domingensis (D.C.) Radlk.	5
Sloanea berteriana Choisy.	4
Manilkara bidentata (A.Dc.) Cher.	4
Dacryodes excelsa Vahl.	4
Calycogonium squamulosum Cogn.	4
Ocotea portoricensis Mez.	3
Cyrilla racemiflora L.	2
Securidaca virgata Sw.	2
Piper aduncum L.	2
Psychotria berteriana Dc.	2
Marcgravia rectiflora Tr. & Pl.	2
Mikania fragilis Urban.	2
Cordia borinquensis Urban.	1
Didymopanax morototoni (Aubl.) Dcne. & Pl.	1
Psychotria brachiota Sw.	1

Continued Table 6

Vascular plants, at least partly living, originating before radiation, growing in the radiation area in the fall of 1967, on the soil showing reduced conditions.

Species	Individuals
Palicourea riparia Benth. & Hook.	33
Eugenia stahlii (Kiaersk) Krug. & Urban	10
Heteropteris laurifolia (L.) Juss.	10
Rourea glabra Griseb.	6
Drypetes glauca Vahl.	6
Manilkara bidentata (A. Dc.) Cher.	6
Inga fagifolia (L.) Willd.	6
Ixora ferrea Jacq. Benth.	5
Sloanea berteriana Choisy.	4
Guarea ramiflora Vent.	4
Miconia tetrandra Sw.	3
Calycogonium squamulosum Cogn.	2
Cordia borinquensis Urban.	2
Myrcia leptoclada Dc.	2
Euterpe globosa Gaertn.	2
Homalium racemosum Jacq.	2
Casearia arborea (L.C. Rich.) Urban.	2
Cecropia peltata L.	1
Didymopanax morototoni (Aubl.) Dcne. & Pl.	1
Alchornea latifolia Sw.	1
Casearia sylvestris Sw.	1
Matayba domingensis (Dc.) Radlk.	1
Inga vera Willd.	1
Ocotea portoricensis Mez.	1

OPTICAL MEASURE OF LEAF AREA INDEX*

C.F. Jordan

To calculate total fallout burden in the canopy and to calculate quantity of stable elements in the canopy for the biogeochemical cycling studies, total biomass of the canopy leaves must be known. Biomass can be calculated by multiplying average leaf biomass per m^2 by the leaf area index. Average leaf biomass is easy to obtain, but a method is required to measure leaf area index over a large portion of the forest. I found that leaf area index is proportional to the following ratio of light intensities measured at the forest floor: $\frac{800 \text{ mu}}{675 \text{ mu}}$. The principle underlying this relationship is that the canopy is relatively transparent to light in the infra-red, while it absorbs relatively large amounts of light in the visible red. Therefore, the more leaves in the canopy, the greater will be the difference in intensity of radiation at these two wavelengths at the forest floor.

On three sunny days, light was measured on every platform of the walk-up tower. The $\frac{800 \text{ mu}}{675 \text{ mu}}$ ratio was plotted against height, and leaf area index at the tower site (Fig. 1). Leaf area index was measured by throwing a string with a weight on the end off the top of the tower 16 times, and counting the number of leaves touching the string. The slight irregularities in Fig. 1 are probably caused by insufficient light readings at each level. Although total light intensities vary throughout the day, the infra-red/red ratio remains constant when measured above the canopy (Fig. 2).

It appears that after additional calibrations are made on the walk up tower and on other towers in the forest, infra-red/red ratios may be a suitable method for surveying the leaf area index of the entire forest.

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*continuing effort

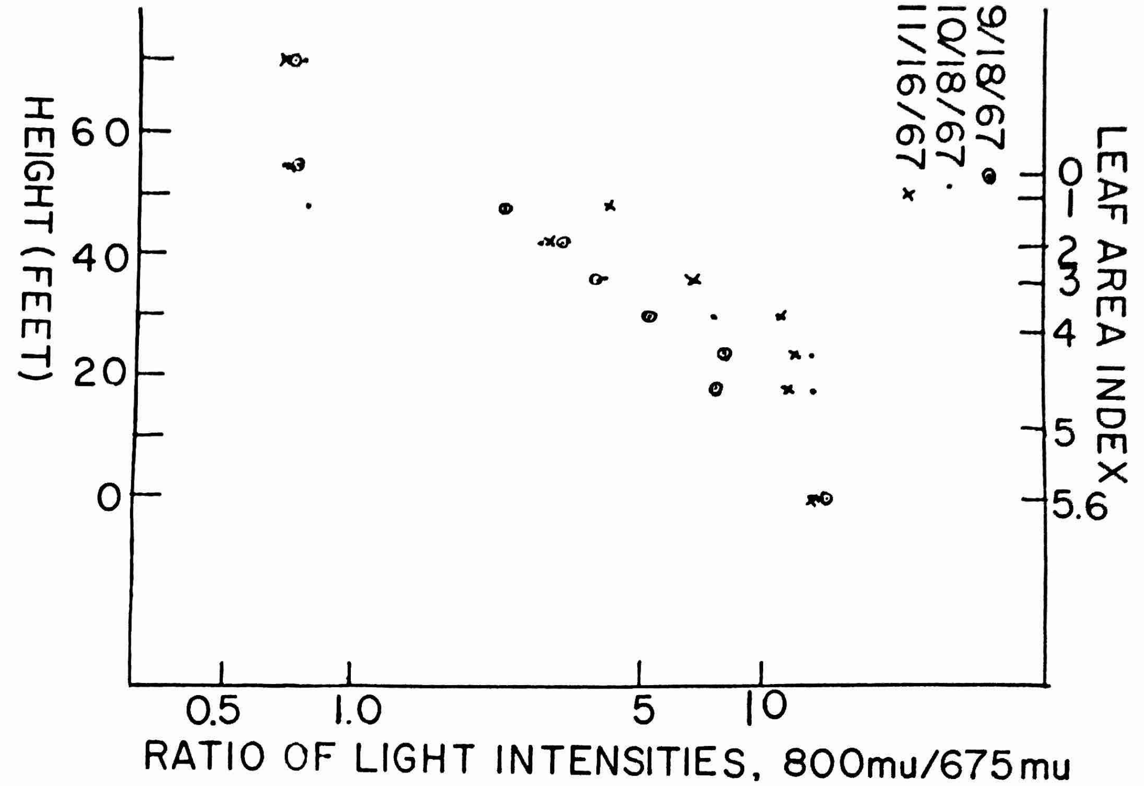

Figure 1. Infra-red/red ratio as a function of leaf area index.

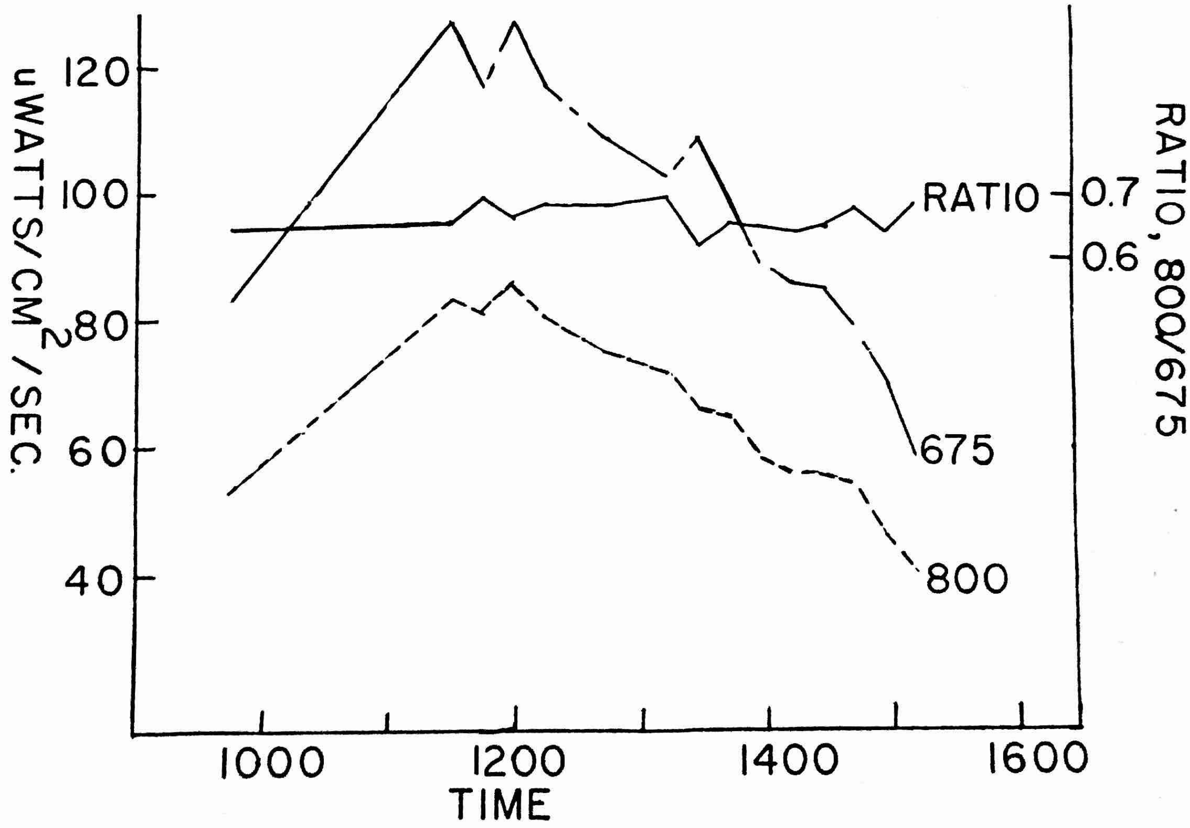

Figure 2. Light intensities at 800 and 675 mu, and the ratio between the two, as a function of time. Measurements taken above canopy, Nov. 16, 1967.

RADIONUCLIDE RESIDENCE TIMES IN FOREST COMPARTMENTS*

Jerry R. Kline

The measurement of radionuclide residence time in the El Verde forest is now being terminated after 730 days during which time ten samples of plant material per month were collected for measurement of fallout radionuclide content by gamma ray spectrometry. Estimates of effective half-life and environmental half-life were obtained by plotting the monthly data on a semilogarithmic scale as a function of time and fitting a regression line by the method of least squares. The values for the slopes of the lines obtained in this manner were used to compute half-life. Measurements were also made of environmental half-lives in the vegetation of the Elfin Forest at the top of El Yunque mountain over a similar time interval but with less frequent sampling.

Mean radioactivity, effective half-lives, and correlation coefficients are given in Table 1 for the nuclides: ^{144}Ce, ^{137}Cs, ^{95}Zr, and ^{54}Mn. The average effective half-lives were found from these data to be 228 days, 450 days, 120 days, and 250 days, respectively. Environmental half-lives computed from these data were 1140 days for ^{144}Ce, 469 days for ^{137}Cs, a doubling time of 141 days for ^{95}Zr, and 1774 days for ^{54}Mn.

The above data are subject to some restrictions prior to interpretation. First there is small but finite input of nuclides to the system. This input affects values for ^{95}Zr most seriously. This nuclide is invariably detected in incoming rain water by the use of an ion exchange column. The source of this nuclide is probably from the Chinese nuclear test of May 9, 1966, since this test caused the greatest deposition in Puerto Rico although subsequent tests may contribute also. The effect of input on half-life estimates for the other nuclides is not known but is thought to be small. This is because they are normally not found in the monthly sample of rain water which is processed through the ion exchange column. That there is at least occasional input is shown in Figure 1. The column which collected from 2/29/68 - 4/18/68 shows the presence of ^{137}Cs, ^{144}Ce, and ^{95}Zr. The most dominant peak in the spectrum is from the natural fallout nuclide ^{7}Be. The column which collected from 1/31/68-2/29/68 shows only ^{7}Be and ^{95}Zr. This is a typical spectrum and represents what has been found during six months of sampling which went before. It is possible that the forest receives an annual spring input rather than a continuous deposition year around.

A second restriction on the interpretation of the residence time data arises from the function used to compute environmental half-lives. The computation of this quantity is shown by equation 1.

$$T_{env} = \frac{T_r \times T_{eff}}{T_r - T_{eff}} \qquad (1)$$

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*completed

Where Tenv = environmental half-life, Tr = radioactive half-life, and Teff = effective half-life. It is apparent from the equation that as the effective half-life approaches the radioactive half-life, the estimate of environmental half-life approaches infinity. Figure 2 shows the relationship between effective half-life and environmental half-life for ^{95}Zr, ^{54}Mn and ^{137}Cs. A curve for ^{144}Ce would appear similar to that of ^{54}Mn since these nuclides have similar radioactive half-lives.

For ^{54}Mn Teff = 250 days and Tr = 291 days. These are sufficiently close to one another so that a small error in Teff results in a large error in the estimation of Tenv. This is evident from Figure 2. A similar situation exists in the case of ^{144}Ce where Teff = 228 days and Tr = 285 days. Thus it is concluded that the computed environmental half-lives for these nuclides have no literal meaning and should not be so interpreted. If the effective half-lives had been short, the environmental half-lives could have been accurately computed. It is apparent, therefore, that both nuclides are relatively persistent in the tropical vegetation and that once they enter the biological systems the dominant mode of removal is probably radioactive decay rather than leaching or other dispersal in the environment.

The value of 469 days for the environmental half-life of ^{137}Cs is accurately estimated since the effective half-life (450 d) is short with respect to the radioactive half-life (10950 d). The value of 469 days is, however, an upper estimate because of the uncertainties involved with input. If there was no input whatever the reported value for environmental half-life would be the correct one. With input the true value is shorter than the one indicated.

A lower limit on environmental half-life for Cs in vegetation can be obtained from another experiment in which leaves were contaminated by direct application of droplets of solution containing ^{134}Cs. Preliminary data from this experiment are shown in Figure 3. These data are corrected for radioactive decay so that estimates of environmental half-life can be obtained directly. This quantity is estimated roughly from the data to be about 200 days. This is a lower estimate and not necessarily accurate because in this type of experiment foliar uptake and translocation to other leaves are known to take place. Thus the contaminated leaves are reduced in activity due to translocation to uncontaminated leaves as well as by leaching or other mechanisms. In the case of ^{137}Cs foliar uptake also takes place without doubt. Since all leaves have initially the same exposure to atmospheric fallout, however, no net change of ^{137}Cs concentration will occur from this mechanism. The artificial contamination experiment is continuing. It is anticipated that the environmental half-life estimated from this experiment will increase as the foliar absorption mechanism declines in importance. This will ultimately enable an accurate estimate of environmental half-lives to be made through the convergence of upper and lower limits. At present the environmental half-life of ^{137}Cs from atmospheric fallout is estimated to be in the interval from 200 to 469 days in the tropical forest at El Verde.

Table 1 shows other significant aspects of fallout radionuclide behavior in the tropical forest. It is apparent that understory vegetation has significantly greater burdens of all nuclides except ^{95}Zr than canopy vegetation. The residence times of the nuclides are not different between canopy and understory however. Thus the storage capacities of vegetation in the two locations are different but the input-output relationships are the same. This is somewhat paradoxical at this time since it was showed previously that most of the canopy depletion could be accounted for by leaf fall. Data are presented elsewhere in this report which show a more rapid leaf turnover in the canopy than in the understory. Thus we would expect to have a longer effective half-life in the understory than in the canopy. The existing data do not provide a solution to this problem.

Data were also collected from canopy and litter in the Elfin Forest (Table 2). Average values for all nuclides are higher in this forest than at El Verde but the effective half-lives are approximately the same.

Table 1

Mean radioactivity, effective half-lives, and correlation coefficients for ^{144}Ce, ^{137}Cs, ^{95}Zr, and ^{54}Mn in several compartments of the rain forest at El Verde, Puerto Rico.

Nuclide	Parameter	Canopy	Understory	Leaf Fall	Surface Litter
^{144}Ce	Mean activity[1]	3.0 ± 0.8	5.3 ± 1.2	3.9 ± 0.7	6.5 ± 1.7
	$T_{1/2}$ (effective)[2]	293 720 143	205 361 97	265 550 174	206 398 139
	Correlation	0.36**	0.56**	0.36**	0.75**
^{137}Cs	Mean activity	5.6 ± 0.5	9.6 ± 0.7	4.7 ± 0.3	5.5 ± 0.8
	$T_{1/2}$ (effective)	437 604 342	425 548 346	466 555 401	472 846 327
	Correlation	0.60**	0.72**	0.73**	0.68**
^{95}Zr	Mean activity	1.1 ± 0.1	1.1 ± 0.2	1.2 ± 0.2	1.3 ± 0.3
	$T_{1/2}$ (effective)	147 209 113	130 212 93	94 108 84	110 144 90
	Correlation	0.71**	0.75**	0.85**	0.92**
^{54}Mn	Mean activity	0.6 ± 0.2	1.5 ± 0.3	1.1 ± 0.1	1.2 ± 0.3
	$T_{1/2}$ (effective)	274 553 182	200 247 167	266 290 135	262 415 192
	Correlation	0.45**	0.77**	0.89**	0.78**

[1] pCi/g

[2] days; with 95% confidence interval

**significant at 99% level (2 tailed test)

Table 2

Mean radioactivity, effective half-life, and correlation coefficients for ^{144}Ce, ^{137}Cs, ^{95}Zr, and ^{54}Mn in canopy and leaf litter of the Elfin Forest in the Luquillo Mountains of eastern P. Rico.

Nuclide	Parameter	Canopy		Leaf Litter	
^{144}Ce	Mean activity[1]	11.4 ± 8.8		17.6 ± 5.5	
	$T_{1/2}$ (effective)[2]	282	480 200	287	584 190
	Correlation	0.69**		0.85**	
^{137}Cs	Mean activity	10.3 ± 2.0		NS	
	$T_{1/2}$ (effective)	352	596 249	NS	
	Correlation	0.70**		NS	
^{95}Zr	Mean activity	1.6 ± 0.6		0.7 ± 0.2	
	$T_{1/2}$ (effective)	156	307 105	167	330 112
	Correlation	0.71**		0.93**	
^{54}Mn	Mean activity	1.6 ± 0.6		2.6 ± 1.2	
	$T_{1/2}$ (effective)	240	494 159	210	257 177
	Correlation	0.69**		0.82**	

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[1] pCi/g

[2] half times are in days, bracketed by 95% confidence interval

**significant at 99% level (2 tailed test)

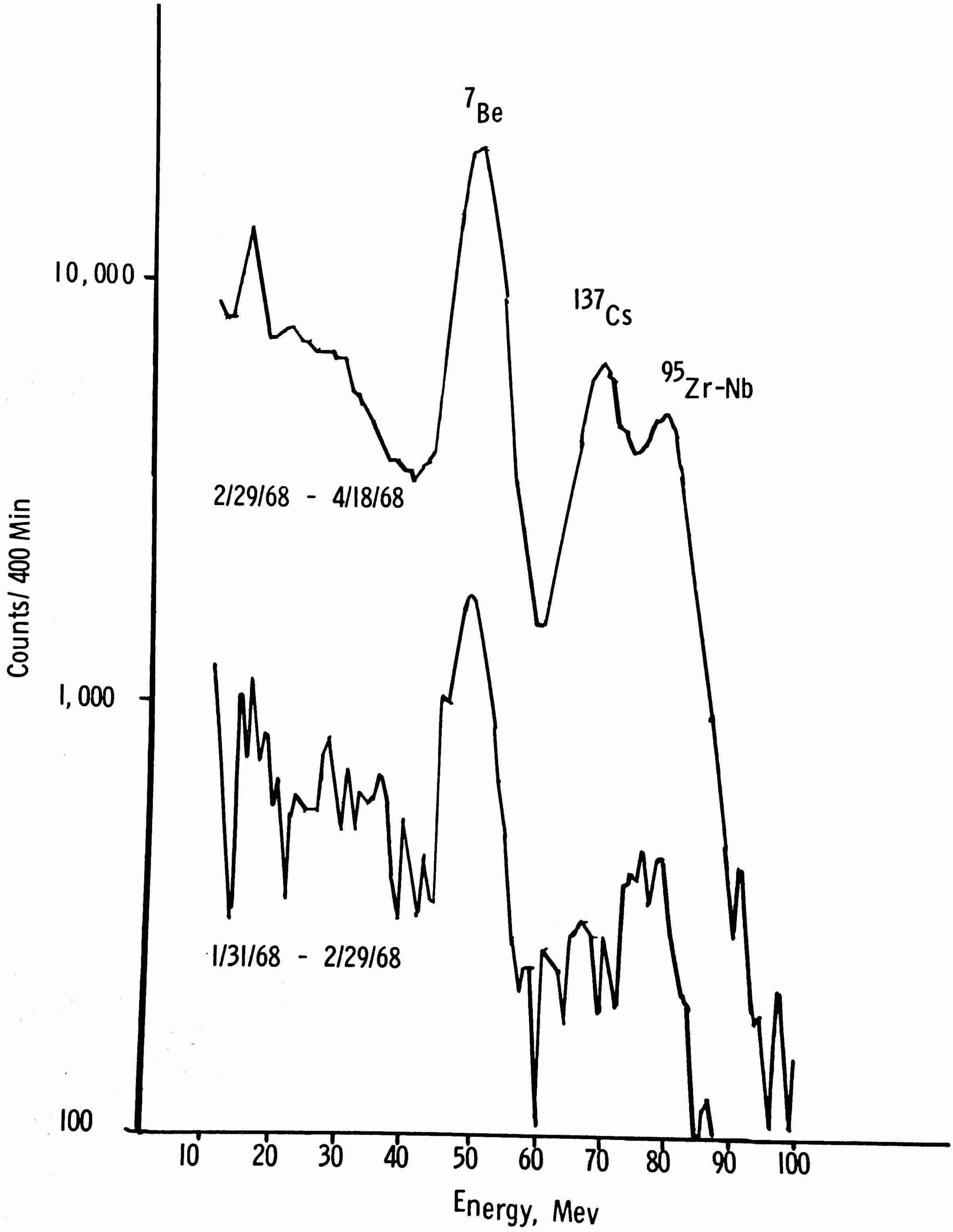

Figure 1. Gamma ray spectra of ion exchange columns which had passed the total amount of rainfall from a one square meter area during the time indicated. Levels of fallout are lower than the natural radioisotope ^{7}Be.

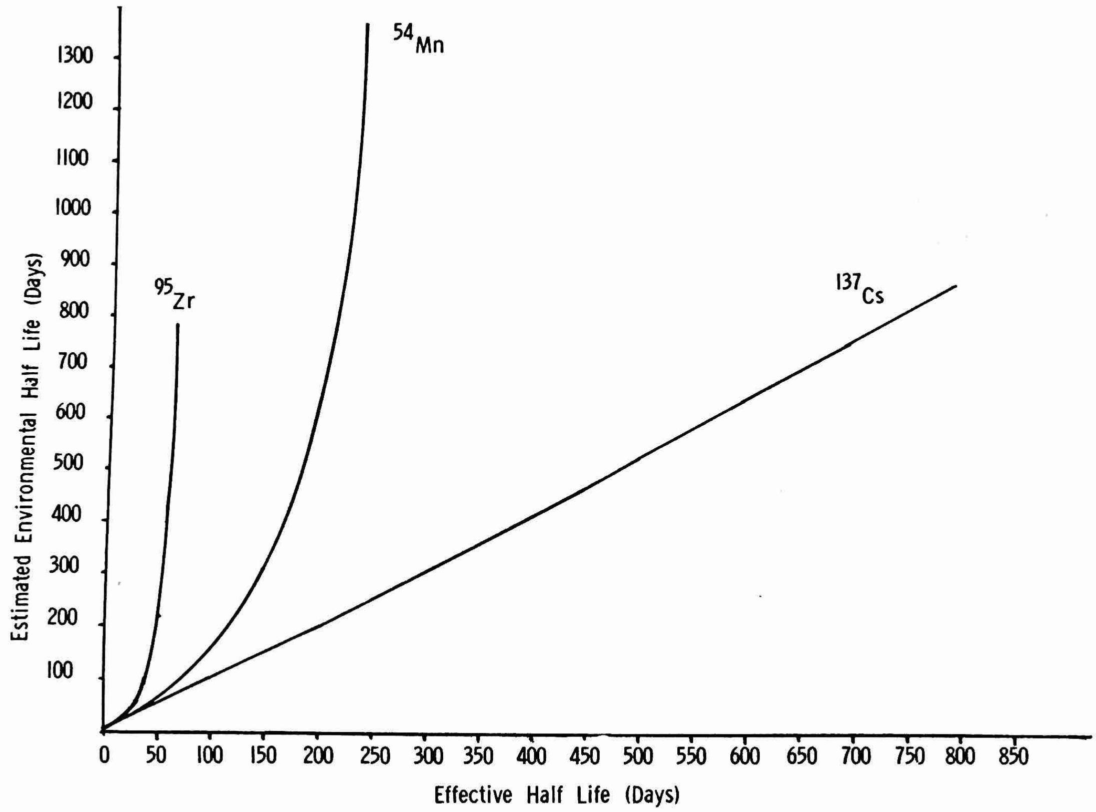

Figure 2. Relationship between estimated environmental half life and effective half life for some fallout radionuclides.

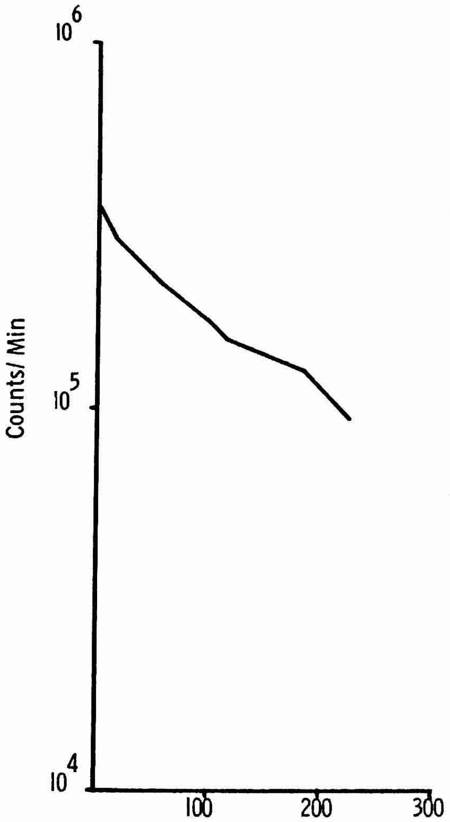

Figure 3. Preliminary curve showing effective half life of Cs which was artificially placed on leaf surfaces as ^{134}Cs.

DIFFERENTIAL LEAF TURNOVER*

C.F. Jordan

Fallout studies at the El Verde site showed that understory leaves had a higher level of radioactivity than canopy leaves. It was at first suspected that differences might be due to a greater amount of epiphyllae on understory leaves than on canopy leaves, since it is known that epiphyllae-covered leaves have higher radioactivity than leaves with no epiphyllae. However, a study revealed that while there may be a slightly greater amount of epiphyllae in the understory, the difference is not great enough to account for differences in radioactivity. It was then hypothesized that canopy leaves have a faster turnover rate than understory leaves, and therefore do not intercept fallout for as long a time as understory leaves. To determine this, 898 understory leaves, and 400 sun leaves in the canopy were punched on Aug. 10, 1967, and counted on Jan. 7, 1968.

Table 1 shows that canopy leaves may actually have a higher turnover rate. To be sure, leaves must be counted again in Aug. 1968, and perhaps again in Jan. 1969.

Metabolism rates in 12 groups of canopy and shade leaves of <u>Manilkara bidentata</u> were studied in an attempt to shed light on the cause of differential turnover rates. The only conclusion was that canopy leaves photosynthesize much more rapidly than understory leaves, undoubtedly because of more light in the canopy.

Table 1

Comparison of survival of canopy leaves vs. understory leaves of three species.

Species	No. of sun leaves punched, 8/10/67	%sun leaves remaining, 1/17/68	No. of shade leaves punched 8/10/67	% of shade leaves remaining 1/17/68
<u>Manilkara bidentata</u>	93	52%	241	85%
<u>Dacryodes excelsa</u>	143	63%	229	83%
<u>Sloanea berteriana</u>	164	65%	428	82%
Total	400	62%	898	83%

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*continuing effort

STEM FLOW IN THE TROPICAL RAIN FOREST

Carl F. Jordan

In order to determine the stem flow portion of the rain forest water budget, 27 trees of 5 common species, ranging in d.b.h. from 1.6 inches to 30.7 inches, were fitted with stem flow collectors, which drained into collection barrels. After every storm or period of intermittent rain, quantity of water in the barrels was measured with calibrated dip sticks. Measurements on 21 of the trees began in July 1967, and measurements of the remaining trees began in December 1967. Data for this report was collected through February 1968. Calculations for the purpose of predicting the amount of stem flow in the forest as a whole during a given rainstorm were based on an average of 44 readings for each tree measured from July and 15 for each tree measured from December. Figure 1 is the final result of these calculations. It shows the amount of water, in inches, reaching the forest floor due to stem flow as a function of the amount of rainfall. Throughout the entire range stem flow is close to 18 percent of rainfall.

The procedure for the calculations is of special interest because the intermediate results give insights as to the factors involved in quantity of stem flow.

The first step was to calculate the regression of quantity of stem flow on amount of rain for each tree. It was assumed that this was a straight line relationship, because after stem flow begins doubling the quantity of rainfall should double the amount of stem flow. Of course it is not a straight line near the origin, as shown in Fig. 2. However, since rainstorms of less than 1/4 inch rarely occur in the study site, and when they do, they contribute very little toward the total water budget, a straight line relationship was assumed.

The regression equations were of the form $Y = ax + b$, where Y is the stem flow in liters, x is rainfall in inches, a is the slope of the regression, and b is the Y intercept. The slope of each regression was then plotted as a function of the diameter of the tree from which the regression was obtained (Fig. 3). Intermediate size trees collected the greatest amount of water from a given storm, and thus had the greatest slopes in their regression equations (Fig. 3). The data shows no relationship between species of tree and amount of runoff.

The Y intercept was also plotted as a function of diameter (Fig. 4). The values of Y intercept greater than one are due to the straight line assumption. After the points were plotted, the curves of Figs. 3 and 4 were estimated by eye and drawn in.

From the curves equations were determined for each tree size class (Table 1). Using these equations, quantity of stem flow for .5, 1 and 2 inches of rain was calculated for each size class of tree. This quantity was then multiplied times the number of trees of each size class per hectare (Table 2). Density data for trees in the 4 inch size class and above were taken from an 8100 sq. meter survey, and for trees in the 2 in. class from a 2000 sq. meter area.

Total amounts of stem flow per size class per hectare for a given size storm were added together to give total liters of stem flow per hectare for the three sizes of storm. Liters per hectare were converted to inches of rain by the factor: 1 inch of water equals 254,000 liters per hectare. Stem flow as a function of inches of rain was then plotted in Fig. 1.

Fig. 1 shows that stem flow is almost a constant percentage of rainfall as would be expected. With 2 inches of rain, stem flow is .35 inches, or 17.5%, and at one inch, it is .18 inches or 18%. At one quarter inch it is .055 inches, or 22%. The higher percent nearer the origin is probably due to the straight line assumption of the regression equations.

The correlation coefficient (r) between stem flow and rainfall was also calculated for all 27 trees. The average r was .76, and one standard deviation was .15. The lack of higher correlation probably is because quantity of stem flow depends on intensity of storm as well as total amount of rainfall. However, if we assume there are equal amounts of heavy and light rainfall, effects on stemflow due to variations in storm intensity will cancel themselves out, and average stemflow should be more accurate than would be suggested by a correlation coefficient of .76.

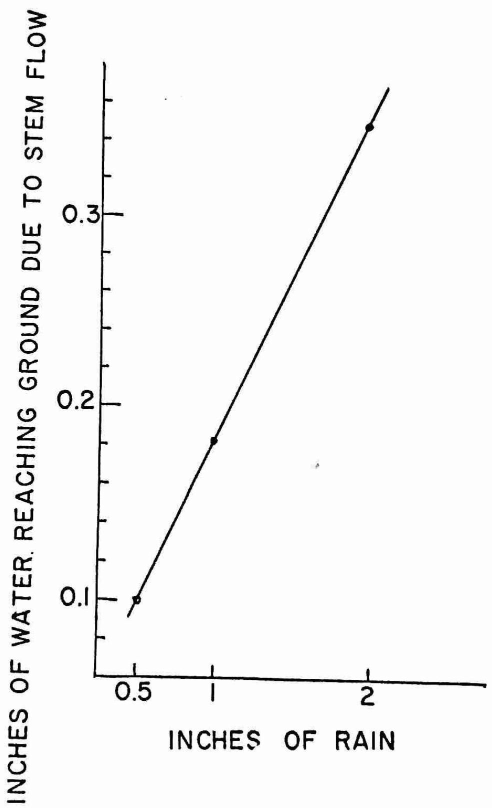

Figure 1. Relationship between amount of stem flow and total rainfall.

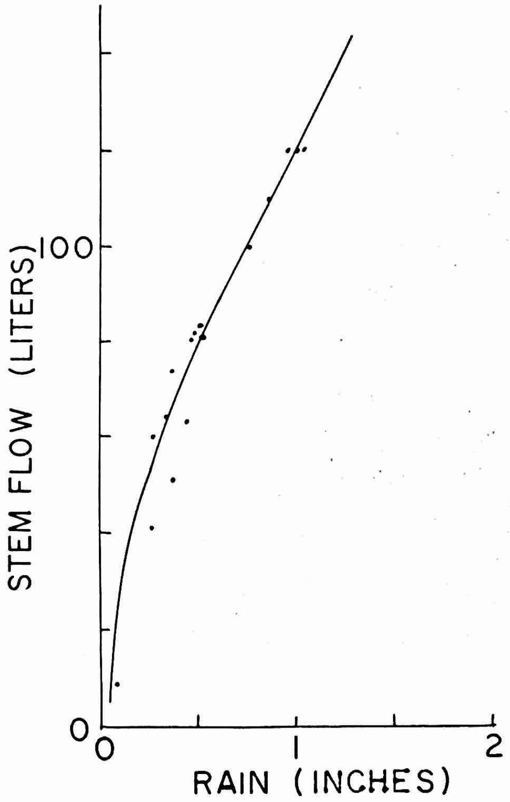

Figure 2. Stem flow on one Euterpe globosa as a function of rainfall, based on field data.

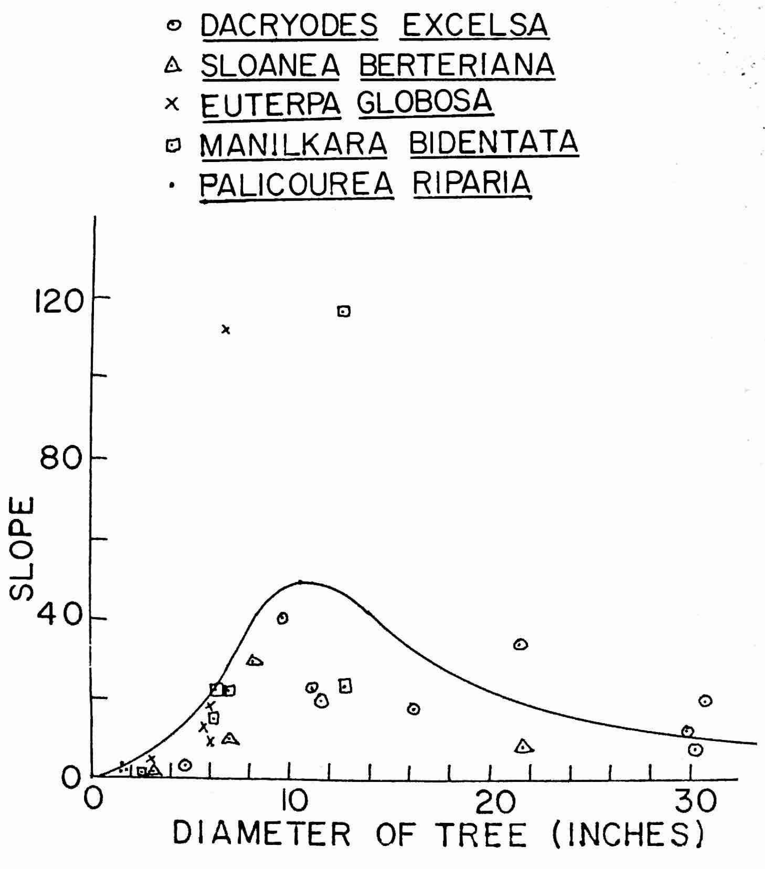

Figure 3. Slope of regressions of stem flow in liters on rainfall in hundredths of an inch, as a function of diameter of tree.

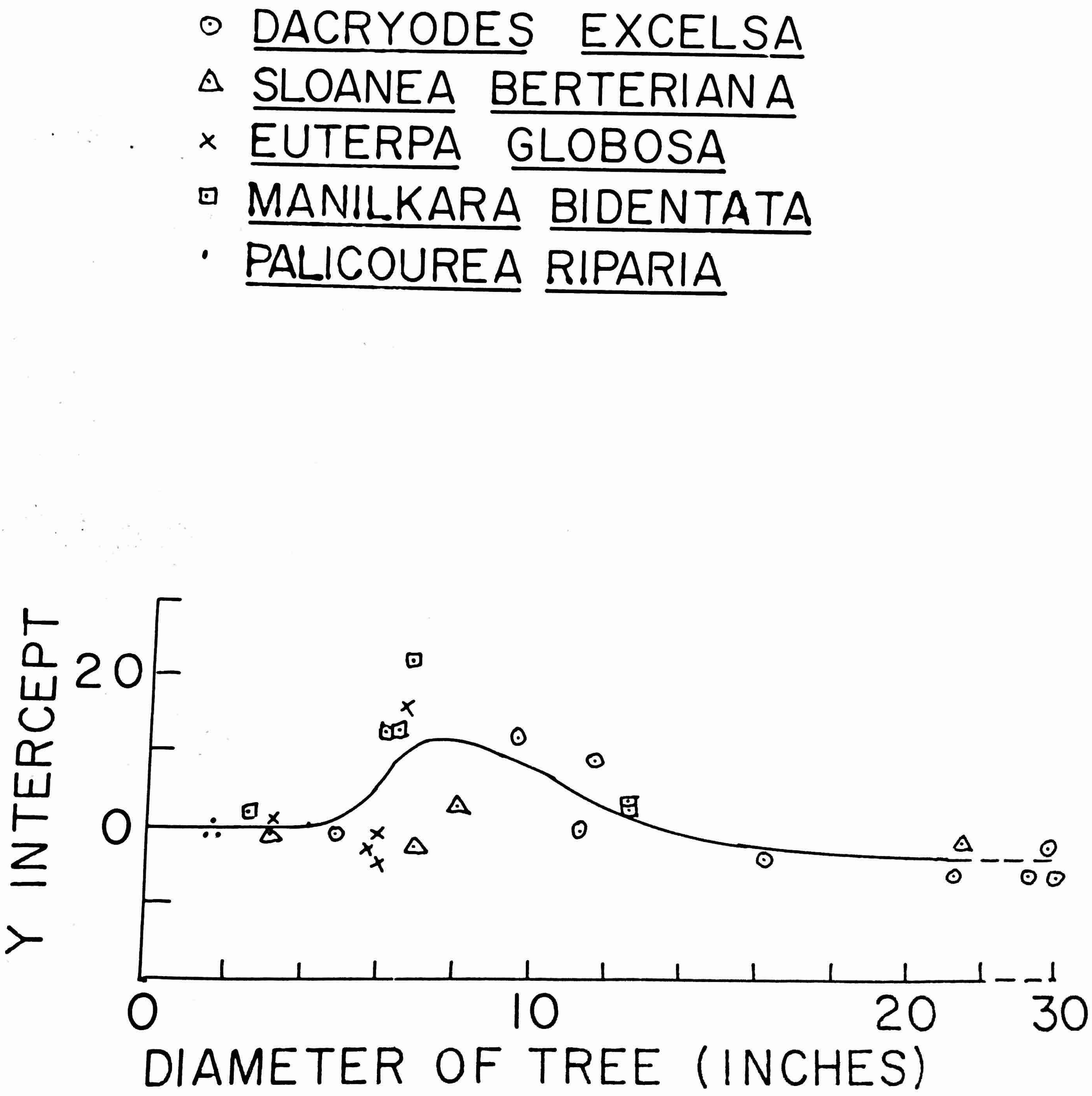

Figure 4. Y intercept of regressions of stem flow in liters on rainfall in hundredths of an inch, as a function of diameter of tree.

Table 1

Equations for predicting liters of stem flow as a function of rainfall in inches and hundreds.

Size class inches	Formula
2	$Y = 4x + 0$
4	$Y = 11x + 0$
6	$Y = 21x + 5$
8	$Y = 38x + 11$
10	$Y = 48x + 8$
12	$Y = 48x + 3$
14	$Y = 42x - 1$
16	$Y = 33x - 2$
18	$Y = 27x - 3$
20	$Y = 22x - 4$
22	$Y = 18x - 4$
24	$Y = 16x - 4$
26	$Y = 13x - 4$
28	$Y = 12x - 4$
30	$Y = 11x - 4$

Table 2

Density of trees in individuals per hectare for 2 inch size classes.

Size class of tree	Tree/hectare
2	4,285
4	355
6	425
8	118
10	81.4
12	33.3
14	20.9
16	22.2
18	12.33
20	4.93
22	3.70
24	2.46
26	2.46
28	3.70
30	1.23

FLOW OF SOIL WATER IN THE LOWER MONTANE TROPICAL RAIN FOREST*

C.F. Jordan

To construct a stable-element budget of a forest the flow pattern of soil water as well as the volume of soil water and concentration of elements in it must be known. This qualitative study was made to determine the flow pattern of soil water in the tropical rain forest at El Verde.

The terrain near El Verde consists of numerous finger-like ridges, with small valleys between, many of which are occupied by intermittent streams. The study site was located on the side of one of these ridges, where the slope was about 30 degrees.

Although the soil in the area contains a high proportion of clay, the clay is well aggregated with the result that the soil is relatively light in the upper horizons. However, at a certain depth, which depends in part on slope, vegetation, and amount of rain throughfall; the bulk density increases quite sharply (Table 1).

An hypothesis concerning soil water movement based on in formal observations was first made. It was: Water infiltrates very quickly into the upper soil and there is virtually no runoff above the surface of the mineral soil. As the water reaches the denser lower soil, it percolates downslope above this denser layer parallel to the soil surface. (Fig. 1).

The experimental design to test this hypothesis follows:

1. If there is no surface runoff, a runoff collection pan placed just below the litter of a plot which extends downslope just a few centimeters should collect just as much runoff during a given amount of rain as a plot a meter or more in length.

2. If runoff infiltrates into the soil in an almost vertical direction until it meets the resistance of the denser soil, at which point the flow parallels the soil surface; then a collection pan placed just above the denser soil in a plot which runs a meter or more downslope should collect more water than a similarly placed pan in a plot only a few centimeters in length.

Downslope cross-sections of the runoff plots showing the positions of the collection pans and hypothesized lines of water flow are shown in Fig. 1.

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*completed

Procedures

Two plots were marked out, one 1 meter on each side, and one 1 meter wide and extending downslope 15 cm. (Fig. 1). The soil was carefully dug away on all four sides of the plots, down to a depth of 45 cm. Collection pans which extended the full width of each plot were installed on the downslope side of each plot below the litter for the first trials, and at a depth of 30 cm. for the other trials.

Rainfall was applied by siphoning water through a tube to a shower head and passing the head uniformly over the plots. A volume of water that was equivalent to 4 cm of rain falling on that plot was delivered to each plot for each trial.

Results

Trials 1-4 (Table 2) show that the volume of water collected in the pans beneath the litter was approximately the same in both the long and the short plots. This means that if there is any runoff on top of the soil, it does not move downslope more than 15 cm, the length of the small plot.

The water actually collected probably does not represent soil surface runoff for two reasons: 1. The upslope edge of the pan lays underneath the downslope 2 cm of litter, and therefore some of the water collected was moving straight downward through the litter.

2. In places the collection pan was as much as 3-4 cm deep in the mineral soil, because the soil does not form a perfectly straight contour for a distance of one meter. As a result, some of the water collected was subsurface flow.

Trials 5,6,8, and 9 show that when the pans were at 30 cm, there was more water collected in the longer plot. This could occur only if the water moved downslope at an angle, and not straight down.

Trial 7 shows that rate of rainfall apparently does not affect the results.

Results of these tests show that the soil water infiltrates almost vertically, but when it reaches denser soil, it flows downslope.

Table 1

Bulk densities of soil at different depths at the study site in the tropical rain forest near El Verde.

Depth (cm)	No. of samples	Average bulk density $\left(\frac{\text{dry wt. in gram}}{\text{vol. in c.c.}}\right)$	One standard deviation
0-5	4	.748	.048
5-10	4	.789	.058
35-40	4	.784	.095
40-45	4	.988	.074

Table 2

Results of runoff experiments

Trial No.	Plot size (cm)	Depth of pan	Amt. of water supplied (liters)	Equivalent cm of rainfall	Rate of rainfall (cm/hr)	Amt. collected in pan (liters)
1	15 x 100	litter	6	4	10	2.0
2	15 x 100	"	6	4	10	1.8
3	100 x 100	"	40	4	10	.7
4	100 x 100	"	40	4	10	1.3
5	15 x 100	30 cm.	6	4	10	2.3
6	15 x 100	30 cm.	6	4	10	2.7
7	15 x 100	30 cm.	6	4	60	3.1
8	100 x 100	30 cm.	40	4	10	7.5
9	100 x 100	30 cm.	40	4	10	8.0

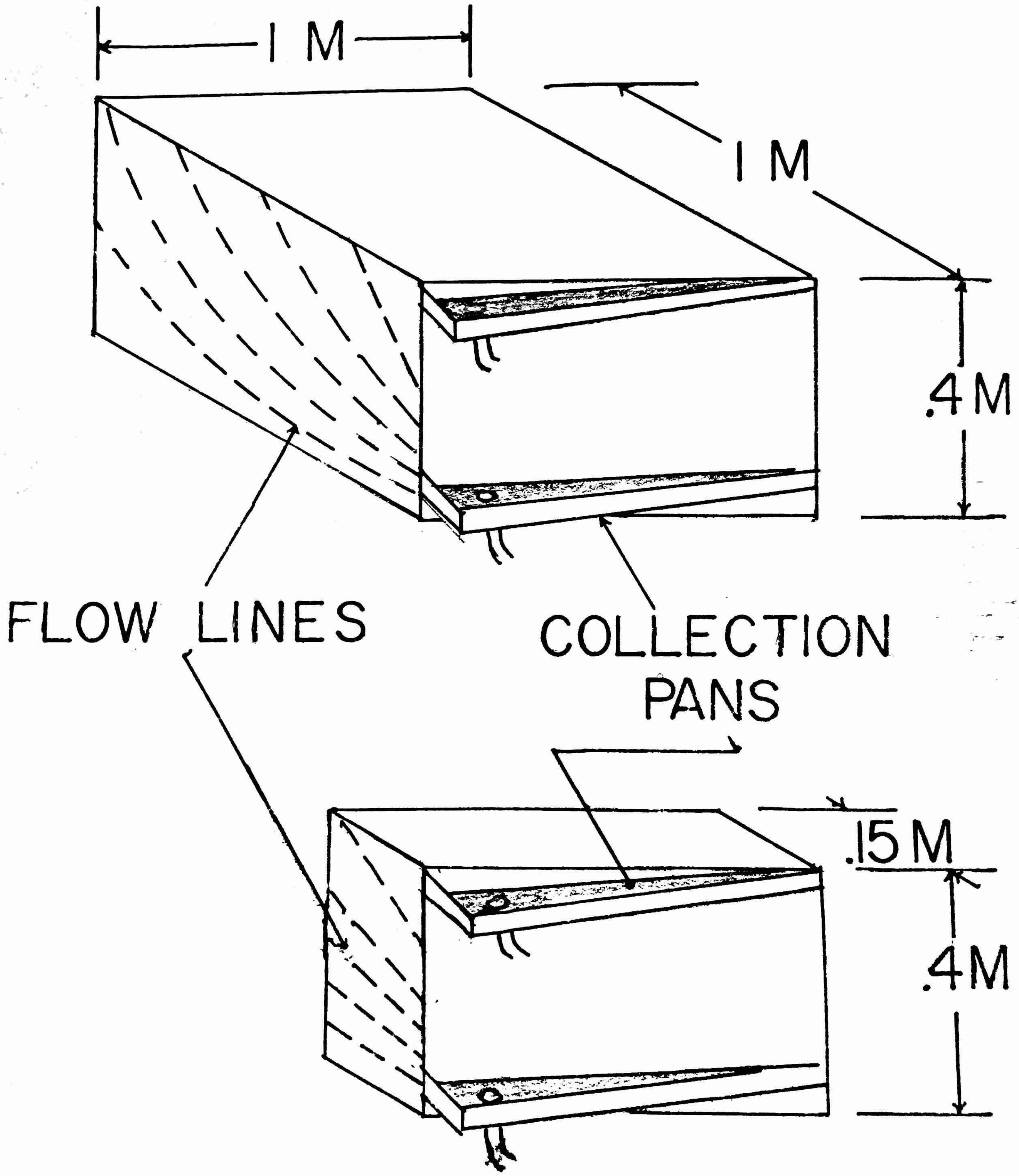

Figure 1. Hypothesized lines of water flow, and position of collection pans, in experimental soil blocks.

KINETICS OF STABLE ELEMENT MOVEMENT IN THE FOREST*
1. WATER BUDGET OF THE FOREST

C.F. Jordan

Part one of the stable element kinetics study was concerned with element concentration in the forest water. This section deals with the quantities of water moving between various compartments of the forest.

Total rainfall is measured with a standard weather bureau tipping bucket rain gauge located above the canopy. Through-fall is collected in 12 rain gauges, 5 ft. long x 2 inches wide x 1 ft. deep. Readings are made weekly. Evaporation from the soil surface is not detectable. Stem flow and transpiration studies are sub-projects within themselves and are reported in following sections. Other portions of the water budget are calculated from the following formulas:

Evaporation from leaves = Rain - (throughfall + stem flow).
Runoff and deep drainage = (throughfall + stem flow)-transpiration.

Total water budget for one year is given in Table 1. Weekly cumulative totals are graphed in Fig. 1. Total amounts of water moving through various portions of the soil are available from the computer print out described in the previous section. To make this data meaningful, the performance of the lysimeters collecting the soil water and the manner in which the soil water moves were studied. These are the subjects of two separate reports included in this volume.

Table 1

Water budget of the rain forest at El Verde from Feb. 20, 1967 through Feb. 20, 1968.

Total Rainfall	281.00 cm	
Through fall	195.37 cm	
Stem flow	50.56 cm	
Evap. from leaves	35.00 cm	(Rain-throughfall + stem flow)
Transpiration	59.00 cm	
Run off & Deep Drainage	186.93 cm	(throughfall + stem flow - transpiration)

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*continuing effort

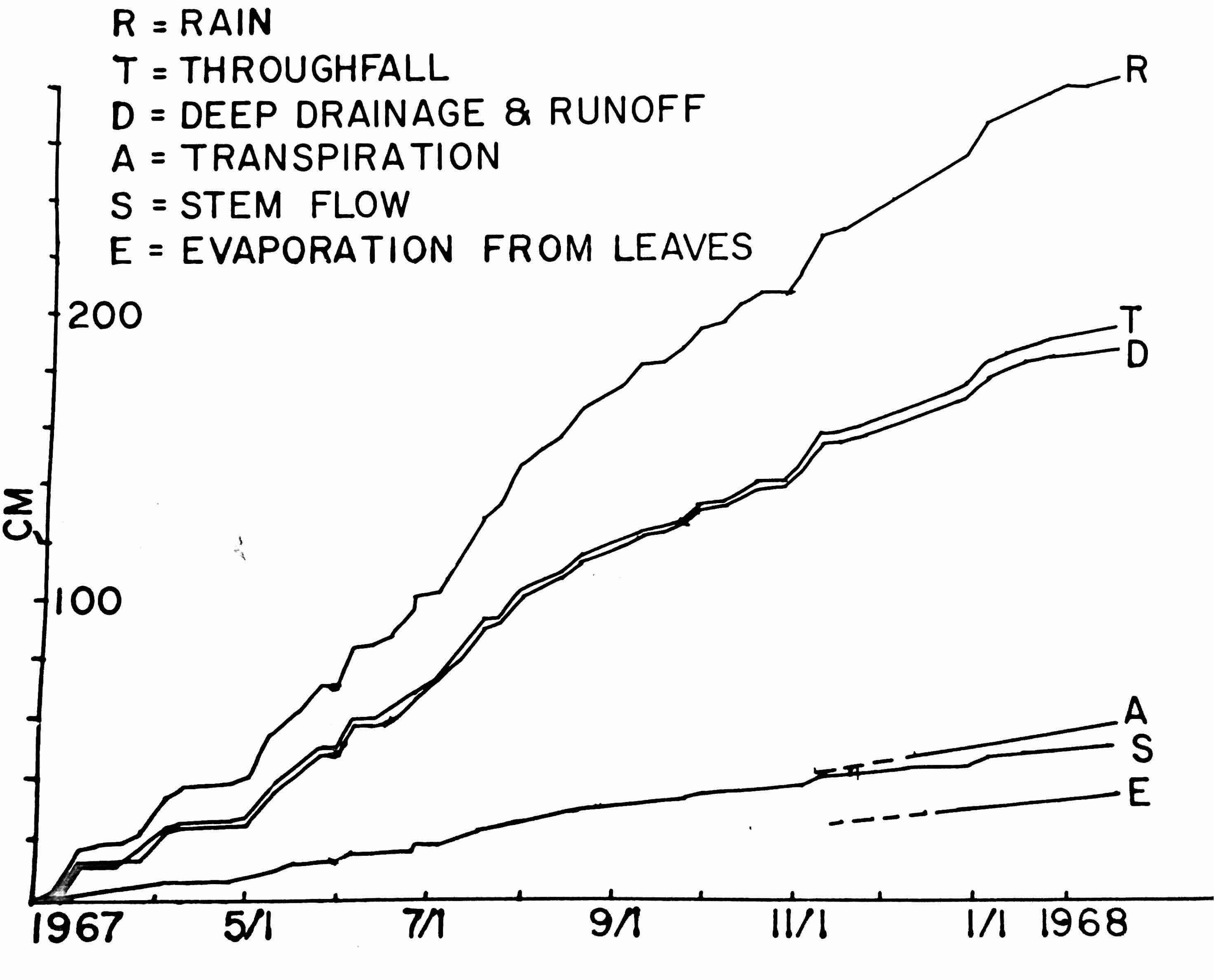

Figure 1. Weekly cumulative centimeters of water in various segments of the forest.

KINETICS OF STABLE ELEMENT MOVEMENT IN THE FOREST*
2. CONCENTRATION OF ELEMENTS IN FOREST WATER

C.F. Jordan

The study of stable element kinetics in the tropical rain forest is broken into several parts: 1) Concentration of elements in the forest water. 2) Water budget. 3) Leaf fall and element content of litter (incorporated into other reports). Concentration of elements in the water moving between compartments multiplied by the amount of water moving between compartments (water budget) will give the rate of element movement between compartments except for that movement that results from leaf fall. This section is concerned with element concentration in forest waters.

Collection stations for forest water analyzed for element content are given in Table 1. Samples are collected weekly. Conductivity of all samples is measured and pH is taken on one complete collection per month. A weighted subsample of each water sample is added to a composite, which is analyzed monthly for Ca, Na, Mg, and Mn.

Conductivity and pH data start in March 1967. A computer program for determining averages and standard deviations of conductivity, pH, and volume for all locations (such as shallow litter) has been completed and de-bugged. Fig. 1 is an example of the data print-out. The minus numbers and zeros in the middle group are caused by the computer clearing. Table 2 is an example of individual element concentrations. Manganese is barely detectable in most samples. Cobalt, strontium and cesium were not detectable by atomic absorption methods. Other elements will be determined in the future depending upon equipment availability.

Element concentration in the stem flow of one large *Sloanea berteriana* was somewhat higher than other trees and concentration in several large trees of the species *Dacryodes excelsa* was substantially higher than in the rest of the trees. Therefore, these trees are treated separately.

In the soil waters of New Jersey, in a previous study I found that a considerable proportion of the total elements being moved were adsorbed or incorporated in suspended material, mostly of organic nature. Two different treatments of the tropical rain forest soil water failed to show a measureable amount of elements associated with organic or inorganic matter suspended in the water.

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*continuing effort

Table 1

Collection stations for forest water that is analyzed for stable element content.

Location	Number of collectors
Above canopy	2
Below canopy (through-fall)	10
Stem flow	27
Shallow litter	8
Deep litter	6
A horizon (soil) aerobic conditions	9
A horizon (soil) anaerobic conditions	4
B horizon (soil)	4
River (normal flow)	4
River (high stage)	2
Brook	4
Litter*	2
A horizon (soil)*	2
B horizon (soil)*	2
Sapprolite*	2

*These collectors eventually to be used for tritium microsystem analysis.

```
      GROUP  2
       6  /  26  /  67

                VOL              PH              COND

    TOTAL     17640.00          29.59           208.80

    AVER.      2940.00           4.93            34.79

    S.D.       2528.52           0.30            14.45



      GROUP  1
       0  /   0  /  67

                VOL              PH              COND

    TOTAL         0.00           0.00            -4.80

    AVER.         0.00           0.00            -4.80

    S.D.          0.00           0.00             0.00



      GROUP  3
       6  /  26  /  67

                VOL              PH              COND

    TOTAL     13844.00          36.20           213.89

    AVER.      1977.71           5.17            30.55

    S.D.       2445.83           0.38             8.67
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Figure 1. Data print out of computer program for average and standard deviation of volume, pH, and conductivity of forest water samples.

Table 2

Individual element concentrations in the forest waters for Jan., 1968. Five weekly sub-samples from each collection station were weighted and pooled, then average concentration for all stations in each location was determined.

Location	Na		Ca		Mg		Mn	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Above canopy	3.5	0.7	0.6	0.0	0.2	0.0	0.0	0.0
Below canopy	5.5	2.3	1.0	0.3	0.4	0.1	0.0	0.0
Stem flow								
3 *Dacryodes excelsa*	15.3	8.5	5.1	2.3	1.6	0.7	0.6	
1 *Sloanea berteriana*	10.0		1.3		0.2		0.2	
Other trees	4.9	2.3	1.0	0.4	0.3	0.2	0.0	0.0
Shallow litter	6.9	1.8	2.1	0.6	0.8	0.2	0.0	0.0
Deep litter	5.6	1.2	1.7	0.3	0.7	0.1	0.0	0.0
A horizon (soil)								
aerobic conditions	6.8	2.3	1.0	0.3	0.6	0.2	0.0	0.0
anaerobic conditions	6.2	1.9	0.9	0.1	0.5	0.1	0.0	0.0
B horizon	6.0	0.8	1.2	0.3	0.5	0.1	0.0	0.0
River, normal flow	4.5	0.7	1.5	0.0	0.7	0.1	0.0	0.0
River, high stage	4.0	0.0	1.2	0.1	0.5	0.0	0.0	0.0
Brook	6.0	1.4	2.1	0.0	1.1	0.1	0.0	0.0
Litter*	9.0	2.8	2.7	0.3	0.8	0.1	0.0	0.0
A horizon*	7.5	2.1	1.0	0.6	0.6	0.1	0.0	0.0
B horizon*	13.0	2.8	1.0	0.6	0.7	0.1	0.0	0.0
Sapprolite*	10.5	0.7	1.2	0.1	0.7	0.0	0.0	0.0

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*At site to be used for tritium.

CHEMISTRY OF SUCCESSIONAL VEGETATIONAL*

C.F. Jordan

The stable element concentration of the plants appearing in the radiation damaged area is being determined for two reasons: 1. It is part of the overall biogeochemical study of the montane tropical ecosystem. 2. It is a part of the radiation recovery story.

Leaves of the most common seedlings, saplings, and sprouts, and stems and roots of several species were collected, and plant parts of the same species were pooled (i.e. all roots of Miconia racemosa). Samples were then dried, ground, ashed, dissolved in .1 M HCl, and analyzed on the atomic absorption spectrophotometer.

Leaves of species common in the irradiated area generally are much higher in calcium, somewhat higher in magnesium, and at about the same level of manganese, strontium, and cobalt, as leaves of mature forest species (compare Table 1 with data in section on chemistry of climax vegetation). However, leaves of the sprouts which formed from pre-irradiation trees have almost the same element content as the canopy leaves of the same species in the undisturbed forest (Table 2). Calcium and magnesium content of leaves appears higher than that of stem, and stem than that of roots (Table 3).

More extensive sampling will be undertaken to confirm these indications.

Table 1

Stable element content of leaves of species common in the radiation recovery area.

Species	ppm of Ca	Mg	Mn	Sr	Co
Cecropia peltata (#1)	12100	3775	80	67	1
Cecropia peltata (#2)	15300	3375	104	94	1
Psychotria berteriana	11200	4775	191	83	-
Miconia tetrandra	21100	4750	1841	91	3
Palicourea riparia	10100	5500	67	47	3
Alchornia latifolia	12800	3550	562	63	-
Drypetes glauca	14200	10605	734	125	-
Miconia racemosa	35375	3650	86	85	2

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*continuing effort

Table 2

Stable element content of leaves of species occurring as sprouts in the irradiated area, and as canopy trees in the mature forest.

Species	Successional Situation (Sprouts)					Mature Forest (Canopy)				
	ppm of					ppm of				
	Ca	Mg	Mn	Sr	Co	Ca	Mg	Mn	Sr	Co
Eugenia stahlii	8200	4525	41	33	1	8400	4468	135	57	1
Manilkara bidentata	6900	3500	21	35	-	6743	3556	30	46	1
Sloanea berteriana	7900	2125	280	27	-	6389	2134	368	23	1
Ocotea moschata	6500	4850	361	38	-					
Croton poecilanthus	6900	3250	712	51	-					

Table 3

Stable element content of leaves, stem, and roots of species common in the radiation recovery area.

Species	Leaves					Stem					Roots				
	ppm of					ppm of					ppm of				
	Ca	Mg	Mn	Sr	Co	Ca	Mg	Mn	Sr	Co	Ca	Mg	Mn	Sr	Co
Miconia racemosa	35375	3650	86	85	3	11400	3550	129	40	2	3100	3300	334	13	7
Miconia tetrandra	21100	4750	1841	91	3	6400	1425	1770	35	1	1800	750	1058	12	2
*Manilkara bidentata**	6900	3500	21	35	-	2600	1500	10	22	-					
*Eugenia stahlii**	8200	4525	41	33	1	7200	2175	30	37	-					
*Bannisteria heteropsis**	12800	5100	1633	55	1	6400	1700	275	28	-					
*Croton poecilanthus**	6900	3250	712	51	-	17200	1425	405	125	1					
*Sloanea berteriana**	7900	2125	280	27	-	5900	1175	54	22	-					

*Sprouts

ELEMENTAL COMPOSITION OF CLIMAX VEGETATION*

Jerry R. Kline

Previous measurements of fallout radionuclides in rain forest vegetation showed that there was a consistent difference in the amounts of ^{137}Cs, ^{144}Ce, and ^{54}Mn contained in leaves between canopy and understory. Understory plants were contaminated to a greater extent than canopy plants. Analyses for stable elements were therefore begun to determine whether they had the same type of distribution.

Analyses were carried out for Ca, Sr, Mg, Mn, and Co in the leaves of 10 different species in the canopy and understory from one location at the El Verde Field Station. Results are given in Table 1. With three species, Manilkara, Sloanea, and Dacryodes, pairs of canopy - understory samples were obtained. These show no consistent tendency for understory plants to be enriched in elemental content. In the case of Eugenia and Micropholis, the elemental composition is similar to that of the other trees which have the potential to reach the canopy. These two species are found in the canopy although in this case the individuals involved were immature and were sampled in the understory. These results indicate that elemental content of leaves is not related to forest structure.

Plants which are adapted to survival in the understory do seem to be enriched in Ca and Sr however. This is illustrated by the Ca and Sr contents of Calycogonium and Palicouria which have average mature heights of 12 and 3 meters respectively. The pattern for the other elements measured is less consistent. Both understory species are relatively enriched in Co. Calycogonium has considerably higher Mn levels than the other plants but its Mg levels are not particularly high. The situation is reversed in the case of Palicourea which has high Mg levels and ordinary Mn levels.

Within the canopy species group, each individual seems to have its own distinctive complement of elements. The Dacryodes for instance has considerably lower levels of Ca, Sr, and Mg than Manilkara, but it has from 3 to 10 times higher concentrations of Mn. It is apparent, however, that there is no general difference between canopy and understory in elemental content.

Table 2 shows computed specific activity of ^{54}Mn for canopy and understory. The canopy has 9.7 pCi/mg while the understory has 22.2 pCi/mg. This indicates that there is partitioning of the fallout ^{54}Mn which is quite independent of the cycling of stable Mn through normal biological routes. It has been previously suggested that this partitioning might occur due to the fact that the radionuclide is injected into the system through aerial deposition rather than through root uptake. The deposited nuclide is probably intercepted on leaf surfaces and retained there through the action of epiphyllae. Thus specific activity on any particular leaf is more a function of the interception ability of the leaf than it is of mineral cycling. If mineral cycling were the dominant mode of entry of radionuclides into the leaves we would of course expect that the specific activities would be everywhere the same. The fact that they are not

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*continuing effort

several years after major production of ^{54}Mn indicates that there must be rather slow turnover of minerals in tropical vegetation by mineral cycling. This supports the environmental half time measurements which appear elsewhere in this report and which indicate the same thing.

Attempts were made to measure stable Cs in plants to permit the computation of specific activity but the levels of the stable element were too low to be detected by atomic absorption. ^{137}Cs shows the same kind of canopy-understory distribution as ^{54}Mn and it is concluded that it also is transported independently of mineral cycles involving root uptake. This conclusion is drawn by analogy with the Mn situation and from the fact that none of the stable elements measured so far have exhibited understory enrichment which is related to the fact that understory leaves live longer than canopy or sun leaves and thus have a longer period in which to intercept nuclides. Understory leaves probably also reintercept nuclides which have been lost from canopy leaves by leaching and thus have a somewhat greater exposure to contamination than canopy leaves.

Table 1

Elemental contents of canopy and understory leaves at El Verde

Species	Location	Element Ca	 Sr	 Mg	 Mn	 Co
		ppm				
Sloanea berteriana	Canopy	6389 ± 710	23.5 ± 0.9	2134 ± 433	368.6 ± 24.6	0.7 ± 0.13
" "	Understory	5533 ± 940	23.6 ± 1.1	1787 ± 62	339.3 ± 25.1	1.2 ± 0.23
Dacryodes excelsa	Canopy	2589 ± 187	7.0 ± 0.4	1051 ± 121	232.9 ± 23.6	0.3 ± 0.12
" "	Understory	2775 ± 111	9.9 ± 0.8	1475 ± 151	320.0 ± 40.7	0.4 ± 0.08
Manilkara nitida	Canopy	6743 ± 470	46.0 ± 2.0	3556 ± 177	30.6 ± 5.6	1.0 ± 0.15
" "	Understory	8300 ± 549	50.9 ± 3.1	3948 ± 120	94.6 ± 12.9	1.1 ± 0.17
Euterpe globosa	Canopy	4057 ± 227	23.2 ± 1.2	3775 ± 107	251.6 ± 21.4	0.5 ± 0.18
Ormosia krugii	Canopy	3122 ± 111	9.6 ± 0.6	1178 ± 51.3	248.7 ± 11.7	0.5 ± 0.12
Calycogonium squamulosum	Understory	27400 ± 2780	158.4 ± 23.5	2297 ± 202	1627 ± 127.5	3.0 ± 0.47
Eugenia stahlii	Understory	8400 ± 1312	57.2 ± 4.21	4468 ± 250	135 ± 10.1	1.3 ± 0.27
Micropholis garciniafolia	Understory	4920 ± 656	38.3 ± 3.5	2124 ± 210	351.5 ± 52.2	0.7 ± 0.24
Palicourea riparia	Understory	10425 ± 461	142.9 ± 8.0	5721 ± 130	276.0 ± 52.6	2.2 ± 0.35

Table 2

Specific activity of ^{54}Mn in canopy and understory leaves in the forest at El Verde

Species	Canopy Mn mgm/gm	 ^{54}Mn pCi/gm	 ^{54}Mn/Mn pCi/mgm	Understory Mn mgm/gm	 ^{54}Mn pCi/gm	 ^{54}Mn/Mn pCi/mgm
Dacryodes excelsa	0.23	2.1	9.0	-	-	-
Manilkara nitida	0.03	0.82	26.8	0.09	4.0	42.3
Sloanea berteriana	0.37	2.6	7.1	0.34	4.3	12.7
Ormosia krugii	0.25	0.8	3.2	-	-	-
Euterpe globosa	0.25	0.6	2.4	-	-	-
Eugenia stahlii	-	-	-	0.14	3.7	27.4
Palicourea riparia	-	-	-	0.28	4.8	18.8
Micropholis garcinifolia	-	-	-	0.35	3.6	10.2
Averages	0.27	1.4	9.7	0.24	4.1	22.2

TRANSPIRATION*

To estimate the loss of chemical elements from the ecosystem, the quantity of water going into deep drainage and runoff must be known, as well as the element concentration in this water. The only presently feasible way to estimate the proportion of rainfall that goes into deep drainage and into runoff is to calculate it from the formula given in the water budget section. A transpiration measurement is required for this estimate.

Transpiration has been estimated by several methods. By placing an evaporation pan above the canopy and assuming that the vapor pressure deficit there governs the transpiration of the canopy, Odum estimated transpiration to be 1.84 mm/day.

A second estimate of transpiration is derived from the data in "Tritium movement in soil of a tropical rain forest" by Kline and Jordan in this volume. In that report, the lysimeter was 18 cm deep. It took 21 cm of rain to move the tritium peak down to the lysimeter. The 21 cm of rain fell over a period of 20 days. Therefore, 3 cm of rain were lost by transpiration over a 20 day period, or 1.50 mm/day. It was assumed that there was no evaporation from the soil surface.

A third estimate of transpiration was obtained by determining change in moisture content of the soil during dry periods. This was done by measuring the amount of artificially applied rain required to obtain freely flowing water in small soil plots. Freely flowing water was collected in lysimeters, the performance of which are described in another section of this report. Transpiration, estimated by this method, was 1.55 mm/day.

These three independent estimates of transpiration all were very similar. If a value of 1.5 mm/day for transpiration is used, and assuming that water moves equally through all the xylem, it should take a pulse of tritium approximately 6 days to reach the top of a canopy tree. Preliminary results from an experiment in which tritium was injected into a canopy tree on Mar. 6, 1968, indicate that this estimate may be valid.

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*continuing effort

RADIONUCLIDE BEHAVIOR IN TROPICAL SOIL*

Jerry R. Kline

A tracer experiment described in a previous report was terminated with the conclusion that very little cycling of radionuclides from soil to understory vegetation took place through roots (See PRNC-102, p. 146). After termination of the vegetative phases of the experiment, soil and litter measurements were continued to determine, if possible, whether radionuclide reactions in these compartments could explain the small amount of cycling by plants.

^{134}Cs was leached from the organic surface litter of the soil with an effective half-life of approximately 15 days. Upon reaching the soil, however, the nuclide movement became extremely slow. Figure 1 shows the penetration of the nuclide into the soil after 18 months of leaching. The relationship is exponential and shows that the activity is reduced by about 1/2 in the soil for every inch of depth. This behavior is unexpected for highly weathered soils in a high rainfall area. It indicates that the tropical soils have rather effective binding mechanisms which restrict movement.

The existence of such binding mechanisms in soil is shown in Figure 2. Three soils were extracted in duplicate with neutral normal ammonium acetate solution five times in succession. The amount of ^{134}Cs remaining in the soil after each extraction was measured. The results show that the first extraction removed approximately 30-40% of the nuclide but that subsequent extractions were very ineffective in removing ^{134}Cs. Similar results were obtained with ^{54}Mn (Figure 3). The results for both nuclides indicate that significant reversion to relatively insoluble chemical forms took place in the soil during the period of 18 months in the field.

An effort was made to characterize the chemical forms of the nuclides in the soils. Samples were extracted with ammonium acetate solutions to measure exchangeable forms. A second group of samples was treated with H_2O_2 to decompose the organic matter and then extracted with ammonium acetate (NH_4Ac) solution to determine the quantity of organically bound nuclides. A third group was extracted with 0.1 M HCl to determine if precipitation in acid soluble forms in the soil had occurred.

Results of these extractions are given in Figure 4. From 64 to 72% of the total ^{134}Cs was retained by the soil regardless of whether it was treated with NH_4Ac, H_2O_2, or HCl solution. ^{54}Mn on the other hand was released in significant amounts by the destruction of organic matter with H_2O_2 and was almost completely extracted by the HCl. This differing behavior indicates that the two nuclides are in different forms in the soil. From 30 to 40% of ^{134}Cs is exchangeable, but undetectable amounts are associated with organic matter or precipitated acid soluble compounds. Only about 18% of the ^{54}Mn is exchange-

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*continuing effort

able while possibly over 30% of it became associated with organic matter, and most of the remainder was in some acid soluble chemical form.

The behavior of ^{134}Cs could be explained if the soils contain expanding lattice clay minerals since fixation of alkali metals by clays is a well established phenomenon. At present it is not known whether these soils have this type of mineral. X-ray diffraction studies of these soils are planned to determine if these minerals are present. ^{54}Mn is accounted for almost entirely within the exchangeable, organic, and acid soluble forms.

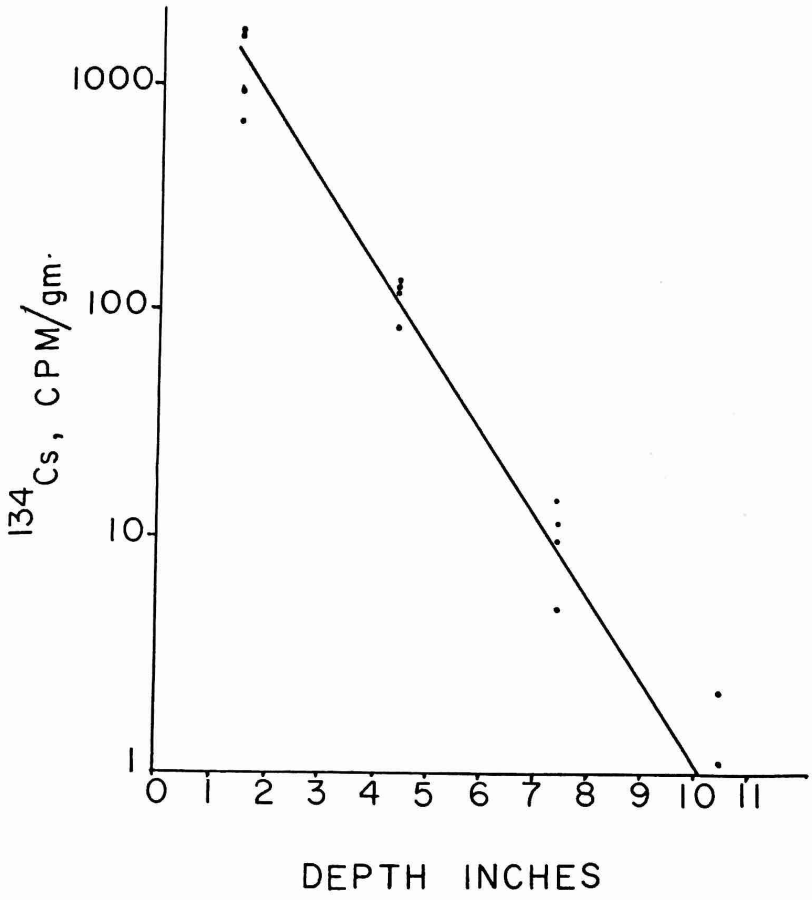

Figure 1. Penetration of ^{134}Cs into the soil of the tropical rain forest at El Verde, Puerto Rico, 18 months after application.

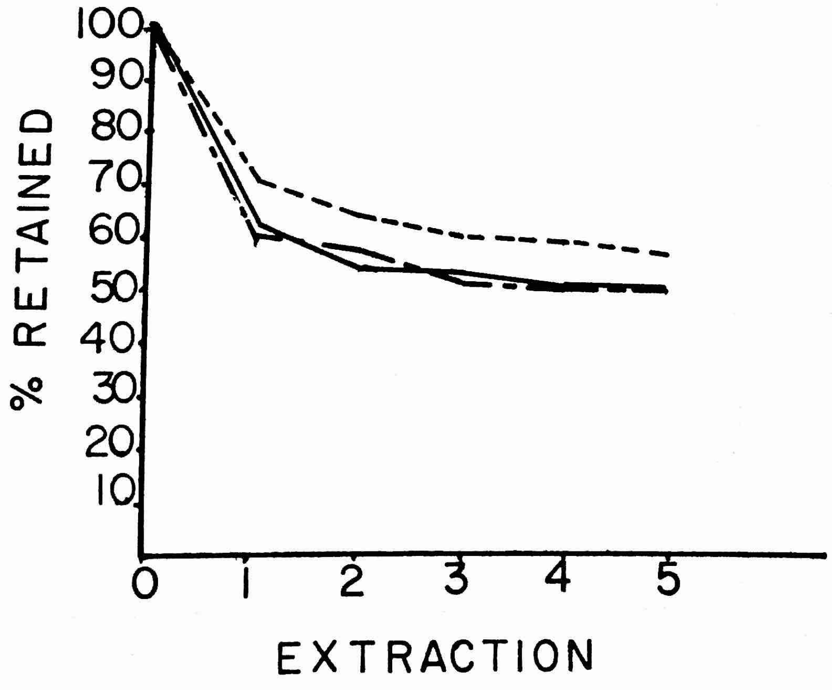

Figure 2. Retention of ^{134}Cs in soil against successive extractions with neutral normal ammonium acetate solutions. Soils were collected from the El Verde Field Station 18 months after the nuclide was applied.

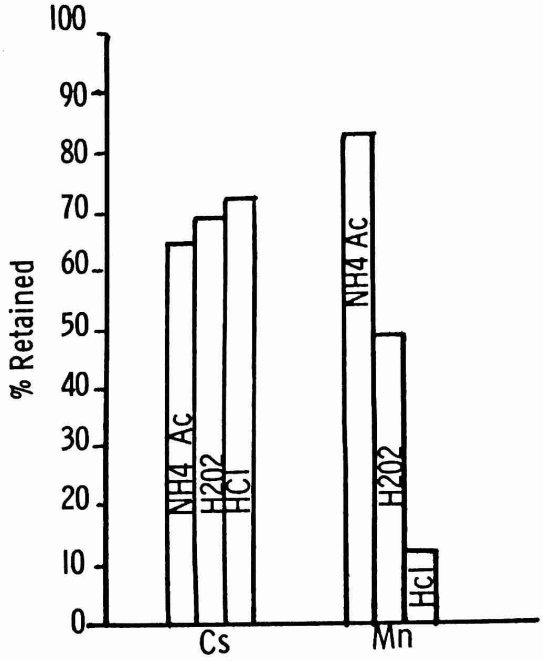

Figure 3. Retention of ^{54}Mn in soil against successive extractions with neutral normal ammonium acetate solutions. Soils were collected from the El Verde Field Station 18 months after the nuclide was applied.

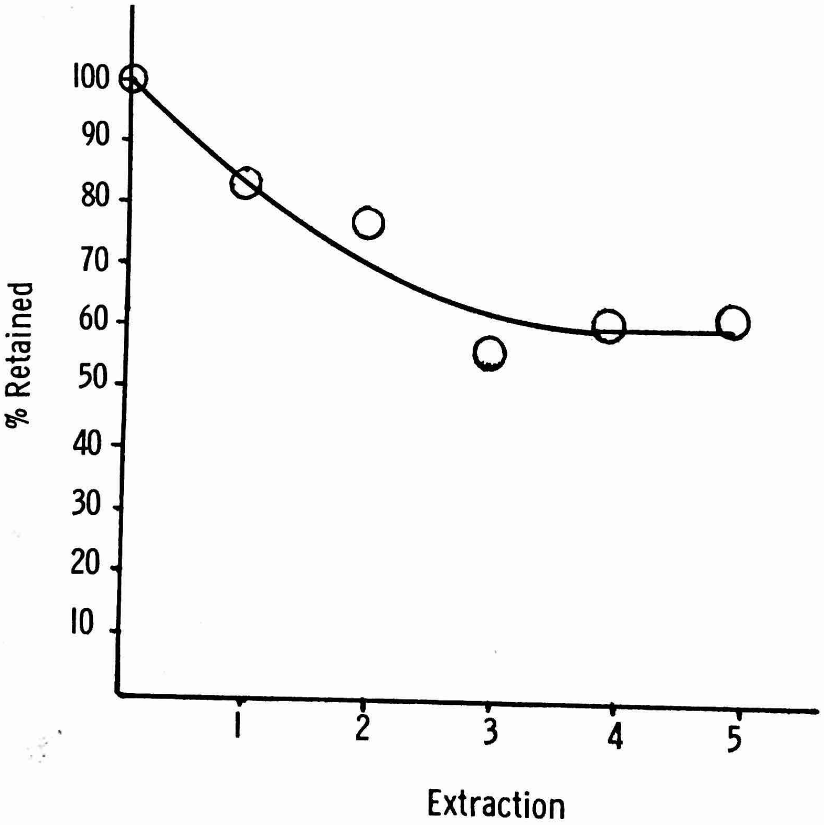

Figure 4. Retention of ^{134}Cs and ^{54}Mn after various treatments.

FALLOUT RADIONUCLIDE DISTRIBUTION IN VEGETATION OF PUERTO RICO*

Jerry R. Kline

The objective of this investigation was to make a systematic determination of fallout radionuclides contained in vegetation on the island of Puerto Rico. Five north-south transects of the island were made for the purpose of gathering plant and soil material. Along each transect 6 to 12 samples of plant leaves, litter, and soil were collected at each of 5 to 7 sampling sites. The sampling sites were selected according to elevation above sea level and each transect included sites at 50, 500, and 1000 meters above sea level on the north and 500 and 50 meters elevation on the south. This sampling pattern conforms to the geographical structure of the island which has a central mountain range surrounded by low level coastal plains. In some cases the elevation in the center of the transect was significantly greater than 1000 meters. When this was encountered the point of maximum elevation was sampled as well as a 1000 meter location both to the north and to the south of the peak. When this was done the transect has a total of 7 sites. Elevations were preselected on a contour map and were then verified on-site using a barometric type automobile altimeter. The altimeter was calibrated every day at sea level.

When collected the samples were oven-dried and counted in bulk by gamma scintillation spectrometry. Data were corrected by computer solution of simultaneous equations. Averages were calculated for all species at each site except those which are epiphytes. These were averaged separately. Data for ^{144}Ce, ^{137}Cs, ^{95}Zr, and ^{54}Mn are given in Table 1 for all leaves collected in each transect. Samples collected on the eastern end of the island are generally higher in radionuclide content. There is little tendency, however, for longitudinal gradients to occur in transects 2, 3, 4, and 5 which were taken progressively towards the west. Altitudinal gradients were present however in all five transects with highest levels of radioactivity present at highest elevations. In general there was less radioactivity in vegetation of the south coast than on the north coast. This is consistent with lower rainfall which normally occurs in this area.

Samples of epiphytic plants were also collected wherever possible in all transects. These were averaged separately and the data are given in Table 2. These samples consisted of bromeliads, ferns, and mosses. The levels of radioactivity are considerably higher in these plants than for leaves taken from the same locations. The role of epiphytes as accumulators of airborne radioactivity which was first observed at the El Verde Field Station seems to be general wherever such plants are found.

Single samples of litter were also collected at each sampling site. Results for these samples are shown in Table 3. These results indicate that there is no detectable east-west gradient of radioactivity. Altitudinal sequences are present however. The litter is enriched in radioactivity relative to fresh leaves at each site. This suggests that the

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*continuing effort

nuclides are accumulating in the litter and are not being recycled biologically or leached by rainfall at rates comparable to leaf turnover in the system.

Preliminary conclusions from this study are 1) There are no east-west gradient of radioactivity in vegetation on the island, 2) The role of epiphytic plants such as bromeliads, ferns and mosses as accumulators of airborne radioactivity is general. These plants should be included in any environmental surveys where radioactive contamination is suspected 3) Radionuclides appear to be accumulating in the litter at all sites sampled. The behavior of radionuclides in this variety of environments is therefore similar to El Verde where extensive evidence indicates the loss from the litter by either biological recycling or leaching is low.

Table 1

Distribution of fallout radionuclides in vegetation on the Island of Puerto Rico.

Elevation meters	Nuclide	Transect 65°45'	66°00'	66°30'	66°45'	67°00'
50 North	^{144}Ce	1.58	0.73	0.20	0.87	1.21
	^{137}Cs	0.77	0.49	0.29	0.77	0.49
	^{95}Zr	0.79	0.41	0.13	0.11	0.13
	^{54}Mn	0.12	0.07	0.05	0.06	0.07
500 North	^{144}Ce	0.71	1.55	0.10	0.99	1.00
	^{137}Cs	2.84	0.92	0.75	0.63	0.78
	^{95}Zr	0.43	0.52	0.19	0.27	0.55
	^{54}Mn	0.18	0.08	0.05	0.13	0.09
1000 North	^{144}Ce	4.25	3.45	0.50	4.23	0.98
	^{137}Cs	7.54	2.93	0.87	4.66	1.01
	^{95}Zr	0.89	1.24	0.34	0.20	0.18
	^{54}Mn	0.95	0.70	0.11	0.46	0.10

Continued Table 1

Elevation meters	Nuclide			Transect		
		65°45'	66°00'	66°30'	66°45'	67°00'
500 North	$^{144}\mathrm{Ce}$	0.80	1.08	0.27	0.21	0.13
	$^{137}\mathrm{Cs}$	1.65	1.01	0.44	0.35	0.25
	$^{95}\mathrm{Zr}$	0.38	0.59	0.29	0.07	0.06
	$^{54}\mathrm{Mn}$	0.13	0.09	0.18	0.05	0.04
50 South	$^{144}\mathrm{Ce}$	0.26	0.67	0.52	0.12	0.67
	$^{137}\mathrm{Cs}$	0.51	0.27	0.18	0.11	0.37
	$^{95}\mathrm{Zr}$	0.18	0.78	0.12	0.07	0.19
	$^{54}\mathrm{Mn}$	0.12	0.17	0.06	0.13	0.12
Greater than 1000 meters*	$^{144}\mathrm{Ce}$			2.81	0.43	
	$^{137}\mathrm{Cs}$			6.20	3.44	
	$^{95}\mathrm{Zr}$			0.49	0.32	
	$^{54}\mathrm{Mn}$			0.56	0.24	
1000 South	$^{144}\mathrm{Ce}$			0.70	1.40	
	$^{137}\mathrm{Cs}$			0.94	0.21	
	$^{95}\mathrm{Zr}$			0.72	0.48	
	$^{54}\mathrm{Mn}$			0.23	0.21	

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Table 2

Distribution of fallout radionuclides in epiphytic plants on the Island of Puerto Rico.

Elevation meters	Nuclides	Transect 65°45'	66°00'	66°30'	66°45'	67°00'
50 North	^{144}Ce	0.36		1.78	1.47	2.18
	^{137}Cs	3.21		3.25	1.57	2.83
	^{95}Zr	0.81		0.41	0.15	0.29
	^{54}Mn	0.06		0.20	0.19	0.18
500 North	^{144}Ce	0.94	0.05	4.80	2.30	0.54
	^{137}Cs	7.56	1.29	1.48	1.24	5.28
	^{95}Zr	0.86	0.41	12.08	0.24	0.42
	^{54}Mn	0.33	0.05	0.55	0.09	0.01
1000 North	^{144}Ce	16.81	13.18	0.45	0.94	1.58
	^{137}Cs	34.48	34.38	3.02	2.78	7.17
	^{95}Zr	2.38	5.90	0.29	0.15	0.36
	^{54}Mn	1.88	2.37	0.14	0.15	0.19
500 South	^{144}Ce	0.05	0.37	0.85	4.48	3.20
	^{137}Cs	0.51	2.95	2.14	2.38	0.05
	^{95}Zr	0.32	0.44	0.19	0.05	0.36
	^{54}Mn	0.05	0.28	0.20	0.24	0.32

Continued Table 2

Elevation meters	Nuclides	Transect				
		65°45'	66°00'	66°30'	66°45'	67°00'
50 South	^{144}Ce	0.07		1.49	1.02	
	^{137}Cs	2.23		3.31	2.22	
	^{95}Zr	0.11		0.32	0.14	
	^{54}Mn	0.26		0.19	0.06	
Greater than 1000 meters	^{144}Ce			12.80	3.76	
	^{137}Cs			15.63	7.23	
	^{95}Zr			2.00	0.25	
	^{54}Mn			0.32	0.24	
1000 South	^{144}Ce			1.17	1.18	
	^{139}Cs			1.99	9.72	
	^{95}Zr			0.11	0.92	
	^{54}Mn			0.11	0.46	

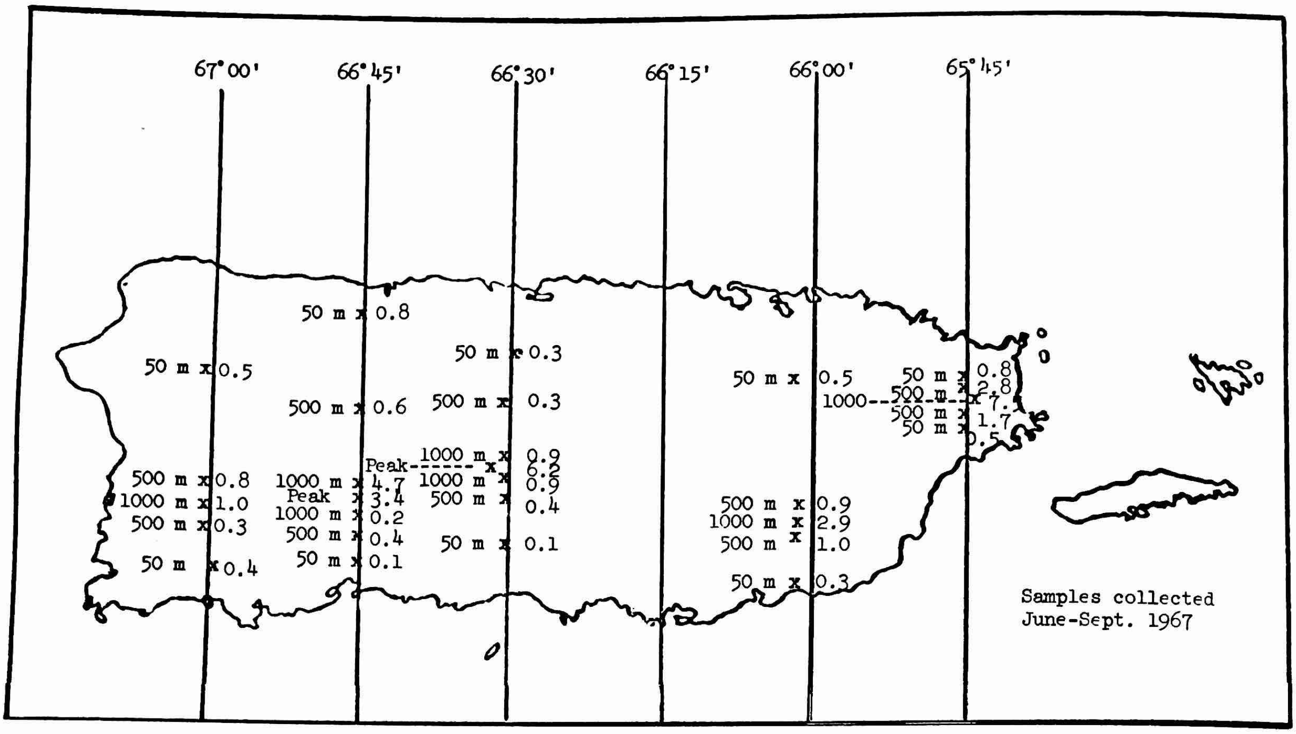
Table 3

Distribution of fallout radionuclides in ground litter on the Island of Puerto Rico.

Elevation meters	Nuclides			Transect		
		65°45'	66°00'	66°30'	66°45'	67°00'
50 North	$^{144}\mathrm{Ce}$	2.25	0.64	0.05	0.63	1.12
	$^{137}\mathrm{Cs}$	1.22	0.96	0.05	0.75	0.86
	$^{95}\mathrm{Zr}$	0.05	0.21	0.24	0.33	0.47
	$^{54}\mathrm{Mn}$	0.03	0.13	0.05	0.04	0.05
500 North	$^{144}\mathrm{Ce}$	3.98		1.28	1.14	1.80
	$^{137}\mathrm{Cs}$	3.22		0.78	1.59	1.36
	$^{95}\mathrm{Zr}$	0.71		0.44	0.17	0.50
	$^{54}\mathrm{Mn}$	0.47		0.05	0.20	0.10
1000 North	$^{144}\mathrm{Ce}$	15.66	10.50	1.02	1.42	3.28
	$^{137}\mathrm{Cs}$	17.00	11.32	1.42	1.20	4.27
	$^{95}\mathrm{Zr}$	2.00	2.58	0.10	0.09	0.31
500 South	$^{144}\mathrm{Ce}$	0.05	1.10	0.46		3.20
	$^{137}\mathrm{Cs}$	1.46	1.19	0.37		0.79
	$^{95}\mathrm{Zr}$	0.05	0.12	0.20		0.14
	$^{54}\mathrm{Mn}$	0.5	0.12	0.04		0.06

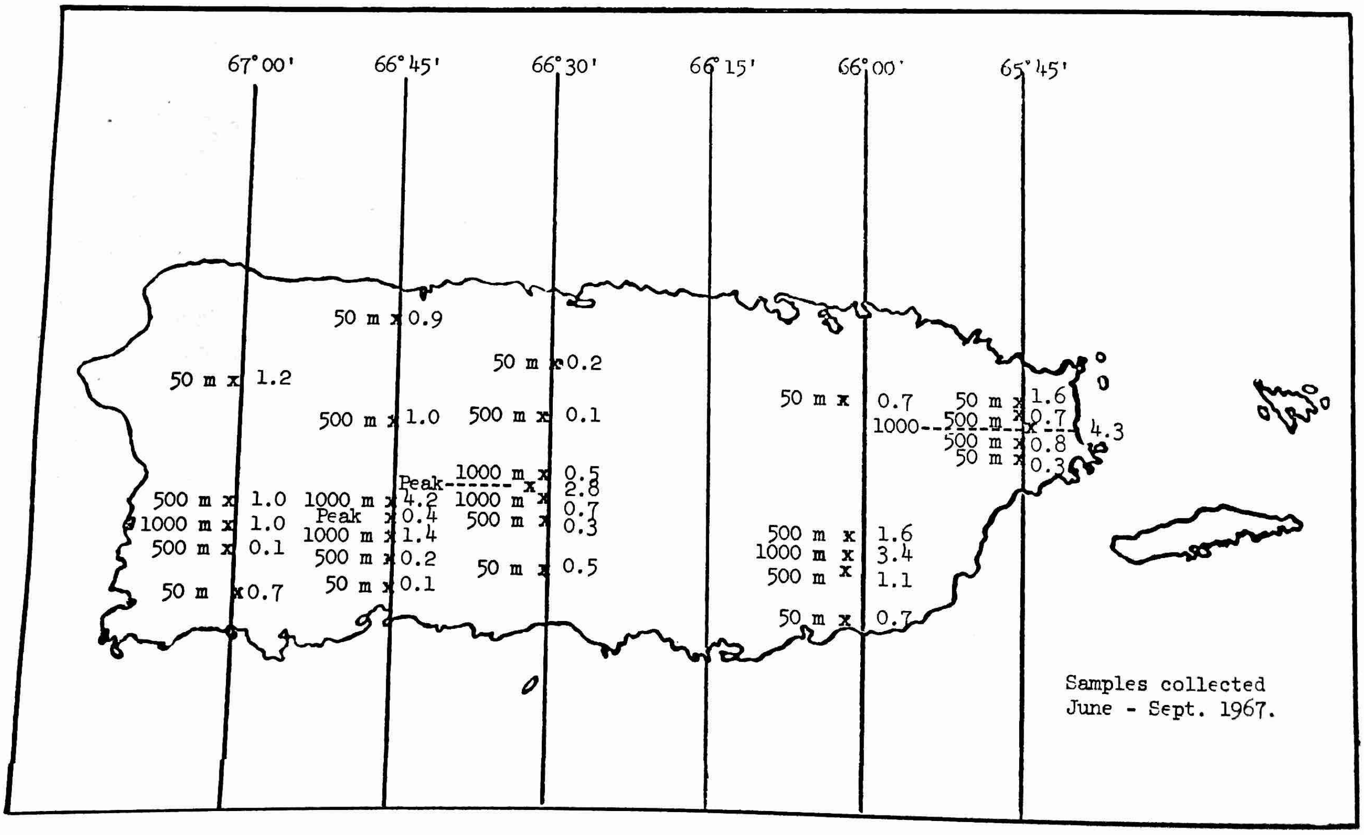
Continued Table 3

Elevation meters	Nuclide			Transect		
		65°45'	66°00'	66°00'	66°45'	67°00'
50 South	^{144}Ce	1.01	0.01	0.05	1.18	
	^{137}Cs	1.02	0.05	0.15	0.82	
	^{95}Zr	0.19	0.09	0.19	0.14	
	^{54}Mn	0.03	0.05	0.05	0.05	
Greater than 1000 meters	^{144}Ce			5.84	5.25	
	^{137}Cs			9.93	16.59	
	^{95}Zr			0.26	0.25	
	^{54}Mn			0.47	0.96	
1000 South	^{144}Ce			4.82	0.99	
	^{137}Cs			2.97	1.52	
	^{95}Zr			0.49	0.10	
	^{54}Mn			0.33	0.38	



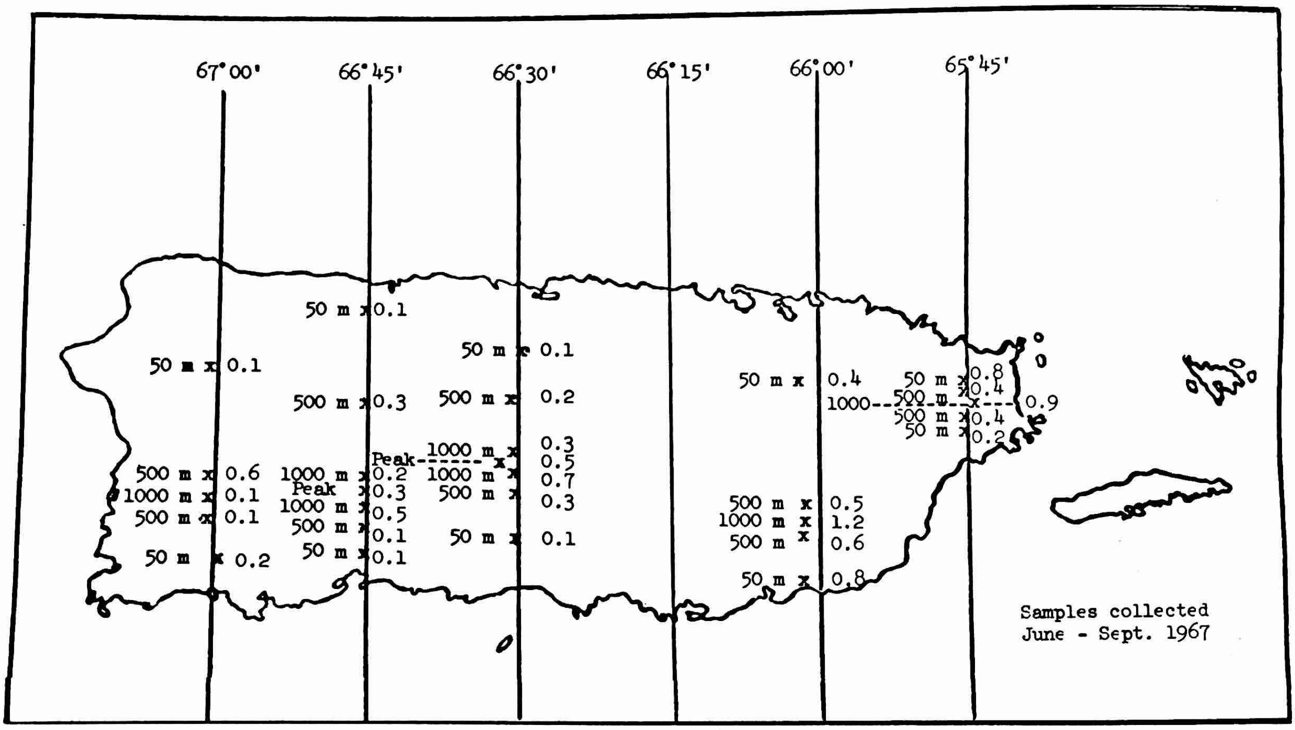
Samples collected
June-Sept. 1967

Figure 1. Distribution of ^{137}Cs in vegetation on the island of Puerto Rico. Sampling sites are shown by X. Values to the left of each site are elevations in meters and to the right are pCi/gm.



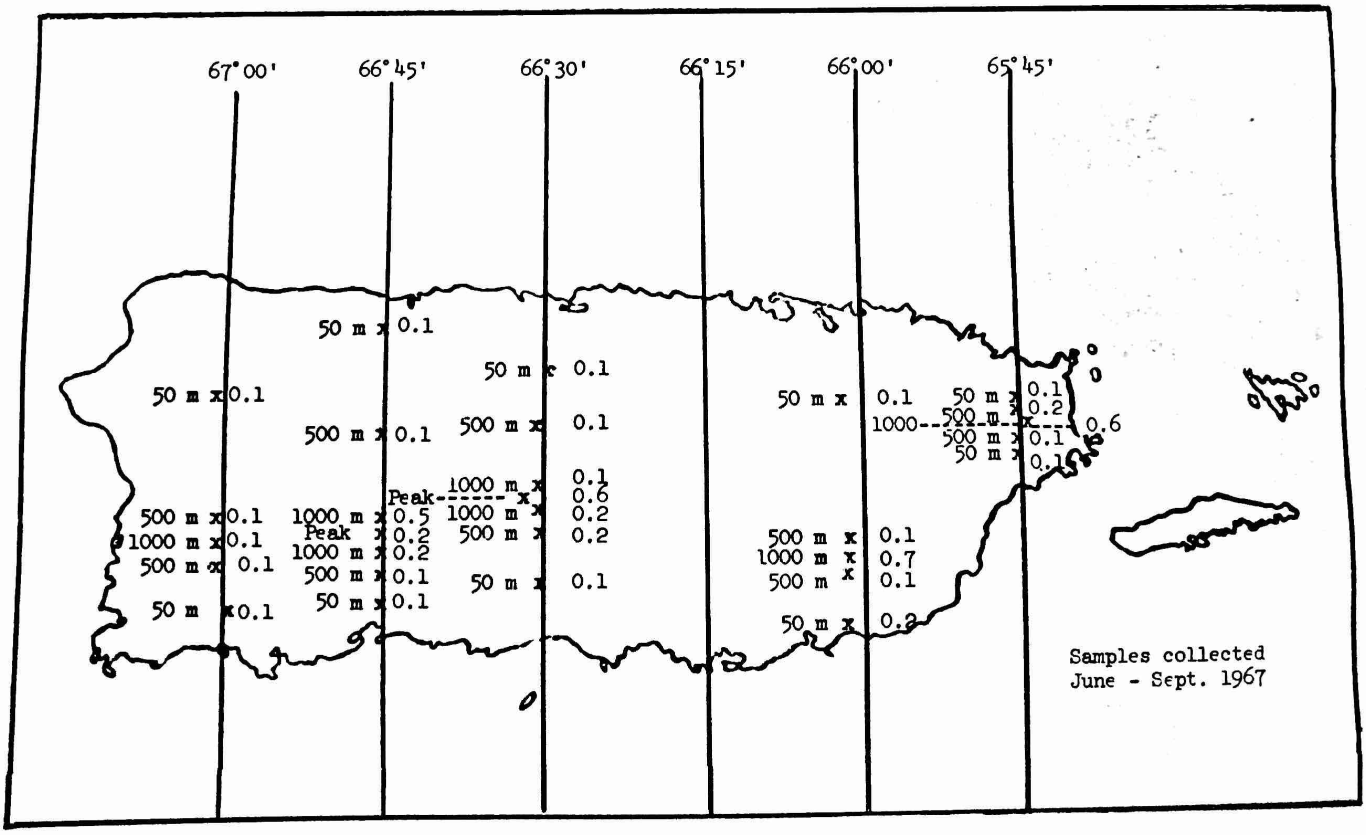
Samples collected
June - Sept. 1967.

Figure 2. Distribution of ^{144}Ce in vegetation on the island of Puerto Rico. Sampling sites are shown by X. Values to the left of each site are elevations in meters and to the right are pCi/gm.



Samples collected June - Sept. 1967

Figure 3. Distribution of ^{95}Zr - ^{95}Nb in vegetation on the island of Puerto Rico. Sampling sites are shown by X. Values to the left of each site are elevations in meters and to the right are pCi/gm.



Samples collected June - Sept. 1967

Figure 4. Distribution of ^{54}Mn in vegetation on the island of Puerto Rico. Sampling sites are shown by X. Values to the left of each site are elevations in meters and to the right are pCi/gm.

REACTIONS OF NUCLIDES WITH EPIPHYLLAE*

Raymond Henzlik and Jerry R. Kline

Epiphyllae are mixtures of organisms which grow on the surfaces of leaves in the rain forest. Their populations may include algae, fungi, lichens, liverworts, mosses or bacteria. These organisms have been suspected of playing a role in the nutrient cycling mechanisms of the forest because they were found to contain large amounts of fallout radionuclides. Experiments were carried out in cooperation with Dr. Raymond Henzlik, an Oak Ridge Research Participant from Ball State University, to examine some reactions of these organisms with radionuclides.

Leaves from four species of trees were contaminated with radioactive solutions containing ^{134}Cs and ^{85}Sr for a period of 20 minutes after which the leaves were washed in tap water for 6 minutes. All species had leaves which had epiphytic growth and those which did not. The results are shown in Table 1. Epiphyllae were from 4 to 7 times more efficient in retaining radionuclides than were leaves which had no surface growth. This indicates that these organisms may be adapted to deriving their mineral nutrient requirements by interception of rain water or canopy leachate.

Minerals which are intercepted by epiphyllous leaves may be transferred to the leaves by foliar uptake. If this happened it could be an important source of nutrients for the higher plants of the area. An experiment was done to determine whether leaves received nutrients from labeled epiphyllae. Excised leaf sections containing labeled epiphyllae were placed firmly against the surfaces of leaves in the field and held there for 24 hours. Leaves in the field were matched for those having surface growth and for those which did not. After up to 10 days, the leaves were harvested sectioned, and counted.

The results (Table 2) show that epiphyllae took up more radioactivity from the labeled overlays than did clean leaf surfaces. The activity in the tip portions of the leaves probably indicates surface translocation since the leaves are adapted to shedding water in this direction. The activity in the basal portion of the leaves may indicate some uptake and translocation by the leaf. It is apparent, however, that most of the activity remained in the region of the leaf which was originally contaminated. It is concluded that epiphytes of this type are not efficiently adapted to furnishing their higher plant hosts with minerals through foliar uptake. The strong binding adaptation exhibited by these organisms for mineral elements suggests that the opposite may be true. Minerals leached from leaves by rain water may be the source of nutrients for the epiphyllae.

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*continuing effort

Table 1

Adsorption of ^{134}Cs and ^{85}Sr on epiphyllous and non-epiphyllous leaves of the tropical rain forest.

Leaf surface	^{137}Cs CPM/sect	^{85}Sr CPM/sect
Epiphyllous	9134	5363
Non-epiphyllous	1405	1269

Table 2

Uptake of radionuclides by epiphyllous and non-epiphyllous leaves and translocation of the nuclides within the leaves.

Leaf surface	Region	^{137}Cs CPM/sect	^{85}Sr CPM/sect
Epiphyllous	tip	171	498
	overlay	1062	2604
	base	42	180
Non-epiphyllous	tip	26	34
	overlay	117	332
	base	12	8

NEUTRON ACTIVATION OF TROPICAL SOILS AND PLANTS*

Jerry R. Kline

The objective of this investigation was to measure the characteristics of thermal neutron irradiated soils and plants of the tropics, and to determine those elements which can be feasibly determined by non-destructive neutron activation. Eleven soils of Puerto Rico and 5 from Panama are included in the study. Two samples of ashed plant material were also included.

One hundred milligram samples of oven dried, crushed soils were weighed into specially constructed polyethylene packets in preparation for the irradiation. Six such packets along with chemical standards were then placed in a screw top polyethylene capsule and the capsule was irradiated in the PRNC research reactor for one hour at a flux of 2×10^{12} $n/cm^2/sec$. After a one to 3 day period of cooling the samples were counted by gamma scintillation spectrometry using a shielded 3 x 3 NaI(Tl) crystal connected to a 400 channel spectrometer. Three types of measurements were made for each sample. These were 1) Gross gamma decay rates, 2) Observation of gamma-ray spectra to determine which nuclides were present, 3) Quantitative analysis of prominent elements in the spectra.

Figure 1 shows gross gamma decay patterns for 6 of the soils of this study. The others are omitted for clarity since similar decay curves were obtained. Regardless of the orgin of the sample the curve are characterized by initial rapid decay rates for the first 100 hours after irradiation. Half-lives for samples in this portion of the curves are 15-20 hours which implies that the dominant radioactivity is 15 hour ^{24}Na. This was verified by observation of the spectra and is consistent with what has been found previously by the author for temperate zone soils.** As ^{24}Na decays away the curves go through a sharp bend lasting from 100 to 300 hours and then assume a half-life of approximately 1400 hours or 58 days. This portion of the decay curve is dominated by radioactivity from ^{59}Fe ($T\ 1/2 = 45$ d) and ^{46}Sc ($T\ 1/2 = 84$ d) with probably minor contributions from other nuclides. This is also consistent with what has been found for temperate zone soils. It is concluded from these studies that neutron irradiated tropical soils have essentially the same complement of elements undergoing neutron capture as temperate zone soils in spite of the fact that they are subject to much more intense weathering.

*completed

**Kline, J.R., J.F. Foss, and S.S. Brar. Lanthanum and Scandium distribution in three glacial soils of Western Wisconsin. In preparation. Preprints available.

Gamma ray spectra of several of the soils in this study are shown in Figures 2-8. Two spectra are shown for each soil. The first of each pair was taken from 4-7 days after irradiation and is therefore in a stage of decay corresponding to the rapidly curving portion of the decay curves. The second spectrum was taken 54 days after irradiation and corresponds to the slowly decaying portion of the decay curves.

The nuclides most prominantly present in many of the early spectra include ^{51}Cr, ^{82}Br, ^{46}Sc, ^{59}Fe and ^{24}Na. Some of the spectra show traces of ^{140}La while most of the soils seem to have below detectable limits of this element. All of these elements have been observed previously in a variety of temperate zone soils. One of the differences between tropical soils and temperate soils seem to be the apparent paucity of La in the tropical soils. This is consistent with the conclusions of Kline _et al_*, who suggested that La is probably easily leached from soils.

The older gamma ray spectra are dominated by ^{51}Cr, ^{46}Sc, and ^{59}Fe. In this respect they are very similar to temperate soils. Further analyses will be done of the data to determine whether these soils contain the rare earth elements Eu and Sm. These elements have been found in many temperate soils. Their presence or absence in tropical soils will give some indication of rare earth weathering behavior.

Quantitative analyses were made for Cr, Sc and Fe. Results are shown in Table 1. Fe values range from 3.5 to over 17% with the majority of samples having Fe contents between 7 and 10%. These are reasonable levels for tropical soils which have undergone selective removal of silica during the process of laterization. Temperate zone soils by contrast have Fe contents which may range from 0.5 to 3%. Sc values range from 7.3 to over 60 ppm. These values are generally higher than have been found in the temperate zone. The author has for instance found a range of 1-10 ppm Sc in a group of soils from Minnesota. Kline and Brar* have showed a general association between Fe and Sc in a world wide collection of soils. High Fe soils are almost always found to be high in Sc also. The results from the tropical soils are consistent with this relationship which was established by independent measurement previously.

Cr levels ranged from 37 to 175 ppm. These amounts are about in the same range as has been found in other groups of soils. No relationships have thus far been found between Cr and other elements of soils.

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*Kline, J.R., and S.S. Brar. Instrumental analysis of neutron irradiated soils. In preparation. Preprint copy avail.

Table 1

Amounts of Fe, Sc, and Cr in some tropical soils

Soils	Depth inches	Fe %	Sc ppm	Cr ppm
El Verde (Control Center)	0-12	9.7	47.0	70.0
El Verde (Control Center)	12-24	9.3	55.1	37.2
El Verde (Rad. Center)	0-5	5.0	7.3	157.2
El Verde (Rad. Center)	5-12	7.5	14.4	174.9
El Verde (Rad. Center)	12-24	7.9	18.4	110.3
Elfin forest (PR)	0-12	9.3	22.8	59.2
Elfin forest (PR)	12-24	9.5	60.5	-
Elfin forest (PR)	24-36	10.4	41.4	-
Limestone (Bayamón, PR)	0-6	7.8	26.2	-
Cambalache (Manatí, PR)	0-6	17.1	33.4	-
Guajataca gorge (Quebradillas, PR)	0-6	3.5	10.6	-
Chepo, Panama	0-6	7.9	28.8	-

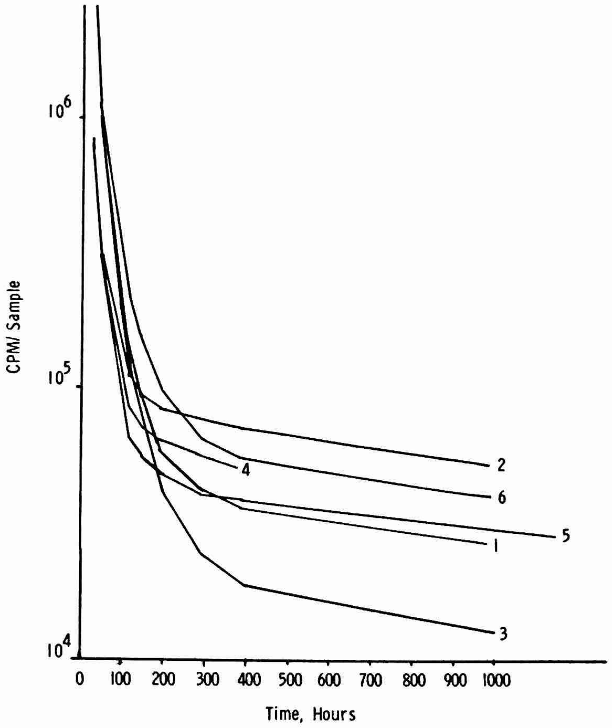

Figure 1. Gross gamma decay curves for some neutron irradiated soils of Puerto Rico and Panama. Soils were irradiated for 1 hour at a flux of $2x10^{12}n/cm^2/sec$. No. 1, Bayamón, P.R.; 2, El Yunque peak P.R.; 3, Quebradillas,P.R.; 4, El Yunque peak subsoil, P.R.; 5, Chepo Panama; 6, Manatí, P.R.

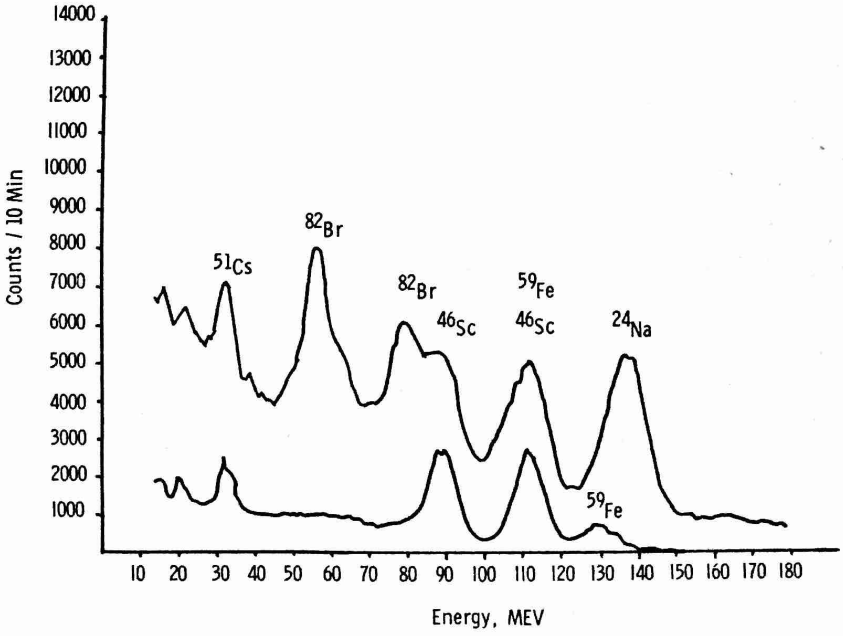

Figure 2. Gamma ray spectra of neutron irradiated surface soil from El Verde, Puerto Rico. Upper curve taken 100 hours after irradiation; lower after 450 hours.

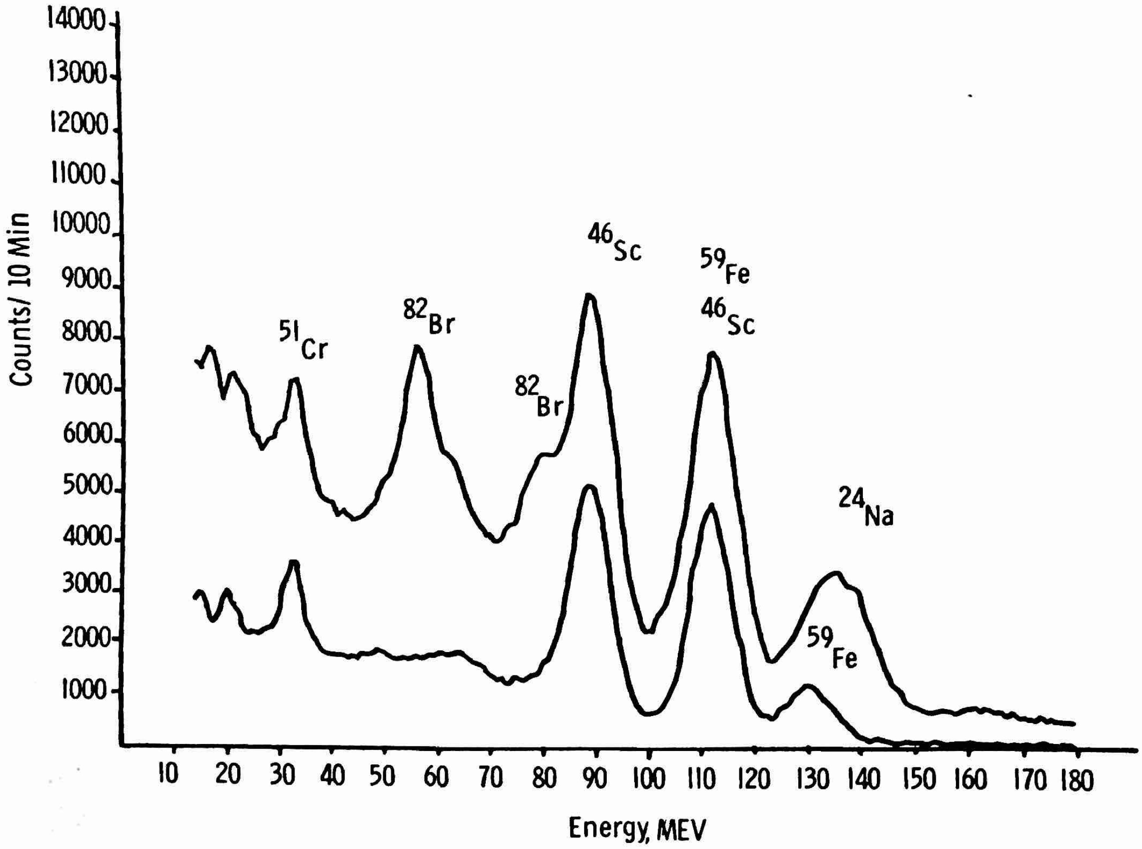

Figure 3. Gamma ray spectra of neutron irradiated soil taken from the 5-12 inch depth at El Verde Puerto Rico. Upper curve 100 hours after irradiation; lower after 450 hours.

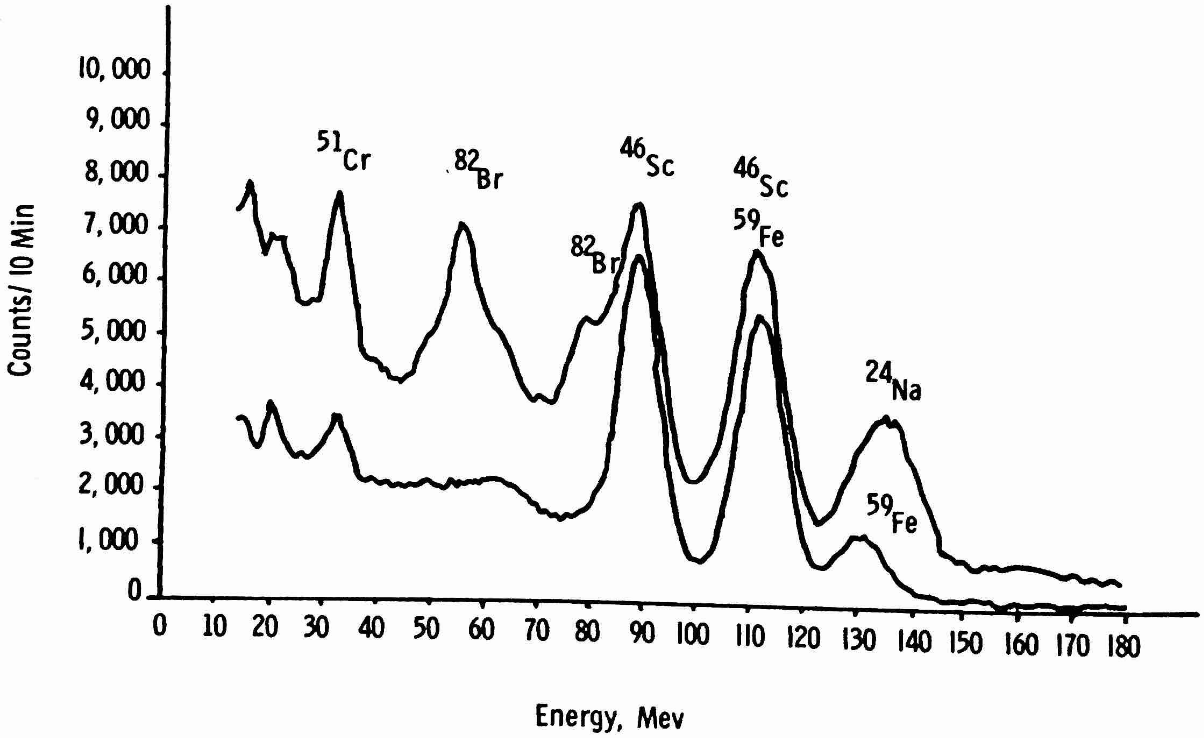

Figure 4. Gamma ray spectra of neutron irradiated soil taken from the 12-24 inch depth at El Verde Puerto Rico. Upper curve 100 hours after irradiation; lower after 450 hours.

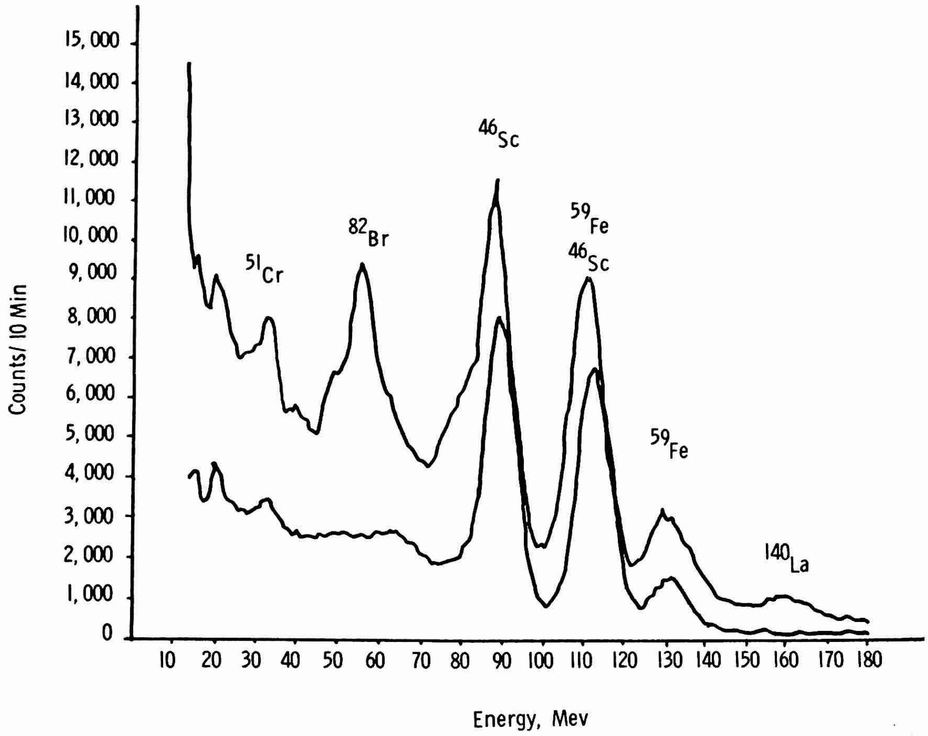

Figure 5. Gamma ray spectra of neutron irradiated surface soil taken from the Elfin forest on El Yunque peak, Puerto Rico. Upper curve 100 hours after irradiation; lower after 450 hours.

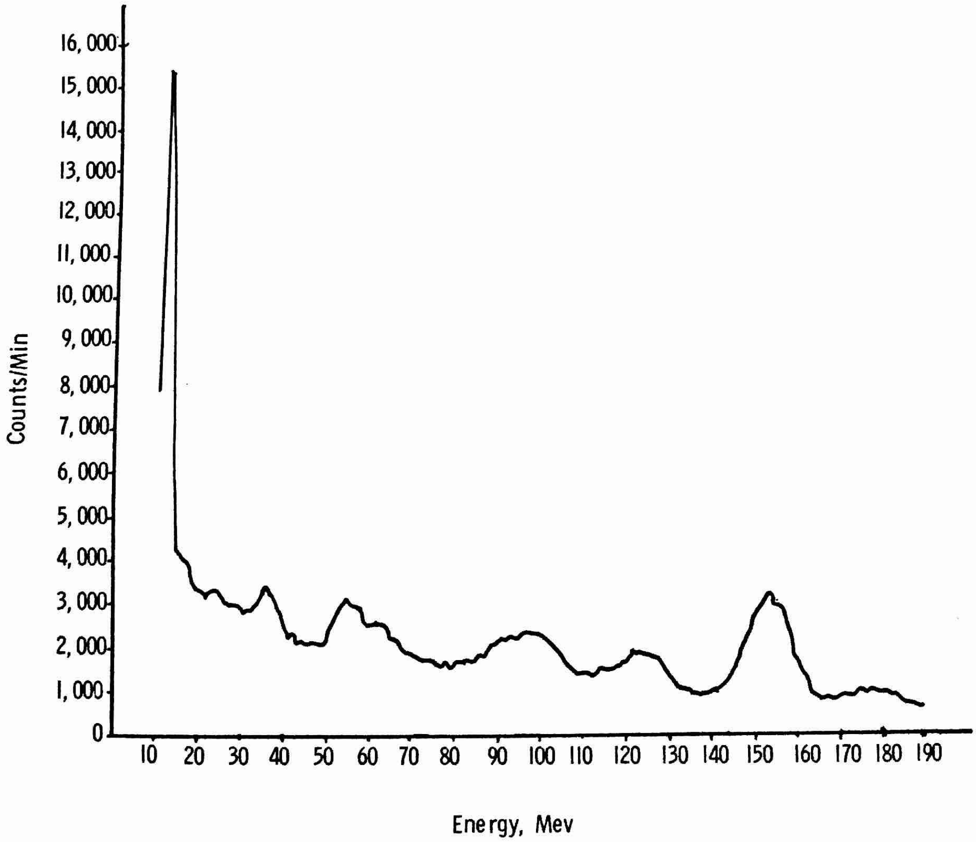

Figure 6. Gamma ray spectrum of neutron irradiated surface soil taken from Darien Province Panama. 100 hours after irradiation.

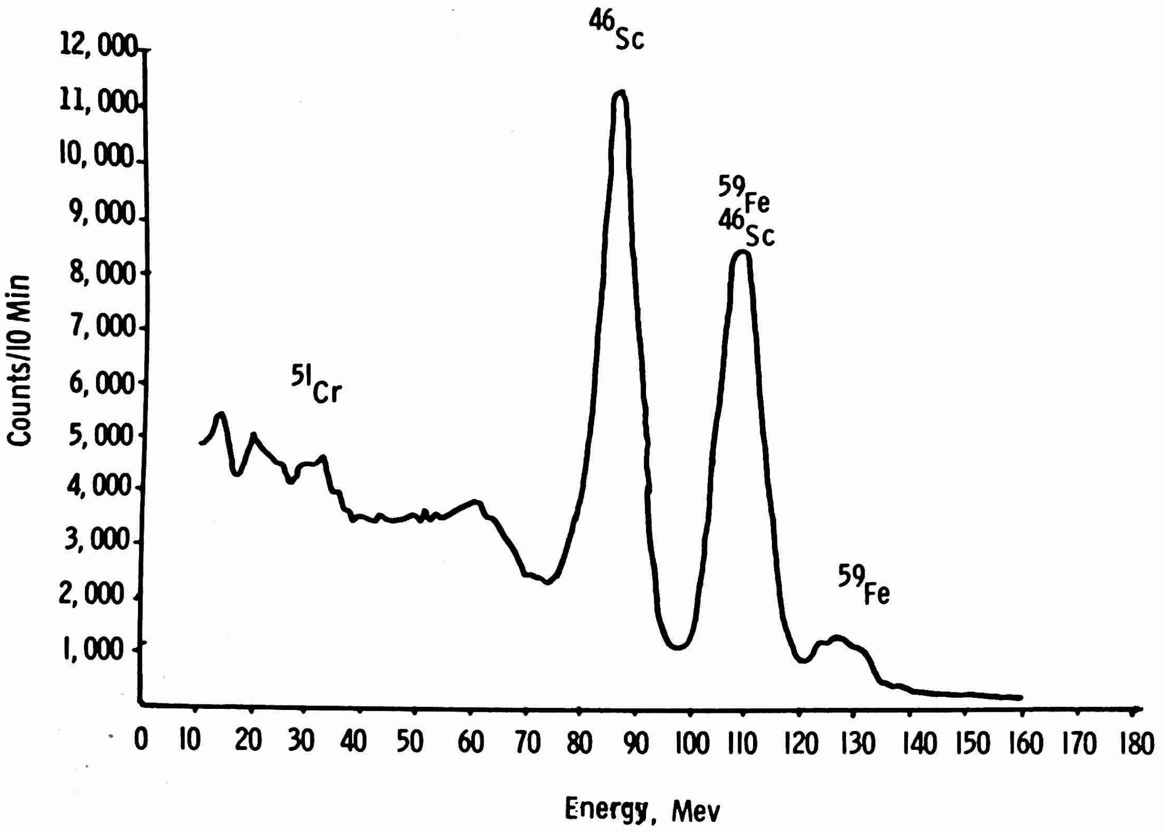

Figure 7. Gamma ray spectrum of neutron irradiated surface soil taken from Darien Province Panama. 1500 hours after irradiation.

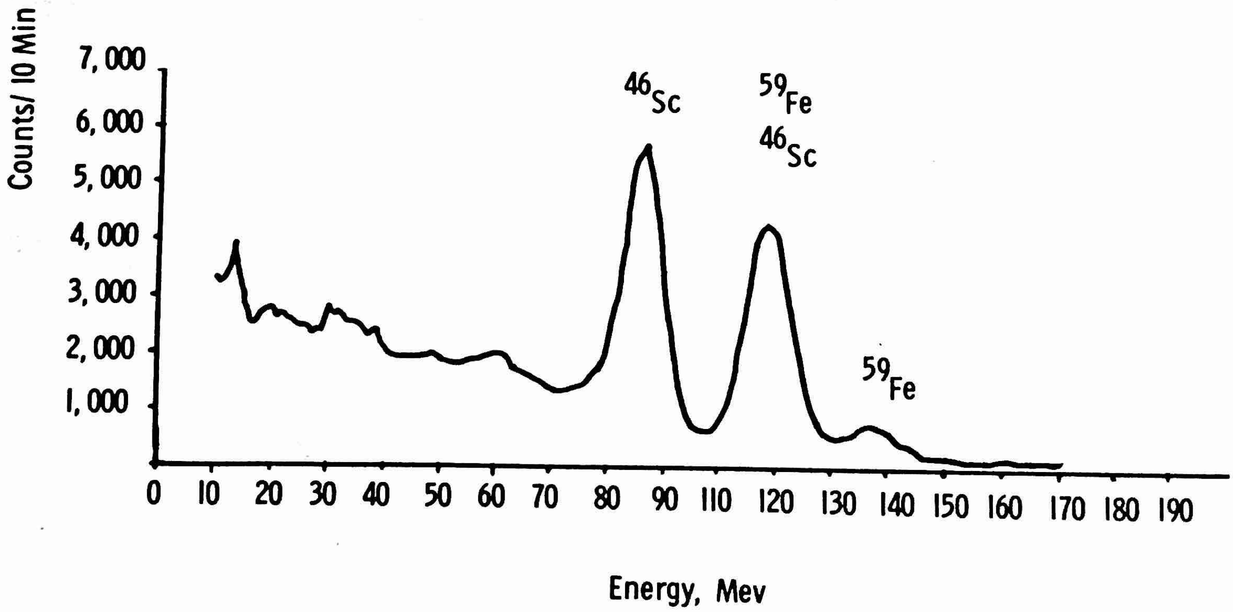

Figure 8. Gamma ray spectrum of neutron irradiated surface soil taken from a mangrove swamp in Darien Province Panama. 1500 hours after irradiation. Early spectra dominated by ^{24}Na not shown.

TERMITE NESTS AND TUNNELS IN THE RADIATION CENTER AT EL VERDE*

Elizabeth McMahan**

Richard Wiegert and the forest work crew in May 1966, mapped the Radiation and Control Centers to a radius of 80 m and located 24 nests of Nasutitermes costalis. All were active except #22 and #23 in the Radiation Center and #24 in the Control Center. P. Murphy had noted in 1964 that Wiegert's #23 nest had been active prior to irradiation. Nests #22 and #24 probably had been abandoned prior to irradiation. (See Fig. 1).

In the summer of 1966 McMahan studied the termites of both centers, examining Wiegert's nests and locating a new one (#25) about 35 feet up in a Cyrilla tree, the only tree nest discovered in the forest area. Special attention was given nests #19, #20, and #14 which lay within 33 m of the Cs source. Their accumulated doses of radiation were 6000 r, 1000 r, and 500 r respectively. All three were still active in 1966, but #19 and #20 were in a deteriorated condition. McMahan failed to find nymphal stages in these two nests and only a few in #14 and concluded that irradiation had sterilized the primary reproductives as well as any potential supplementary reproductives.

On March 28, 1967, McMahan re-examined these nests and found that all three had been abandoned. Other nests were not systematically checked at this time.

In July 1967, she examined all nests previously mapped (plus a new one, #26, which she found in the Control Center). This time #15 (at 50 m) and #21 (at 80 m) in the Radiation Center were found to be abandoned. Out of 11 nests known to have been active in this Center in May 1966, 5 had been abandoned by July 1967. All of the 10 known active nests in the Control Center (plus nest #26) were still active. (See Fig. 1 for map of nests).

Nests at 50-80 m received accumulated doses of only about 100-200 r, but this may have been sufficient to sterilize reproductives. A nest in which no brood is developing must necessarily deteriorate as natural mortality decimates the population. (A nest usually represents the offspring of a single reproductive pair).

A study is under way to compare ratios of nymphs and mature workers present in the remaining nests, both in the Radiation and in the Control Centers. Results may help to indicate whether or not sterility has been the chief factor in nest abandonment.

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*continuing effort

**University of North Carolina

Tunnels

Tunnels of wood carton connect nests with dead branches or other food sources. McMahan in the summer of 1966, surveyed these tunnels on the trees of the Radiation, Control, and North Cut Centers. Every upright trunk with a diameter above 1/2 inch, dead or alive, was examined for the presence of tunnels. When a tunnel was found, it was examined for occupants, which might be either *Nasutitermes costalis* or *Parvitermes discolor*. (*P. discolor* is another species common in the centers, but is not a nest-builder).

Approximately 10% of the trees in each center exhibited tunnels. Only 12% of the tunnels in the Radiation Center were occupied (usually by *Parvitermes*), while 52% of those in the Control Center, and 38% of those in the North Cut Center were occupied.

The tunnels in the three Centers were recensused in the summer of 1967. This time only 8% of the Radiation Center tunnels were occupied, while 49% of the Control Center tunnels and 42% of the North Cut Center tunnels were occupied. Table 1 summarizes the tunnel data.

These data indicate that the termite population in the Radiation Center continues to decrease. Since there are now fewer *Nasutitermes* nests in this center, the decrease in *Nasutitermes*-occupied tunnels should be expected. It is interesting to note, however, that *Parvitermes* occupation is also low, as compared with the North Cut Center. The latter also has no *Nasutitermes* nests within 30 m of point zero but does have a large number of *Parvitermes*-occupied tunnels.

The data may indicate that recolonization of a rain forest area in which the termite populations have been wiped out is a slow process. It will be interesting to continue this study for another year.

Table 1

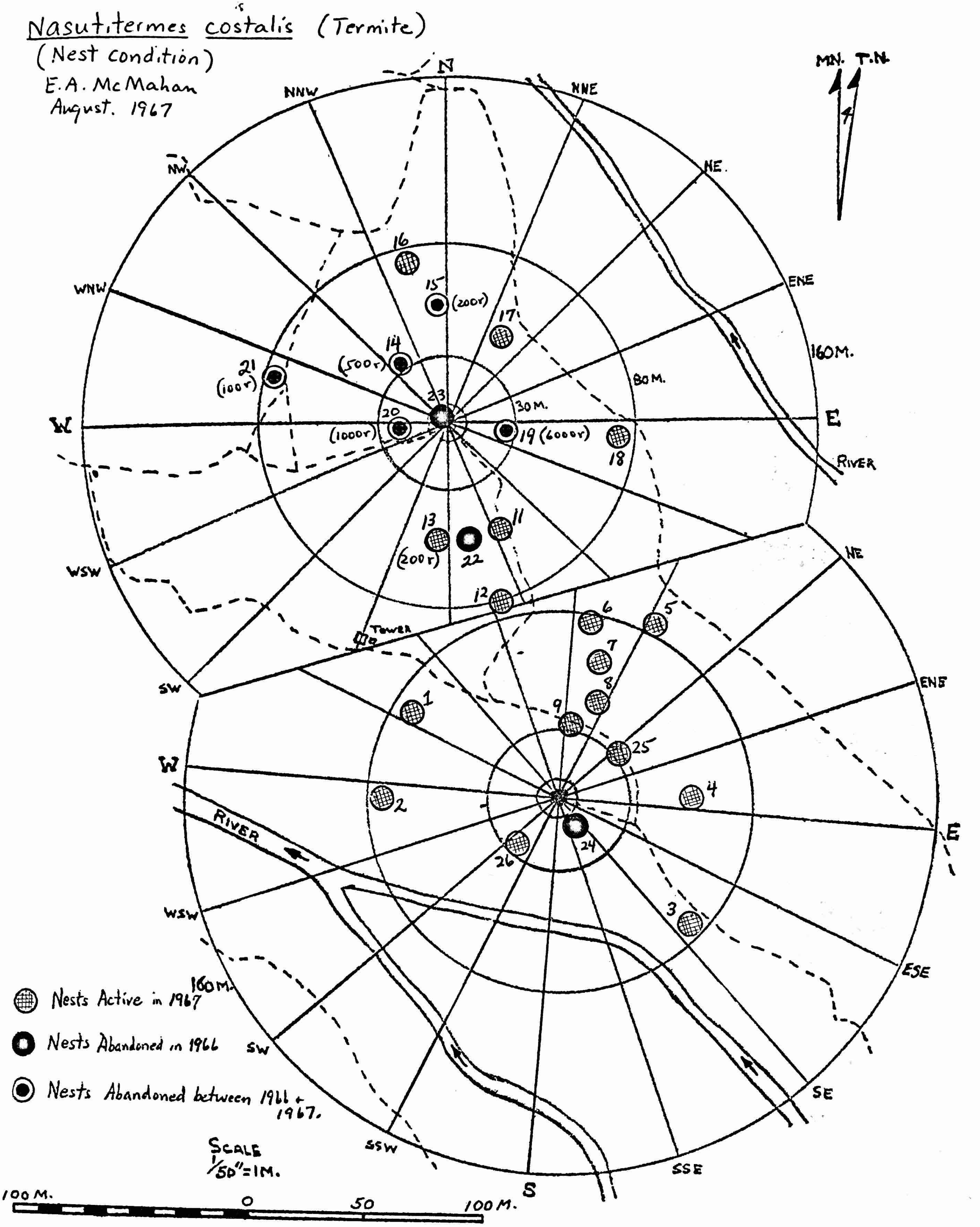
Results of Tunnel Census in Experimental Centers

	1966			1967		
Center	No Trees with tunnels	% Occupied	N:P[a]	No Trees[b] with tunnels	% Occupied	N:P
Radiation	89	12	1:2.7	101	8	1:7
Control	92	52	1:1.1	111	49	1:1.6
N. Cut	28*	38	$1:10^2$	77	42	1:15

* Checked to only 20 m radius

[a] Ratio of *Nasutitermes* to *Parvitermes* occupation (not exact)

[b] Increase in tree no. due mostly to finding of old tunnels missed in 1966.



Nasutitermes costalis (Termite)
(Nest condition)
E.A. McMahan
August. 1967

SOIL RESPIRATION*

C.F. Jordan

Soil respiration in the mature forest and the irradiated area was measured by putting a relatively large box (250 liter capacity, covering .625 m^2 of soil) over the soil surface, and measuring CO_2 build up inside the box. An objection to this approach for measuring soil metabolism is that the build up of CO_2 in the box inhibits further respiration. However, Fig. 1 shows that in a large box inhibition began only after about 20 minutes, when air inside the box was not circulated. When a small fan inside the box circulated the air, inhibition began sooner. Only changes during the first 10 minutes of each trial were used in calculations.

Table 1 summarizes the results for the three sampling dates. Soil in the irradiated area was respiring at a considerably higher level than soil in the mature forest. In two of the irradiated area plots. The higher respiration was partially due to grass, but in the third irradiated area no grass was present, yet respiration still was high. On Feb. 14, respiration was lower in all areas, especially the well drained soil in the mature forest. This could be due to the fact that previous to Feb. 14, there were 11 rainless days, a relative drought in the rain forest.

Table 1

Soil respiration in the rain forest.

Area	Grams carbon respired /m^2/hr. Nov. 22, 1967	 Jan. 5, 1968	 Feb. 14, 1968
Mature forest, well drained soil		.06	.008
Mature forest, poorly drained soil	.11	.07	.03
Irradiated area, 100% grass covered, well drained soil		.12	.10
Irradiated area, 50% grass covered, poorly drained soil		.09	.07
Irradiated area, beneath secondary vegetation, well drained soil		.10	.09

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*continuing effort

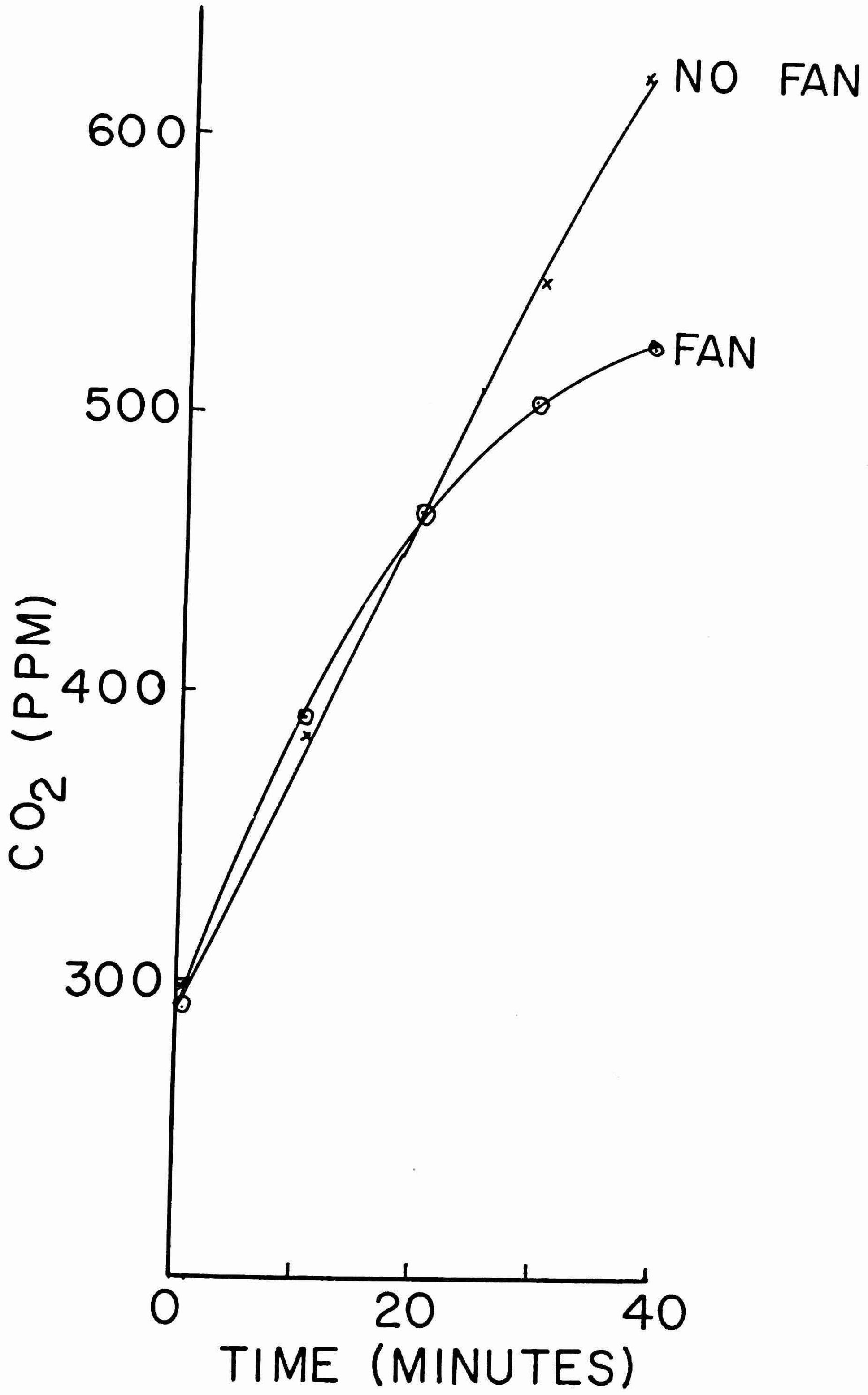

Figure 1. Buildup of CO_2 inside the soil metabolism box, with and without a fan circulating air inside the box.

GIANT CYLINDER EXPERIMENT*

C.F. Jordan

On July 18, 1967, the giant cylinder was operated with the fan pulling through 30% more air than on previous runs in an attempt to reduce loss of air through the top of the cylinder by diffusion or turbulence. The fan flow was increased from 588,557 to 865,100 liters/min by decreasing the size of the pulley on the fan. In order to differentiate the metabolism of the canopy from that of the soil, air was sampled sequentially at four heights; 20 ft. above the canopy, mid canopy, below canopy, and 4 ft. above the ground. The sampling system consisted of a timer mechanism operating four solenoid valves.

The most meaningful data was the difference in CO_2 concentration between the above-canopy and below-canopy intakes for the first night. The chart data from this night was transferred to graph paper and the scale expanded (Fig. 1) to facilitate computations. From midnight to 0600, July 19, 1967, respiration of the canopy alone was .443 $gC/m^2/hr$. This value is close to the value Odum obtained for the whole forest prism, on previous cylinder runs. The higher respiration rate on July 19 could be a result of the more rapid passage of air through the cylinder in this experiment.

The concentration of CO_2 in the air taken in by the intake nearest the ground increased when the intake was lowered toward the ground, and decreased when the intake was raised, indicating that CO_2 diffusion from the soil, especially near the fan, can confound results, at least with a high rate of air movement through the cylinder.

The morning of July 20, the timing mechanism became erratic, making interpretation of results impossible. Smoke bomb tests of the draw of the cylinder failed when the bombs failed to ignite. Pulses of CO_2 were released at various levels on the tower by means of a fire extinguisher, while the analyzer intake was in front of the fan. Table 1 gives time for pulse to travel from release to recording on chart.

On July 21, wind tore the sides of the cylinder, and the experiment was terminated.

I do not recommend continuation of the giant cylinder work as it now exists. However, these experiments have been valuable in that they have provided experience that will be useful in any furture ecosystem metabolism studies.

*completed

The following are my recommendations for any future giant cylinder work:

1. Walls of the cylinder (or hexagon) should be of rigid material such as plexiglass, because one of the most serious problems with the polyethylene walls was billowing. The rigid walls should be in panels that can be tilted like venetian blinds, so that during windy days the panels may be opened. With solid walls for the cylinder and because an almost constant temperature inversion exists in the forest; build-up and decrease of CO_2 at various levels can be converted to forest metabolism in the same manner as G. Woodwell did at Brookhaven National Laboratory. The differences between the Brookhaven situation and El Verde situation is that Woodwell measured respiration dueing inversions on calm nights when there was an assumption of no horizontal air movement while at El Verde, even in no-wind situations, there is air drainage down the mountain. With air drainage there is no build-up at the various levels.

2. The top of the cylinder should be fitted with some sort of turbulence causing device, so that wind passing across the top of the cylinder does not suck air up out of the cylinder (Bernoulli effect).

3. At other locations where there is no inversion and a fan must be used, the fan or fans should be large enough, and spaced in such a manner, that there is a uniform flow throughout the cylinder, yet moving air slowly enough so that metabolism rate is not a function of fan speed.

4. A whole battery of CO_2 intakes should be spaced throughout the cylinder to determine intra-cylinder variations.

Table 1

Time for CO_2 pulse to travel through the cylinder from release elevation to fan at the bottom.

Release elevation feet	Time, Minutes
12	4
24	5
36	5
48	7

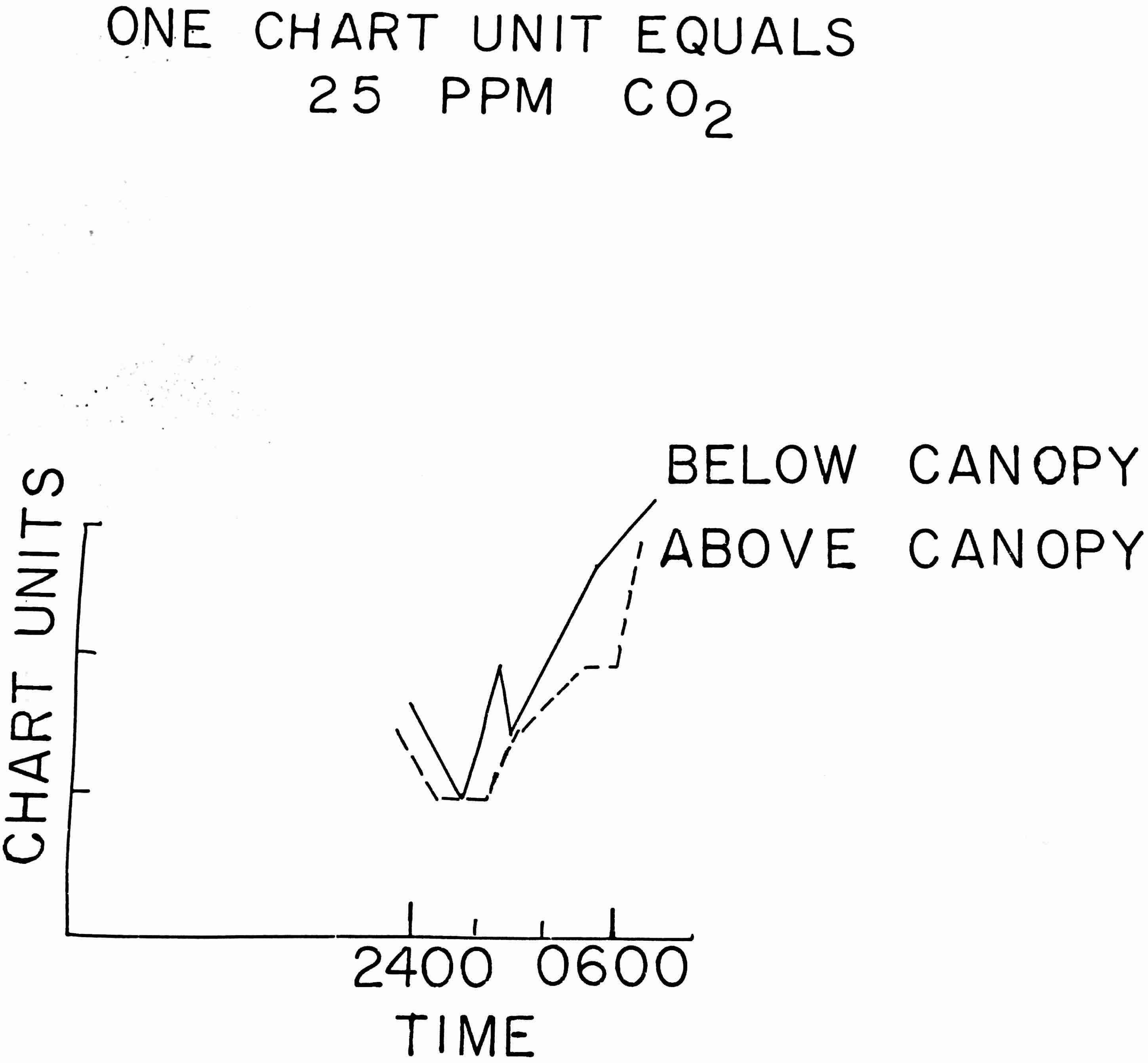

Figure 1. Expansion of chart read-out for the giant cylinder experiment, the night of July 19-20, 1967.

PERFORMANCE OF THE ZERO-TENSION LYSIMETER*

Carl F. Jordan

INTRODUCTION

An "Ebermayer" (Kohnke *et al*. 1940) type of lysimeter was recently described (Jordan 1968) which collects water moving through undisturbed soil (Fig. 1), and which apparently eliminates the surface tension that occurs at the soil-air interface in this type of lysimeter. This lysimeter, called the Zero-Tension Lysimeter, is a 2 x 12 inch stainless steel trough, inside of which are two parallel bars which run the length of the trough. The film of water at the soil-air interface flows over and down the bars, and the capillary force between the bars pulls the water into the collection tube (see Jordan 1968, for a detailed description of lysimeter). The objective of this investigation was to determine the "effective collection area" of this lysimeter under various conditions, so that results of studies utilizing this lysimeter can be quantitative.

"Effective collection area" of a lysimeter is a theoretical area of the soil surface above the lysimeter from which all entering water moves in a straight line toward the lysimeter and outside of which, no water moves into the lysimeter. It is calculated by multiplying the area of the top of the lysimeter (154.8 cm^2 in the case of the Zero Tension Lysimeter) times the effective collection area factor, f. Factor f is defined as:

$$\frac{\text{volume of water collected / cm}^2\text{ of top of lysimeter}}{\text{volume of infiltrating rainfall / cm}^2\text{ soil surface}}$$

when the soil moisture is at field capacity or above.

Although several types of "Ebermayer" lysimeters have been described (Joffe 1929, Shilova 1955, Cole 1958), no tests have been reported on the performance of these lysimeters. Cole, Gessel, and Held (1961), and Cole (1963) apparently assume that by setting suction on their lysimeter to a pressure equivalent to the soil moisture tension at field capacity, they collect soil water only from directly above the lysimeter.

MATERIAL AND METHODS

A Zero-Tension lysimeter, as described by Jordan (1968), was tested under field conditions, and in a test box under closely controlled conditions.

*Lysimeter are being used to study radioactive and stable isotope movement in the soil. To quantify these studies, certain characteristics of the lysimeters must be understood, such as, from what volume of soil does the lysimeter collect. The following report concerns performance characteristics of the lysimeters used at the El Verde site.

Soils

The field tests were made in a lower montane tropical rain forest near El Verde, Puerto Rico, in a soil belonging to the Los Guineos clay series (Roberts 1942). No recent mapping has been done in the area. The soil at the test site was described in 1966 by the U.S. Soil Conservation Service. The upper soil horizon, where the lysimeters were located, is a strongly acid, slightly plastic clay, with a weak, fine subangular blocky structure, brown in color (7.5 YR 5/6), and with organic matter from above in worm channels. There is an abrupt smooth boundary above lower horizons.

For the test box experiments, two soil types were used: 1. Los Guineos clay from a site similar to that of the field test; 2. An undescribed alluvial soil from the flood plain of the Rio Grande River, one mile south of the town of the Rio Grande, Puerto Rico.

As a basis for comparison of the soils used in the tests bulk densities were measured (Table 1) by the core method (Blake 1965), and particle size distribution was determined (Table 2) by the pipette method (Day 1965).

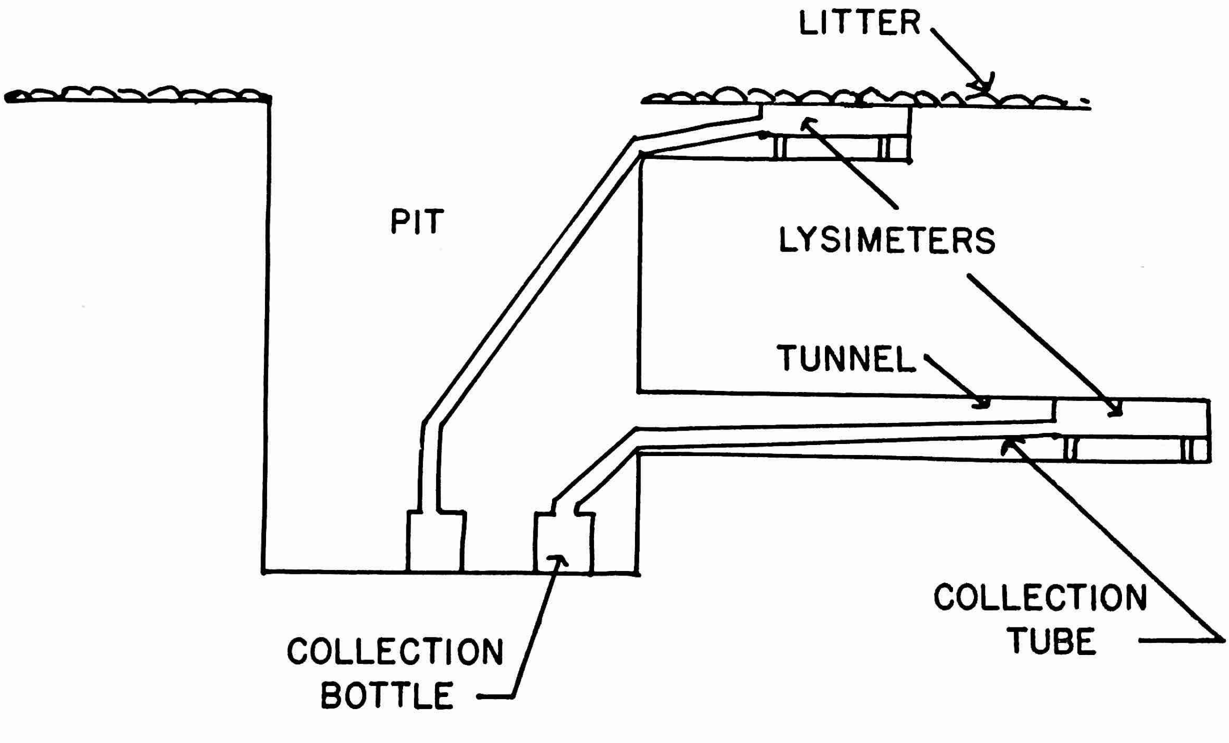

Figure 1. Cross section of a pit and tunnel, showing an installation of Zero-Tension Lysimeters.

Table 1

Bulk densities of soils in which lysimeter was tested.

Soil	No. of samples	Average bulk density	One standard deviation
Los Guineos clay, field sample, 0-5 in. depth	4	.748	.048
Los Guineos clay, test box	4	.708	.054
Alluvium, test box	4	.732	.099

Table 2

Particle size distribution of soils used in lysimeter tests. Numbers in parenthesis are size of particles, in millimeters.

Soil	% Sand	% Silt	% Clay
Los Guineos clay	25 (.05)	38 (.05-.002)	37 (.002) Edmisten, 1965 using hydrometer method)
Alluvium	49 (.02)	30 (.02-.002)	21 (.002)

Test Box

The bottom of the test box was 1/2 inch plywood, 79 cm on each side. The sides of the box were made of 1/4 inch plexiglass, 50 cm high. From a 3/4 inch hole in the center of the bottom of the box, a polyethylene tube led to a four liter trap, which was connected to a vacuum pump. The hole in the box was covered with screening and glass wool. The bottom of the box was lined with approximately 4 cm of coarse sand, to allow water which drained from the soil above to flow easily toward the hole in the center. The sand was covered with 20 cm of soil, and 4 cm of partially decomposed litter.

A lysimeter was buried approximately 12 cm below the mineral soil surface in the test box. A collection tube ran from the lysimeter through a hole in the side of the box to a collection bottle. Artificial rain was applied through a siphon tube to an ordinary shower head which was passed over the box in a systematic manner.

For all tests, 20 liters of water were applied, an amount equivalent to 3.2 cm of rain over the area of the test box and field plots. The rate of application for most tests was 27 cm/hr for a seven minute period, a rate and duration similar to the numerous summer showers which occur at the test site. All the artificially applied rainfall infiltrated into the soil, and there was no surface accumulation or runoff, even when rainfall application was 54 cm/hr.

To ensure that all the trials in the test box were comparable, it was necessary to make sure that the moisture content of the soil at the beginning of each trial was the same. The most convenient soil moisture level to start each trial was field capacity. Field capacity was attained by applying rainfall to the soil box until a water table began to build up in the bottom of the box (visible through the plexiglass walls), and then removing this free water with the pump, which sucked the free water from the bottom of the box. At the point when all free water was removed and the pump was sucking mostly air, field capacity was assumed.

The pump was operated continually during all trials.

Field Tests

Two lysimeters were installed as for field use (Jordan 1968) at a depth of 12 cm on a flat ridge top in the Los Guineos clay. String was laid out in a square, 79 cm on a side, on top of the soil surface, so that each lysimeter would be underneath the center of a square. Artificial rain was applied in exactly the same manner as for the test box. Artificial, rather than natural rain was used, because point to point variations in rainfall through vegetation are large, and these variations make accurate rainfall input measurements impossible.

Before the test runs were made in the field, rain was applied until the lysimeter just began to collect water. Then the application was halted until drainage stopped, at which time a test run was started. This procedure ensured that an amount of water, equivalent to that applied to the soil surface, percolated through the level of the lysimeter.

RESULTS AND DISCUSSION

Experimentally obtained values of the effective collection area factor f are given in Table 3. Values of f for tests 1-20 are very close to one, indicating that the effective collection area of the lysimeter is equal to the actual top area of the lysimeter, for the soils and conditions tested.

Tests 1-10, made in the test box filled with Los Guineos clay, show that varying the rates of rainfall does not change the effective collection area. Tests 11 and 12 in Los Guineos clay show that changing lysimeters does not change results. Tests 13-16, made with alluvium as a test soil, show that the effective collection area may be the same in various soil types. In the field tests with Los Guineos clay (17-20), f varies more than in the test box, but still appears to be close to one.

Tests 21-24 were made to determine the effect rocks and roots would have on the amount of water collected in the lysimeter. In test 21, a rock, 30 cm in diameter placed on the soil surface, reduced the collection by almost half. For test 22, a piece of flat plastic was carefully placed in the soil so that it was 1/2 inch above the lysimeter, and covered half the length of the lysimeter. The fact that the f value was very close to .5 indicates that volume of lysimeter collections which are less than expected may be directly proportional to areas above the lysimeter blocked by rocks or other solid materials. For trial 23, a 1/2 inch dowel was placed so it ran downward at about a 30 degree angle and ended just above the lysimeter. For trial 24, the dowel was removed, but the channels remained. The effect of simulated roots and root channels under these conditions was to reduce the volume of water collected in the lysimeter. However, root channels in the test box, decreased the amount of water collected, in heavy, compact soils root channels running above one lysimeter might cause the volume collected to be greater than the volume collected from another lysimeter without a root channel above it.

Since the effective collection area of the lysimeter is equivalent to the actual top area of the lysimeter under conditions of vertical drainage, the lysimeter must be a tension free collector, neither resisting downward flow (in which case effective collection area would be smaller than top area of the lysimeter) nor increasing suction of the soil interface (in which case the effective collection area would be greater than the top area of the lysimeter).

SUMMARY

The Zero-Tension Lysimeter was tested under laboratory conditions and in the field, and was found to be a passive collector of gravitational soil water. It neither resisted nor increased downward movement of this water, and, effectively, collected water only from the soil directly above the lysimeter. It appears to be a suitable device for the quantitative measure of water flux in soils under field conditions.

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Table 3

Volumes of soil water collected in Zero-Tension Lysimeters under various test conditions and effective collection area factor f calculated from these volumes. Volume of water applied in all tests was 20 liters.

Test No.	Lysimeter No.	Rate of rainfall (cm/hr)	Volume of water collected (liters)	Average volume, and one standard deviation (liters)	f	Average f, and one standard deviation	Remarks
1	1	27	.505	.487 ± .031	1.02	.98 ± .070	Los Guineos clay
2	1	27	.485		0.98		"
3	1	27	.480		0.97		"
4	1	27	.495		1.00		"
5	1	27	.475		0.96		"
6	1	54	.555		1.13		"
7	1	54	.429		0.87		"
8	1	11	.460		0.93		"
9	1	11	.455		0.92		"
10	1	6	.535		1.08		"
11	2	27	.445	.485 ± .063	0.90	.98 ± .114	"
12	2	27	.525		1.06		"
13	3	9	.415	.483 ± .054	0.84	.97 ± .114	alluvium
14	3	27	.470		0.95		"
15	3	27	.500		1.01		"
16	3	27	.550		1.11		"
17	4	17	.320	.391 ± .094	0.65	.79 ± .189	field test
18	5	32	.510		1.03		"
19	4	35	.310		0.63		"
20	5	35	.425		0.86		"
21	1	27	.320		0.65		rock on surface
22	1	27	.220		0.45		obstacle in soil
23	1	27	.430		0.87		simulated root
24	1	27	.315		0.64		root channel

BIOELIMINATION OF ZN^{65} IN THE SNAIL CARACOLUS CARACOLLA*

George E. Drewry

The primary objective of this study is to establish the form, slope, and variability in the curve of elimination of tracer $Zinc^{65}$ by the snail Caracolus caracolla. The standardized live gamma counting methods and high recapture probabilities established for this species make it feasible to follow the course of tracer bioelimination by individual animals in both the field and the laboratory. A secondary objectives is to discover, by dissection and gamma counting, the relative deposition of tracer zinc in various organs. The preliminary data to be presented here is drawn from three data sources. A field population of snails in the vicinity of three $Zinc^{65}$ labeled trees has been marked and sampled regularly as described elsewhere. Bioelimination in these snails is available directly from the data; in addition their gross behavior patterns, ranges etc. are under study. In general, however, their bioelimination curves do not stand alone because they have access to an additional supply of tracer, and continuing uptake could introduce subtle distortions in the bioelimination curve as well as sharp disruptions of the baseline. To complement these data, therefore, a second field population, whose members had established ranges in a part of the forest remote from the tracer area, was labeled by moving it for one night into the tracer area, then marked and released overnight on Dec. 7, 1967. All were recovered and twenty-nine exhibited sufficient uptake to be useful. A third population of laboratory animals was labeled by the same method on Dec. 6, 1967. In this case thirty animals were released, twenty-nine recovered and twenty-six exhibited high-level uptake.

The overnight uptake by the fifty-six members of these two populations is interesting by itself and is summarized in Table 1. Means are presented in counts per minute per snail rather than by weight for two reasons. One is that there was no correlation of uptake level with snail weight, and since the counts could not be reduced by washing in water it was concluded that the bulk of the uptake was by ingestion of labeled bryophytes and lichens. The counts presented were taken 24 hours after release, 12 hours after recapture and followed the first defecation by each animal. Fecal material was removed before counting and counted separately for several animals, it was radioactive in approximate but not perfect proportion to the snail producing it. If the primary route of uptake was by ingestion it follows that either the food was not labeled uniformly or the meals were not proportional to the weights of the animals, both of which are probably true. The second reason for leaving weight out of the calculation is a fact that has been overlooked in some published bioelimination studies, that weight changes subsequent to uptake represent dilution changes in counts per unit weight that are not bioelimination per se. An insoluble pellet of a long-lived isotope implanted in a growing animal would appear to become eliminated if activity were expressed as a function of weight. The variation of count rate in Table 1 is great and the standard deviation exceeds the mean in individuals from one tree. In actuality the distribution is more nearly Poisson than normal, as illustrated by separating the positive and negative components of the standard deviation. Tree C, which is much more frequently utilized than the other two by the resident snail population, contributed less variation and a lower count rate. Whether these were the result of six months of utilization prior to these uptakes cannot be answered at present but may emerge from the community data to be analyzed later.

Bioelimination has been analyzed for five of the laboratory snails and three samples from the overnight labeled free population. Mean curves are presented in Figure 1. All data is corrected for radioactive decay of Zinc^{65}. The ordinate in this Figure is a log scale and it is clear that these curves are either not exponential decay or that they have two or more compartments. The points could be fitted by two lines with a knee near 17 days, unfortunately the need was not detected for counts at this critical time and the experiment must be repeated. Some of the data in subsequent figures suggests such a break, but decay is pictured as a curve in all of the figures in accordance with the smoothest fit for Figure 1. The slope is exponential after 30 days in all data. Figure 1 also indicates that free snails eliminate zinc more rapidly than the caged snails. This could be due to differences in activity or to recycling within the cage, but the latter hypothesis is discredited by a failure of the absolute count rates of the caged snails to converge, in fact they tended to diverge with time. Figure 2 presents data from counts of 12 snails that were introduced to the Zinc^{65} study area around the time of initial contamination. None of these snails established ranges in the area and they were recaptured at distances of up to 100 meters from the area. They left again immediately on release and some were recaptured several times in this manner. Although snails of this category were prone to climb trees and experience secondary high level uptakes before they move away, they were relatively immune to low-level uptake so that the times of uptake and unbroken periods of elimination are relatively dependable. Only such elimination periods are plotted in Figure 2. A curve for the time following day 20 has been fitted using the method of least squares. It has a half-life slope of 64 days.

Figure 3 is a similar curve plotted for the recapture counts of the six wide-ranging snails showing the longest periods between high-level uptakes. Low-level uptake is not ruled out for these animals but their ranges are mostly outside of the contaminated area and the minor fluctuations in their individual curves are well within the range of routine counting error. Therefore, if they experienced low level uptake it was continuous, which is not true for many of the narrow ranging snails that remain much closer to the source of uptake. The point scatter in Figure 3 is due to individual differences rather than to counting variation, as demonstrated in Figure 4, which gives individual curves for two of the animals in Figure 3 with the fitted curve of Figure 3 for references (dotted line). These two animals exhibit the maximum and minimum half-life slopes included in the composite of Figure 3, differing by more than a factor of two. Both snails are adults with similar weights. They had similar weight gains during the period of observations, but the one with the more rapid elimination seems to be the more active snail having a range about three times the area of the other, which it

Table 1

Summary of overnight Zinc^{65} uptake by 56 snails on Dec. 5 & 6, 1967

Tree	Number Snails	Number lost	Not feeding	Sample	Mean Uptake cpm/snail	Standard deviation	Positive rms deviation	Negative rms deviation
A	20	1	2	17	761	± 894	± 1.276	- 467
B	20	0	1	19	634	± 447	+ 634	- 286
C	20	0	1	19	416	+ 245	+ 269	- 222
tot	60	1	4	56	597	+ 580	+ 804	- 338

Table 2

Summary of snail dissection data

Snail Number	Hours after uptake	Gut & Liver	Liver	Gut	Other soft Tissue	Liquids	Shells	Gross cpm
1	30	45%	-	-	44%	10%	1	326
2	30	40%	-	-	31%	24%	10%	529
3	30	35%	-	-	48%	12%	5%	243
4	72	52%	-	-	35%	12%	1%	426
5	240	74%	72%	2%	19.5%	5.5%	1%	397
6	264	78%	75%	3%	11%	6%	2%	277

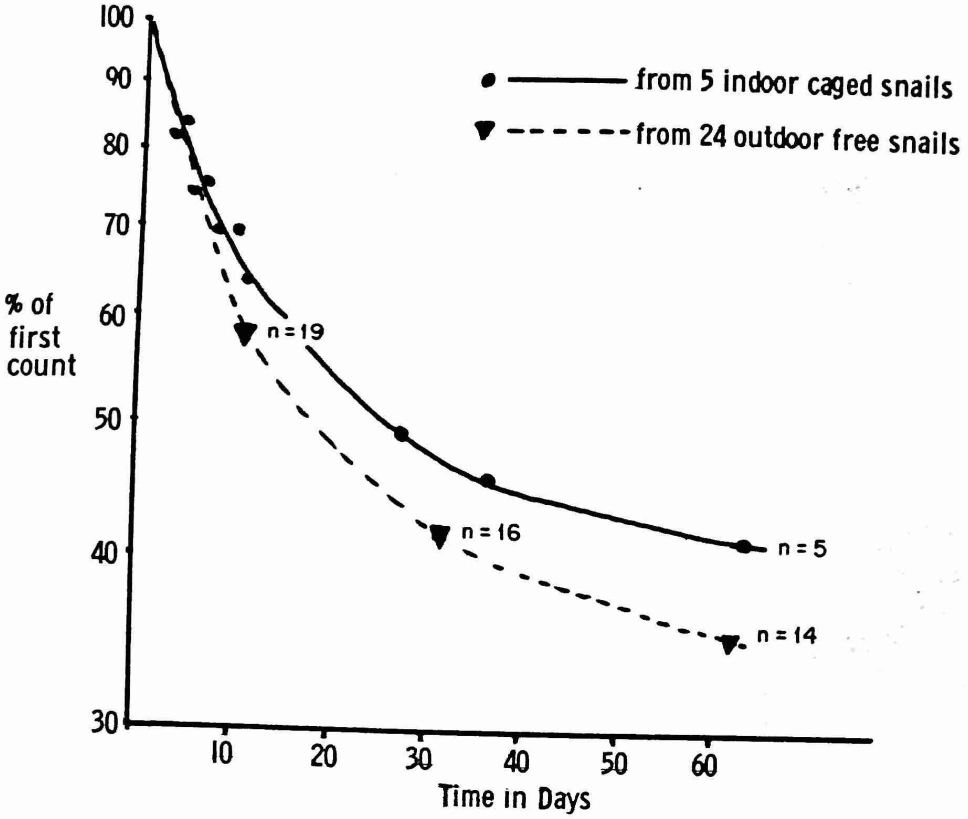

Figure 1. Bioelimination of Zinc^{65} during the first 63 days after initial uptake.

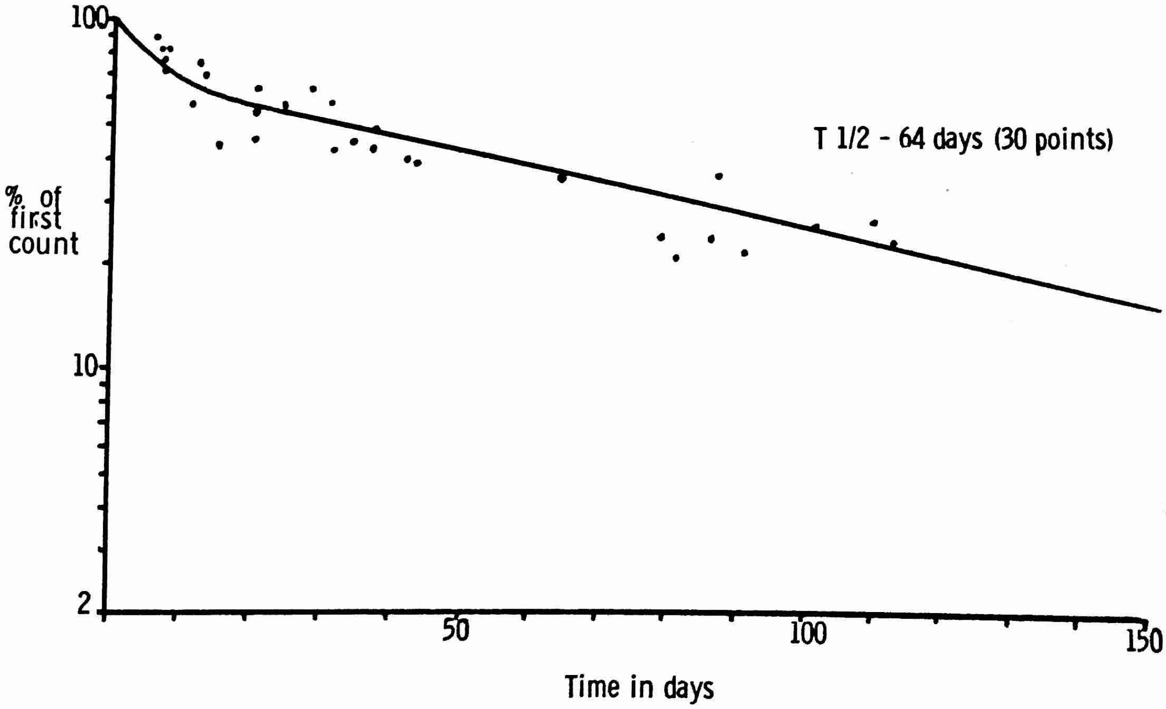

Figure 2. Bioelimination of Zinc^{65} in involuntary transient snails (snails initially stocked in experimental area) which voluntarily moved far away from the contaminated area.

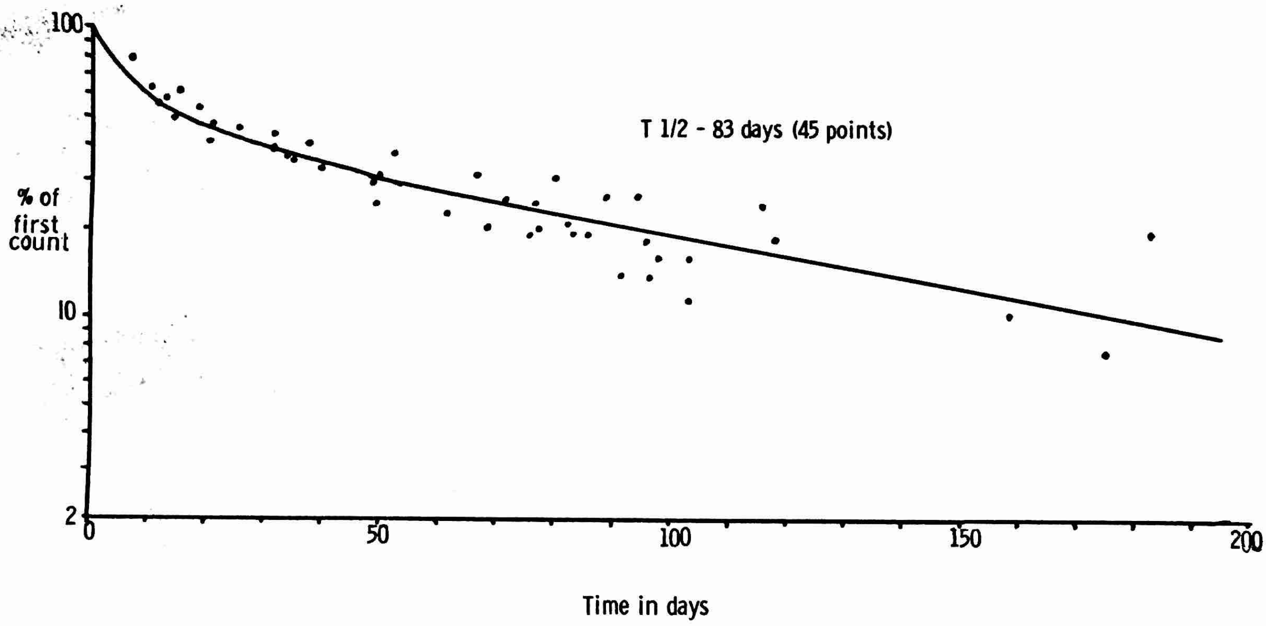

Figure 3. Bioelimination of Zinc^{65} win wide ranging snails that did not show clear evidence of additional uptake after their first uptake.

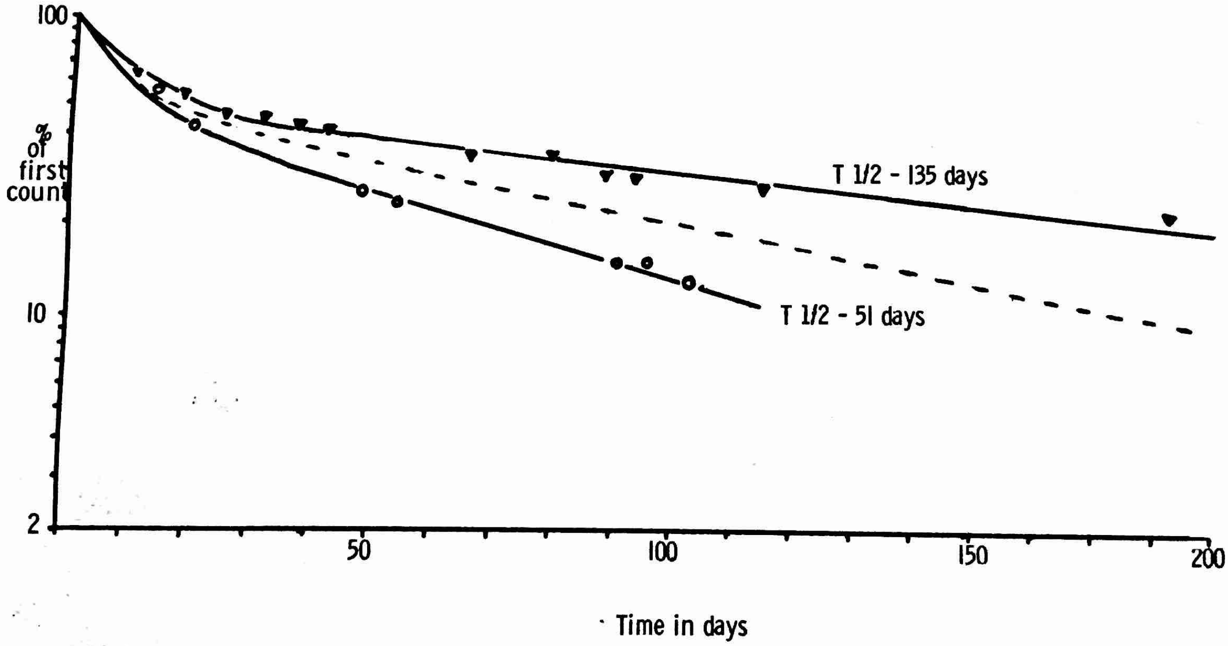

Figure 4. Individual bioelimination curves for the two extreme individuals of Figure 3 to illustrate that point scatter in Figure 3 is due to individual variation rather than counting artifacts.

crossed and recrossed at frequent intervals. With the added note that the range of the more sedentary individual had a greater percentage of its area within the contaminated area, increasing the likelihood of continuous low-level uptake and that the composite slope of Figure 3 would be similar to the 64 days of Figure 2 without the contribution of this individual; I consider that 64 days is the best current estimate of the biological half-life of Zinc ^{65} in this species.

Table 2 presents preliminary data from the dissection of six snails at listed times after tracer uptake. Although these data must be supplemented considerably before conclusions are validated, the trend exhibited is noteworthy. Zinc^{65} seems to be either concentrated or selectively retained in the liver. Unfortunately separation of gut and liver, which is an extremely tedious operation owing to the enclosure of much of the former in the latter, was not attempted in the first animals examined. Additional dissections planned for this series were postponed until another experiment, because of an apparent disease developing among the caged snails that reduced the samples for the bioelimination studies. Eventually more than half of the caged population was lost.

In summary, results in this study are preliminary but encouraging. Bioelimination has been followed in individuals as well as in populations and holds the promise of being correlated with activity levels, other behavior patterns, and environmental variables. It is not a simple exponential decay, but has a minimum of two compartments. After a rapid post-uptake decline lasting almost twenty days it levels into a smooth half-life slope in the vicinity of 70 days, which appears to differ somewhat from one individual to another. During the first 10 days following uptake there seems to be an increase in the relative concentration of this isotope in the liver at the expense of other organs and tissues.

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BEHAVIOR AND NATURAL HISTORY OF THE SNAIL CARACOLUS CARACOLLA IN A TRACER-LABELED ENVIRONMENT.*

George E. Drewry

In the process of following the movement of ^{65}Zn from tree trunk epiphyte communities through the food chain, 151 Caracolus caracolla snails were painted with fluorescent paint and given numbers to facilitate collection and rapid identification. Objectives of the study were to ascertain approximate population density, extent of utilization of three tagged tree trunks in foraging by the population, the level of tracer that would be maintained in the population, and enough background information on the natural history of the species to provide understanding of the energetics and dynamics of the forage patterns observed. An additional objectives was developed as the study progressed: an attempt to explain observed differences between individuals in their ranges and susceptibility to tracer uptake. Toward these ends all snails observed within five meters of a triangle formed by three trees were collected, numbered, live-counted, painted, and released at a central point to be resampled on a regular schedule, if they remained in the area and accesible for collection. In most cases animals were counted on the evening of the day they were collected and released the following day. The location of each animal collected was recorded at the time of capture to within about one meter in the study zone and with less accuracy as distance from the central point increased. Collection effort was standardized with one hour each collection day being spent within the 200 m^2 of the central study zone and a second hour walking in a widening spiral outward from it. Collections were made about every other day for the first month after tracer application, once a week for the next three months, and twice monthly thereafter.

The snails studied have been divided into several categories for purpose of comparison. Snails captured three or more times without the location of capture giving evidence that they are moving out of the study area and whose apparent range (from the location data) remained partly or wholly within the study zone, were considered to be resident snails. Of the 151 marked animals, 76 have received this classification. Three other residents have ranges well outside of the study area. At the beginning of the study 24 snails were collected at another location and carried into the study area. None of these animals established ranges there and all were gone in a few weeks. These snails were called involuntary transients. Similar to them in behavior, but entering the study area of their own volition, were 13 snails labeled voluntary transients. The remaining 35 snails are ones about which insufficient information was available for classification. Most have been recently marked and may represent immigrants. All snails were divided provisionally into juvenile and adult classes on the basis of shell morphology and a correlation between shell features and the onset of testicular sperm formation in ten dissected individuals was made. Puberty occurs between the weights of 18 and 23 and is marked externally by the development of a lip on the shell opening and a little later by extension of the lip to close ventrally the cavity within the shell spiral. Individuals are oviparous and structurally

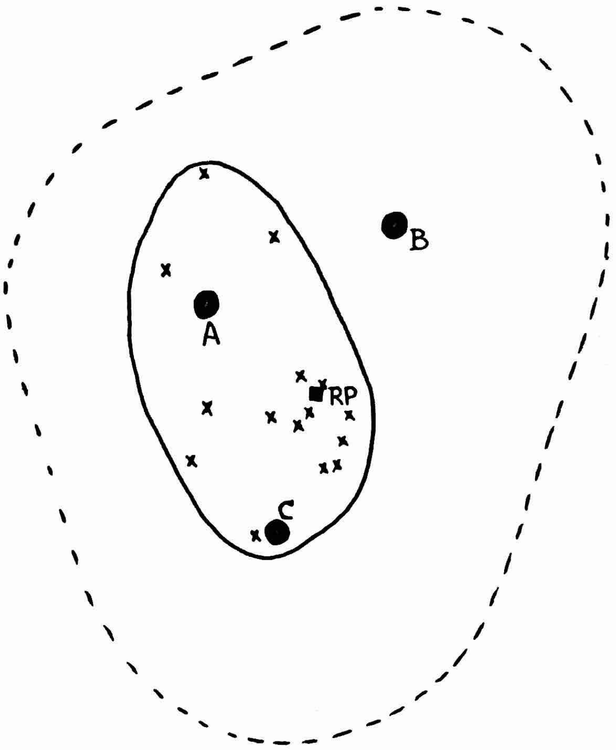

Figure 1. Method of determining range for an individual snail. Dark circles (A,B, & C) are Zinc^{65} labelled trees. Dark square (RP) is release point. Dotted line is 5 meter limit of study zone. X's are individual collection points.

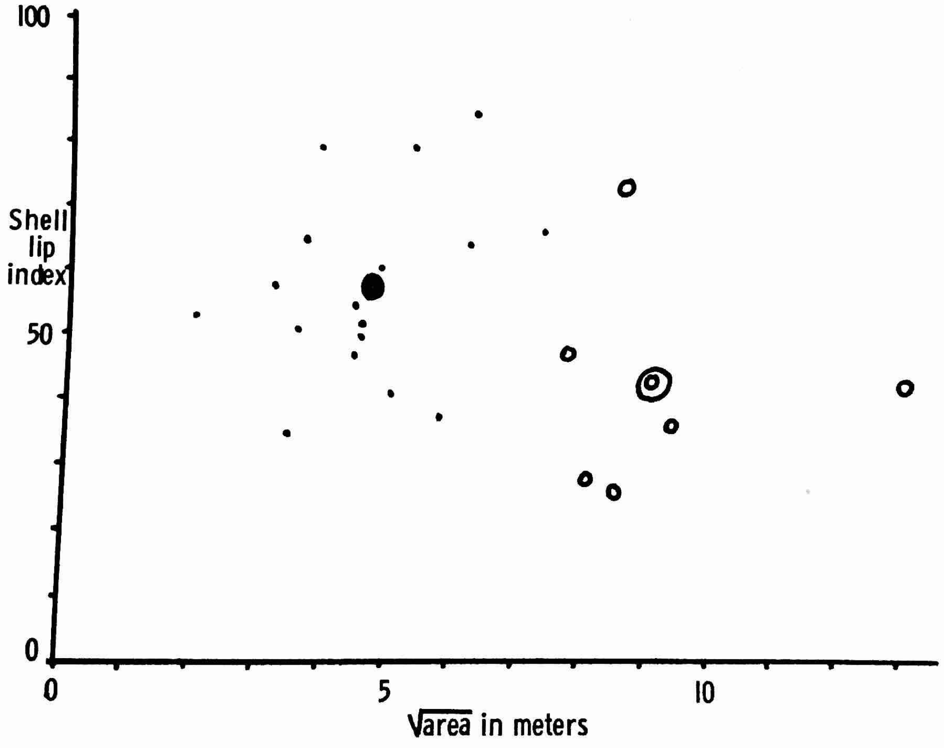

Figure 2. Correlation of shell lip thickness (with a size correction) versus size of observed range (as $\sqrt{\text{area}}$), all adult snails. Points are snails classified as narrow-ranging, open circles wide-ranging, and large symbols are means.

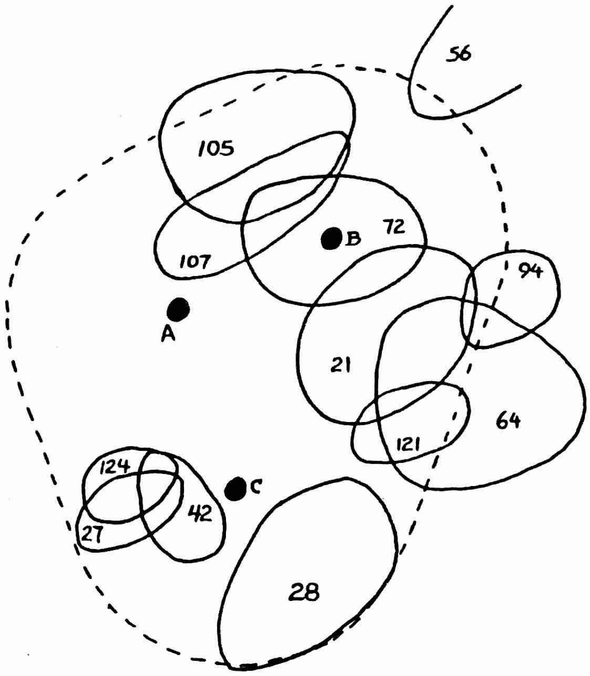

Figure 3. Observed ranges of 12 resident snails that exhibited no measureable uptake of $Zinc^{65}$. Dark circles (A,B, & C) are tagged trees. Dotted line is 5 meter limit. Number of days spanned by observations on each snail is written in the range for that snail.

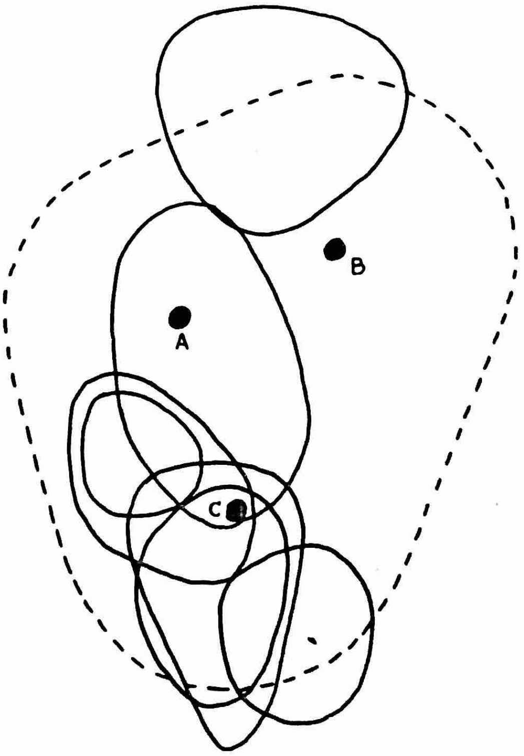

Figure 4. Observed ranges of 7 resident snails that exhibited occasional low-level uptakes of $Zinc^{65}$ without any high-level uptake. Reference points same as in Figure 3.

bisexual; functional bisexuality is assumed on the basis of testicular activity in all adults dissected and observations of copulation in which intromission was accomplished by both members of the pair. Egg production has not been studied, however, and it is not impossible that protandry or other temporal separation of sexual function could occur.

Sexual behavior was of particular interest since it was first invoked as a possible explanation for the marked disparities observed in size of the range of individual snails. The range of areas for 8 or more captures is from 4.6 m^2 to 237 m^2 and these extremes also encompass the ranges of all individuals captured 3 times or more. Observed ranges were plotted to scale for each of the 79 resident snails and their extent estimated by sketching a rounded boundary around the points (as in Figure 1), cutting out and weighing the figure so obtained, and multiplying the weight by a scaling factor. This procedure was found to expedite area determinations for many of the ranges which were clearly not circular. On the basis of the areas obtained the resident snails were divided into wide-ranging and narrow-ranging categories with a break point near 56 m^2. Some overlap was permitted because a few snails with ranges smaller than 56 m^2 exhibited rapid range crossing behavior similar to that of the wider-ranging individuals and it is now believed that the distinction is a real one, although its meaning remains obscure. It is clear that the size of the snail is not a factor. Each category included a full selection of sizes from the smallest juveniles to the largest adults and the size of the range is not at all correlated with the size of the snail. The presence of juvenile wide-ranging snails does not support the hypothesis that range size is related to sexual behavior. An effort was made to find morphological characteristics correlated with range size and Figure 2 shows a slight negative correlation between the thickness of the shell lip and territory size in a sample of 24 adults. This sample will be expanded as additional individuals are recaptured. It was necessary to use a lip thickness index (correcting for size) as the lip in both groups continues to thicken after formation as the animal grows. The index chosen was: $I = 100 \quad x \; .16 \, (y - 1.8)$ where I is the index value, x the lip thickness in inches, y the shell diameter in inches and 1.8 a chosen zero intercept below the diameter at which the lip actually begins to form. The formula is based on the actual regression of lip thickness on shell diameter in wide-ranging snails and an index value of 43 is average for them. It is noteworthy that there is large variation in all shell parameters in adults of snail and also in the relationship of shell diameter to weight. It appears that the shell is large enough at maturity for considerable expansion of the soft parts without shell growth and that additions to the shell are made in irregular amounts and only at intervals.

The breakdown of resident snails into range classes and age classes is as follows: of the 76 resident snails, 54 are narrow-ranging and 22 wide-ranging; there are 24 narrow-ranging juveniles and 30 adults; and a wide-ranging juvenile and 13 adults. Of these, 7 juvenile and 4 adult narrow-ranging snails and 1 juvenile wide-ranging snail have not been captured in the last 100 days of the study and are presumed to have left the area or died and 2 snails are known to have died: one juvenile narrow-ranging and 1 adult wide-ranging snail. The remaining 62 snails constitute the resident population of the area together with immigrants which have not

Table 1

Summary of tracer uptake by resident snail population, with separation of narrow-ranging snails (NR) wide-ranging snails (WR) juveniles (J) and adults (A).

	Snail Sample			High Level Uptake				Low Level		No Uptake	
	No. ind.	No. capt.	Capt. ind.	No. HLU	HLU capt.	No. snails	%	No. snails	%	No. snails	%
NRJ	24	142	5.9	15	.106	10	42	7	29	7	29
NRA	30	205	6.8	14	.068	9	30	13	43	8	27
tot	54	347	6.4	29	.084	19	35	20	37	15	28
WRJ	9	58	6.4	10	.172	9	100	0	0	0	0
WRA	13	118	9.1	11	.093	8	62	2	15	3	23
tot	22	176	8.0	21	.119	17	77	2	9	3	14

Table 2

Summary of weight changes in the resident snail population

	No. Uptake			Low Uptake			High Uptake						
	No.	%	av. chng. snail	No.	%	av. chng. snail	No.	%	av. chng. snail	No.	%	av. chng. snail	
animals gaining wt.	7	33	5.4%	9	41	8.7%	21	58	9.4%	37	47	8.5	by cat. 7.8
animals losing wt.	13	62	-6.9%	12	55	-9.9%	13	36	-10.8%	38	48	-9.2%	" " 9.2
animals not changing	1	5		1	4		2	6		4	5		
Total animals	21	100		22	100		36	100		79	100		
net change			loss 1.5%			loss 1.2%			1oss 1.4%	weighted mean loss -0.7%			
										cat. av. mean loss -1.4%			

yet been recognized as having established ranges. The 35 new snails marked since day 100 (the data is analyzed to day 220) balance well with the 13 voluntary transients and 14 disappearing residents in the first 100 days and suggest that the population is near equilibrium at between 70 and 100 snails in an area which, taking into account the full extent of the residents ranges, measures about 300 m^2. It is believed that the majority of snails remaining in the study area more than 2 weeks are marked, but this is difficult to prove as the terrain provides numerous hiding places and the conspicuous estimation such as mark and recapture in-applicable. Also the collector's knowledge of the favorite hiding places of the long term resident narrow-ranging snails introduces an almost unavoidable bias in their favor.

Two other behavioral characteristics should be mentioned in passing on to a discussion of tracer uptake. One is the considerable homing ability of snails removed from their accustomed ranges. The three snails classified as outside residents have ranges actually centered about 15 m from the central release point while two of the voluntary transients have established (or returned to) ranges more than 50 m from the release point. The latter two snails have been brought in twice from the same small areas, which are rocky and extremely difficult to search, returning thus twice each. The three 15 residents go regularly to their ranges after each release, arriving usually in two or three days, and have done so an average of 11 times each. The compass directions involved are different, and whether navigation is accomplished by direction finding or knowledge of the terrain is not clearly established. The latter is suggested, however, by the fact that the involuntary transients, which were released over 600 m from their collection point, left the release point in all directions and frequently chose another direction if recaptured and released again. Another outstanding characteristic is the tendency of transient snails to climb trees. A group of 60 snails tagged for bio-elimination studies, reported in another paper, were carried into the study area, released on the ground within a foot of the labeled tree trunk, and collected the next day. Of 59 recovered, 58 or 98% had climbed in one day. The 24 involuntary transients introduced into the area were released in a similar manner and 23 or 96% of them had fed on the tagged trunks before the first recapture. In 63 additional recaptures of members of this group following releases at the central release point, there was evidence of feeding on a labeled trunk 10 times or .16 zinc uptakes per capture. The voluntary transients had an even higher rate of utilization, having .23 uptakes per capture as a group even though this activity was confined to 6 of the 13 or 46% of the members.

In contrast to transients, the resident community was less active in climbing and foraging on the ^{65}Zn labeled tree trunks. The more than 150 individuals of various groups actually collected from the trunks established a firm base-line for deducing whether a snail had actually been on a trunk or was carrying ^{65}Zn that had been removed from the trunks by another agent. Several snails which had ranges including the bases of the labeled trees, but which never climbed the trees, exhibited base-lines of low-level

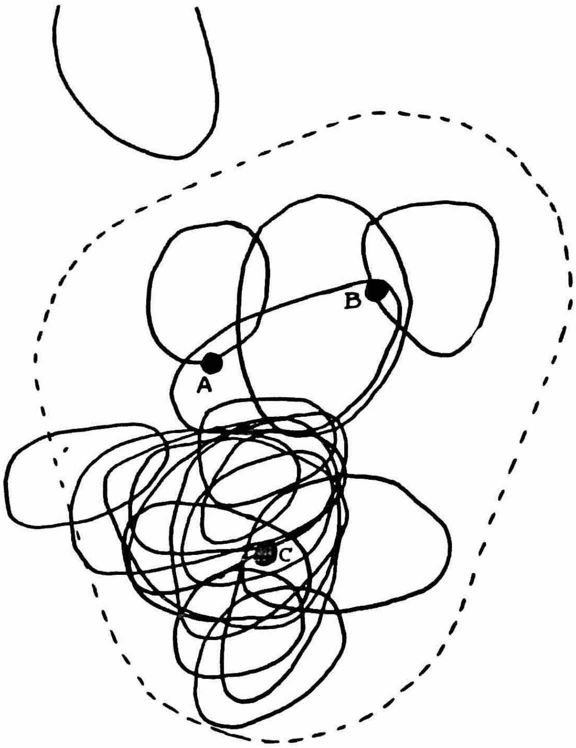

Figure 5. Observed ranges of 10 resident snails that exhibited more or less continuous low-level uptake of Zinc^{65} without any high-level uptake. Reference points same as in Figure 3.

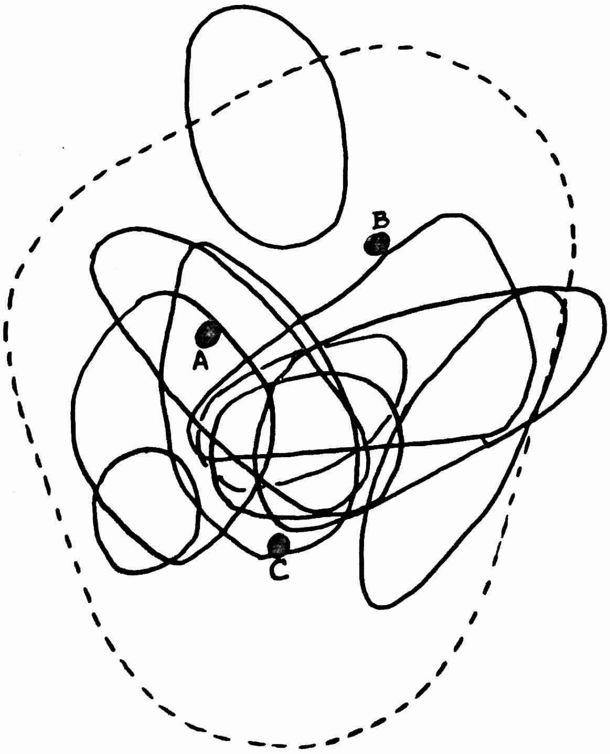

Figure 6. Observed ranges of 19 resident snails that exhibited high-level uptakes of Zinc^{65}. Reference points same as in Fig. 3.

uptake that never exceeded 100 counts/min in the gamma spectrum from 1.01 to 1.21 Mev for one inter-capture interval. In contrast animals collected directly from the trunks exhibited an abrupt increase that was never less than 100 counts/min, this level or greater is called a high-level uptake and is taken to indicate foraging on the trunk itself. Of 22 wide-ranging snails, 17 (77%) utilized the tagged tree trunks, of these 9 (100%) of the juveniles but only 8 (62%) of the adults are represented. The rate of utilization was 21 uptakes in 176 captures or .12 uptakes per capture. Of 54 narrow-ranging snails 19 (35%) utilized the tagged trunks. Juveniles and adults were more similar in this category having 10 (42%) and 9 (30%) individuals respectively represented. The rate of utilization was 29 uptakes per 347 captures or .08 uptakes per capture. Juveniles in both groups exceeded adults in rate of utilization, the juvenile rate in narrow-ranging snails being 155% of the adult rate and 185% in the wide-ranging group. See Table 1 for a more complete breakdown of these categories.

Of the snails in both range classes that did not directly utilize the tagged trunks, some exhibited no uptake of ^{65}Zn while others had either continuous or intermittent low-level uptake. The sample (n =5) in this category in wide-ranging snails is too small for analysis, but in narrow-ranging snails it is interesting that about half of both adults and juveniles had no uptake and the other half exhibited low level uptake. Figures 3, 4, 5, and 6 suggest that micro-geography played a part in this phenomenon. The tagged trees are represented as dark circles and labeled A, B, and C. The ground between them is level and low. The lower four ranges in Figure 2 are on the tops of very large boulders while the ones in the vicinity of tree B are in the highest ground in the study zone. The snail that spent 72 days within 3 meters of tree B without detectable uptake also provides evidence that this tree, which is a palm with long mosses as epiphytes, was not releasing much of its tracer burden to the surrounding soil. Figure 5 suggests that three-fourths of the residents snails utilizing labeled trunks did so on tree C, whose epiphytes are mainly leafy liverworts and lichens. All of the ranges depicted in Figures 2-5 are those of narrow-ranging snails. Figure 6 presents ranges of 11 wide-ranging snails for comparison. Those ranges of snails exhibiting high-level uptake are marked with an asterisk, low-level is marked 0, and no uptake marked 00.

An important question that must be considered in a study of this type is the effect that the experimental treatment had on the parameters under study. Indeed the overall weight of the 79 resident snails that received the most halding, declined by a factor of 1.4% per snail. This figure conceals both increases and decreases of up to 25% in some individuals. Gross figures are about equal percentage wise in adults and juveniles. There is no evidence of a correlation, however, between weight loss and number of captures, as one would expect if there were a causal relationship. There is likewise no evidence that the isotope levels had any effect on weight, the gross figures (Table 2) being 1.5% loss in snails with no uptake, 1.2% loss for low-level uptake and 1.4% loss for high level uptake. The snails with high-level burdens of ^{65}Zn had higher average percentages of both gain and loss and there exists the very remote possibility that the levels of tracer involved had a stimulating effect on activity level or

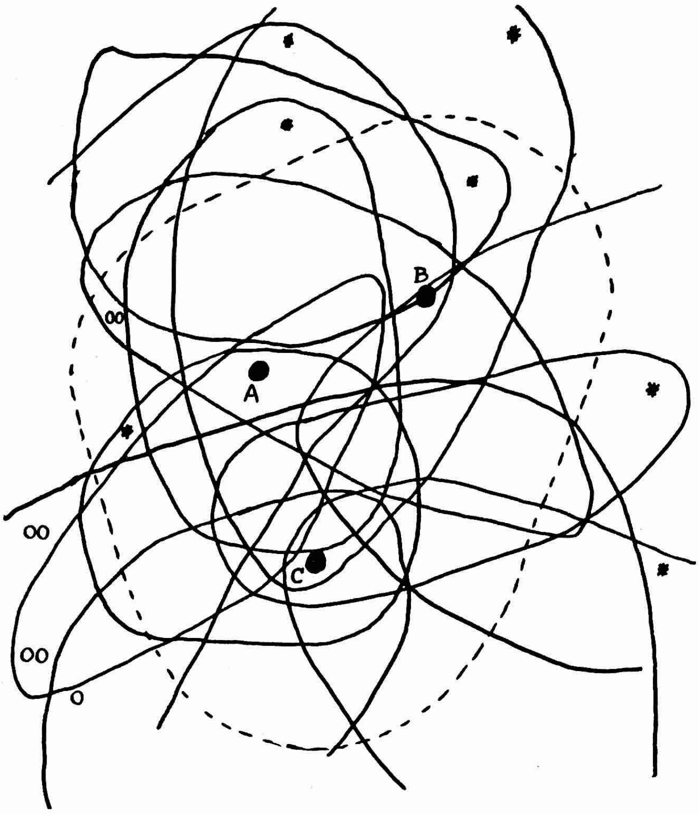

Figure 7. Observed ranges of 11 wide-ranging snails within the study zone. Reference points same as in Figure 3. Ranges of snails having high-level uptake marked *,low-level uptake marked O, and no uptake marked OO.

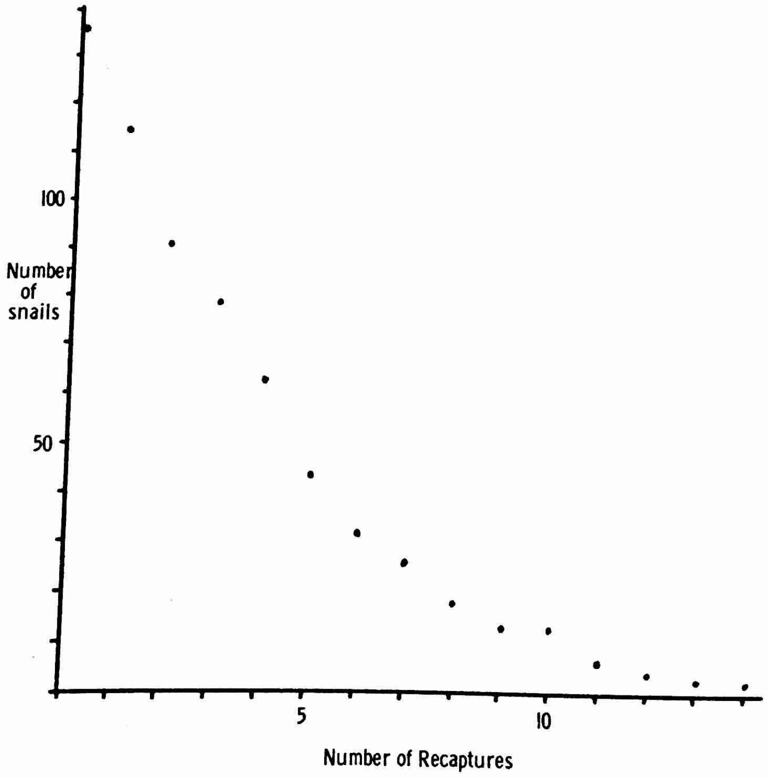

Figure 8. Number of snails at each recapture as a function of number of recaptures.

some similar parameter. Heatwole (in press), who had worked over a longer period with these snails, states that most of the growth occurs in the months from March to July, while this study has covered so far the remaining months from August to February. There is also no evidence of positive or negative behavioral response to handling in a plot of sample size versus recapture number (Figure 8). One would expect a break in the curve if there were a tolerance level whose transgression resulted in death or departure. A consistent mean interval between recapture of about 13 days or 2 sample periods for recaptures 1 through 15 likewise indicates that the snails do not become more evasive or less so after multiple handlings. The plot of apparent range area versus number of recaptures indicates a slight increase in both narrow and wide-ranging snail ranges that can easily be ascribed to improved information.

In summary the population of Caracolus caracolla in an area of rain forest has been found to consist of about one resident snail for every 3 to 5 m^2 with residence times for some extending at least 220 days. There is a continual flux of transient snails moving through and the loss of about .17% of the resident population per day from death and/or emigration is made up by newly established residents. Two extremes with intermediate types apparently exist with respect to the size of the area over which a resident snail ranges and these behavior patterns seem to be correlated with shell morphology and the tendency to forage on tree trunks. Wide-ranging snails have, on the average, thinner lips on their shells and a 50% higher probability of foraging on trunks. Transient snails, whose ranging characteristics cannot be established in a study of this magnitude, have an even higher probability of utilizing tree trunks, and a snail moved far from familiar territory has a near certainty of climbing the nearest tree before moving away. Snails experimentally moved into an area seem to have a very low probability of establishing themselves near where they are released. Juvenile snails are very similar to adults in size of range and general behavior, but seem to have a slightly greater tendency to forage on tree trunks. The particular trees chosen for tagging in this experiment probably do not provide a reliable estimate of overall trunk utilization in feeding, as only one of them appears to have been used to an appreciable extent. Finally there is no evidence that the snails respond adversely to the large amount of handling involved in this study as there have been no noticable changes in either their behavior or general health.

The remaining objective of the study, that of determining the level of tracer maintained in the population, could be derived in estimate form from crude analysis of the raw data. It is desired, however, to submit the data to careful analysis utilizing bioelimination rates as well as corrections for radioactive decay, and these rate constants are only now being established within acceptable confidence limits. The dynamics and equilibrium constants in ^{65}Zn uptake and bioelimination by snails will be the subject of a subsequent report. A deficiency in this study as an indicator of the absolute extent of tree trunk foraging in Caracolus caracolla has also appeared in the fact that utilization of the three trunks tagged is obviously unequal, so a sample of three cannot be deemed representative. It is also clear from the recapture location data that the snails utilized the trunk of a tree adjacent to tree C up to 5 times as often as they did of C, which was the most heavily used of the three in the sample.

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Stiven, Alan E. (in press) Respiration in the snail *Caracolus caracolla* and an estimate of the relative density and biomass of litter snail A. Tropical Rain Forest. H.T. Odum ed.

PHENOLOGY*

J.R. Kline and C.F. Jordan

Leaf fall and fruit fall collections continue to be made in order to study possible long term variations, and as an index of recovery in the irradiated center. Leaf fall data for May 1967 through April 1968 are given for the radiation center and the control center in Figure 1. Fruit fall for the same time interval is given in Table 1. Both leaf fall and fruit fall are intended to form a continuous record with previous annual reports. Longer term behavior can be determined by consultation of these paper.

Table 1

Fruits of various species collected from May 1967 through March 1968

Species	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Croton poecilanthus	1	0	1	1	3	-	1	2	0	1	1
Didymopanax moratotoni	-	9	-	-	-	-	-	-	-	-	-
Sloanea berteriana	50	26	31	7	2	7	5	6	-	-	2
Dacryodes excelsa	1	1	-	5	6	13	4	1	4	-	3
Matayba domingensis	15	8	6	5	5	-	-	-	-	-	-
Manilkara nitida	-	-	-	-	-	-	-	-	1	-	-
Securidaca virgita	-	-	-	-	-	-	-	2	17	-	-
Ormosia krugii	1	9	3	4	2	4	7	5	0	2	3
Euterpe globosa	68	165	37	58	17	8	61	7	11	12	5
All others	2	84	14	17	29	78	83	25	16	2	2

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*continuing effort

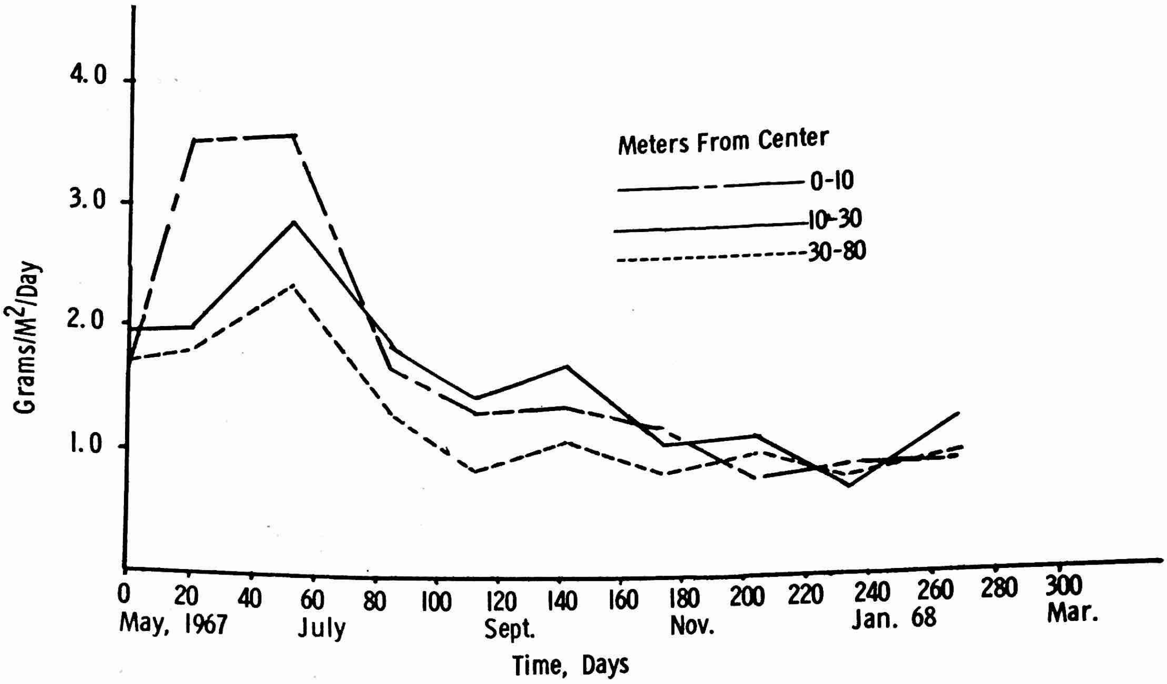

Figure 1. Leaf fall in the control area of the rain forest at El Verde Puerto Rico.

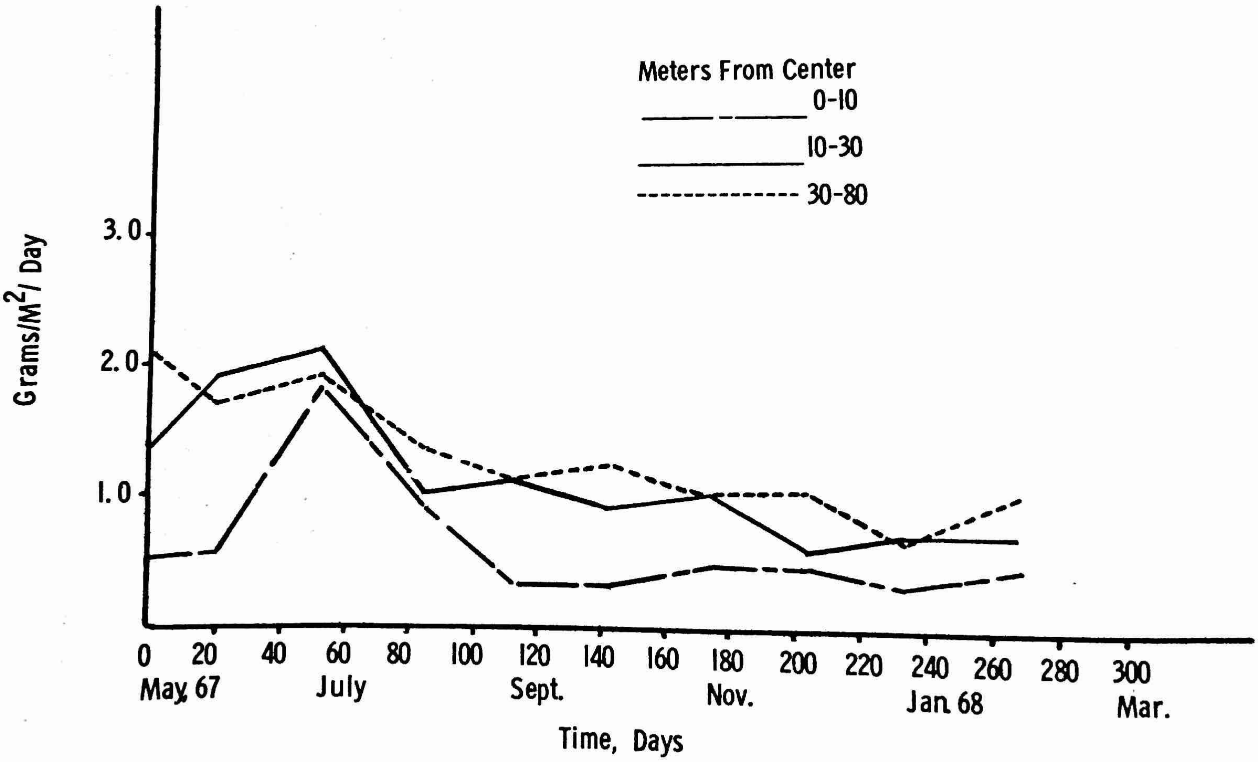

Figure 2. Leaf fall in the irradiated area of the rain forest at El Verde Puerto Rico. Irradiation was terminated after 92 days in April 1965.

RAIN FALL AT EL VERDE*

Douglas Krom

The following rain fall table is submitted as part of a Project policy of using the Annual Report as a vehicle for reporting various continuously recorded quantities which are useful as background data in other experiments but which normally would not be reported independently through open literature channels. This table is continuous with the one which appeared in the Terrestrial Ecology Annual Report for 1967.

Table 1

Weekly rainfall at El Verde

Month	Week	Rainfall inches
June, 1966	1- 7	0.84
	8-15	5.59
	16-23	2.87
	24-30	2.67
July, 1966	1- 7	1.99
	8-15	1.78
	16-23	5.69
	24-31	4.08
August, 1966	1- 7	1.58
	8-15	4.89
	16-23	2.35
	24-31	
September, 1966	1- 7	2.39
	8-15	5.47
	16-23	2.68
	24-30	3.09
October, 1966	1- 7	0.59
	8-15	3.39
	16-23	4.88
	24-31	0.49
December, 1966	1- 7	5.38
	8-15	2.57
	16-23	2.82
	24-31	5.65

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*continuing effort

Continued Table 1

Month	Week	Rainfall inches
January, 1967	1- 7	0.49
	8-15	3.08
	16-23	3.00
	24-31	1.43
February, 1967	1- 7	1.03
	8-15	2.49
	16-23	1.41
	24-30	3.20
March, 1967	1- 7	2.26
	8-15	0.32
	16-23	0.30
	24-31	1.50
April, 1967	1- 7	5.34
	8-15	0.88
	16-23	0.02
	24-30	0.95
May, 1967	1- 7	4.94
	8-15	3.21
	16-23	3.62
	24-31	0.16
June, 1967	1- 7	1.99
	8-15	0.08
	16-23	2.25
	24-30	4.54
July, 1967	1- 7	1.92
	8-15	5.59
	16-23	2.76
	24-31	4.66
August, 1967	1- 7	2.21
	8-15	1.87
	16-23	3.15
	24-31	1.77
September, 1967	1- 7	1.55
	8-15	3.12
	16-23	1.25
	24-31	2.67

INSECT IDENTIFICATIONS*

George E. Drewry

The following identifications for insects collected at El Verde were made by Dr. Ronald Hodges of the U.S. National Museum and are submitted as an addendum to the checklist reported in the 1967 Rain Forest Project Annual Report.

Family	Subfamily	Number of species	Genus and species where known	
Pyralidae	Pyraustinae	61	Sparagmia gigantalis Guenee	1
			Pantographa limata Grote & Robinson	1
			Terastia meticulosalis Guenee	1
			Azochis rufidiscalis Hampson	h
			Margaronia flegia (Cramer	1
			Margaronia costata (Fabr.)	1
			Margaronia elegans (Moschler)	1
			Margaronia nitidalis (Cramer)	1
			Margaronia marginepuncta Schaus	1
			Margaronia sibillalis (Walker)	1
			Margaronia sp.	1
			Sylepta onophasalis (Walker)	1
			Sylepta elevata (Fabr.)	1
			Sylepta ceresalis (Walker)	1
			Sylepta silicalis (Guenee)	1
			Sylepta sp. a	1
			Sylepta sp. b	1
			Pycnarnon receptalis (Walker)	1
			Mesocondyla concordalis Hubner	1
			Mesocondyla sp.	1
			Crocidolomyia palindalis (Guenee)	1
			Neoleucinodes elegantalis (Guenee)	1
			Pyrausta cerata (Fabr.)	1
			Pyrausta cardinalis (Guenee)	1
			Pyrausta sp.	1
			Phostria humeralis (Guenee)	1
			Phostria simialis (Guenee)	1
			Phostria prolongalis (Guenee)	1
			Desmia tages (Cramer)	1
			Desmia ufeus (Cramer)	1
			Maruca testualis (Geyer)	1
			Pilocrocis infuscalis (Guenee)	1
			Pilocrocis lauralis (Walker)	1
			Pilocrocis ramentalis (Lederer)	1
			Epipagis mopsalis (Walker)	1
			Syngamia florella (Cramer)	1
			Syngamia cassidalis (Guenee)	1
			Syngamia sp.	1
			Pachyzancla phaeropteralis (Guenee)	1
			Pachyzancla perusialis (Walker)	1
			Lygropia lelex (Cramer)	1
			Bradina hemingalis Schaus	1
			Hileithia ductalis Moschler	1
			Diasemia ramburialis Duponchel	1
			Samea carrelalis Schaus	1
			Lamprosema zoilusalis (Walker)	1
			Lamprosema indicata (Fabr.)	1
			Lamprosema stenialis (Guenee)	1

*continuing effort

Family	Subfamily	Number of species	Genus and species where known	
Pyralidae	Pyraustinae	61	*Lineodes metagrammalis* Moschler	1
			Argyractis serapionalis Schaus	1
			Argyractis sp.a	1
			Argyractis sp.b	1
			Cataclysta sumptiosalis Moschler	1
			Cataclysta miralis Moschler	1
			Scoparia sp.	1
			Gonopionea sp.	1
			Condolorrhiza sp. a	1
			Condolorrhiza sp. b	1
			Undulambia sp.	1
			-	
			-	
	Pyralinae	1	*Pyralis manihotalis* Guenee	1
	Epipaschiinae	5	*Jocara ferrifusalis* Hampson	1
			Jocara sp.	1
			Tetralopha scabridella Ragonot	1
			Tetralopha sp.	1
			Pococera atramentalis (Lederer)	1
	Crambinae	4	*Argyria lacteela* (Fabr.)	1
			Diatraea saccharalis Fabr.	1
			Crambus sp.	1
			-	
	Chrysauginae	3	*Pachymorphus subductellus* Moschler	1
			Caphys bilinea Walker	1
			Parachma sp.	1
	Schoenobiinae	3	*Rupela* sp. a	1
			Rupela sp. b	1
			Rupela sp. c	1
Thyrididae		3	*Rhodoneura leuconotula* Pagenstecher	1
			Rhodoneura thiastoralis (Walker)	1
			Rhodoneura myrsusalis (Walker)	1

STAFF

There are 10 full-time employees in the Terrestrial Ecology Project: 3 scientists, 3 technicians, 3 field workers, and 1 secretary. In addition the Project has one part-time technician and cooperative working arrangements with 4 scientists from other organizations who are conducting research at El Verde. A staff list follows.

SCIENTIFIC

A. Resident

Jerry R. Kline, Ph.D., Project Director
Carl F. Jordan, Ph.D., Associate Scientist I, Plant Ecologist
George E. Drewry, Ph.D., Associate Scientist I, Animal Ecologist

B. Visiting

Raymond E. Henzlik, Ph.D., Oak Ridge Research Participant from Ball State University, June-August, 1967. Worked on radionuclide behavior in epiphyllae.

Elizabeth McMahan, Ph.D., University of North Carolina. Worked on radiosensitivity of termites during summer 1967. Will continue field studies of termites in the irradiated center at El Verde during 1968.

Joe, A. Edmisten, Ph.D., Botanist, University of Georgia. Worked on nitrogen fixation by epiphyllae.

John Koranda, Ph.D., Lawrence Radiation Laboratory. Worked on tritium behavior in tropical ecosystems.

TECHNICAL

Douglas Krom, Electronics Technician I, Weather Station Operator
Alejo Estrada Pinto, Research Assistant I, Field Botanist
Abel Rossy, Research Technician, Gamma Ray Spectroscopist
José Colón, Research Technician (1/2 time), Atomic Absorption operator

FIELD WORKERS

Moisés Parrilla Rosario, Maintenance Foreman
Doroteo Martínez García, Field Worker
Juan Martínez Maisonet, Field Worker

SECRETARIAL

Ana Josefina Correa López, Administrative Secretary II

PAPERS PRESENTED AT SCIENTIFIC MEETINGS AND PUBLICATIONS

Papers Presented

The following papers were presented at society or symposium meetings.

1) Kline, J.R.,J.E. Foss, and S.S. Brar. La and Sc distribution in three glacial soils of western Wisconsin. Presented to Soil Science Society of America, November 5-10, 1967. Washington D.C. (Manuscript submitted).

Publications

The following manuscripts have been submitted for publication in addition to those listed above.

1) Edmisten, Joe, and J.R. Kline. Nitrogen fixation by epiphyllae. Submitted to Ecology.

2) Jordan, C.F. Vegetative sprouting following irradiation of a tropical rain forest. Submitted for inclusion in the book A Tropical Rain Forest. H.T. Odum ed.

3) Kline, J.R., and C.F. Jordan. Tritium movement in soil of a tropical rain forest. Science, 160: 550-551 (1968).

4) Kline, J.R., and S.S. Brar. Instrumental analysis of neutron irradiated soils. Submitted to Soil Science Society of America Proceedings.

APPENDIX

MANUSCRIPTS WHICH HAVE BEEN PREPARED AND SUBMITTED FOR PUBLICATION SINCE JUNE 1967.

TRITIUM MOVEMENT IN SOIL OF TROPICAL RAIN FOREST

J.R. Kline and C.F. Jordan

ABSTRACT

Tritiated water applied to the surface of soil in a tropical rain forest was found in free water of the litter and top 18 cm of soil as long as 7 months after the application. Plant roots, even in the high rainfall environment of a tropical rain forest, therefore are exposed to tritiated water for a considerable time after release.

Tritium might be released to the tropical environment through military or peaceful thermo-nuclear detonations. The behavior of such release in the tropical ecosystem is not well known although Koranda (1) found tritium in soils and plants of Eniwetok toll 12 years after testing of thermonuclear weapons had ceased there. We now report on the residence half-times of tritium in clay soils of the tropical rain forest in the Luquillo Mountains of Eastern Puerto Rico.

A soil plot, 0.94 m^2 in area, was prepared by installing a lysimeter (2) 18 cm below the soil surface, from a horizontal tunnel originating outside the plot, without disturbing the soil above it. Free water percolating through the soil was collected in the lysimeter, drained into a plastic collection vessel, and sampled after every rain for three weeks and weekly thereafter. The downslope terminus of the plot was fitted with a metal tray placed as nearly as possible at the litter-soil interface to collect and sample surface run-off water. Two rain gauges (3) were placed at the sides of the plot to measure rainfall at the forest floor. Above, canopy rainfall was measured by a standard tipping bucket rain gauge on a tower. From a garden sprinkling can, one liter of tritiated water (concentration, 20 mCi/liter) was applied to the plot. The sampling program lasted 210 days after the tritium was applied. Tritium was determined by standard methods of liquid-scintillation counting in 1-ml water samples. We did not convert results to absolute activities because all we required was the variation of count rates to time.

Tritium activity in soil water collected 18 cm below the surface reached a peak in approximately 16 days and declined exponentially during the rest of the experiment. (Fig. 1). The effective half-life after reaching the peak (uncorrected for tritium decay) in this soil (found by least-squares analysis) was 16.3 days. The curve represents the spatial distribution in soils and was obtained in the soil profile with a fixed-point collector which measures the shape of the distribution. Thus, the time distribution is interpreted as a mirror image of the moving spatial distribution (at peak) passing through the lysimeter. Tritium therefore moved through the soil profile with a sharp leading edge, followed by a long exponentially declining tail.

The first phase of tritium release in soil-surface water has an effective half-life of approximately 2.9 days; the second phase had a half-life of 35.6 days. The first phase of tritium loss in the surface probably reflects penetration of the moving front of tritium into the profile and dilution and equilibration with the incoming waters which saturate the surface litter. The second longer lived phase may represent partially release of tritium trapped as immobile water, in the tortuous pore spaces of the soil near the surface. The fact that the effective half-life of this phase is longer than in the soil profile means that, in the soil surface or surface litter, there is some compartment which has less complete equilibration with incoming fresh water than indicated by the soil profile. Such compartments could include the water used in metabolism by soil and litter organisms.

Cumulative rainfall during the experiment was 184 cm above the forest canopy and 137 cm at the forest floor (Fig. 2). Although the rainfall pattern had many highs and lows of input, tritium loss occurred as a more-or-less smooth function of time.

A theoretical model for the behavior of tritium in soils (3 or 4) contends that tritiated water applied as a unit pulse to a soil surface will move downward in the soil profile as a front or peak which separates pre-existing water from water entering the system after the tritium input. According to the model, the peaking phenomenon occurs because of the rapid rate of self diffusion in soils, as compared to the slow rate of bulk water movement. The rapid exchange prevents the tritium pulse from overtaking old water in the soil, and from being overtaken by new inputs of water, and can be used (6) to measure evapotranspiration. Vertical diffusion causes the natural peak to broaden during downward movement in the soil, but we expect concentrations of tritium in the free soil water after the peak to approach zero if all phases of immobile water are equally rapidly exchanged with the freely moving water (5).

Clay soil has many tortuous pore spaces, however, which may inhibit free molecular diffusion of tritiated water. In clay soils there are other sites (such as clay water films and exchangeable hydrogen) which could have a restricted molecular exchange with the freely moving bulk water. Such diffusion-restricted compartments would result in exponential die-away curves since the process of removal would be essentially successive dilution in an infinite series.

The two-phase-release curve in the soil litter and mineral surface supports the view that there are in soil somewhat isolated compartments of immobile tritium which do not have complete, rapid exchange with the freely-moving bulk water.

We conclude that the basic model proposed by Zimmerman et al. (3), for tritium movement in soils must be modified to allow for the existence in clay soils of isolated compartments of immobile water which do not have completely free molecular exchange with the more

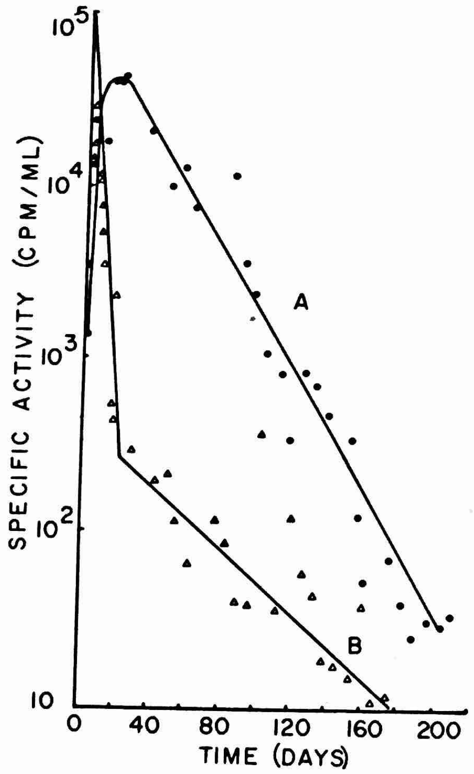

Figure 1. Loss rates of tritium from soil and from surface litter in a tropical rain forest. (A) tritium in free soil water collected 18 cm below the surface; (B) tritium in free surface water.

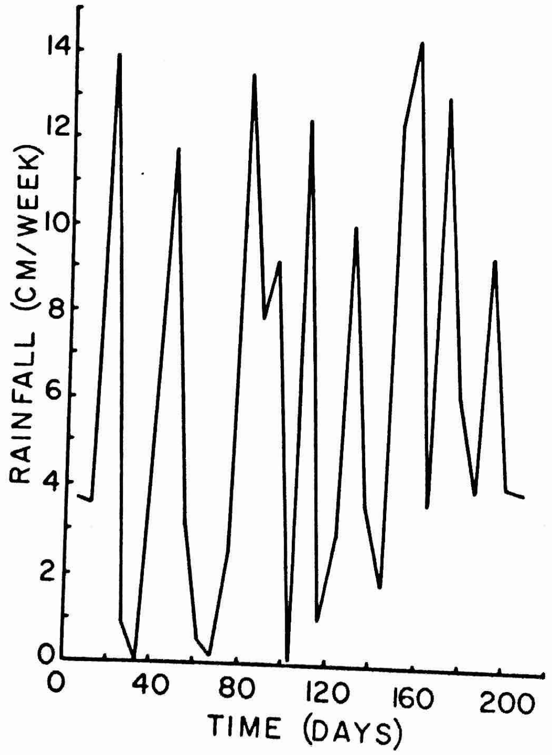

Figure 2. Rainfall input to the tropical rain forest during the experimental period. Fluctuations in tritium activity in free soil water and surface water are independent of rainfall fluctuations.

rapidly moving phases. Even in clay soils of the tropical rain forest, most of the tritium pulse passed through the profile in the form of a peak or front in a manner similar to that shown by Zimmerman et al. After the peak however, the profile remained labled. This behavior must be considered in predicting the bioenvironmental effects of thermonuclear detonations. If tritium moved in soils as a peak analogous to the movement on a chromatographic column, it would be carried out of the major rooting zone of most plants in high rainfall areas relatively quickly. The residual labelling of the soil profile as shown here, however, implies that plant roots would be exposed to tritium long after the input, and that food products grown on these soils would be correspondingly contaminated.

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EFFECTS OF IONIZING RADIATION ON THREE NEOTROPICAL TERMITES SPECIES (ISOPTERA, TERMITIDAE)

Elizabeth A. McMahan

ABSTRACT

Adult workers and soldiers of three termite species from a montane rain forest in Puerto Rico (Nasutitermes costalis, N. nigriceps, and Parvitermes discolor) were irradiated with a cobalt-60 source in two series of tests. Two dose rates (615 rads/min and 42 rads/min) and three accumulated doses (3000r, 6000r, 12,000r) were used. Primary data consisted of LT_{50} values. Significant differences in radiation sensitivity between N. costalis and P. discolor (Series I) but not between N. costalis and N. nigriceps (Series II) were found. For all species, workers were more radiosensitive than soldiers. Mortality was positively correlated with dose rate and with dose magnitude, as expected. There is evidence that these rain forest termites may be more radiosensitive than adult insects have generally been found to be. Such as result might be correlated with their habitual lack of exposure to harsh environmental conditions.

Introduction

Most studies of the effects of ionizing radiation on insects have indicated that adults are at least 100 times less sensitive to the lethal effects of such radiation than are vertebrates (See O'Brien and Wolfe, 1964, for summaries). Insect resistivity has been attributed to the relatively low rate of cell division in adults, except for cells of the gonads. Doses of 60,000 r and up have usually been required for killing adult insects, and lower doses result in sterility (Lindquist, 1958; O'Brien and Wolfe, 1964). Effects vary with age of insect, developmental stage, oxygen tension, temperature, and nutritional status. This paper reports results of experimental irradiation of adult termites.

In the summers of 1966 and 1967 field and laboratory studies were made of termite populations in a Puerto Rican montane rain forest, a portion of which had been experimentally exposed to a cesium-137 gamma emitting source for 92 days in the early spring of 1965 (Odum, in press).

Most of the termites represented two species, <u>Nasutitermes costalis</u> and <u>Parvitermes discolor</u>, both members of family Termitidae. <u>N. costalis</u> builds nests of wood carton, a material produced by the termites themselves, while <u>P. discolor</u>, lives in decaying logs and dead tree trunks. Both species build carton tunnels to food sources outside their living quarters. Life span for members of these species is not certain, but it is assumed to be similar to that of other termite species: five years or more for workers and soldiers (Harris and Sands 1965).

In the summer of 1966, fifteen months after cessation of irradiation, tunnel occupation within a 30 meter radius of the irradiated center was compared with that of comparable areas in two control centers. In one control center the trees had been topped by machete to simulate radiation damage to the canopy, while the other control center was left undisturbed. Only 13% of the tunnels in the irradiated center were found to be occupied, while 38% and 49%, respectively, were occupied in the two control centers.

In addition, the nest population of <u>N. costalis</u> in the irradiated area appeared to differ from those outside in containing fewer inhabitants, and especially fewer immature colony members. All nests within 80 meters of point 0 in the three centers were examined periodically. In the summer of 1966, the irradiated center contained 11 nests, the disturbed control center had none, and the undisturbed control center had 12. Of the 11 still-active nests in the irradiated center, one had received a total dose of 6000 r, one 1000 r, another 500 r, and the eight others had received accumulated doses of 200 r or less. These doses are relatively low, yet by July, 1967, five of these 11 irradiated nests had become abandoned, as opposed to only one (very small) of the 12 non-irradiated nests present in the comparable area of the undisturbed control center. Tunnel occupation had decreased further in the irradiated center while remaining approximately the same in the control centers.

These comparisons of tunnel and nest occupation indicated that the irradiation, although relatively low, had affected adversely the termites in the cesium center. A logical hypothesis seemed to be that the irradiation had resulted in sterilization of reproductives and potential reproductives, with consequent failure of adult and soldier replacement by developing brood. A further supposition was made that perhaps termites are more sensitive to ionizing radiation than most insects have been found to be.

Preliminary Experiments, 1966

In the summer of 1966 a preliminary laboratory test of radiation sensitivity was carried out on a population of N. costalis, all termites taken from a single nest in an unirradiated portion of the rain forest. Four experimental groups, each composed of 20 adult workers, 20 soldiers, and 10 young nymphs were taken from a population that had been given a dose of 6000 r at a rate of 67 rads/min. from a cobalt-60 source. These four groups were matched with similar but unirradiated groups from the initial nest population. All irradiated termites were dead in 6 days, while 68% of the controls were still active at that time. Nymphs were more sensitive than adults, and adult soldiers appeared to be slightly more resistant than adult workers.

Experiments, 1967

A more extensive test of radiation sensitivity was planned for the summer of 1967, comparing different termite species and utilizing several radiation dosages. The first series compared the two termite species most common in the rain forest, N. costalis and P. discolor. Series I also included testing of a species of hompteran found to be very prevalent in the irradiated center, but extremely poor survival of both control and experimental leafhoppers showed that holding conditions during the test were too poor for conclusions to be reached. These homopteran results, therefore, are mentioned only briefly in this report. The second series compared N. costalis with yet another termite species, N. nigriceps.

Experimental Animals

Nasutitermes costalis, N. nigriceps and Parvitermes discolor all have a true worker caste and nasuti-type soldiers. Only adult workers and soldiers were used in the present experiment. Soldiers are smaller than workers; Table 1 gives average weights of both castes for the three species.

All termites in each test population were taken from a single colony, and all colonies were from outside the experimental centers. N. costalis individuals for both experimental series were taken from the same nest.

The N. costalis termites in Series I were collected by breaking the nest a large platic sheet and transferring appropriate individuals to plastic containers using camel's hair brushes. The large nest fragments with most of the remaining colony, were then placed at the base of a tree, shielded from rain, and left undisturbed until the beginning of Series II, 10 days later. Again, termites were shaken from the nest fragments and transferred to plastic containers. Parvitermes individuals were collected by breaking open a large infested rotten log and brushing the termites into dishes from which they were transferred to the experimental containers. N. nigriceps individuals were taken similarly from a large tunnel on a rotting tree trunk, because no nest was found. Ordinarily N. nigriceps is not found at altitudes much above 500 feet but the species had invaded an area adjoining a forestry road in the experimental area at about 1000 feet. Members of this population were used in Series 2.

The homopterans were leafhoppers in all stages of nymphal development, plus adults. They were selected for testing because of their great prevalence in the area. Average adult weight was .90 mg. They were collected within 15 meters of the cesium site on leaves of Ichnauthus pallens (Sw) Munro, a grass typical of open spaces in this rain forest.

The Ichnauthus had invaded the center following defoliation of the trees after irradiation. It was heavily infested with the leafhoppers, most of which were juveniles feeding on the under sides of leaves and on stems. Many winged adults were also present, and both nymphs and adults were very active. Collecting consisted in finding a well-infested leaf, detaching it gently by a scissor-cut and quickly placing the entire leaf inside a small plastic experimental jar. An attempt was made to put at least 10 leafhoppers in each container, but no exact count was attempted at the time of collecting.

All populations compared in a given series were collected on the same day. It took approximately two hours to collect each species and to segregate the individuals appropriately in the small experimental containers. Irradiation was on the succeeding day.

Experimental Containers

The plastic jars in which the experimental animals were held and tested were 4 cm high and 4 cm in diameter. Each had a screw-top lid, and a circular floor of dampened paper toweling.

The termite jars also contained a 2 cm x 1 cm chunk of damp, decaying wood and a 3 cm length of dampened Cecropia petiole, 1 cm in diameter. Both of these food sources had been found previously to be acceptable to termites as food. All the wood chunks used in the containers had been taken from the same piece of decaying wood.

The homopterans were placed in similar containers but with only the damp circle of paper toweling as a "floor", and no wood. Their food source consisted of the leaves of Ichnauthus to which they were attached when collected. Fresh (uninfected) leaves were added every other day to these containers. Container lids were loosely screwed in place.

Irradiation

Three radiation doses (3000 r, 6000 r, and 12,000 r) were used, with two dose rates for each: 615 rads/min. and 42 rads/min. Irradiation was carried out in the Puerto Rico Nuclear Center in Rio Piedras, using a cobalt-60 source. All containers in a given series were irradiated simultaneously, dose rate being controlled by distance from the source, and dose magnitude by time of removal. Control containers received exactly the same treatment as experimental containers except that they were not irradiated.

Procedures

Series 1 compared the radiation sensitivity of Nasutitermes costalis, Parvitermes discolor, and the homopteran. Table 2 indicates the overall experimental set up: Six experimental conditions and one control per species, with 4 replicates of each, making a total of 84 containers. At the start of the experiment, the termite containers each held 20 workers and 5 soldiers. The homoptera containers each held an average of 10 leafhoppers.

Following appropriate irradiation of the experimental containers all were kept at ambient temperatures (approx. 26° C) and humidity at the El Verde rain forest station. Each morning all containers were opened in a constant sequence and the inhabitants were removed gently for examination. Number of survivors was recorded and dead individuals were discarded.

Because of their strong tendency to hop, the leafhoppers were gently transferred into a closable plastic bag for counting. The termites usually remained clinging to the wood chunks or Cecropia petioles and were transferred for examination to a bowl lined with a pliable plastic sheet. Every individual was accounted for before survivors were returned gently to their containers.

Series II was carried out ten days later in exactly the same way as Series I except that workers and soldiers of N. costalis and N. nigriceps were tested.

Results

Holding conditions for termites during the experiments, while apparently not as bad as those for the leafhoppers, were also poor, as shown by high control mortality rates. Table 3 gives survival percentages on the eighth day following treatment for both control and irradiated termites and leafhoppers. Total accumulated dose and dose rate are disregarded. The eighth day was chosen for the comparison because it was the maximum point of survival for experimental individuals of N. nigriceps, the termite species first reaching 100% mortality. In subsequent analyses, the experimental data have been corrected for control mortality. Results for Series I and Series II have been kept separate in all analyses because the large differences in mortality for control individuals (see N. costalis, Table 1) indicate that conditions in the two series were too different to permit pooling.

Time, in days, at which 50 percent of experimental termites were dead (LT_{50}) was calculated for each experimental condition for each termite species and used as the primary datum in analyses.

Comparison of Worker and Soldier. The result supported those of the preliminary tests of 1966 in showing that soldiers are more radioresistant than adult workers. Figures 1 and 2 give soldier and worker mortality curves for Series I and II, respectively, when data for irradiation conditions (dose rate & total accumulated dose) are pooled. In Series I, the average LT_{50} values for N. costalis soldiers and workers are 4.1 and 2.7 days; comparable figures for P. discolor are 9.7 and 8.5. In Series II for N. costalis, they are 1.45 and 1.40; and for N. nigriceps, they are 3.55 and 2.90. In all cases, soldier survival exceeded worker survival.

Effects of Accumulated Dose and Dose Rate. As expected, there was a positive correlation both between mortality rate and size of accumulated dose and between mortality rate and dose rate. These effects are shown in Table 4 and 5, in terms of mean of LT_{50} values, with data for soldiers and workers pooled. In order to evaluate the significance of the LT_{50} mean values and the interaction between levels of dose size and dose rate for different species, analyses of variance, using a factorial arrangement of the treatments taken two sets at a time, were applied to the data shown in Tables 4 and 5. The results are given in Tables 6-13. They show that size of total dose affected significantly the time of death for N. costalis and N. nigriceps but not for P. discolor (Tables 6, 7, 8, 9), and that the differences resulted only at the higher, not at the lower, dose rate (Tables 10, 11, 12, 13).

Species differences. The average time of death following irradiation differed significantly for N. costalis and P. discolor (Series I, Table 10 and 11, Figure 1) at both high and low dose rates. On the other hand, N. costalis and N. nigriceps did not show such differences at either rate. (Series II, Tables 12 and 13, Figure 2).

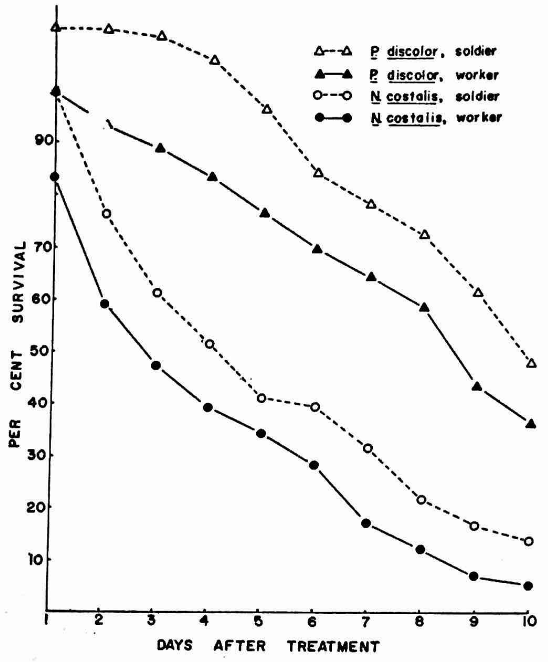

Figure 1. Comparison of soldier and worker survival rates after irradiation for P. discolor and N. costalis in Series I. Percentage figures go above 100 because all data are corrected for control mortality. Dose rate and dose magnitude data are pooled.

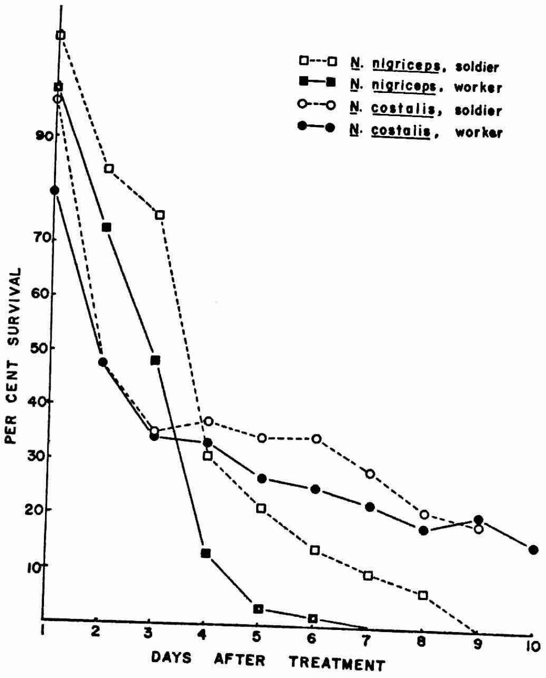

Figure 2. Comparison of soldier and worker survival rates after irradiation for N. nigriceps and N. costalis in Series II. Percentage figures go above 100 because all data are corrected for control mortality. Dose rate and dose magnitude data are pooled.

Table 1

Average Weights of Workers and Soldiers for Three Termite Species

Caste	Parvitermes discolor	Nasutitermes costalis	Nasutitermes nigriceps
Soldier	0.82 mg	1.54 mg	2.44 mg
Worker	2.03 mg	4.64 mg	6.99 mg

Table 2

Experimental Plan for Series I

Species	Control Containers	Irradiated Containers (615r/min)			Irradiated Containers (42r/min)		
		3000r	6000r	12,000r	3000r	6000r	12,000r
Nasutitermes	4	4	4	4	4	4	4
Parvitermes	4	4	4	4	4	4	4
Homoptera	4	4	4	4	4	4	4

Table 3

Per Cent Survival of Termites and Leafhoppers on Eight Day Following Irradiation[a]

Series I

Termite	Nasutitermes costalis		Parvitermes discolor	
	Control	Experimental	Control	Experimental
Soldier	93.33	19.83	75.00	54.10
Worker	83.33	9.79	85.00	49.38

Series II

Termite	Nasutitermes costalis		Nasutitermes nigriceps	
	Control	Experimental	Control	Experimental
Soldier	70.00	15.00	25.00	6.68
Worker	43.75	8.13	15.00	0.00

Series I

	Control	Experimental
Leafhopper	0.00	1.85

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[a] All dose rate and total accumulated dose data pooled.

Table 4

Average LT_{50} Values (+ 95 Per Cent Confidence Limits) of _N. costalis_ and _P. discolor_ for Levels of Total dose and Dose Rate (Series I).

Total Dose (r)	Dose Rate	_N. costalis_	_P. discolor_
3000	High (615 rads/min)	8.61 days	11.38 days
	Low (42 rads/min)	7.50	7.06
6000	High	2.65	7.78
	Low	4.29	10.90
12,000	High	0.99	4.65
	Low	1.61	8.54

Table 5

Average LT_{50} (+ 95 Per Cent Confidence Limits) of _N. costalis_ and _N. nigriceps_ for Levels of Total Dose and Dose Rate. (Series II).

Total Dose (r)	Dose Rate	_N. costalis_	_N. nigriceps_
3000	High (615 rads/min)	6.05 days	2.59 days
	Low (42 rads/min)	9.65	9.35
6000	High	1.31	2.87
	Low	3.57	3.46
12000	High	0.89	3.53
	Low	1.44	3.97

Table 6

Analysis of Variance of Total Accumulated Dose and Dose Rate Affecting Time of Death of N. *costalis*, with Treatments Arranged in Factorial Design (Series I).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	5	198.88	....	....
A. Total dose	2	190.26	95.13	55.04**
B. Dose rate	1	0.89	0.89	0.51 n.s.
AB Interaction	2	7.73	3.86	2.24 n.s.
Error	18	31.11	1.73	....
Total	23	229.99	....	....

Table 7

Analysis of Variance of Total Accumulated Dose and Dose Rate Affecting Time of Death of P. *discolor*, with Treatments Arranged in Factorial Design (Series I).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	5	125.05	....	....
A. Total dose	2	38.32	19.16	3.10 n.s.
B. Dose rate	1	4.73	4.73	0.77 n.s.
AB Interaction	2	82.00	41.00	6.64**
Error	18	111.07	6.17	....
Total	23	236.12	....	....

Table 8

Analysis of Variance of Total Accumulated Dose and Dose Rate Affecting Time of Death of *N. costalis*, with Treatments Arranged in Factorial Design (Series II).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Treatments	5	238.14	....	....
A. Total dose	2	201.40	100.70	15.08**
B. Dose rate	1	27.41	27.14	4.11 n.s.
AB Interaction	2	9.33	4.67	0.70 n.s.
Error	18	120.18	6.68	....
Total	23	358.32	....	....

Table 9

Analysis of Variance of Total Accumulated Dose and Dose Rate Affecting Time of Death of N. nigriceps, with Treatments Arranged in Factorial Design (Series II).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	5	127.58	....	....
A. Total dose	2	35.17	17.59	11.22**
B. Dose rate	1	40.43	40.43	25.80**
AB Interaction	2	51.98	25.99	16.59**
Error	18	28.21	1.57	....
Total	23	155.79	....	....

Table 10

Analysis of Variance of Total Accumulated Dose and Species Differences Affecting Time of Death of N. costalis and P. discolor, with Treatments Arranged in Factorial Design (Series I).

High Dose Rate: 615 rads/min

Source of Variation	Degrees at Freedom	Sum of Squares	Mean Squares	F
Treatments	5	308.05	....	
A. Total dose	2	213.38	106.69	59.59**
B. Species	1	89.01	89.01	49.71**
AB Interaction	2	5.66	2.83	1.58 n.s.
Error	18	32.23	1.79	....
Total	23	340.28	....	

Table 11

Analysis of Variance of Total Accumulated Dose and Species Differences Affecting Time of Death of N. costalis and P. discolor, with Treatments Arranged in Factorial (Series I.

Low Dose Rate: 42 rads/min.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Treatments	5	213.11	....	
A. Total dose	2	30.08	15.04	2.46 n.s.
B. Species	1	113.84	113.84	18.64**
AB Interaction	2	69.19	34.60	5.66*
Error	18	109.96	6.11	....
Total	23	323.06	....	

Table 12

Analysis of Variance of Total Accumulated Dose and Species Differences Affecting Time of Death of *N. costalis* and *N. nigriceps*, with Treatments Arranged in Factorial Design (Series II).
High Dose Rate: 615 rads/min

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Treatments	5	67.86	....	....
A. Total dose	2	25.23	12.61	7.96**
B. Species	1	0.37	0.37	0.23 n.s.
AB Interaction	2	42.26	21.13	13.34**
Error	18	28.51	1.58	....
Total	23	96.36	....	....

Table 13

Analysis of Variance of Total Accumulated Dose and Species Differences Affecting Time of Death of *N. costalis* and *N. nigriceps* with Treatments Arranged in Factorial Design (Series II).

Low Dose Rate: 42 rads/min

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	5	494.59	....	....
A. Total dose	2	255.82	127.91	1.50 n.s.
B. Species	1	85.65	85.65	1.00 n.s.
AB Interaction	2	153.11	76.56	0.90 n.s.
Error	18	1537.29	85.41	......
Total	23	2031.88	....	....

Interaction effects. In addition to the significant main effects, significant interactions were shown for various sets of treatments (See Table 7,9, 11, and 12). Inspection of the data reveals that these significant interactions are the result of wide differences in mortality between replicates within single treatments. Although N. costalis data are consistent in showing positive correlations between mortality and both total dose and dose rate, P. discolor and N. nigriceps data are not always consistent. In almost every case the inconsistency is due to high mortality in some containers and low in others for the same experimental condition. Factors responsible for these wide differences between replicates are not known.

Discussion

Menhinick and Dodson have pointed out that no general principle for predicting radiosensitivity of insects, similar to the nuclear volume method for higher plant, has so far been elaborated. Their studies, in which 12 species of insect (none in order Isotopera) were irradiated in a Cobalt-60 source at doses ranging between 1000 and 512,000 r and at two dose rates (3000 r/min or 30,000 r/min), indicated that there seemed to be little relation of sensitivity to taxonomic grouping. Their studies did show, however, that within each order, radiosensitivity appeared to be correlated with weight. Other investigators testing the radiosensitivity of other organisms, have obtained similar results.

These termite data support the apparent positive correlation between weight and radiosensitivity, although not entirely consistently. One should expect, on this basis, to find an increase in sensitivity in going from soldier to worker (see Table 1) and from P. discolor to N. costalis to N. nigriceps. The only departure from the expected trend is the lack of evidence for greater sensitivity of N. nigriceps over N. costalis.

Both the high (615 rad/min) and the low (42 rads/min) dose rates resulted in increased mortality for all species. Size of total dose was significantly effective in producing differential mortality only when dose rate was high. The reason for this result probably lies in the unexplained variation in mortality of replicates within a single experimental treatment, as mentioned previously.

The original question pertaining to a supposed heightened radiosensitivity of termites over most other insects has not been answered unequivocally by these studies. High mortality among control termites indicated that holding conditions were poor. The results obtained are comparable, however, with those of the preliminary tests conducted in 1966. At that time a N. costalis nest was broken up into large chunks, two-thirds of which were divided equally between two closed plastic wastebasket containers. One container, with its thousands of inhabitants, was given a total of 6000 r at the rate of 67 rads/min. The other container was not irradiated. From each of these two populations, four replicate groups were selected and placed in small plastic jars, each group consisting of ten adult workers, ten soldiers, and five nymphs, a total of 25 individuals. The jars were examined daily. Mortality was high for both control and experimental (irradiated) termites, but after six days all termites in the four experimental jars were dead while 67% of those in the four control jars still survived. Even more striking was the comparison between the two original populations in the two waste-basket containers. All of the thousands of inhabitants of the irradiated basket were dead as compared with virtually none of the termites in the nonirradiated basket. It appeared that holding conditions in the large basket containers were considerably better than those in the small plastic jars, and more closely approximated conditions in nature. Nevertheless 100% mortality had occurred among the irradiated termites six days after they had received only 6000 r, given at a rate of 67 rad/min.

When the data for 1966 and 1967 are viewed together they appear to suggest that these termites are more radiosensitive than most other adult insects that have been studied. Male cockroaches (Periplanets americana) were found to have LT_{50} values of 14 days at 10,000 r (Wharton and Wharton 1959); the boll weevil (Anthonomus grandis) had LT_{50} values of 6 days for males and 7 days for females at a dose of 15,000 r (Davich and Lindquist 1962); both male and female plum curculios (Conotrachelus nenuphar) had values in excess of 10 days at 10,000 r (Lippold, Gambrell and Massey 1968); and Female adult large milkweed bugs (Oncopeltus fasciatus) had an LT_{50} of 28 days at 10,000 r. These values should be compared with the lower LT_{50} values for the three termite species, given in Tables 4 and 5.

Woodwell (1967) had suggested that organisms which are adapted to harsh environmental conditions tend to be radioresistant. The converse would be that organisms which have not had to adapt to stringent conditions might be more sensitive to ionizing radiation. These rainforest termites, by virtue of their colonial habits and geographical distribution, are protected against environmental extremes. It will be interesting to see how termites living in other, more demanding, environments compare in radiosensitivity with these rainforest termites.

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Acknowledgments

This work was financed by the U.S. Atomic Energy Commission, through the Puerto Rico Nuclear Center. Miss Heidi Pabón and Mrs. Dina Biringer of the PRNC carried out the actual irradiation of the insects. Dr. A.E. Stiven gave statistical aid.

NITROGEN FIXATION BY EPIPHYLLAE*

Joe A. Edmisten and Jerry R. Kline
University of Georgia and Puerto Rico Nuclear Center

Preliminary studies on nitrogen fixation in the lower montane rain forest of eastern Puerto Rico indicated nitrogen levels of 2 to 3% in leaves of leguminous plants and in the leaf nodulated Psychotria (1). Leaves from non leguminous plants normally had less than 1% N although several cases were found where the levels were over 3%. Leaves with the largest visible growth of epiphyllae appeared to have the highest content of N. This suggested that some components of the mixed epiphyllae communities could fix atmospheric N.

Ruinen (3) reported that epiphyllae fixed nitrogen in vitro and suggested that the bacteria Azotobacter and Beijerinckia might be responsible. Stewart's review (4) suggested that nitrogen fixation occurs in the phyllosphere. We now report the results of a preliminary experiment which was carried out using N_2^{15} to determine qualitatively whether N fixation occurs in the phyllosphere under field conditions in the tropical rain forest.

Methods

Shade leaves of a grapefruit tree (Citrus paradisi) at the edge of a small clearing in the lower montane rainforest were selected for the experiment since their epiphyllae populations appeared similar to those in the forest. Five undisturbed leaves were enclosed in plastic bags which were sealed by taping securely to the stems. Hypodermic needles with rubber tube connections were used for removal of the normal atmosphere and subsequent replacement by an atmosphere consisting of 75% Argon, 20% oxygen and 5% N_2^{15}. Metal pinchcocks on the rubber tube connections to the needles were used to prevent the loss of the artificial atmosphere during a 48-hour exposure period. During the period of exposure, the bags remained inflated indicating that the systems were well-sealed.

At the end of 2 days of exposure to N_2^{15}**, the leaves were cut from the tree and the epiphyllae were scraped from the leaves. It was planned to measure the amount of N^{15} in the epiphyllae from each leaf, but the amounts available were too small for Kjeldahl conversion to ammonia. The epiphyllae from the 5 leaves were therefore pooled as one sampled and were sent along with4 of the scraped leaves to a commercial laboratory (Isomet Corp., Palisades Park, N.J.) for analysis.

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*This work was supported in part by the University of Georgia and in part by the Puerto Rico Nuclear Center which is operated by the University of Puerto Rico for the U.S. Atomic Energy Commission under contract AT(40-1)-1833.

Results

The results of this experiment are given in Table 1. The pooled sample of epiphyllae scraped from five leaves had taken up 9.67% of their total nitrogen from the gaseous N_2^{15} during the 48-hour exposure period. The other samples analyzed were leaves from which the epiphyllae had been scraped. Leaf #1 was a young leaf with about 50% of its upper surface covered by black fungal and bacterial matter which resisted removal by the scraping technique used. As a result most of the black material was left on the leaf. Leaves 2,3, and 4 were older leaves with large amounts of lichens and liverworts. Most of the material classified as "pooled epiphyllae" in Table 1 came from these three leaves. The results show that nitrogen fixation occurred in the organisms on leaf surface and implies that some transference to the host leaf took place since these leaves are enriched by a factor of 2 or move over the natural isotopic abundance of N^{15} which is 0.37% (2). Some of the enrichment of N^{15} in the leaves could be due to the inability to remove all of the epiphyllae by scraping. It is doubtful that the total enrichment is accounted for in this way however since in the case of leaves 2,3, and 4 the surfaces were visually free of colonies after scraping.

Total nitrogen in the samples was 5% for the epiphyllae and averaged 1.6% for the leaves from which the epiphyllae were taken. This is supporting evidence that nitrogen is fixed by some members of these mixed communities.

The occurrence of nitrogen fixation by epiphyllae suggests the possibility of a symbiotic relationship between these organisms and the higher plants. Nitrogen might be furnished to the leaves by the micro-organisms through foliar uptake while they in turn receive inorganic nutrients from the trees. Whether or not the relationship is truly symbiotic, these organisms must add to the pool of available nitrogen in the rain forest through leaf fall and cell turnover.

At this stage it is not known which components of the mixed communities are active nitrogen fixers. Attempts are being made to isolate and culture the responsible organisms, however at this point it is apparent that a potentially important source of biologically available nitrogen in the tropical rain forest has been demonstrated under field conditions.

**N_2^{15} of 95% isotopic purity was obtained from Nuclear Equipment Chemical Corp., Farmingdale, N.Y.

Table 1

Amounts of total nitrogen in leaves and epiphyllae and percent of total N as N^{15} after 48-hours exposure to N_2^{15}.

Sample	Wt. of Material grams	Total N grams	N^{15} %
Pooled epiphyllae	0.2259	0.0114	9.67
Scraped leaf #1	1.1703	0.0234	5.65
" " #2	1.7533	0.0085	0.99
" " #3	1.2940	0.0280	0.70
" " #4	1.1351	0.0220	0.81

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MOVEMENT OF ^{85}SR AND ^{134}CS BY THE SOIL WATER OF A TROPICAL RAIN FOREST

Carl F. Jordan

Introduction

The dynamic of radionuclide movement in tropical soils were studied by analyzing soil water collected weekly at various depths, after the nuclides were applied to the soil surface.

Methods

A study plot was prepared by inserting aluminum garden edging around a 96 x 120 cm plot to a depth of about 3 cm on three sides. The fourth side was dug away, and two 2 x 12 inch zero-tension lysimeters (Jordan, 1968) were installed beneath the litter, and two at 5 inches in the manner shown in Fig. 1. On Aug. 10, 1967, 1 mCi of ^{85}Sr and .8 mCi of ^{134}Cs in 2500 ml of water were applied evenly to the plot with a garden sprinkling can. Lysimeter water collections were made weekly, boiled to dryness, taken up in 5 ml. of 1 M Hcl, and 3 ml were counted on a single channel gamma analyzer. Results were corrected for physical decay and background, and activity per ml collected was calculated. Then the two litter samples for each week were averaged and plotted. The results of these calculations are referred to as "activity" in the remainder of this paper.

Activity of each sample was multiplied by volume collected from each lysimeter for each date, and total radioactivity that moved through the litter and 5 inch level was calculated as of Jan. 2, 1968 (145 days after start of experiment).

Rainfall above the canopy was measured with a standard tipping bucket rain gauge, and below the canopy with twelve 5 ft. x 2 in rain gauges. Data was not treated statistically, because data from 1968, not included in this report, could influence results. Lines on graphs were drawn in simply as an aid to interpreting data.

Results

Activity of ^{134}Cs in the litter water decreased at a rapid rate for the first two weeks following application, and from then on, rate of decrease of activity was lower (Fig. 2). At 5 inches, activity increased to a peak at 3 weeks, after which activity at first dropped off sharply, then after 7 weeks, it dropped off more slowly (Fig. 2).

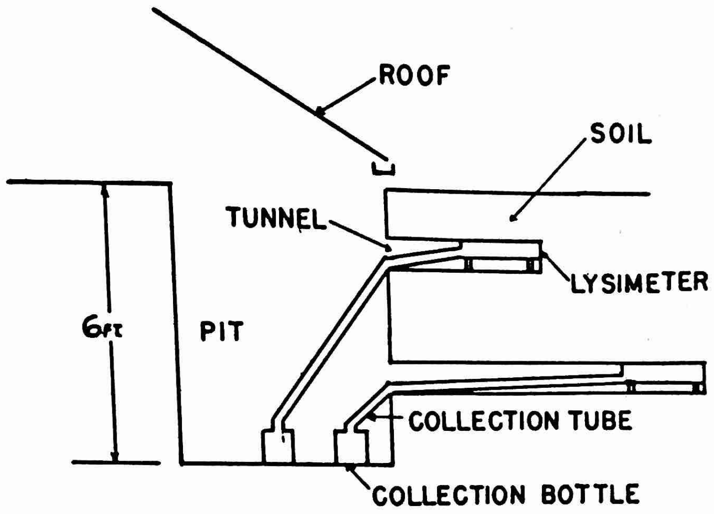

Figure 1. Cross section of lysimeter pit, showing manner of installation of zero-tension lysimeters. Tunnels are packed with soil after installation. For litter layer lysimeters, litter layer is peeled back, lysimeter is installed, and litter is then replaced.

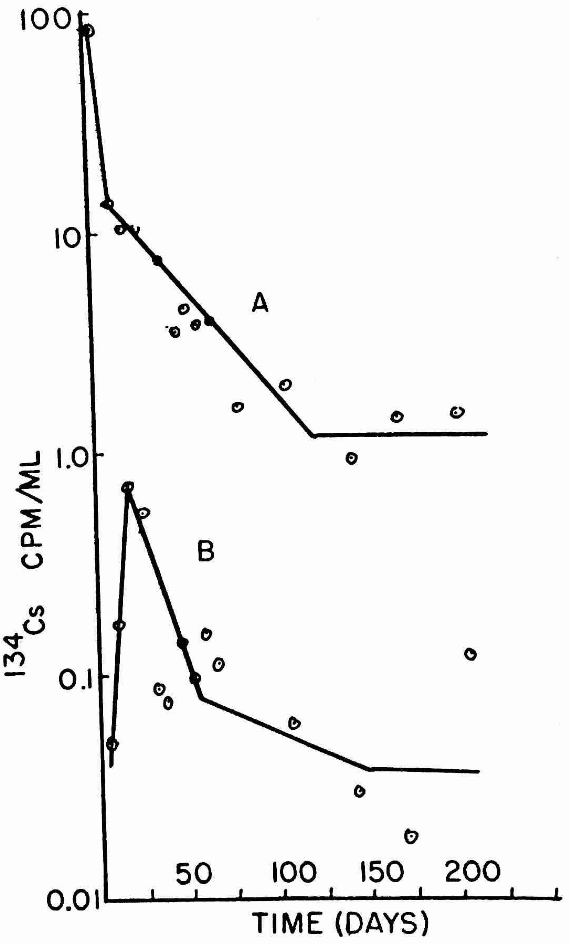

Figure 2. Activity of ^{134}Cs in the soil water, collected in lysimeters beneath the litter (A), and at 5 inches (B).

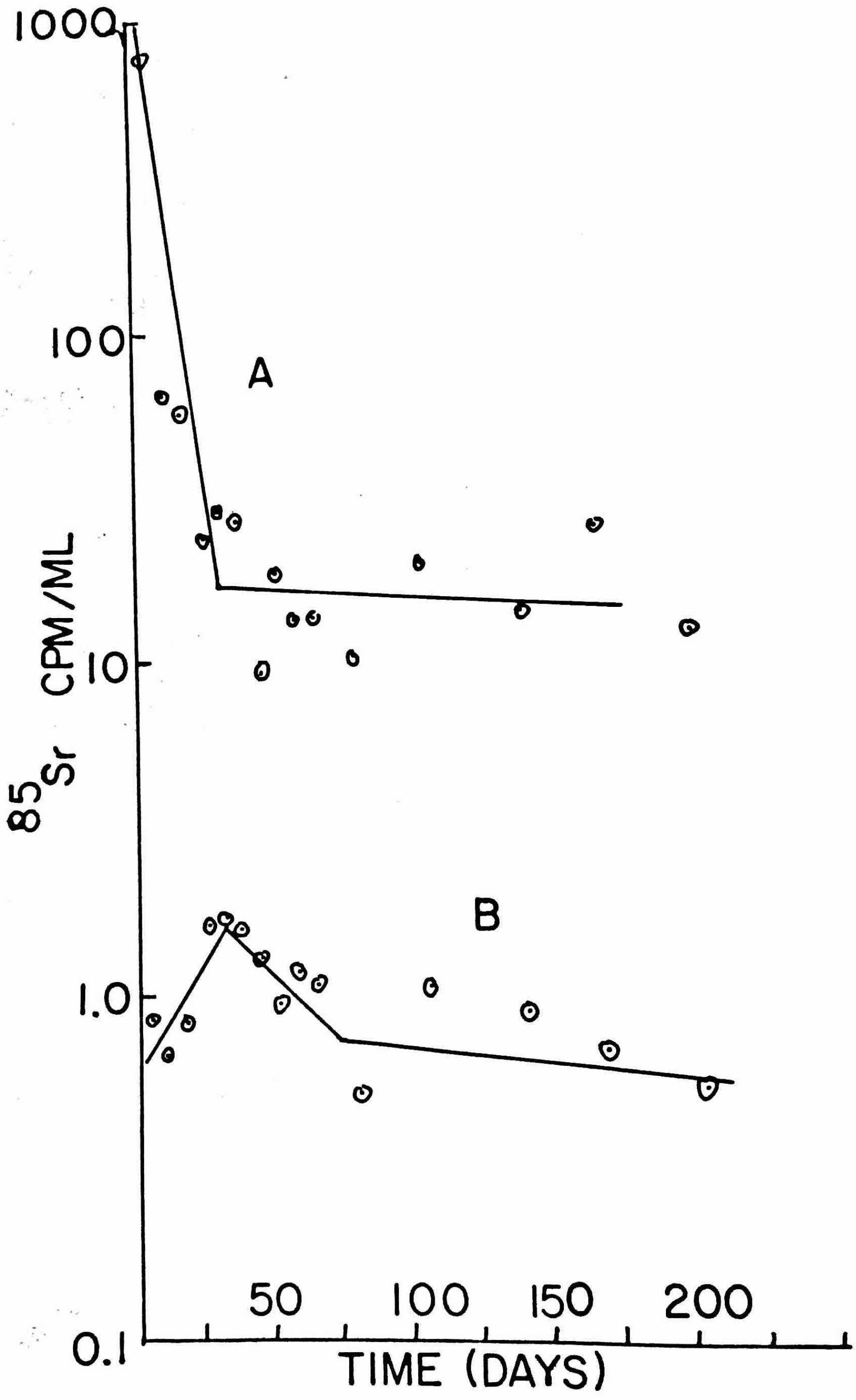

Figure 3. Activity of ^{85}Sr in the soil water, collected in lysimeters beneath the litter (A), and at 5 inches (B).

Activity of ^{85}Sr in the litter water dropped off sharply for about 4 weeks, after which it stayed relatively constant (Fig. 3). At 5 inches, there was slight peak in activity, followed by an almost constant level after 10 weeks (Fig. 3).

As of Jan. 2, 1968, 33% of the ^{85}Sr applied to the entire surface had moved out of the litter, and .57% had moved through the 5 inch level. Twenty seven % of the ^{134}Cs had moved out of the litter, and .32% had moved through 5 inch level.

Total rainfall from 8/10/67 to 1/2/68 was 103 cm above the canopy and 76 cm below the canopy.

Discussion

The very low total amounts of ^{134}Cs and ^{85}Sr in the soil water indicate that most of these radionuclides have become bound in the litter and upper few cm of soil. This is an agreement with Kline's data (1968) which shows that half the activity of ^{134}Cs and ^{85}Sr applied in a similar manner was in the upper 2.5 cm of soil after 18 months.

Presumably, ^{134}Cs and ^{85}Sr were adsorbed by the litter when the solution was sprinkled on the plot. Following adsorption, there were two or three different released rates into the soil water. The rapid decrease in activity in the first few weeks following application could be due to rapid removal of ions adsorbed to the surface of living or non-living organic matter, and soil. The later, more gradual release rate could be due to ions initially incorporated into living organisms, and then gradually released, or, to replacement of adsorbed ions by others ions moving doward.

At the 5 inch depth, there is a rapid increase in activity in the first few weeks followed by a gradual decrease in ^{85}Sr activity and a sharper decrease in ^{134}Cs. The peak of activity and first decrease of each nuclide in the soil water reflects the initial injection spike which had broadened out to a peak of activity at the 5 inch level. The following almost uniform release of ^{85}Sr probably is due to phenomenon mentioned in the above paragraph, while the declining release rate of ^{134}Cs could be caused by the ^{134}Cs gradually being incorporated into the crystal lattice of the clay soil. When fixation is completed, rate of ^{134}Cs release should be steady.

Before the final portion of the regression lines can be treated statistically, and final conclusions reached, about a year's more data are required.

The concentrations of ^{134}Cs and ^{85}Sr in the soil water apparently are not a function of the amount of rain in an individual storm since weekly rainfall totals ranged from 0 to 14 cm. Concentration rather appears to be a function of the total amount of water that has moved through the soil.