

PRNC-119 BIOLOGY AND MEDICINE CTID-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 ---Page Break--- Table of Contents Page Abstract * Subproject Reports Radiation Recovery 3 Optical Measure of Leaf Area Index 26 Radionuclide Residence Times in Forest Compartments 28 Differential Leaf Turnover 34 Stem Flow in the Tropical Rain Forest 35 Flow of Soil Water in the Lower Mountain Tropical Rain Forest 41 Kinetics of Stable Element Movement in the Forest 1. Water Budget of the Forest 45 Kinetics of Stable Element Movement in the Forest 2. Concentration of Elements in Forest Water 49 Chemistry of Successional Vegetation 51 Elemental Composition of Climax Vegetation 53 Transpiration 56 Radionuclide Behavior in Tropical Soil 61 Fallout Radionuclide Distribution in Vegetation of Puerto Rico 64 Reactions of Nuclides with Epiphyllae 70 Neutron Activation of Tropical Soils and Plants 72 Termites Nests and Tunnels in the Radiation Center at El Verde 79 Soil Respiration 80 Giant Cylinder Experiment 84 Performance of the Zero-Tension Lysimeter 88 Bioelimination of Zn65 in the Snail Caracolus caracolla 98 Behavior and Natural History of the Snail Caracolus caracolla in a Tracer-Labeled Environment 100 Phenology of Rain Fall at El Verde 113 Insect Identifications 115 Staff of Papers Presented at Scientific Meetings and Publications 118 Appendix: Manuscripts Which Have Been Prepared and Submitted for Publication Since June 1967. 120 Tritium Movement in Soil of Tropical Rain Forest 120 Effects of Ionizing Radiation on Three Neotropical Termite Species (Isoptera, Termitidae) 124 Nitrogen Fixation by Epiphyllae 129 Movement of Sr90 and 137Cs by the Soil Water of a Tropical Rain Forest 134 ---Page Break--- TERRESTRIAL ECOLOGY PROGRAM 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) 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 PRIC-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 PRIC 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 behavior 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. ---Page Break--- Figure 1, Irradiated area, Nov. 1966. Pipes and cement platform in center supported source. ---Page Break--- 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 m² 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 20 m² 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 the quantity of new vegetation in the irradiated area has been increasing, the 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. Continuing effort ---Page Break---

Table 1 Biomass correlation statistics

A Correlations

Y = Biomass in grams of dry weight

X = Basal diameter in inches of an inch and diameter in sh

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 $Y = .0203x^2 + .7657x - 2h.40$ (N = 35)

Prytolecea $Y = .0376x^2 - 2.ho76x + 28.1843$ (N = 13)

Grasses and Sedges $Y = 426$. (% coverage of one m²) (N = 10)

Desmodium $Y = 615$. (% coverage of one m²) (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. ---Page Break---

Continued Table 1 © Determining best correlation

Determined from 10 samples of *Piper aduncum*

x x Correlation coefficient, height weight oT height weight 9h

Ataneter height +93, height weight (adjusted for dia.-wt, correlation) 2h 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, te: Diameter (X) Dry Weight (Y)

3 (a=.95) (qh 8 of an inch) (grams) — 20 Le 3.0 50 20.4 27 10 56.9 27 100 168.5 2.8 200 1395.0 3.0 ---Page Break---

eat area nteses of nev ant old vegetation in the tiredtated and bechanteally stripped areas Rag RE GT he. IT AE Trradiated area, new vegetation 6 hag 8.06 Trettation Ls 663 als Tevadinted area, old vegetation 20 2k Stripped area, old vegetation 253 a aBe 3.08 | mnie 3

'Summary of species and individuals in various categories, in the irradiated area, in 1960 and 1967, ee Mo of species Mo, of individuals 1 pe dean ett (3) new vegetation o aor Sprouts. 2 es Old vegetation a st Poorly drained soil (2900) new vegetation © Le Sprouts 2 i 01d vegetation 2 ar Total, 1966 ome 5,26 967 Weld drained soil Tew vegetation 2 4m Sprouts & 'eet Old vegetation 38 oS Poorly drained soil new vegetation 8 3,268 Sprouts a 258 Old vegetation a ie 'otal, 1967 rae 8en

'Several species occur in several groups. Therefore, total number of species for entire area does not equal the sum of the individual groups. a ---Page Break---

Table & Biomass of new plants and sprouts in the

irradicated area in 1966 and 1967

'Total gms. in area (ary weight) (ary weight) 1966 Well drained soil (386m) New vegetation 951,388 Sprouts 26,678 Poorly drained soil (290m) New vegetation 36,691 Sprouts 43,899 Total, 1966 163,656 1967 Well drained soil New vegetation 323,256 Sprouts 123 Poorly drained soil New vegetation 139,893 Sprouts 8 Total, 1967 519,620 *This is the

average biomass/n° for total area. ---Page Break--- 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, day weight Puytolaces teosandra 11,406 Desmodius procumbens 25,779 Psychotria berteriana 13,033 Palicourea riparia 15,497 Tabebuia heterophylla 5,967 Didymopanax noroton 12,559 Grasses and sedges 32,804 Sprouts 31,577 Other herbs 10,199 Percent, total biomass 6.9% 2.5% 15.7% 1.9% 9.1% 3.6% 7.6% 20.0% 19.2% 6.2% ---Page Break--- Table 6 Number of individuals of each species in 676m² 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 the "individuals" column for these species indicate the number of quadrats in which the 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
Falicoures riparia Benth. & Hook.	ash
Gecropia peltata L.	21
Didymopanax morototoni (Aubl.) Dene. & PL.	igi
Icnanthus pallens (Sw.) Munro; Benth.	183*
Gasearia bicolor Urban.	150
Aichornea latifolia Sw.	32
Tinociera doningenis (Lam.) Knobl.	2
Miconia racemosa (Aubl.) D. Don.	108
Tabebuia pallida Miers,	98
Securidaca virgata Sv. & Rajania cordata L.	58
Eyrsonina coriacea (Sw.) D.	iy
Prytolaces icosandra L.	43
Aichorneopsis portoricensis Urban.	pt
Miconia tets (Sw.) D. Don.	31
Paspalum conjugatum Berg.	3
Drypetes glauca Vahl.	31
Nepsera aquatica (Aubl.) Naud.	a
Miconia prasina (Sw.) D.	3
Dacryodes excelsa Vahl.	19
Desmodium procumbens (Mill.) Hitchc.	16
Solanum rugosum Dunal.	45

Gasearia arborea (L.C. Rich.) Urban.	ah
Inga vera Willd.	B
Grotton poecilanthus Urban.	20
Clidemia strigillosa (Sw.) D.	10
Spermacoce confusa Rendle.	10
Heteropteris laurifolia (L.) Juss.	T
Ocotea leucoxyion (Sw.) Mez.	T
6 Sapium laurocerasus Desf.	---
Page Break --- — Continued	

Table 6 — Sloane berteriana Choisy

Gcotea moschata (Pavon) Mez.
Smilax coriacea Spreng.
Solanum tormin Sw.
Iodendron nocturnum Jacq.
Ipomoea repanda Jacq.
Icorudolphia volubilis (Willd.) Britton.
Tetragastris balsamifera (Sw.) Kuntze.
Guettarda laevis Urban.
Matayba domingensis (De.) Radlk.
Qcotea portoricensis Mez.
Hedychium coronarium Koenig
Peperomia rotundifolia (L.) H.B.K.
Euterpe globosa Gaertn.
Gasearia sylvestris Sy.
Piper aduncum
E. Ficus sintenisti Warp.
Grille racemiflora L.
Piper analago E.
Piper treleaseanum Britton & Wilson

Citrus spp. Gordia suleata De. Fanicus boliviense Hack. Polypodium spp. Guatteria caribaea Urb.
 Bugenia stahlii (Ktaersk) Krug & Urban. Naregravia rectiflora Tr. & Pl. Henrietella fasciularis (Sv.)
 φ. Weight Guarea raniflora Vent. Gotta borinquensis Vian, Manilkara bidentata (A.De.) Cher. Inga
 fagifolia (E.) Willd, Meliosma herberti Rolfe. Elephantopus mollis L, Rourea glabra Griseb. BO WUU
 REE EUE HEHE EH HEE ME BAD 11ND 10 ---Page Break--- 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. 15 Palicourea riparia Benth. & Hook. 33
 Rourea glabra Griseb. 64 Dacryodes excelsa Vahl. 2 Matayba domingensis (De.) Radlk. 22
 Drypetes glauca Vahl. 18 Hirtella 3 serosal Bese % Inga fagifolia (L.) Willd. 2 Geotea moschata
 (Favon) Nez. 2 Guettarda leevis Urban. 2 Miconia prasina (Sv.) Dc. 10 Groton pocelanthus Urban.
 10 Nelioana herberti Rolfe. krugit Urban Tetragastris balsamifera (Sw.) Kuntze Mirepholis
 garcinifolia Pierre. Maregravia rectiflora Tr. & Pl. Byrsonima coriacea (Sw.) De. Heteropteris
 trifoliata 1. Tie, Poliocarpus calinoides (Eichl.) Gilg. Faychotria berteriana De. Idesia gisuicifolia
 Urban. Iresia epleniens (Sv.) De. Hajania cordata 1. Wiconia racemosa (publ.) De. Geotea
 portoricensis Moz. Txora ferrea (Jaca.) Benth. PEPER RRR FEAD OO ---Page Break--- 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. 5 *Rourea glabra* Griseb. *Eugenia stahlii* (Kiacrok) Krug & Urban 5 *Dacryodes excelsa* Vahl. 3 *Palicourea riparia* Benth. & Hook. 3 *Manilkara bidentata* (A.De.) Cher. 2 *Tetragastris balsamifera* (Sw.) Kuntze 5 *Esteropteris lauriolia* (L.) Juss. *Inga fagifolia* (L.) Willd. 20 *Drypetes glauca* Vahl. 5 *Irytera leptoclada* De. 1 *Heliosma*

Herberti Baise. *Natayta domingensis* (De.) Radlk. *Sascaria arborea* (L.C, Rich.) Urban. *Hirtella rugosa* Pers. *Euterpe globosa* Gaertn. *Eropholis garciniaefolia* Pierre. *Miconia prasina* (Sr) De Guettarda *laevis* Urban. *Grmosia krugii* Urban. *Nora ferrea* (Jacq.) Wee. *Geotea Leucoxylon* (Sv.) Mee. *Onia tetrandra* (Se) D. Don. *Geotea moschata* (Pavon) or *Zinociera domingensis* (Lax.) Knobl. *Gordie boringuensis* Urban. *Aichornea latifolia* Sw. *Georopia peltata*. *Erythrina coriacea* (Sw.) De. *Homalium racemosum* Jacq. *Cascaria sylvestris* Sv. *Smilax coriacea* Spreng. *Casearia guianensis* (Aubl.) Urban. *Aichorneopsis portoricensis* Teen. *Didymopanax norototent* (Hib1.) Dene. *Buchenavia capitata* (Vahl.) Bichl. *Tabebuia pallida* Miers. *Geotea floribunda* (Sw.) Nez. *Daphnopsis philippiana* Krug & Urban. PEPE HEE PER RRUWUU REE EE ON OO ---Page Break--- Continued Table 6 *Ardisia glauciflora* Urban. *Geotea yortoricensis* Nez. *Schlegelia brachyantha* Urban. Unknown species *Cordia sulcata* De. 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 *Tenanthus pallens* (Sw.) Munro; Benth. 133 *Scouridaca vilgats* Sw. *Psychotria berteriana* De. *Morototoni* (Aubl.) Dene & Pl. 63 *Bectegte Pelteata* L. 56 *Aichornea latifolia* Sw. *Groton poecilanthus* Urban. 3 *Drypetes glauca* Vahl. 2 *Desmodium procumbens* (Mill.) Hitch. 26 *Linociera domingensis* (Lam.) Knobl. 23 *Miconia tetrandra* (Sw.) D. Don. 20 *Inga vera* Willd. 1 *Miconia racemosa* (Aubl.) De. *Dacryodes excelsa* Vahl. 8 *Rajania cordata* L. 38 *Fanioum bolivense* Hack. 4 *Seleria* spp. 5 *Eugenia stahlit* (Kisersk) Krug & Urban. *Inga fosifolia* (L.) Willa. *Gesesia blassium* Urban. *Paspalum conjugatum* Berg. *Miconia tetrandra* (Sw.) D. Don. *Heteropteris aquatica* (Ach) Neva. *Miconia prasina* (Sw.) De. *Howes glabra* oriseb. PUM agassa 13, ---Page Break---

Continued Table 6 *Casearia arborea* (L.C. Rich.) Urban *Matayba domingensis* (De. Radlk.) Keo *Fuialphia volubilis* (Willd.) Britton Bye ey! *Alchorneopsis portoricensis* Petan *Heteropteris laurifolia* L. (Juss.) *Ixora ferrea* (Jacq.) Benth. *Smilax coriacea* Spreng. *Brytolacea icosandra* L. *Piper hispidum* Sw. *Cissampelos parciria* L. *Bauregesia erecta* L. *Sloanea berteriana* Choisy. *Marogravia rectiflora* Tr. & Pl. *Piper treleaseanum* Britton & Wilson *Trichilia pallida* Sw. *Henriettelia Tascicularis* (Sv.) C. Wright. *Bolanus rugosum* Dunal. *Guarea raniflora* Vent. *Gayaponia americana* (Lam.) Cogn. *Euterpe globosa* Gaertn, *Tournefortia hirsutissima* L. *Coccocymbium pirifolium* Desf. *Calycogonium squamulosum* Cogn. *Dicotyledon Teucrognion* (ov) Meee *Guettarda laevis* near *Dendropanax arboreum* (i.) Dene. & P. *Mikania fragilis* Urban. *Guettarda caribaea* Urban, *Philodendron Lingulatum* (L.) C. Koch, *Cordia boringuensis* Urban *Casearia sylvestris* Sv. PEP EHEE EE HHO DUN DUD RUWWUWUWL EE ee uh ---Page Break--- Continued Table 6 Sprouts, originating after radiation, in the radiation area in the fall of 1966, on the soil showing reduced conditions. Species *Groton poecilanthus* Urban. *Palicourea riparia* Benth. & Hook *Marogravia rectiflora* Tr. & Pl. *Rourea glabra* Griseb. *Sloanea berteriana* Choisy. *Drypetes glauca* Vahl. *Heteropteris laurifolia* (L.) Juss. *Casearia sylvestris* Sv. *Nga vera* Willd. *Eugenia stahli* (Beene) Krug. & Urban. *Byrsonima coriacea* (Sw.) De. *Ixora ferrea* (Jacq.) Benth. *Manis Didentata* (A.De.) Cher. *Casearia arborea* (L.C. Rich.) Urban. (Se.) D. Don. *Guettarda portoricensis* Nez. *Nga fagifolia* (L.) Willa. *Calycogonium squamulosum* Cogn. *Cordia boringuensis* Urban. *Rourea domingensis* (Dc.) Radlk. *Wiconia prasina* (Sw.) De. 15 ---Page Break--- 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 *Rourea*

glabra Griseb. *Heteropteris laurifolia* L. Juss. 38 *Byenia stemit*

(Kiaersk) Krug. & Urban 18 *Euterpe globosa* Gaertn, 18 *Drypetes glauca* (Hy cv *Inga fagifolia* (L.) Wint.) 10 *Guarea raniflora* Vent. do *Nanilkara bidentata* (A. De.) Cher. *Cordia borinquensis* Urban *Sloanea berteriana* Chotay *Miconia tetrandra* (Sw.) D. Don. *Dacryodes excelsa* Vahl. *ixora ferrea* (Jacq.) Benth. *Tabebuia pallida* Miers. *Ocotea portoricensis* Nez. *Calycogonium squamulosum* Cogn. *Aichornea latifolia* Sw. *Matayba domingensis* (De.) Radlk. *Casearia sylvestris* Se. *Marcgravia rectifolia* Tr. & Pl. *Tetragastris balsamifera* (Sw.) Kuntze. *Homalium racemosum* Jost. *Miconia sina* (Sw.) De. *Mieropholis gaertnifolia* Per. *Hirtella rugosa* Per. *Groton pocaccianthus* Urban. *Cecropia peltata* L. *Inga vera* Willd. *Casearia arborea* (I.C. Rich.) Urban *Gyrilta racemiflora*, *Piper analogum* L. *Myreia splendens* (Sw.) De. *Ormosia krugii* Urban *Cassipourea alba* Griseb. *Ilex deflexa* (Poinc.) De. *Pisonia subcordata* Sw. *Dennstaedtia adiantoides* BPP E EEE EER RRR MWWWU FEE EON OOO (H. & BL) Moore 16 ---Page Break--- 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* De. 643 *Dioclea rotundifolia* (Aubl.) Dene. & Pl. 323 *Tenanthus pallens* (Sw.) Munro; Benth. Bee *Falicourea riparia* Benth. & Hook. *Ballida* Mers. 2a *Einociera domingensis* (Lam.) Knobl. and *Miconia sintenisii* Cogn. 263 *Securidaca virgata* Sw. 126 *Casearia bicolor* Urban. 126 *Casearia arborea* (I.C. Rich.) Urban. 91 *Wiconia prasina* (Sw.) De. 7 *Cecropia peltata* L. 95 *Fospalum conjugatum* Berg. 8 *Desmodium procumbens* (Mill.) Hitchc. 8 *Rourea glabra* Griseb. 6 *Erythrina coriacea* (Sw.) De. 58 *Aichornea latifolia* Sw. 51 *Mikania frigida* Urban, 56 *Dryopteris deltoidea* (Sw.) Kuntze. 3 *Euterpe globosa* Gaertn. 50 *Alchorneopsis portoricensis* Urban. 49 *Matayba domingensis* (De.) 49 *Drypetes glauca* Vahl. 39 *Dacryodes excelsa* Vahl. 39 *Neptunia aquatica* (Jas.) Naud. 31 *Miconia tetrandra* (Sw.) 30 *Guarea trichiliciae* L. 29 *Guarea*.

raniflora Vent. 21 '*Eugenia stahlii* (Kiaersk) Krug. & Urban. 19 *Menilkara bidentata* (A.De.) Cher. ag *Bloanea berteriana* Choisy. 1 *Heterotrichum cymosum* (enn) Urban. 18 oe *Wepholepis rivularis* (Vahl.) Mett. ar eZ *Solemum rugosum* Dunal. 6 *Ocotea leucaxyion* (Sw.) Mex. 15 *Hisophila boringuefia* Maxon. & *Inga vera* Willd. 3B aT ---Page Break--- SSS Continued Table 6 SSS *Heteropteris laurifolia* (L.) Juss. *Hirtella rugosa* Pers. '*Tetragastris balsamifera* (Sv.) Kuntze *Eger etunem* 1, *ponoea repanda*' Jacq. *Commelina* Sp. *Panieum oliviense* Hack. *Homalium racemosum* Jacq. *Geotea moschata* (Pavon.) Mez. '*olacca icosantra* iL. *Digscorea polygonoides* "H.&B.; Willa. *Guettarda laevis* Urban. *Sapium lairocerasus* De *Clusia gundlachii* Stahl. *Maregravia rectiflora* 'Ty. & Pl. *Elephantoptis mollis* L. *Cordia borinquensis* Urban. *Doliceo galinofdes* (Eichl.) Gilg. *Henriettella fascicularis* (Sw.) Sauville. *Gyrilis racemiflora* —E~ *Borreira ocimoides* (Burm. £.) De. *Myreia splendens* (Sw.) De. *Piper treleaseanum* Britton & Wilson, *Gordia*' *sulcata* De. *Daphnopsis philippiana* Krug. & Urban, *Rajania cordata* 1. *Casearia sylvestris* Sw. *Solanum torvum* Sy. *Qootea portoricensis* Mex. *Desmodium* sp. *Solanum* sp. *Inga fagifolia* (L,) Willa. *Bpermacoce tenuior*' L, *Hedychium coronarium* Koenig. *Roystonea boringuefia* Cook. *Omosia krugii* Urban, *Micropholis garcinifolia* Pterre, *Meliosma herbertii* Rolfe. *Miconia racemosa* (Aubl.) De. *Paullinia pinata* L, *Heliconia binai* L. *Paspalum Smilax coriacea* Spreng. e OF ERE FEU AAT wooo I GEE % % HERR OO BBYHMMY 18 ---Page Break--- Continued Table 6 *Sauvagesia erecta* Ly *Trorea ferrea* Jacq; Benth. *Piper amalago* 1. *Eupatoriuz odoratum* 1. *Ficus laevigata* Vahl. *ania cordifolia* (L.F.) Willd, *Glidenia strigillosa* (Sv.) De. fun sp. *Gayaponia americana* (Lam.) Cogn. *piawe rigeeeee*. 1 *Eugenia janbos* 1. *Guatteria caribea* Urban. *Cestrum macrophyllum* Vent. Unknown species *Myreia leptoclada* De. *Comocledia glabra* (Schultes) Spreng. *Spigelia anthelmia* 1. *Scleria* sp. BE PPP PPE E REPPE RRR % 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 Faychotria berteriana De. 2 Fourea glabra Griseb. 6 Matayba domingensis (De.) Radlk. 2 Miconia sintenisii Cogn. 20 Eugenia stahlia (Kiaersk) Krug. & Urban. 15 Groton poecilanthus Urban, and Dacryodes excelsa Vahl. 3 Hyreia leptoclada De. 2 Inga fagifolia (L.) Willa. Neliosma herbertii Rolfe. Miconia krugii Urban, and Geotea moschata (rev) of Heteropteris laurifolia (L.) Juss. Miconia prasina (Sw.) De. Casearia arborea (L.C. Rich.) Urban, Marcgravia rectiflora Tr. & Pl. Tetragastris balsamifera (Sw.) Kuntze. Tabebuia pallida Mier. fragilis Urban, Cordia boriguensis Urban. Trichilia pallida Sw. Alchorneopsis portoricensis Urban. Drypetes glauca Vahl. Manilkara bidentata (A.De.) Cher. Piper aduncum. Didymopanax morototoni (Aubl.) Decne. & Pl. Cecropia peltata L. Irysonina coriacea (Sw.) De. Solanum rugosum Dunal. Linociera domingensis (Lam.) Knobl. and Casearia bicolor Urban. Hirtella rugosa Pers. Heteropteris latifolia. Geotea portoricensis Nez. Wieropholie garcinifolia Pierre. and Ixia glauciflora Urban. Gyathes arborea (E.) J.B. Smith. Dioscorea polygonoides H.B.K.; Willd. Schlegelia brachyantha Urban. Inga vera Willd. 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 Individuals Sloanea berteriana Choisy 6 Eugenia stahlia (Kiaersk) Krug. & Urban, 32 Hourea glabra Griseb. 5 Palicourea riparia L., and Manilkara bidentata (A.De.) Cher. 5 Heteropteris laurifolia (L.) Juss. 2 Inga fagifolia (L.) Willa. 2 Dacryodes excelsa Vahl. 3 Euterpe globosa Gaertn. Guettarda laevis Urban. 5 Tetragastris balsamifera (Sw.) Kuntze 3 Hyreia leptoclada De. 2 Matayba domingensis (De.) Radlk. 20 Ormosia krugii Urban. Hirtella rugosa Pers.

Micropholis garcinifolia Pierre. Miconia tetrandra Sw. Inora ferrea Jacq. Benth. Drypetes glauca Vahl. Gordonia bourgeonensis Urban. Neliosna herbertii Rolfe. Tinociera domingensis (Lam.) Knobl. Byrsonima coriacea (Sw.) De. Daphnopsis philippiana Krug. & Urban. Condia sulcata De. Miconia prasina (Sw.) De. Timalium racemosum Jacq. 'Geotea moschata (Favon.) Nesz., Tasearia arborea Tabebuia pallida Miers. Didymopanax morototoni (Aubl.) Dene. & Fl. Cecropia peltata L. Croton racemosus' 1. Geotea Leucoxydon (Sv.) Mec. Waregravia rectiflora Tr. & Pl. Croton poecilanthus Urban. PEPE PPB EEE EE RD DWUWOY FEE 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. 88 Palicourea riparia Benth. & Hook. 383 Tenanthus pallens (Sv.) Munro; Benth. 28 Securidaca virgata Sw. 198 Miconia sintenisii Cogn. 126 Psychotria berteriana De. 122 Didymopanax morototoni (Aubl.) Dene. & Pl. 108 Desmodium procumbens (Kill.) Ten., 106 Cecropia peltata L. 8 Croton poecilanthus Urban. 2 Mikania fragilis Urban. 6 Paspalum conjugatum Berg. 58 Tinociera domingensis (Lam.) Knobl. 55 aL ---Page Break---
 ----- Continued Table 6 ee Drypetes glauca Vahl. 2 Nespereira aquatica (Aubl.) Naud. to Miconia prasina (Sw.) De. My Ings vers Wilda. 35 Alchorneopsis portoricensis Urban. 35 Alchornea latifolia Sw. 32 Panicum oliviense Flack. 30* Casearia bicolor Urban. Croton racemosus L. 22 Guarea trichilobata, Euterpe globosa Gaertn. Dacryodes excelsa Vahl. 19 Waregravia rectiflora Tr. & Pl. 19 Selenicereus stahlianus (Kiersk) Krug. & Urban. 1T Rourea glabra Griseb. 1 Piper aduncum 1, Dryopteris deltoidea (Sv.) Kuntze. 6 Phytolacca icosandra L. 16 Byrsonima coriacea (Sw.) De. 16 Matayba domingensis (De.) Radlk. 35 Guettarda laevis Urban. Roney, compressina (Sw.) Deaae. 3 Geotea Teusoxylon (Sv.) Nez B Casearia arborea (L.C. Rich.) Urban. 1 Smilax coriacea Spreng. 1 Honaliun racemosum Jacq. 10 Scleria canescens Boeck. 10* Rajania condata L. 10

Bauvagesia erecta, Miconia tetranira Sw., Heteropteris laurifolia (L.) Juss., Psychotria brachiata Sw., Gyathea arborea (E.) J.E. Smith, Borreria ocimoides (Burm. F.) De., Ixora ferrea Jacq.; Benth., Casearia arborea (L.C., Rich.) Urban, Elephantopis mollis L., Guisia gundlachii Stahl, Sapiun

laurocerasus Desf., Inga fagifolia (E.) Willd., Heterotrichum cymosum (Wendl.) Urban, Trichilia pallida Sw., Pothonorphe umbellata, xunth, roo eeuuustas 22 ---Page Break--- a Continued Table 6 — Dryopteris deltoidea (Sw.) Kuntze, Gordonia boringuensis Urban, Misophila borinquenia Maxon, Casearia sylvestris Sw., Solanum rugosum Dunal, Hedychium coronarium Koenig, Heroidolphia volubilis (Willd.) Britton, Berteroa Choisy, Ficus leavigata Vahl, Bidens pilosa L., Eupatorium foratum L., Fulcrea squarrosa Michx., Piper treleaseanum Britton & Wilson, Menispermum bidentatum (A. De.) Cher, Spigelia tenuior L., Nephrolepis rivularis (Vahl.) Mett., Solanum torvum Sw., Mikania cordifolia (L.F.) Willd., Clidemia strigillosa (Sw.) De., Ocotea moschata, Odontosoria sp., Unknown grass, Polypodium chnoodes Spreng., Unknown species, Myreia splendens (Sw.) De., Unknown species, Philodendron lingulatum (L.) C. Koch, Desmodium Foystonea boringuefia Cook, Ocotea floribunda (Sw.) Mez, Guarea raniflora Vent., Solanum sp., Gonzalagunia hirsuta (Jacq.) Schum., Haintun petiolarum Desv., Gissampelos pareira L., Heterocentron splendens (Sw.), Ocotea portoricensis Mez, Guapoa americana (Lam.) Cogn., Polypodium sp., Ficus trigonata L. BEBE EE EEE HERD DUM DUUUWOY FREE PEPE BERR REE 23 ---Page Break--- 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., Croton poecilanthus Urban, Heteropteris laurifolia (L.) Juss., Rourea glabra Griseb., Tabebuia patida Miers., Inga fagifolia (L.) Willd., Casearia sylvestris Sw., Eugenia stahlia (Kisetsk) Krug & Urban, Deppeia glauca Vani, Casearia arborea (L.C., Rich.) Urban, Matayba domingensis.

(D.C.) Radlk. Sloanea berteriana Choisy, Manilkara bidentata (A. Dc.) Cher. Dacryodes excelsa Vahl. Calyeogonion squamosus Cogn. Quercus portericensis. The, Quercus rasenflore L. Becurldace virgata Sv. Piper aduncum. Payotria berteriana De, Marcgravia rectifolia Tw. & Pl., Manis Tragus Urban, Condia boringuensis Urban. Didymopanax morototoni (Aubl.) Dene. & Pl. Psychotria brachiota Sv. HEE RRR ONW FEE EU ADOW 2h ---Page Break--- 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 'Bygenta stahlit (Kiacrsk) Krug. & Usben 10 Heteropteris laurifolia (L.) Juss. ie Fourea glabra Griseb. Drypetes glauca Vahl, Manilkara bidentata (A. De.) Cher. Inga fagifolia (L.) Wiad. Tora ferrea Jacq. Benth. Sloanea berteriana Choicy. Guarea raniflora Vent. Weonia tetrantha Sv, Calyeogonion squamosum Cogn. Condia boringuensis Urban. Iryea leptoclaia Be. Heteropsis globosa Goertn. Honaliun recenoicum Jac. Casearia arborea (L.C. Rich.) Urban. Seoronia peltata, morototoni (Aubl.) Dene. & Pl. eee istifolia Sv. Casearia sylvestris Sv. Nectandra domingensis (De.) Radlk. Inga vera Wild, Deoten portoricensis Mex. PEEP EEE RR DW EEA 25 ---Page Break--- 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 studies, total biomass of the canopy leaves must be known. Biomass can be calculated by multiplying average leaf biomass per n by the leaf average area. Average leaf biomass is easy to obtain, but a method is required to measure leaf area index over a large portion of the forest. The form that leaf area index is proportional to the following ratio of light intensities measured at the forest floor: as . 'The principle underlying this relationship is that the canopy is relatively transparent to light in the infrared, while it...

absorbs relatively large snouts 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 00 mi "ratio was plotted against height, and leaf area index at the tower site (Fig. 1). Leaf area index was

measured by lowering 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, continuing effort ---Page Break---

(1334) LHOI3H vk Oo eo 5 6 6 T T T T ou Bun -o
 ©xX3QNI V3uv 4V37 05 1.0 51 RATIO OF LIGHT INTENSITIES, 800mu/675mu Figure 1,
 Infra-red/red ratio as a function of leaf area index. « = 2 a > q a g o 3 @ = ° ni g 3 oO g g n a o
 1000 1200 1400 1600 TIME Figure 2, Light intensities at 800 and 675 nm, and the ratio between
 the two, as a function of time. Measurements taken above canopy, Nov. 16, 1967. eT ---Page
 Break--- 'RADIONUCLIDE RESIDENCE TIMES IN FOREST COMPARTMENTS Jerry R. Kine 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 I for the nuclides: e.g., Li, Be, and Y. The average effective half-lives were found from these data to be 228 days, 150 days, 120 days, and 250 days, respectively. Environmental half-lives computed from these data were 110 days for Li, 69 days for Be, a doubling time of 1 day for ^{95}Zr , and 177 days for Mn. The above data are subject to some restrictions prior to interpretation. First, there is a small yet 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. PBF Cohort, which collected from 2/29/68 - 3/18/68, shows the presence of Te, Li, and ^{90}Zr . The most dominant peak in the spectrum is from the natural fallout nuclide ^7Be . The column which collected from 1/31/68- 2/29/68 shows only ^7Be . 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-round. 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. The environmental half-life (T_{env}) is defined as the time required for the concentration of a substance in the environment to reduce to half its initial value due to both radioactive decay and environmental processes. Where T_{env} = environmental half-life, T_r = radioactive half-life, and T_{eff} = effective half-life. It is apparent from the equation that as the effective half-life approaches the radioactive half-life, the rate of environmental half-life approaches infinity. Figure 2 shows the relationship between effective half-life and environmental half-life for ^{95}Zr , ^{54}m , and ^{137}Cs . A curve for ^{137}Cs would appear similar to that of ^{54}m since these nuclides

have similar radioactive half-lives. For ^{54}M , $T_{\text{eff}} = 250$ days and $T_{\text{r}} = 291$ days. These are sufficiently close to one another so that a small error in T_{eff} results in a large error in the estimation of T_{env} . This is evident from Figure 2. A similar situation exists in the case of ^{137}Cs where $T_{\text{eff}} = 228$ days and $T_{\text{r}} = 285$ 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 whatsoever, 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. ---Page Break--- 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 ^{97}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 shown 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, i.e., activity, effective half-lives, and correlation coefficients for ^{137}Cs , ^{95}Zr , and ^{60}Co . Mean activity: 3.0 ± 0.8 (^{137}Cs) or 6.0 ± 0.7 (^{60}Co). Mean activity: 56 ± 0.5 (^{95}Zr) or 28 ± 0.2 (^{60}Co). Mean activity 2 ± 0.2 (^{60}Co) or 3 ± 0.2 (^{95}Zr). Mean activity: 10.3 ± 2.0 (^{137}Cs) or 7 ± 1.5 (^{60}Co). Correlation: 0.69% for ^{137}Cs , 0.85% for ^{95}Zr . Mean activity: 1.6 ± 0.6 (^{137}Cs) or 2.6 ± 1.2 (^{60}Co). Correlation: 0.93% for ^{137}Cs , 0.82% for ^{95}Zr . Times are in days, bracketed by 95% confidence interval, significant at 0.01 level (2-tailed test).

Table 2 Mean radioactivity, effective half-life, and correlation coefficients for ^{137}Cs , ^{95}Zr , and in canopy and leaf litter of the Elfin Forest in the Luquillo Mountains of eastern P. Rico.

Mean activity canopy leaf litter: 11.6 ± 5.5 (^{137}Cs), 2.6 ± 0.2 (^{95}Zr). Effective half-life: 262 days (^{137}Cs), 480 days (^{95}Zr). Correlation: 0.69% for ^{137}Cs , 0.85% for ^{95}Zr .

Gamma ray spectra of ion exchange columns which have 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.

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

3. Preliminary curve showing effective half-life of Cs which was artificially placed on leaf surfaces as ^{137}Cs , 33 ---Page Break--- 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, 698 understory leaves, and 100 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 *Mantikora Didentata* 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. Comparison of survival of canopy leaves vs. understory leaves of three species. A species of water fern found on the surface of shade for late Paste, e/0)eT rnnininer /i1/68 asene'paied eee ailer. Table 2 shows that on Dec. 6 some experimental leaves still survived. ---Page Break--- '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, the 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 14 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 the quantity of stem flow. The first step was to calculate the regression of the quantity of stem flow on the 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 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 show

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, the quantity of stem flow for 0.5, 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 35 ---Page Break--- per hectare (Table 2). Density data for trees in the 14 inch size class and above were taken from a 6100 sq. meter survey, and for trees in the 2-4 inch class from a 2000 sq. meter area. Total amounts of stem flow per size class per hectare for a given size stem were added together to give total liters of stem flow per hectare. Liters per hectare were converted to inches of rain by the factor: 1 inch of water equals 25,000 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 1.35 inches, or 17.5%, and at one inch, it is 0.18 inches or 18%. At one quarter inch it is 0.055 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 0.76, and one standard deviation was 0.15. The lack of higher correlation probably is because the quantity of stem flow depends on the intensity of the storm as well as the total amount of rainfall. However, if we assume there are equal amounts of heavy and light rainfall, effects on stem flow due to variations in storm intensity will cancel themselves out, and average stem flow should be more accurate than would be suggested by a

correlation coefficient of .76. O2 | CY) OST INCHES OF RAIN INCHES OF WATER REACHING GROUND DUE TO STEM FLOW Figure 1. Relationship between amount of stem flow and total rainfall, 36 ---Page Break--- 3° 8 STEM FLOW (LITERS) v 2 RAIN (INCHES) Figure 2. Stem flow on one Euterpe globosa as a function of rainfall, based on field data, 4 © DACRYODES EXCELSA 4 SLOANEA BERTERIANA x EUTERPA GLOBOSA © MANILKARA BIDENTATA + PALICOUREA RIPARIA 120 ° % 20, 30 DIAMETER OF TREE (INCHES) Figure 3. Slope of regressions of stem flow in liters on rainfall in hundredths of an inch, as a function of diameter of tree. 3T ---Page Break--- © DACRYODES EXCELSA 4 & SLOANEA BERTERIANA EUTERPA GLOBOSA © MANILKARA BIDENTATA * PALICOUREA RIPARIA x - ty 20/- ° © a - ° uu - — “ ° z° wee 8 a No td 20 630 0 10 DIAMETER OF TREE (INCHES) Figure 1b. Y intercept of regressions of stem flow in liters on rainfall in hundredths of an inch, as a function of diameter of tree. 38 ---Page Break--- Table 1 Equations for predicting liters of stem flow as a function of rainfall in inches and hundreds. Size class inches Form 2 $y = ix + 0$ & $Y = slx + 0$ 6 $Y = sealx + 5$ 8 $Y = 3é + n$ 0 $y = hex + 8$ 2 $Y = Mx + 3$ Le hex - 1 16 $Y = 33x - 2$ 18 $Y = 2\% - 3$ 20 Yao = h 22 l& - & 2h ex = 4 26 Bx = k 28 sl - & 30 Yeux - 4 39 ---Page Break--- 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 hes 8 118 10 a1. a 33.3, a 20.9 16 22.2 18

12.33 20 4.93 3 3.70 2h 2.46 26 2.46 28 3.70 30 1.23 ---Page Break--- 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). A hypothesis concerning soil water movement based on informal 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 down slope along 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 completed. A ---Page Break--- 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 the 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. he ---Page Break--- Table 2 Bulk densities of soil at different depths at the study site in the tropical rain forest near El Verde. Depth (cm) 0-5 5-10 35-40 Average bulk density (g/cm³) 0.78 0.58 0.75 0.95 0.88 Results of runoff experiments Trial No. Plot size (cm) 1 x 10 2 35 x 100 300 x 200 300 x 200 35 x 100, 35 x 200 35 x 100 300 x 100 100 x 100 Depth of Ant.

of water Equivalent on Rate of Of rainfall rainfall pan litter 30 cm. 30 cm. 30 cm. (liter) BEB
nanbEaa 4 4 4 4 4. (exfur) Ant. collected in pan (liters) 2.0 1.8 ---Page Break--- FLOW

LINES COLLECTION Figure 1. Hypothesized lines of water flow and position of collection pans in experimental soil blocks. ay ---Page Break--- 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 printout 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 HI Verde from Feb. 20, 1967 through Feb. 20, 1968. Total Rainfall 281.00 cm Throughfall 195.37 cm Stem flow 50.56 cm Evap. from leaves 35.00 cm (Rain - throughfall + stem flow) Transpiration 59.00 cm Runoff & Deep Drainage 186.93 cm (throughfall + stem flow = transpiration) continuing effort a5 ---Page Break--- R=RAIN T = THROUGHFALL D = DEEP DRAINAGE & RUNOFF A = TRANSPIRATION S = STEM FLOW E = EVAPORATION FROM LEAVES 200 ot 1967 7" 9171 17 1968 Figure 1. Weekly cumulative centimeters of water

in various segments of the forest. 46 ---Page Break--- 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 water: 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 Zn. 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 debugged. 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 measurable amount of elements associated with organic or inorganic matter suspended in the water. *continuing effort Mr ---Page Break---

Table 1 Collection stations for forest water that is analyzed for stable element content. Number of collectors Location Above canopy 2 Below canopy (through-fall) 20 Stem flow 8 Shallow litter 6 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 Saprolite* These collectors eventually to be used for tritium microsystem analysis. ---Page Break---

GROUP 2 6 / 26 / 67 vol TOTAL 17640400 AVERAGE 2940400 Sed 2528052 GROUP 1 07 67 vol TOTAL 0.00 AVERAGE 0400 Sed 0600 GROUP 3 6 / 26 / 67 vol TOTAL 13844600 AVERAGE 1977671 Sed 2445083 PH 29059 4493 0430 PH 0400 0400 0200 PH 36020 5017 0038 COND 208480 34479 14045 COND 4480 4680 0400 COND 213089 30055 8.67 Figure 1. Data printout of computer program for average and standard deviation of volume, pH, and conductivity of forest water samples. ---Page Break---

Section station were weighted concentration for all stations in each location Table 2 Location Above canopy Below canopy Stem flow Individual element concentrations in the forest waters for Jan., 1968, Five weekly sub-samples from each co: and pooled, then average concentration was determined. ... 9... ... & ... 6 9) 2m |dmedemevd ci ... Hmedh equnadqroog ... He maa NaQrotedar ... MEQW QUAQNeceHoH ... GoCcssCargg | g ne RIS] Be Be ales Zee 82 uss 88 a Hei! WB mata ph seu eye uaie ag, aaaaace 50 *At site to be used for tritium, ---Page Break---

CHEMISTRY OF SUCCESSIONAL VEGETATION* C.F. Jordan The stable element concentration of

The plants appearing in the radiation damaged area are 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 0.1 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 the 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 stems, and stems than that of roots (Table 3). More extensive sampling will be undertaken to confirm these indications.

Stable element content of leaves of species occurring in the radiation recovery areas — Georgia peta (hh) at 55 ta. Seoropin pettate (#2) 15300 3375 high Pytotria bertertame 11000 ATT ag) 0109 12800 se. mm wh og sm erg a Pragetes glauce Meo 19605 Bh ase Miconte macenose 3875 36585 sg ee *continuing effort ju ---Page Break---

oe mnie 2 state element content of leaves of species occurring in the Sevadiavea aren, and an canon te Ga' nature Forest, as succession at sttuntion Mature Forest Species 'eprosts) (caso) ym ot mm of cs fe Sr co a agenda stanst eco hsos M33 000 6 35 Ta Mootinare bigentate 00 3500 ons 356 0 Mk stoanea bertertaca 00 tes 26 aT eof ash 0a 65 Mp0 36138 Sion oetnamtmas 0 ajo 2 = mole 3 Stable element content of Asares, stem, and roots of species common in the radiation recovery areas species Miconte.

tetrantra Manttkare bidentata Bagenta stants Buntoterta heteropeist Croton poretLentiuey
bertersana® Sonn 35575 3650 86 zuio0 brs0 18, 6900 3500 8200 505 32800 5100 1633 6700
3250 The '900 2125 260 & 3 3 % 1 600 = 17200 wm 1 oe wesimm 351 wo. ee ap 0 st - a wes hos
1052 a a sprouts ---Page Break--- 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 Cs, Ba, and K 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 Bugenis 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
Palicourea 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 K levels are not
particularly high. The situation is reversed.

In the case of Palicourea, which has high Mg levels and ordinary Y levels, each individual within the
canopy species group 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 the computed specific activity
of nin for canopy and understory; the canopy has 9.7 p0i/ng while the understory has 22.2 ECI/ns.
This indicates that there is partitioning of the fallout, 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 continuing effort 53
---Page Break--- Several years after major production of Shin indicates that there must be a rather
slow turnover of minerals in tropical vegetation by mineral cycling. This supports the environmental
half-life 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. 137Cs shows
the same kind of canopy-understory distribution as Dlvn, 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 microlides. Understory leaves probably also intercept microlides which have been lost from canopy leaves by leaching and thus have a somewhat greater exposure to contamination than canopy leaves. ---Page Break --- Table 2. Nutrient contents of canopy and understory leaves at HL Verde species location = ce strongest comparisons Canopy vs. understory S: macrophytes exception Canopy Be merce understory Beet entres species — canopy mg: 8 Understory see Bis piers glotore Canopy oust a cmstie engi canopy it 9.6 1 0.6 ABT E UT O52 one understory 27100 + 2780 58.2 23.5 wapTt woe YET UeT.5_ 3.0, 0.8T Understory 600 \$1512 57.2 Mil WMBE 290 135 10d” 23 o:eT Understory Mgmo + 655 3832 35 aiahs 20 B85 52.2 OTE OW Understory 10les + WL 12.9 8.0 STALE 10 e604 526 224 0.95 minie 2 Specific activity of Thin in canopy and understory leaves in the forest at HL Verde cur Uetepetory a. hg Sees eels attest we eile aif ‘Pacrotres exceise 0.23 co 9.0 - - - Mental activity 0.03 ote 6.8 09 ko tes Slows berteriama 0.57 26 ota rey wet frente emt 0.25 08 ae - : : ‘Euterpe globose 0.25, 0.6 eu - - - - - 0.24 37 rh - ; : os ke 388 Morte giat- - : : 0336 wa rernees ont a oka m2 ---Page Break --- ‘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 formulas 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, Odun estimated transpiration to be 1.8 m/aay. 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 m/aay. It was assumed that there was no evaporation from the soil surface. A third estimate of transpiration was obtained by determining the 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 is 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 m/aay 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. *continuing effort 56 ---Page Break--- 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, fo 1k). 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. Ash was leached from the organic surface litter of

the soil with an effective half-life of approximately 15 days. Upon reaching WEN Sins 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 ammonium acetate solution five times in succession. The amount of nuclides 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 nuclides. Similar results were obtained with ^{137}Cs (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 nuclide in the soils. Samples were extracted with ammonium acetate solution 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 (HA) solution to determine the quantity of organically bound nuclides. A third group was extracted with 0.2 M HCl to determine if precipitation in acid soluble forms in the soil had occurred. Results of these extractions are given in Figure 4. A total of the total nuclides was retained by the soil regardless of whether the soil was treated with H_2O_2 or HCl solution. On the other hand, nuclides were released in significant amounts by the destruction of organic matter with H_2O_2 and were almost completely extracted by the ammonium acetate solution. This behavior indicates that the two nuclides are in retreat.

genase in the soil. From 30 to lot of ^{137}Cs the exchangeable, but undetectable amounts are associated with organic matter or precipitated acid soluble compounds. Only about 18 of the 24m is exchange- continuing effort ST ---Page Break --- able while possibly over 30f 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. Sin is accounted for almost entirely within the exchangeable, organic, and acid soluble forms. 58 ---Page Break --- loo 5 DEPTH INCHES Figure 1. Penetration of ^{137}Cs into the soil of the tropical rain forest at El Verde, Puerto Rico, 18 months after application. 100 age % RETAINED EXTRACTION Figure 2. Retention of ^{137}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. 59 ---Page Break --- sss 1 Retained Bsgess s ir Figure 3. Retention of ^{137}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. 0 % ry 10 2 a 3 50 * ao 0 2 to 3 a5 Extraction Figure 4. Retention of ^{134}Cs and ^{137}Cs after various treatments. 60 ---Page Break --- FALLOUT RADIONUCLIDE DISTRIBUTION IN VEGETATION OF PUERTO RICO Jerry R. Kline 'The objective of this investigation was a systematic determination of fallout radionuclides contained in the investigation 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 had 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 ^{137}Cs , ^{90}Sr , ^{134}Cs , and ^{60}Co 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 from 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 HI 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. Altitude in all sequences are present however. The litter is enriched in radioactivity relative to fresh leaves at each site. This suggests that the continuing effort not being recycled radionuclides are accumulating in the litter and are not biologically recycled 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 gradients 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 HI Verde where extensive evidence indicates the loss from the litter by either biological recycling or leaching is low. Table 2 Distribution of fallout radionuclides in vegetation from the Island of Puerto Rico. Elevation Transect meters Radionuclide $65^{\circ}45''$ $66^{\circ}00''$ $66^{\circ}30''$ $66^{\circ}45'$ $67^{\circ}00''$ Mean 1.58 0.73 0.20 0.87 1.21 Total 0.49 0.29 0.47 0.39 Mean 0.79 0.87 0.13 0.12 0.13 Mean 0.12 0.07 0.05 0.06 0.07 500 North Mean 0.71 1.55 0.10 0.99 1.00 Total 0.28 0.92 0.75 0.63 0.78 Mean 0.53 0.52 0.19 0.24 0.55 Mean 0.18 0.08 0.05 0.13 0.09 Mean has 3,850.50 ha 0.98 Total 75h 2.93 0.87 0.66 Mean 0.89 1.24 0.38 0.20 0.80 North 0.95 0.70 0.20 0.10 a 62 ---Page Break--- SaaS Continued Table 1 Elevation Transect meters Radionuclide $65^{\circ}45''$ $66^{\circ}00''$ $66^{\circ}30''$ $66^{\circ}45'$ $67^{\circ}00''$

500 North Mee 0.80 1.08 0.27 0.0.13, Tos 1.65 1.01 OM 0.35 0.25; Wer 0.38 0.59 0.29 -0.0T 0.06 Fh 0.13 0.09 0.18 0.05 0.08 50 South Mee 0.26 0.67 0.52 120.67 3%os 0.51 0.2T 0.280.203 Mee 0.18 0.78 0.120.00.19 Dh 0.12 0.1T 0.06043 0.22 Greater than 444 1000 meters* Ce 2.81 0.43, 3Tos 6.20 3.4 Poe 0.49 0.32 ara 0.56 0.24 2000 south Mice 0.70 1.40 33Tos 0.9h 0.21 on 0.72 0.K8 Mn 0.23 (0.2L 63 ---Page Break--- Elevation meters Muclides. 50 Yorth ae Toe gy 7 500 orth ice Tes Bop en 1000 orth tice 13Tq Bay. Pita 500 South thee 35 zy, Distribution of fallout radionuclides in epiphytic plants on the Island of Puerto Rico. Table 2 Transect $65^{\circ}45''$ $66^{\circ}00''$ $66^{\circ}30''$ $66^{\circ}45'$ $67^{\circ}00''$ 0.36 3.21 0.81 0.06 0.94 7.56 0.86 0.33 16.81 34.8 2.38 1.88 0.05 0.5 0.32 0.05 0.05 1.29 onda 0.05 33.18 34.38 5.90 2.37 0.37 2.95 0.4 0.28 1.78 3.25 onda 0.20 4.60 148 12.08 0.55 0.45 3.08 0.29 o.th 0.85 2.14 0.19 0.20 LAT L5T 0.15 0.19 2.30 12h 0.2 0.09 0.9% 2.78

0.35 0.15 4B 2.38 0.05 0.24 2.18 2.83 0.29 0.18 0.5 5.28 O42 0.02 1.58 TAT 0.36 0.19 3.20 0.05
 0.36 0.32 6h ---Page Break--- EE Continued Table 2 Elevation Transect meters Muclides 65°15"
 66°00' 6630" 66S" E700! south Mee 9.07 aig 1.02 13Teg 2.23 3.31 2.22 Mer 0.12 0.32 0.24 Phin
 0.06 0.19 0.06 "ooo meters gg 12.80 3.76 los 15.63 1.23 on 2.00 0.25 a Ph 0.32 0.2 Bouth Meg aay
 a8 1395 1.99 9.72 on on 0.92 aal o.1 0.N6 65 ---Page Break--- Table 3 Distribution of fallout
 radionuclides in ground litter on the Island of Puerto Rico. oe Elevation Transect, meters Muclides
 65°45" 66°00" 66°30" 66°N5" 67°00" worth Moe 2.25 0.6 0.05 0.63 Tes 1.22 0.96 0.050.750 86 ir
 0.05 0.2L 0.2h 0.33 On Pin 0.03 0.230.050 0.05 North Mee 3.98 2.28 Lak 1.80 . les 3.20 0.78 1.59
 1.36 Poe om Ok 017 0.50 Pha ov 0.05 0.20 0.20 forth Mee 15.66 10.50 1.02 ake 3.28 los a7.00
 132k 20 a Mir 2.00 2.58 0.20 0.09 0.32 sevth Mee 0.05 1100.46 3.20 Mog Ms ag oat 0.79 Moe
 0.050.12 0.20 1b Fhm 0.5 0.12 0.08 0.06 ---Page Break--- rr Continued Table 3 Elevation Transect
 meters Muclide 65°45' 66°00' 66°00" 66°45"

67°00'50" South Mee aol 0.01 0.058 137, Flea 1.02 0.05 0.15.8 %zr 0.19 0.09019 oO. Thm 0.03
 0.05 0.05 0.05 Greater than 1000 meters Mice 5.84 5.25 B3Tq 9.93 16.59 ae 0.26 0.25 ar OWT
 0.96 1000 South We. 482 (0.99 Tos 2.97 1.52 Moe 0.49 0.20 yn 0.33 (0.38 61 ---Page Break---
 Sioe-Septs A98T Figure 1. Distribution of '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/ a. oreo esas tetri 1 Figure 2. Distribution of "4ce in vegetation on the island of Puerto Rico.
 Sampling sites are shown ty X, Values to the left of each site are elevations in meters and to the
 right are p0i/ a. 6 ---Page Break--- Sore ier Figure 3. Distribution of 9zr - 951m in vegetation on the
 island of Puerto Rico. Sampling sites ere shovn ty X. Values to the left of each eite are elevations in
 meters and to the right are pCi/en. ample cottetat Sa eepes 1907 Distribution of °4in in vegetation
 on the island of Puerto Rico. Sampling sites are shown ty X. Yelues to the left of each site are
 elevations in meters and to the right are p0i/ a. Figure 4. 9 ---Page Break--- REACTIONS OF
 NUCLIDES WITH EPIPHYLLAE* Raymond Henzlik and Jerry R. Kine 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 organiens have 'been suspected of
 playing @ role in the nutrient cycling mechanisms of the forest because they vere found to contain
 large smounts of fallout radionuclides, Experiments were carried out in cooperation vith Dr.
 Raymond Henzlik, an Oak Ridge Research Participant from Ball State University, to examine sone
 reactions of these organisms vith radio- nuclides. Leaves from four species of treeg were
 contaminated with radio- active solutions containing 1lcs and S5sr for a period of 20 mimutes after
 which the leaves were vashed in tap water for 6 minutes. ALL species had leaves which had
 epiphytic growth and those

which is not. The results are shown in Table 1. Epiphyllae were from 4 to 7 times more efficient in
 retaining radionuclides than leaf surfaces which had no surface growth. This indicates that these
 organisms may be adapted to deriving their mineral nutrient requirements by interception of
 rainwater 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 rainwater may be the source of nutrients for the epiphyllae. *continuing effort ---Page Break--- a 'Table 1 Absorption of ³⁴cs and ^{sr} on epiphyllous and non-epiphyllous leaves of the tropical rainforest. Leaf surface 23% crw/sect 855p cEu/scct Epiphyllous 5363 Non-epiphyllous 1269 Table 2

Uptake of radionuclides by epiphyllous and non-epiphyllous leaves and translocation of the nuclides within the leaves. Leaf surface region, 3Tes cru/sect Sen crt/sect Epiphyllous tip am 98 overlay 1062 2604 base ko 180 Non-epiphyllous tip 26 3h overlay nz 332 base 1 8 Rn ---Page Break--- NEUTRON ACTIVATION OF TROPICAL SOILS AND PLANTS* Jerry R. Kine 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 PRIC research reactor for one hour at a flux of 2×10^{14} n/cm²/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 origin of the sample, the curves 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 ¹⁵hour ^{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 ^{2a} decays away the curves go through a sharp bend lasting from 100 to 300 hours and then show a half-life of approximately 1400 hours or 58 days. The portion of the decay curve is dominated by radioactivity from ⁵⁹Fe (T 1/2 = 45 days) and ⁴⁶Sc (T 1/2 = 84 days) 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.P. Foss, and B.B. Brar. Lanthanum and Scandium distribution in three glacial soils of Western Wisconsin. In preparation, Preprints: available. 2 ---Page Break--- 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 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 50 days after irradiation and corresponds to the slowly decaying portion of the decay curves. The nuclides most prominently present in many of the early spectra include Si, Cr, Mn, ⁵⁰, ⁵⁹Fe and Zr. Some of the spectra show traces of elements while most of the soils seem to have below detection

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 seems to be the apparent paucity of U in the tropical soils. This is consistent with the conclusions of Kline et al. who suggested that U is probably easily leached from soils. The older gamma ray spectra are dominated by Si, Mn, and ⁵⁹Fe. 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 Bu 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%. Se 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 shown a general association between Fe and Sc in a worldwide 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. *Kline, J.R., and S.S. Brar. Instrumental analysis of neutron irradiated soils. In preparation. Preprint copy avail. ---Page Break--- Table 1 Amounts of Fe, Sc, and Cr in some tropical soils

Depth inches	Some EL Verde (Control Center)	EL Verde (Control Center)	EL Verde (Rad. Center)	EL Verde (Rad. Center)	Elfin forest (FR)	Elfin forest (PR)	Elfin forest (PR)	Limestone (Bayamén, PR)	Caibalache (Manatí, PR)	Guajataca gorge (quebradillas, PR)	Chepo, Panama	0-6	12-24	12-24	2h-36	0-6	0-6	0-6	0-6	9-7	
Fe %	9.3	5.0	19	9.3	9.5	10.4	1.8	1.5	3.5	19	Se ppm	47.0	55.1	13	18.4	22.8	60.5	26.2	33.4	10.6	28.8
Cr ppm	70.0	37.2	197.2	174.0	120.3	59.2	TH	---Page Break---													

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 2×10^{10} n/cm²/sec. No. 1, Bayanén, P.R.; 2, El Yunque peak P.R.; 3, Quebradillas, P.R.; 4, El Yunque peak subsoil, P.R.; 5, Chepo Panama; 6, Vannat, P.R. om is ° Lim os Ps = = THHODODHOM HHH OMM mm ows, 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. B ---Page Break--- gE855 SEBEBBEES ES Counts! 10 Min 0 2% % © 50 © 70 WH 9 WO No 12> G0 WO 150 Ko 170 1m Energy MEV 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. 10,000 B86 # ϕ = counts! 10 tin aye: gee ne 88 0 10 2 3 © 50 @ 70 H %0 100 10 120 10 10 150 100 170 Energy, Mev Figure 4, Gamma ray spectra of neutron irradiated soil taken from the 12-2 inch depth at El Verde Puerto Rico. Upper curve 100 hours after irradiation; lower after 450 hours. 6 ---Page Break--- cant in Figure 5. Counting in Figure 6. sea a ea om 'am am 00 so 00 a0 500 om aon 20 THVSDG DH DMM w HMM me era. Mev 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. vs 5 i 5.0 3, ox ww a 4 1 a 5 4 x 2 'ot d THHSDOVH Owwo www wi ww egy, Me Gamma ray spectrum of neutron irradiated surface soil taken from Darien Province Panama. 100 hours after irradiation. ---Page Break--- Counts! 10 Min 0 0 2 3% 4 50 6 70 9 % 100 110 120 130 140 150 160 170 180 coy, ey Figure 7. Gamma ray

spectrum of neutron irradiated surface soil taken from Darien Province Panama, 1500 hours after irradiation, = S 7.00 = 8 5 coe ee 3 san : 4,00 3,000 200 wo Me 0 10 2 30 4 50 6 7 8 90 NiO 120 130 140 150 160 170 180 190 Energy, Mev Gamma ray spectrum of neutron irradiated surface soil taken Figure 8. from a mangrove swamp in Darien Province Panama. 1500 hours after irradiation. Early

spectra dominated by ^{24}Na not shown. 8 ---Page Break--- '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 60 m and located 28 nests of *Nasutitermes costalis*. All were active except #22 and #23 in the Radiation Center and #1 in the Control Center. P. Murphy had noted in 1964 that Wiegert's #23 nest had been active prior to irradiation. Nests #1 and #24 probably had been abandoned prior to irradiation (See Fig. 1). In the summer of 1966, McMahan studied the termite population of both centers, examining Wiegert's nests and locating a new one (#25) about 35 feet from a *Guaiacum* tree, the only tree nest discovered in the forest areas. Special attention was given to nests #19, #20, and #11 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 #11 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 #16 (at 60 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.

designates the population. (A nest usually represents the offspring of a single reproductive pair). A study is underway 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. continuing effort **University of North Carolina ---Page Break--- '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 36% 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 19% of the Control Center tunnels and 12% 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. + crack to apply 20m rats to of trutstemes to Pevitorce scewption (not ext) reno. de motly 0 flntng of old tme es ---Page Break--- ---Page Break--- SOIL RESPIRATION* C.F. Jordan Sci respiration in the mature forest and the irradiated area was measured by putting a relatively large box (250 liter capacity, covering 625 m² of soil) over the soil surface, and measuring CO₂ buildup inside the box. An objection to this approach for measuring soil metabolism is that 'the buildup of CO₂ 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 snail 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 prior to Feb. 14, there were 11 rainless days, a relative drought in the rain forest. SOIL respiration in the main forest. SSS orans carton respire /e?/ar. dose oe 2 196T den 2s 1968 Pe, aoe Nature forest, well drained 4012 06 008 mature forest, poorly drained soft a on " Irradiated area, 1004 grass covered, 'well drained soil Trradiated area, 50 grass covered, "poorly drained soil ° or Trradiated area, beneath secondary 'vegetation, well drained soil *continuing effort ---Page Break--- NO FAN 600 FAN 500 z 2400} SS oO 300 Lo, Oo 20 40 TIME (MINUTES) Figure 1, Buildup of CO₂ inside the soil metabolism box, with and without a fan circulating air inside the

box. 83 ---Page Break--- pe GIANT CYLINDER EXPERIMENT# C.F. Jordan Ch TY 18, 1967, the giant cylinder with the fan 2 2967, cylinder was operated to ret 30% more air than on previous runs in an attempt to 1988 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 samples were collected 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 CO₂ 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 eC/n@/nr. This value is close to the value Odun 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 CO₂ 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 CO₂ 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 CO₂ 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 future ecosystem metabolism studies, completed 8h ---Page Break--- 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 CO₂ at various levels can be converted to forest metabolism in the same manner as G. Woodwell did at Brookhaven National Laboratory. The difference between the Brookhaven situation and El Verde situation is that Woodwell measured respiration during 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 CO₂ intakes should be spaced throughout the cylinder to determine intra-cylinder variations. Table 1 Time for CO₂ pulse to travel through the cylinder from release elevation to fan at the bottom, Release elevation Time, feet Minutes 4 ah 5 36

5 48 T 85 ---Page Break--- ONE CHART UNIT EQUALS 25 PPM CO₂ BELOW CANOPY ' ABOVE CANOPY CHART UNITS 2400 0600 TIME Figure 1. Expansion of chart read-out for the giant cylinder experiment, the night of July 19-20, 1967. ---Page Break--- PERFORMANCE OF THE ZERO-TENSION LYSIMETER* Carl F. Jordan INTRODUCTION A "Boemmayer" (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 2x12 inch stainless steel trough, inside of which are two parallel bars that 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. The "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 cm² in the case of the Zero Tension Lysimeter) times the effective collection area factor, f. Factor f is defined as: volume of water collected / area of top of lysimeter volume of infiltrating rainfall 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 Hela (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. Lysimeters

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. 87 ---Page Break---

Soils The field tests were made in a lower montane tropical rain forest near El Verde, Puerto Rico, on 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 warm 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 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).

LITTER LYSIMETERS: COLLECTION TUBE COLLECTION BOTTLE

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

---Page Break---

Table 1 Bulk densities of soils in which lysimeter was tested. No. of Average bulk One standard dev. samples density deviation 10s Guineos clay, field sample, 0-5 in.

depth 4 48 048 Tos Guineos clay, test box y +708 054 muviun, test box "732 +099 Table 2 Particle size distribution of soils used in lysimeter tests. Numbers in parentheses are size of particles, in millimeters. Soil Sana los Guineos clay 25 (0.05) Alluviun 4g (0.02) posit 38 (— 0.05-0.002) 30 (| 0.02-0.002) foley 37 (0.002) Famisten, 1965 using hydrometer method) ai (— 0.002) ---Page Break---

'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 1 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 51 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 with 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 the 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 the effective collection area would be smaller than the top area of the lysimeter) nor increasing suction at the soil interface (in which case the effective collection area would be greater than the top area of the lysimeter).

---Page Break---

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, References Blake, G.R. 1965. Bulk density. In Methods of Soil Analysis, Part 1. No. 9 in the series, Agronomy. Am Soc Agr Inc., Madison, Wis. pp. 374-390. Cole, D.W. 1958. Alundum tension lysimeter. Soil Science 85: 293-296. Cole, D.W. 1963. Release of elements from the forest

floor and migration through associated soil profiles. Ph.D. thesis, Univ. of Wash. Univ. Microfilms Inc., Ann Arbor, Mich. Cole, D.W., Gessel, B.P., and Held, E.E., 1961. 'Tension lysimeter studies of ion and moisture movement in glacial till and coral atoll soils. Soil Sci. Soc. Am. Proc., 25: 321-325. Dey, P.R. 1965. Particles fractionation and particle-size analysis. In Methods of Soil Analysis, Part 1, No. 9 in the series, agronomy. Am Soc Agr Inc., Madison, Wis. pp. 545-567. Bamisten, J.E. 1965. Soils. In the Rain Forest Project Annual Report FY-65. PRIC 61. Puerto Rico Nuclear Center, Rio Piedras, Puerto Rico, pp. 136-137. Joffe, J.B. 1929. A new type of lysimeter at the New Jersey Agricultural Experiment Station. Science 70: 147-148. Jordan, C.F. 1968. A simple, tension-free lysimeter. Soil Science 105: 81-86. Kohnke, H., Dredbelbis, F.R. and Davidson, J.M. 1940. A survey and discussion of lysimeters and a bibliography on their construction and performance. U.S. Dept. Agr. Misc. Pub. No. 372. Roberts, R.C. 1942. Soil Survey of Puerto Rico. U.S.D.A. Soil Survey Series, 1936, No. 8, 503 p. Shilova, E.L. 1955. A method for obtaining soil solution under natural conditions. Pedology (Russian) 11: 86-92 ---Page Break--- mine 3 Volumes of soil water collected in Zero Tension lysimeters under various test conditions and effective collection area factor calculated from these values 'Volume of water applied in all tests was 50 liters, rate of flow of average view, all ret character in the earth Sir Mial aida! verge fy ant one se fea eas eae

Sam as » Tow otpece clay > i Ff 5 i at : 5 ol of : : p 2 2 g tert 03. 98 t .070 : T 1 oh . ; i cry l 2 i 3 G = z aia 4 i+ _# 25? a % = 7s = m3 a tosh srt aus : x 3 ca =~) " it 7a pe st pias : 3 3 : 2 SER =—_i—_+ en 2 1 = sian hee 3 i a ar foot chau a ! 3 3 ---Page Break--- BIOELIMINATION OF an? George E. Drewry IN THE SNAIL CARACOLUS CARACOLLA The primary objective of this study is to establish the form, slope, and variability in the curve of elimination of tracer Zinc 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 objective 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-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 2 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 biokinetics studies: that weight changes subsequent to uptake represent dilution changes in counts per unit weight that are not biokinetics 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 and three samples from the overnight labeled free population, the curves are presented in Figure 1. All data is corrected for Tasloustine nec.

of ZincO>. The ordinate in this figure is a log scale and may see 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 mean 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 2 indicates that tree 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 Zinc6S study area around the time of initial contamination. One 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 individuals in Figure 3 with the fitted curve of Figure 3 for reference (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.

Summary of overnight Zinc uptake by 36 months on Dec. 5, 1967

Positive Negative average uptake, Standard error Standard deviation Sample size

---Page Break---

Summary of snail dissection data for each

After zinc uptake

---Page Break---

from 5 indoor caged snails

Figure 1. Bioelimination of Zinc during the first 63 days after initial uptake.

Time in days

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

---Page Break---

Figure 3. Bioelimination of Zinc in wide-ranging snails that did not show clear evidence of additional uptake after their first uptake.

Time in days

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. 98 ---Page Break---

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 9 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. Zinc⁶⁵ 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 bio-elimination 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. References Brungs, W.A. Jr. 1963. Distribution of Cobalt 60,

Zinc 65, Strontium 85, and Cesium 137 in a freshwater pond. U.S. Public Health Service, Environmental Health Series. Morton, J.-E. 1958. Mollusks, an introduction to their form and function. Hutchinson and Co. Ltd. London. ---Page Break--- BEHAVIOR AND NATURAL HISTORY OF THE SWATL CARACOLUS CARACOLLA IN A TRACER-LABELED ENVIRONMENT. * George E. Drewry In the process of following the movement of Zn-65 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 objective 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 accessible 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 m² 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 the 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 the extension of the lip to close ventrally the cavity within the shell spiral. Individuals are oviparous and structurally 100 ---Page Break --- Figure 1. Figure 2, Method of determining range for an individual snail. Dark circles (A, B, & C) are Zinc65 labeled trees. Dark square (RP) is the release point. The dotted line is the 5 meter limit of the study zone. X's are individual collection points. 3 ATG in meters Correlation of shell lip thickness (with a size correction) versus the size of observed range (as

Wérea), all adult snails. Points are snails classified as narrow-ranging, open circles wide-ranging, and large symbols are

means. 201 ---Page Break--- Figure 3. Observed ranges of 12 resident snails that exhibited no measurable uptake of Zinc⁶⁵, 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 low-level uptakes of Zinc-65 without any high-level uptake. Reference points same as in Figure 3. 102 ---Page Break--- 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 m² to 237 m² 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 m². Some overlap was permitted because a few snails with ranges smaller than 56 m² 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 28 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: $I = 100 \times 0.16 (y = 1.8)$ where T 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 snails 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 103 ---Page Break--- nan Summary of tracer uptake by

resident snail population, with separation of narrow ranging fonts (aa) wis-Pending oats (ue) guvadee (3) ant asus (A) SS oat size 7 Ei oe BE sae ay ee like 59 as ' = A 30 m5 6.8 ak . 7 = a ow we os 5 8 ew oe my ou ok 8 tot 2 16 8.0 a id oe mate 2 Summary of velgnt changes in the resident snail population LTB oe gh 8% 1 2 8 OM + or i By Sm es 2 eo 2 ok: 8 8 kt 138 MB 5a sisala not charging ma : 'otal ants 22 100 22 100 36 100 B10 et change ose 1.54 ose 1,24 Ome 2K vetted 'pean lose "OTF 104 ---Page Break--- yet been recognized as having established range parked since day 100 (the date is analyzed to be 25yte¥, emails fhe 13 voluntary transients and the disappearing verona ett Jon ave ae suggest that the population te mete equine St between Jop enatie Which, taking into account the full extent of the residents ranges, measures about 300 a2, ie ie yee ten hiding places and the conspicuous examination such aa mark ant recapture inapplicaple, Algo the collector's knowledge of the favorite bait places of the long term resident narrow-ranging snail increases is most unavoidable bias in their favor, 'vo other behavioral characteristics should be mentioned in passing on to a discussion of tracer uptake. One 48 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 resident snails 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 19

Accomplished by direction finding of 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 bioaccumulation 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 0.16 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 zinc labeled tree trunks. The more than 150 individuals of various groups actually collected from the trunks established a firm baseline for deducing whether a snail had actually been on a trunk or was carrying zinc 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 baselines of low-level uptake. ---Page Break--- Figure 5. Observed ranges of 10 resident snails that exhibited more or less continuous low-level uptake of zinc 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.

Reference points same as in Fig. 3.106 —Page Break— a spectrum from 1.01 uptake that never exceeded 100 counts/min in the gamma spectrum! ... for one inter-capture interval. In contrast, juvenile snails directly from the turned exhibited a abrupt increase in uptake to greater than 100 counts/min; this level or greater is called uptake and is taken to indicate foraging on the trunk itself.

Of 22 monitored snails, 17 (77%) utilized the tagged tree trunks; of these, 9 (2008) were 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. For 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 2 uptakes per 347 captures or .08 uptakes per capture. Juveniles in both groups exceeded adults in the rate of utilization, the juvenile rate in narrow-ranging snails being 156% 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 zinc 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 noses as epiphytes, was not releasing much of its tracer burden to the surrounding soil. Figure 5 suggests that three-fourths of the resident 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 ©, 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 handling 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, 1.26% loss for low-level uptake, and 1.1% loss for high-level uptake. The snails with high-level burdens of ^{65}Zn had higher sub-rare 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 some similar parameter. Treatable (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 remnants from August to February. There is also no evidence of a positive or negative behavioral response to handling in a plot of sample size versus recapture number (Figure 6). 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 leave 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 rainforest has been found to consist of about one resident snail for every 3 to 5 m, 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

0.17% of the resident population per day from death and/or emigration is made up by newly established residents. No 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 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 noticeable 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 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. 109 ---Page Break---

References Brungs, W.A. Jr. 1967. Distribution of Cobalt 60, Zinc 65, Strontium 85, and Cesium 137 in a freshwater pond. U.S. Public Health Service, Environmental Health Series Pub. 10, 999eRH-2li:" 1-52. Heatwole, H., A. Rosey, I. Colorado, R. Amadeo (in press) Effects Of Pelation of a population of the Puerto Rican tree in a Tropical Rain Forest. Stiven, Alan E, (in press) Respiration in the snail *Ceracolus caracolla* and an estimate of the relative density and Biomass of litter snail in a Tropical Rain Forest.

H.T. Odum et al. 'PHENOLOGY JR, 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 papers. Fruit of various species collected from May 1967 through March 1968, selected by June, July, August, September, October, November, December, January, and February, are represented as follows: *Dacryodes excelsa*, *Matayba dominicana*, etc. Continued effort is being made.

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.

Continued effort.

Table 1 — Rainfall inches

January, 1967:

1-7 0.49

8-15 3.08

16-23 3.00

24-31 3.20

February, 1967:

1-7 1.03

8-15 2.00

16-23 2.30

24-30 3.20

March, 1967 7 2.26 85 0:32 16-25 0130 23 1150 April, 1967 Lt 5.38 a5 ores 16-23 0:02 2h-30 0.95

+ 1967 Lt 4.98 Yer 298 85 3:21 16-23 3.62 2-31 016 June, 1967 Fe 1.9 16-23, 2125 24-30 Ash

July, 1967 Lt 1.ge 8-15 5.59 16-23 2.16 2-31 66 August, 1967 7 2.21 85 187 16-23 3:15 2h-31 itt

September, 1967 7 1.55 eas 3:22 16-23 125 24-31 2.6r uh ---Page Break--- INSECT

IDENTIFICATIONS* George E.B. 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. Petty Subfamily Mader of Genus and species where known tes Frrtisne Fyrmurtime 61 Suargetn gigantalis Own 'Tima Grote Robinson assis eeciaaisratis "ouenee aes seen go Stacie caictete (One)

Meoleusinaies sigguntalte (Cuenee) continuing effort us ---Page Break--- Family Pyralidae

Thyrididae Subfamily Number of Genus and species where known "species Pyraustinae Pyralinae

1 Epipaschiinae 5 Crambinae Chrysauginae 3 Schoenobiinae 3 a Lineodes metagrammalis

Moschler Argyractis serapionalis Schaus Aegyrractis sp.a Argyrractis sp.> Gataclysta sumptiosalie

Yoochler Gataclyte miralie Voucher Seetome Condolorrhiza sp. a Condolorrhiza sp. b Undulanbia

sp. Byralis manthotalis gems feartmusalin Tempecn Socare, etralopha scabridella Ragonot

Tetralopha sp. Pococera atranentalis (Lederer) Argyrin lacteeta (Febr.) Diatraea saccharalis Fabr.

Guenee Pachymorphus subductellus Moschler Gaphys bilinca Walker Parachna sp. Rhodoncure

leuconotule Pagenstecher Rhodoneura thiastralis (Walker) Rhodoneura nyrsusalis (Walker) née

bee ---Page Break--- STAFF Project! Oe 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. Drevry,

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. Himisten, 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 Kron, Electronics

Technician I, Weather Station Operator Alejo Estrada Pinto, Research Assistant I, Field Botanist

eel Rossy, Research Technician, Gamma Ray Spectroscopist José Colén, Research Technician

(1/2 time), Atomic Absorption operator FIELD WORKERS Moisés Parrille Rosario, Maintenance Foreman Doroteo Martinez Garcia, Field Worker Juan Martinez Maisonet, Field Worker SECRETARIAL Ana Josefina Correa Lépez, Administrative Secretary II ---Page Break--- PAPERS PRESENTED AT SCIENTIFIC MEETINGS AND PUBLICATIONS Papers Presented The following papers were presented at society or symposium meetings. 2) Kline, J.R., J.E. Foss, and S.B. Brar. La and Se 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) Himisten, 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. Odun 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. 18 ---Page Break--- APPENDIX MANUSCRIPTS WHICH HAVE BEEN PREPARED AND SUBMITTED FOR PUBLICATION SINCE JUNE 1967. ---Page Break--- '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 even in the high rainfall environment of a tropical rain forest. Therefore, plant roots are exposed to tritiated water for a considerable time after release. 'Tritium might be released to the tropical environment through military or peaceful thermonuclear detonations. The behavior of such release in the tropical ecosystem is not well known, although Koranda (1) found tritium in soils and plants of Enewetak 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 Taguillo Mountains of Eastern Puerto Rico. A soil plot, 0.94 m² 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 nCi/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. ---Page Break--- 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 partial release of tritium trapped as immobile water, in 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 cations) which could have a restricted molecular exchange with the slowly moving bulk water. Such diffusion-restricted compartments would result in exponential decay curves since the process of renewal 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 mobile bulk water. ---Page Break---

ACTIVITY (PM/mL) 4080120160200 Time (days) 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, RAINFALL (CM/WEEK) 0e 5 5 2 ol 040 80 120 60 200 TIME (days) 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. ---Page Break---

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 labeled. This behavior must be considered in predicting the bi-environmental 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 labeling 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. References Corey, J.C., D.R. Neilsen, and J.W. Bigger, 1963. *Soil Sci.*, 80: Amer. Proc., 27 (3). Jordan, C.F., 1968, A Simple Tension-Free Lysimeter. Accepted publication by *Soil Science*. Koranda, J.J., 1965. *Health Physics* 11, 1h5. Zimmerman, U., K.O. Munnich, W. Roether, W. Kruetz, K. Schubach, and O. Siegel, 1965. In Proc. 6th Int. Conf. Radiocarbon and Tritium

Dating Pullman, Wash. June 7-11, 1965, ST. , W. Kruetz, K. Schubach, O. Siegel, 1966. Science 161. K.O. Munnich, and W. Roether, 1967a, in Isotope —Chemistry in the Hydrologic Cycle, Geophysical Monograph Series, No. 11. P. Ehhalt, K.O. Munnich, 1967, In Proceedings of The Symposium on Isotopes in Hydrology. IAEA Conf. Vienna, Nov. 14-16, 1966, 567. ---Page Break---
EFFECTS OF IONIZING

RADIATION ON THREE NEOTROPICAL TERMITES SPECT (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 (3000 r, 6000 r, 12,000 r) were used. Primary data consisted of Lethal 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 a result might be correlated with their habitual lack of exposure to harsh environmental conditions. 12h ---Page Break--- 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, *Nasutitermes costalis* and *Parvitermes discolor*, both members of the family Termitidae. *N. costalis* builds nests of wood carton, a material produced by the termites themselves, while *P. discolor* lives in decaying logs and dead tree trunks. Both species build carton tunnels to food sources outside their living quarters. The lifespan 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 36% and 19%, respectively, were occupied in the two control centers. In addition, the nest population of *N. costalis* in the irradiated area appeared to differ from those outside in containing fewer inhabitants, and especially fewer immature colony members. All nests within 60 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. Nest occupation had decreased further in the irradiated center while remaining approximately the same in the control centers.

---Page Break--- These comparisons of tunnel ant 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, In the summer of 1966 a preliminary laboratory test of radiation sensitivity was carried out on a population of *I. 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 60% 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 homopteran 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 Animal Results.

costalis, *H. nigriceps* and *Parvitermes atscoter* In have a true worker caste and nasutiform caste. Soldiers were used in the present experiment. Soldiers are smaller than workers; Table 1 gives names of the castes for the three species. All termites in each test population were taken, and all colonies were from outside the experimental centers. The "degenerate" individuals for both experimental series were taken from the exact site. The *N. costalis* termites in Series T were collected by breaking the nest, a large plastic 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 Z, 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 0.90 mg. They were collected within 15 meters of the cesium site on leaves of *Ichnaeum pallens* (Sv) Minro, a grass typical of open spaces in this rain forest. The *Ichnaeum* 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 undersides of leaves and on

stems. Many winged adults were also present, and both nymphs and adults were very active. Collecting consisted of 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. ---Page Break--- 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 *Ichneutes* 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 setup: Six experimental conditions and one control per species, with replicates of each, making a total of 8 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 *L. nigriceps* were tested. ---Page Break--- Results Holding conditions for termites during the experiment were apparently not as bad as those for the leafhoppers, 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 *H. 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 (Lf50) was calculated for each experimental condition for each termite species and used in the primary data in analyses. Comparison of Worker and Soldier, The results supported those of the preliminary tests of 1966 in showing that soldiers are more radio-resistant 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 L5 values for 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 Tables 4 and 5, in terms of mean of L50 values, with data for soldiers and workers pooled. In order to evaluate the significance of the L50 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 sets 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 assessments-Significantly for *N. costalis* and *P.*

discolor (Series T, Table 10 and 11, Figure 1) at both high and low dose rates. On the other hand, *N. costalis* and *N. nigriceps* do not show such differences at either rate. (Series II, Tables 12 and 13, Figure 2), 129 ---Page Break--- Figure 1. Figure 2. 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. 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. 130 ---Page Break--- Table 1 Average Weights of Workers and Soldiers for Three Termite Species

Species	Worker (mg)	Soldier (mg)
<i>Nasutitermes</i>	2.03	4.64
<i>Parvitermes</i>	2.54	2.44
<i>Homoptera</i>	0.82	6.99

Table 2 Experimental Plan for Series I Control Irradiated Containers Irradiated Containers Species Containers (6150/min) (i2e/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 BL ---Page Break--- Table 3 Percent Survival of Termites and Leafhoppers on Eight Days Following Irradiation Series I Termite *Nasutitermes costalis* *Parvitermes discolor* Control Experimental Control Experimental Soldier 93.33 19.83 15.00 5.10 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 ALL dose rate and total accumulated dose data pooled, 132 ---Page Break--- Table 4 Average Time Values (+ 95 Percent Confidence Limits) of *N. costalis* and *P. discolor* for Levels of Total Dose and Dose Rate (Series I).

Species	Total Dose (r)	Dose Rate	High (615 rads/min)	Low (42 rads/min)
<i>N. costalis</i>	Soldier	8.61 days	12.38	7.50
	Worker	12.38	7.50	7.06
<i>P. discolor</i>	Soldier	2.65	7.78	2.65
	Worker	7.78	2.65	7.78

Table 5 Average Lf50 (+ 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 A. *nigriceps* 3000 High (615 rads/min) 6.05 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. 3.97 133 ---Page Break--- 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), Degrees of Freedom Sum of Squares Mean Square F Treatments 5 198.88 A. Total dose 2 190.26 B. Dose rate 1 0.89 AB Interaction 2 TB Error 18 31.11 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 36.32 B. Dose rate 1 4.73 AB Interaction 2 82.00 Error 18 217 Total 23 236.42 ---Page Break--- 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). Degrees of Freedom Sum of Squares Mean Square F Treatments 5 258 A. Total dose 2 100.70 B. Dose rate 1 48 Interaction 2 9.33 4.67 Error 18 129.18 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). Degrees of Freedom Sum of Squares Mean Square F Treatments 5 127.58 A. Total dose 2 35.17 17.59 B. Dose rate 1 40.43 40.83 AB Interaction 2 51.98 25.99 Error 18 28.21 157 Total 23 155.79 ---Page Break--- 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). 615 rads/min Degrees of Freedom Sum of Squares Mean Squares F Treatments 5 308.05 A. Total dose 2 213.38 B. Species 1 89.01 AB Interaction 2 5.66 Error 8 32.23 Total 23 340.28 Table 12 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 II). Low Dose Rate: 2 rads/min. Degrees of Freedom Sum of Squares Mean Squares F Treatments 5 213.11 A. Total dose 2 30.08 B. Species 1 113.84 AB Interaction 2 6.19 Error 18 109.96 Total 23 323.06 136 ---Page Break--- 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 Degrees of Freedom Sum of Squares Mean Squares F Treatments 5 67.86 A. Total dose 2 25.23 B. Species 1 0.37 AB Interaction 2 42.26 Error 18 28.51 Total 23 96.36 136 ---Page Break--- 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). 42 rads/min Degrees of Freedom Sum of Squares Mean Squares F Treatments 5 301.59 A. Total dose 2 255.82 227.91 1.50 B. Species 1 85.65 85.65 1.00 AB Interaction 2 153.11 76.56 0.90 Error 18 1537.29 85.41 Total 23 2031.86 3 ---Page Break--- 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 for *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 conditions. 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 plants, has so far been elaborated. Their studies, in which 12 species of insects (none in order Isoptera) were irradiated in a Cobalt-60 source at doses ranging between 1000 and 312,000 rads 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 limited 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. nigriceps*. The only departure from the expected trend is the lack of evidence for greater sensitivity of *N. nigriceps* over *N. coarctatus*. Both the high (615 rads/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 original question pertaining to a supposed heightened radiosensitivity of termites over most other insects, which has not been answered unequivocally by these studies. High mortality among contained termites indicated that holding conditions were poor. The results obtained seem comparable.

However, with those of the preliminary tests conducted in 1966. At that time, all *castalis* nests were broken up into several sections, two-thirds of which were divided equally between two closed waste-basket containers. One container, with its thousands of inhabitants, was given a total of 6000 r at the rate of 67 r/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 non-irradiated 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 r/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 (*Periplaneta americana*) were found to have Psp values of 14 days at 10,000 r (Wharton and Wharton 1959); the boll weevil (*Anthonomus grandis*) had Psp 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 (*Gonotrachelus nenuphar*) had values in excess of 10 days at 10,000 r (Lippold, Cambrall and Nassey 1968) and female adult large milkweed bugs.

(*Oncopeltus fasciatus*) had an *Uso* of 28 days at 10,000 r. These values should be compared with the lower *LMsp* 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. 139 ---Page Break---

References Davich, J.B. and D.A. Lindquist, 1962. Exploratory studies on gamma radiation for the sterilization of the boll weevil, *J. Econ. Entomol.* 55: 164-7. Harris, W.V. and W.A. Sands, 1965. The social organization of termite colonies. *Symp. 2001. Soc. Long. No. 14*, 113-131. Lindquist, A.W. 1958. Entomological uses of radioisotopes. In *Radiation Biology and Medicine*, W.D. Claus, Ed. Reading Mass.: Addison-Wesley Publ. Co. Lippold, P.C., F.L. Ganbrell, and I.M. Nagsey, Jr. 1968. Effects of ionizing radiation on the

European Chafer, the plum curculio, and the large milkweed bug. *Ann. Entomol. Soc. Amer.* 61: 151-158. Menhinick, B.F. and G.J. Dodson, 1967. Radiation sensitivity of insects. O'Brien, R.D. and L.S. Wolfe, 1964. *Radiation, Radioactivity and Insects*. Academic Press, N.Y. 211 pp. Odum, H.T., Ed. A. *Tropical Rainforest*. Atomic Energy Commission, In Press. Wharton, D.R.A. and M.L. Wharton, 1959. The effects of radiation on the longevity of the cockroach, *Periplaneta americana*, as affected by dose, age, sex, and food intake. *Radiation Res.* 11: 600-9. Woodwell, G.M., 1967. Radiation and the patterns of nature. *Science* 156, 461-470. Acknowledgments This work was financed by the U.S. Atomic Energy Commission, through the Puerto Rico Nuclear Center, Miss Heidi Pabén and Mrs.

Dina Biringer of the PRIC carried out the actual irradiation of the insects. Dr. A.E. Stiven gave statistical aid. ---Page Break--- NITROGEN FIXATION BY EPIPHYLLAE* Joe A. Binisten 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 N₂ 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% CO₂. 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

N₂ the leaves were cut from the tree and the epiphyllae were scraped from the leaves. It was planned to measure the amount of N₂ 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 sample and were sent along with the scraped leaves to a commercial laboratory (Leonet Corp., Palisades Park, N.J.) for analysis. Per ees rae eerprvet soars tae octet ee Fe Te Te erpecicar ntee rates Severe of, Ooreta ant tn na fa Rico for the U.S. Atomic Energy Commission under contract AT(0-1)- 1833. wa ---Page Break--- Results The results of this experiment are given in Table 1. The pooled sample of epiphyllae scraped from five leaves had taken up 9.676 of their total nitrogen from the gaseous N₂ 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 the leaf surface and imply that some

transference to the host leaf took place since these leaves are enriched by a factor of 2 or more over the natural isotopic abundance of ^{15}N which is 0.37% (2). Some of the enrichment of ^{15}N 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. 95% isotopic purity was obtained from Nuclear Equipment Chemical Corp., Farmingdale, N.Y. ---Page Break---

Table 1 Amounts of total nitrogen in leaves and epiphyllae and percent of total N as N_2 after 48-hours exposure to 1 sample of Material

Material	Total nitrogen	Percent of total N as N_2
Pooled epiphyllae	0.2059	0.0967
Scraped leaf #1	2.1703	0.0231
"8 leaf #2	1.7533	0.0085
"8 leaf #3	1.2940	0.0280
"8 leaf #4	1.6831	0.0220

Banisten, Joe A, 1966. Irradiation, Koch, B.C. 1960. Ruinen, Jakoba. 1965. in the phyllosphere. 393. Stewart, W.D.P. 1967. Literature Cited Activation 'sis Handbook. New York and London. 219 p. 1426-1432. 143 'The Phyllosphere III. Nitrogen-fixing plants. Changes in tropical forest soils after 'The ASB Bulletin, 13, (no. 2): 33. Academic Press, Nitrogen fixation Plant and Soil XXII, no. 3, p. 375- Science, 158: ---Page Break---

movement of ^{85}Sr and ^{134}Cs By THE SOIL WATER OF A TROPICAL RAIN FOREST Carl F. Jordan Introduction The dynamics of radionuclide movement in tropical soils were studied by analyzing soil water collected weekly at various depths, after the radionuclides 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 (Serdan, 1968) were installed beneath the litter, and two at 5 inches in the manner shown in Fig. 1. On Aug. 10, 1967, 1 ml of ^{85}g and 1 ml of ^{130}g 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 1M 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 the 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 the start of the 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 simply as an aid to interpreting data. Results activity of ^{137}Cs in the litter water decreased at a rapid rate for the first two weeks following application, and from then on the 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). ---Page Break--- ex | pir 'COLLECTION TUBE 'COLLECTION BOTTLE 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. 100 100, 150, 200 COOL TIME (DAYS) Figure 2. Activity of ^{85}Sr in the litter water, collected in lysimeters beneath the litter (A), and at 5 inches (B). 5 ---Page Break--- 100 50 100 150 200 COOL TIME (DAYS) Figure 3. Activity of ^{137}Cs in the soil water, collected in lysimeters beneath the litter (A), and at 5 inches (B), 16 ---Page Break--- Activity of ^{85}Sr in the litter water dropped off sharply for about 10 weeks, after which it stayed relatively constant (Fig. 3). At 5 inches, there was a 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 0.57% had moved through the 5-inch level. Twenty-seven percent of the ^{137}Cs had moved out of the litter, and 0.32% had moved through the 5-inch level. Total rainfall from 8/10/67 to 1/2/68 was 103 mm above the canopy and 76 mm below the canopy. A Discussion The very low total amounts of ^{137}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 in agreement with Kline's data (1968) which shows that half the activity of ^{137}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 release 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 other ions moving downward. 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 first few vethos. Me peak of activity and first decrease of each nuclide sertete oti 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 the 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, the rate of ^{134}Ge 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. Time concentrations of ^{134}Cs and ^{85}Sr in the soil water apparently correlate with 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. wT ---Page Break---