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RESPONSES OF SOME GRASSLAND ARTHROPODS TO IONIZING RADIATION

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ABSTRACT

Responses of arthropod communities to ionizing radiation and the interactions of radiation with other environmental parameters are being investigated in (1) studies of biological and physical dosimetry of beta and gamma radiation from simulated fallout in a grassland area, (2) long-term field observations on interactions of the fallout radiation with seasonal changes in composition and structure of the arthropod community, and (3) short-term laboratory studies on interactions of fallout radiation with population dynamics of selected insect species. Beta- and gamma-radiation levels in the simulated fallout area were determined by thermoluminescent dosimetry. Lithium fluoride microdosimeters attached to grasshoppers and crickets in the fallout field indicated that these closely related organisms received significantly different radiation doses owing to differences in habitat. Numbers of soil-, litter-, and grass-inhabiting arthropods collected in the simulated-radioactive-fallout field varied significantly among months and taxa. There was no significant difference in variation between arthropod communities of field enclosures before application of the simulant. The only significant differences among numbers of individuals in taxa comprising the arthropod communities of control and contaminated areas occurred 4 months after contamination. No significant increase in species composition dissimilarity between the contaminated and control areas appeared during the second year following application of the fallout. Consequently the threshold for effects of fallout radiation on species composition of the arthropod community must be above the ~13 rads/day delivered over this time. Data on exposure of laboratory populations of *Folsomia* (Collembola) to beta radiation from ⁹⁰Sr-⁹⁰Y fallout indicate that population dynamics were affected primarily by sensitivity of fertility rates rather than by sensitivity of adults. Dose rates estimated to give an LD_{50/30} or LD_{50/60} for adults were more than twice as high as dose rates required to reduce fertility rates to zero.

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Many ecological situations may be upset by effects of radioactive fallout on insect populations.¹ In particular, beta radiation from fallout may be hazardous to small insects and to insects that pass developmental stages in the soil and litter. Although some information is available on arthropod responses to beta and gamma radiation, it is meager and must be augmented to predict patterns of ecological responses to a nuclear attack and to plan postattack agricultural procedures.

The objective of this study is to assess effects of ionizing radiation from fallout on insects. Collembola were chosen for the laboratory experiments because they are among the most numerous microarthropods in the soil fauna and are important in soil formation. The study, a correlation of field and laboratory data, deals with succeeding levels of ecological complexity: (1) effects of chronic beta radiation on population mortality and fertility and (2) responses of the structure of an arthropod community in a managed grassland ecosystem to beta and gamma radiation. This paper covers the first 2 years of observations on the arthropod community.

Antecedent to any evaluation of radiation effects is the necessity of selecting an accurate, dependable, and practical method of determining radiation levels. Standard means of measuring radiation levels in contaminated areas (ionization chambers, scintillation counters, G-M counters, or silver-activated metaphosphate glass dosimeters) were not feasible in this study, in some instances owing to expense and/or component materials. Furthermore, these devices are not well suited for measurements of dose rates in microhabitats where radiation levels may be low, and most do not measure beta radiation. Existing mathematical models²⁻⁴ for predicting beta- and gamma-radiation dose rates from fallout were inadequate for this study because models are limited in ecological situations by restrictions in geometry, such as surface conditions, presence of grass, and movement of fallout.⁵ Thermoluminescent dosimeters were selected for use since they are mechanically rugged, are available in several geometries and sizes, and measure doses as low as 5 mrad.

METHODS

The study of the effects of simulated radioactive fallout on an in situ arthropod community was conducted at the 0800 Ecology Research Area at the Oak Ridge National Laboratory (ORNL). A quantity of simulated fallout⁶⁻⁸ (2.44 Ci of ¹³⁷Cs on silica sand grains) estimated to give a dose rate of 100 mR/hr at 1 m above ground was applied⁹ in July and August 1968 to a 100-m² field enclosure of the managed grassland ecosystem dominated by *Festuca arundinacea* Schreb. Three sites in the field, one fenced with sheet metal, one fenced and contaminated with fallout, and one roped off, were sampled bimonthly during the first year and monthly thereafter. The roped area was established for comparison with the uncontaminated pen to detect possible

effects of the fencing, which was utilized to rodent-proof the pens and to minimize dispersal of the fallout simulant. Sampling was begun 4 months before application of the fallout simulant. Seventy-eight arthropod taxa were sorted from samples collected with pitfall traps (12.2 cm deep by 6.7 cm in diameter), soil cores (5.0 cm long by 4.4 cm in diameter),¹⁰ and biocoenometers (cylindrical cages 0.25 m² by 1 m in height).¹¹

Beta- and gamma-radiation dose rates in the contaminated enclosures were determined by using cleaved (1 mm³) and extruded 0.5- by 6.0-mm crystals of LiF (Harshaw Chemical Co. TLD-100). This material was used because it is essentially energy independent for beta and gamma radiation. Beta and gamma point dosimetry was begun with the first application of fallout simulant. Extruded crystals of LiF were suspended at several heights above the ground. Some dosimeters were unshielded, and others were enclosed in 2-mm-thick nylon capsules, which were sufficient to shield out the beta radiation but not the gamma radiation. Extruded crystals were placed in and on grass stems and leaves; cleaved crystals were attached to insects during the eighth week after application of fallout simulant.

For the Collembola population study, albite sand grains (44 to 88 μ in diameter) coated with ⁹⁰Sr-⁹⁰Y (Ref. 12) were suspended in glycerol and painted onto charcoal-calcium sulfate substrates in culture jars 4 cm in diameter. Nonradioactive sand grains in glycerol were similarly applied to charcoal-calcium sulfate substrates to prepare control culture jars. Surface dose rates of 3.3, 4.8, 5.1, 5.2, 7.9, 13.5, 14.5, 15.5, 15.6, 17.4, 22.9, 29.0, 29.5, 35.4, 45.9, 66.0, 71.8, 89.1, and 341.7 rads/hr were determined for these plane sources using 0.5- by 6.0-mm extruded LiF crystals. Groups of 8 to 12 adult *Folsomia* species were placed in 10 control and in 19 experimental culture jars. The culture jars were maintained at 20°C, and the substrates were kept saturated with water. The Collembola were fed brewer's yeast, and numbers of adults, juveniles, and eggs were scored biweekly for a period of 98 days.

RESULTS AND DISCUSSION

Soil, litter, and grass components of the grassland arthropod community received significantly different beta- and gamma-radiation exposures owing to changes in distribution of the fallout simulant and to the short range of ¹³⁷Cs beta particles. Gamma and gamma + beta dose rates integrated over the first week in the middle of the contaminated field enclosure (Fig. 1) can be used to estimate the beta-radiation dose rates. Beta particles in air and vegetation have limited ranges, of course, and beta dose rates were used to estimate the vertical distribution of fallout for the point at which the series of dosimeters was suspended. Beta-radiation dose rates during the first week following application indicated that 25 to 30% of the simulant was present on the ground surface, 45 to 50% in the litter layer, and 20 to 30% on leaf surfaces. Eleven weeks after the

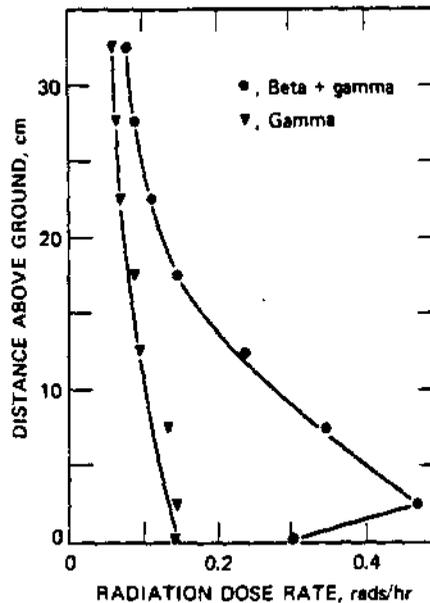


Fig. 1 Distance above ground plotted against gamma and beta + gamma dose rates in the middle of the contaminated enclosure at the 0800 Ecology Research Area during the first week after application of simulated radioactive fallout. The distance between the two dose-rate lines represents the beta-radiation dose rate. N for each point is 2.

first application and eight weeks after the second dosing of simulant (Fig. 2), 50 to 55% of the beta dose appeared on the ground surface, 25 to 30% was delivered in the litter layer, and less than 10% was present at the height of leaf surfaces. Microdosimeters placed on and in grass stems and leaves (Fig. 2) showed that most of the intercepted simulant had been removed from leaf surfaces but some remained trapped in leaf axils. Beta + gamma dose rates in axils ranged from 931 to 1145 mrads/hr, as compared with air dose rates at the same height above ground of 200 to 250 mrads/hr.

Grasshoppers (*Melanoplus* species) and crickets (*Acheta domesticus*) with cleaved crystals of LiF attached to their thorax and abdomen were released in the contaminated enclosure the eighth week after the second application of fallout simulant (Table 1). The dosimeters integrated the dose received by the insects as they moved through various dose-rate levels and thereby provided realistic estimates of "ecological dosimetry."¹³ Differences between dose rates to thorax and abdomen of the same insects were not significant, but there was a significant difference ($P \leq 0.01$) between total exposures of the living grasshoppers and crickets. These two insects are closely related taxonomically, but they occupy different habitats. Crickets dwell primarily on and in litter, where,

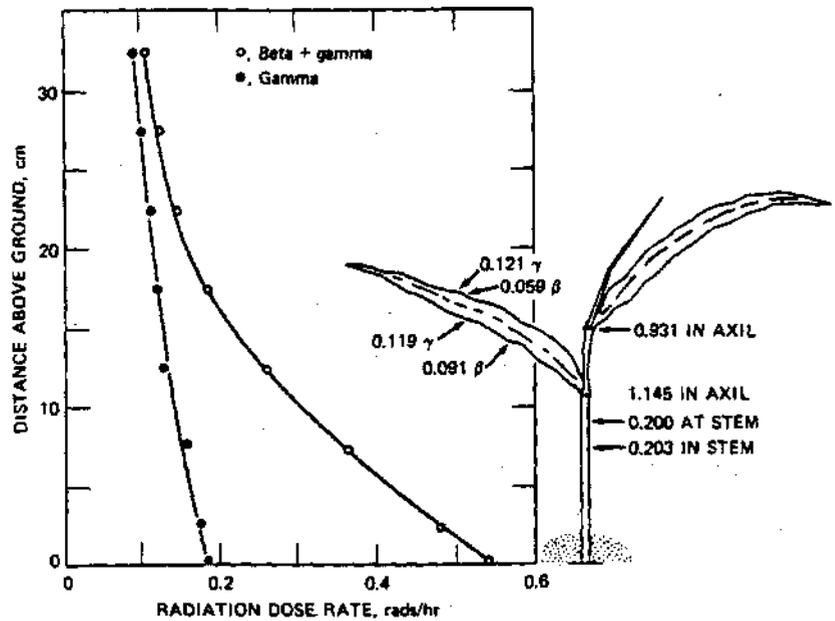


Fig. 2 Distance above ground plotted against gamma and beta + gamma dose rates in the middle of the contaminated enclosure at the 0800 Ecology Research Area during the eleventh week after the first application and the eighth week after the second application of simulated radioactive fallout. The distance between the two dose-rate lines represents the beta-radiation dose rate. Beta, gamma, and the combined dose rates observed for a fescue plant also are presented. N for each point on the dose-rate lines, as well as for the fescue plant, is 2.

Table 1

DOSE RATE TO CRICKETS (*Acheta domesticus*)
AND GRASSHOPPERS (*Melanoplus* SPECIES) FROM
SIMULATED RADIOACTIVE FALLOUT EIGHT WEEKS
AFTER APPLICATION OF 2.44 CI/100 M² OF ¹³⁷Cs

Organism	Dose rate, rads/hr*	
	Thorax	Abdomen
<i>Acheta domesticus</i> , living	0.22 ± 0.003	0.31 ± 0.010
<i>Melanoplus</i> species, living	0.09 ± 0.011	0.10 ± 0.007
<i>Melanoplus</i> species, phantom	0.11 ± 0.005	0.20 ± 0.006

*Plus or minus standard error; N = 10.

in this instance, they were exposed to more beta radiation; grasshoppers dwell higher, on blades of grass. Thus any attempt to predict ecosystem responses to radioactive fallout based on different radiation sensitivities must also deal with the problem of differential radiation exposure.

Biological data in the form of numbers of individuals of each arthropod taxon collected from the managed grassland arthropod community by each pitfall trap, soil core, or biocoenometer are too extensive for presentation here and will be included in a later report. A sequential three-way analysis of variance was applied to data from 26 sampling dates (Apr. 1, 1968, to Mar. 18, 1970) to detect significant changes in structure of the community. Variation among sites, taxa, and sampling dates was first calculated by using the seven sampling dates (Apr. 1 to June 25, 1968) before application of the fallout simulant. An F test indicated significant differences among dates ($P \leq 0.01$) and taxa ($P \leq 0.01$) but not between the control and the contaminated pens nor between either pen and the roped area. Differences among sampling dates would be expected because of seasonal responses of the arthropod community, and differences among taxa would be expected because the taxa normally occur at different population densities. Since original areas possessed comparable arthropod species compositions, subsequent differences in community structure cannot be attributed to any pretreatment variabilities. An analysis of all 26 sampling dates confirmed the difference among dates ($P \leq 0.01$) and among taxa ($P \leq 0.01$) as well as the lack of a significant difference among sites. When initial sampling dates were sequentially deleted and the analysis of variance repeated after each deletion, the only significant difference appearing between the control and the contaminated communities occurred 18 weeks after application of the fallout simulant ($P \leq 0.05$). At this time the soil component of the arthropod community had received 1789 rads of beta + gamma dose (Table 2), the litter component 1724 rads, and the grass component 373 to 1295 rads (variable as a function of height). Continuation of this analysis indicated no other significant differences between the arthropod communities. At the time of the 26th sampling date (Mar. 18, 1970), the soil component of the arthropod community had received 7786 rads of beta + gamma dose, the litter component 7165 rads, and the grass component between 1594 and 5404 rads.

For interpreting changes in arthropod community structure through time, an index of species composition dissimilarity¹⁴⁻¹⁷ was calculated for each sampling date and site pair combination: control enclosure vs. roped area, control enclosure vs. contaminated enclosure, and roped area vs. contaminated enclosure. The number of individuals of each arthropod taxon collected from a site on each sampling period was transformed^{15,16} and used to calculate in Euclidean hyperspace the species composition distance, d , between each pair of sites by the following equations:

$$X = \log(y + 1) \quad (1)$$

$$d_{ij}^2 = (X_{1,i} - X_{1,j})^2 + (X_{2,i} - X_{2,j})^2 \dots + (X_{78,i} - X_{78,j})^2 \quad (2)$$

Table 2
TOTAL DOSE FROM SIMULATED RADIOACTIVE FALLOUT TO THREE
COMPONENTS OF THE MANAGED GRASSLAND ARTHROPOD COMMUNITY*

Year	Sampling date	Time after simulant application, weeks†	Total doses to arthropod compartments, ‡ rads		
			Soil surface	Litter	Grass
1968	Aug. 20	2.0	338	407	77 to 300
	Sept. 10	4.9	601	645	131 to 481
	Sept. 24	6.9	782	810	168 to 605
	Oct. 30	12.0	1245	1230	262 to 922
	Dec. 10	18.0	1789	1724	373 to 1295
1969	Feb. 12	27.1	2459	2232	501 to 1685
	Mar. 6	30.4	2914	2744	602 to 2066
	Mar. 27	33.4	3186	2991	658 to 2253
	Apr. 30	38.1	3613	3378	744 to 2545
	May 6	39.0	3694	3452	761 to 2601
	July 1	46.9	4411	4103	907 to 3092
	July 15	48.9	4592	4267	944 to 3216
	Aug. 8	52.4	4910	4555	1009 to 3434
	Oct. 9	61.3	5717	5288	1173 to 3987
	Oct. 24	63.4	5908	5461	1212 to 4117
	Nov. 26	68.1	6334	5848	1299 to 4409
	Dec. 17	71.1	6606	6095	1354 to 4596
1970	Feb. 11	79.1	7332	6753	1502 to 5093
	Mar. 18	84.1	7786	7165	1594 to 5404

*No radiation dose was detected during seven sampling periods from Apr. 1 to June 25, 1968, prior to fallout-simulant application.

†Date of final application of fallout simulant was Aug. 5, 1968.

‡Soil component is at 0.0 cm above ground, litter component at 0.1 to 2.5 cm, and grass component at 2.6 to 32.5 cm.

$$d_{ij} = (d_{ij}^2)^{1/2} \quad (3)$$

where y = number of each taxon collected from each site

d_{ij} = species composition distance between sites i and j

$X_{1,i}$ = value of taxon 1 for site i

$X_{1,j}$ = value of taxon 1 for site j

etc.

The lower the value of d, the greater is the similarity between sites, and vice versa. Results of this analysis (Fig. 3) indicate a seasonal cycle in species composition. Minimums were reached during the winter months, and maximums

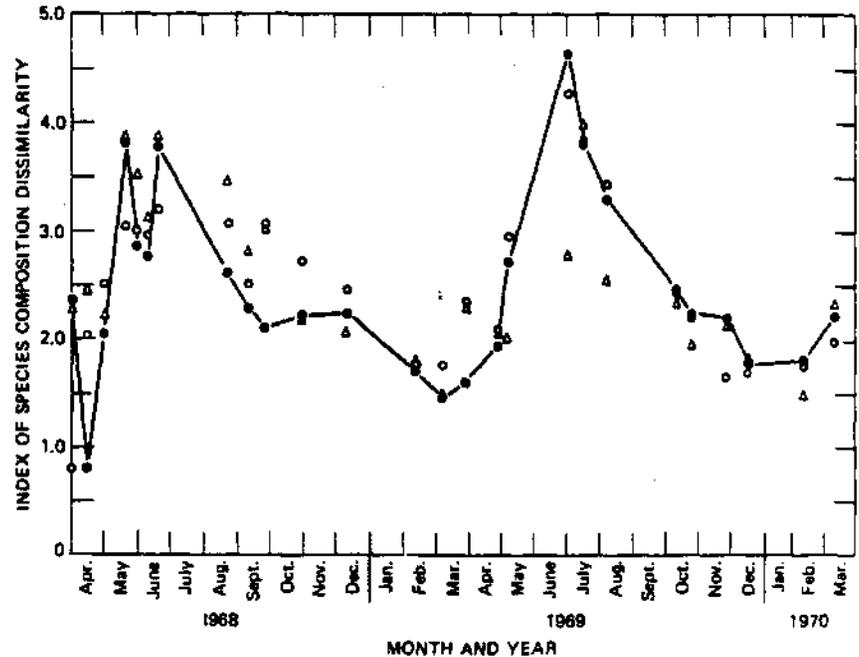


Fig. 3 Index of species composition dissimilarity for the control enclosure vs. the roped area (O), for the control enclosure vs. the contaminated enclosure (●), and for the roped area vs. the contaminated enclosure (Δ) plotted against each sampling date. The effects of changes in species composition in the enclosures is superimposed on a seasonal cycle with minimums of species composition in winter and maximums in summer.

occurred during the summer months. During the winter fewer taxa are active, and the inactive taxa would not contribute to a higher index of dissimilarity. A larger number of active taxa during the summer leads to a greater possible dissimilarity between sites. This sensitive technique¹⁸ for comparison of data shows no significant or consistent change in the dissimilarity between the contaminated pen and either the control pen or the roped area. This analysis indicates that effects of fallout radiation on arthropod species composition of the grassland would not be expected below 13 rads/day delivered over a period of 19 months, a fact also demonstrated in the less rigorous analysis of variance. A likely explanation for this lack of radiation effect lies in the homeostatic mechanisms that enable the community to react to radiation stress in the same manner as to other environmental stresses.⁵ The possibility also exists that, in the context of an entire ecosystem, populations exhibit threshold responses to ionizing radiation. Future analyses, to determine whether either of these suggestions is correct, will be directed toward describing responses of populations and of the soil-litter-grass compartments of the arthropod community.

Additional insights into population responses in fallout areas have been provided by a correlative laboratory study on *Folsomia* species. Survival and reproductive ability of these Collembola were reduced at all 19 beta dose rates tested. The $LDR_{50/30}$ (dose rate estimated to kill 50% of the population in 30 days) for chronically irradiated adults was estimated by least-squares regression analysis to be 174.5 rads/hr (total dose in 30 days of 125.6 krad) and the $LDR_{50/60}$ to be 38.1 rads/hr (total dose in 60 days of 54.9 krad). The effects of chronic beta radiation on fecundity rates (Fig. 4) could not have been anticipated from studies^{19,20} of the effects of acute irradiation alone. After an acute dose of ionizing radiation, fecundity rate of each population was reduced. Under chronic irradiation conditions, however, all fecundity rates were initially at control levels, but rates were reduced through time as doses were accumulated. Change in fecundity rates under chronic irradiation conditions must therefore be represented as the slope of a regression line rather than as a

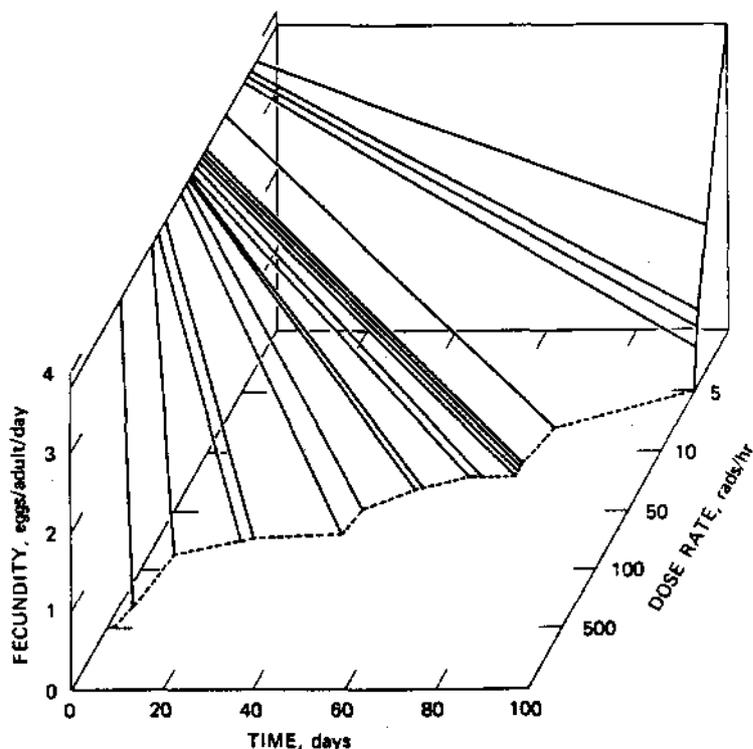


Fig. 4 Isometric projection of fecundity in eggs per adult per day on time in days and ^{90}Sr - ^{90}Y beta-radiation dose rate for *Folsomia* species for continuous exposure at the indicated dose rates. The fecundity rates for each dose rate are presented as a regression on time since the fecundity of each population changed as the total doses of radiation were accumulated.

point. At dose rates greater than 5 rads/hr, fecundity rates rapidly approached zero. Egg mortality (Fig. 5) was increased by chronic dose rates above 13.5 rads/hr, and no eggs hatched at dose rates above 17.4 rads/hr. At 14.5 rads/hr, 38% of the eggs matured into adults, but all were sterile.

These data demonstrate that radiosensitivity of a population of *Folsomia* to beta radiation is manifest primarily in the effect on fertility rates (number of

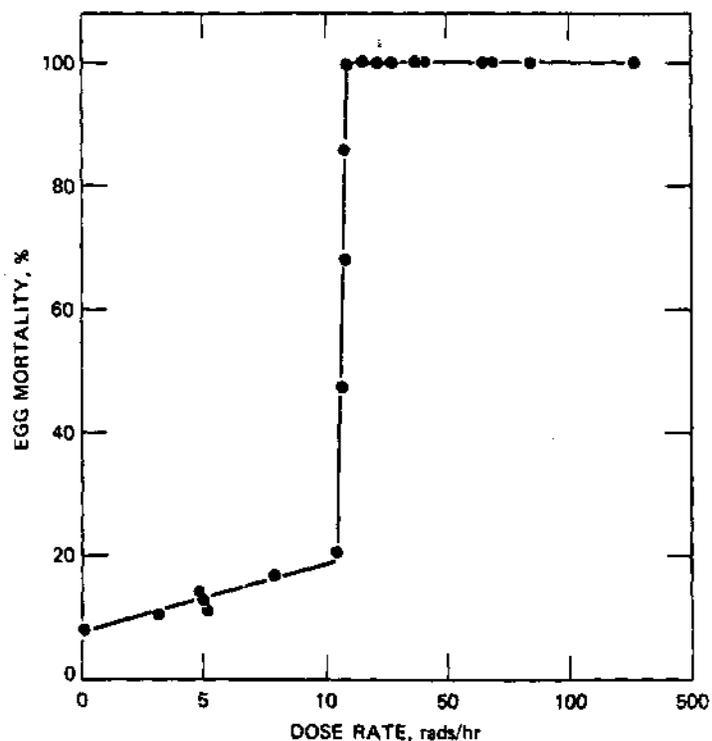


Fig. 5 Egg mortality plotted against ^{90}Sr - ^{90}Y beta-radiation dose rate for *Folsomia* species for continuous exposure at the indicated dose rates. The point at 0 rads/hr represents the mean of 10 control populations.

eggs surviving) rather than on mortality rates of adults. Dose rates estimated to give an $\text{LDR}_{50/30}$ or $\text{LDR}_{50/60}$ for adults are more than twice as high as dose rates required to reduce fertility to zero. Sensitivity of fertility rates to acute irradiation has been demonstrated for another Collembolan (*Sinella curviseta*) population.¹⁹ For the acute irradiation regime in that study, substantial recovery occurred several weeks following irradiation. If a natural population of these Collembola were subjected to acute irradiation during a seasonal cycle of low reproductive activity, recovery could occur before the population entered its

period of maximum reproductive activity. The ecological significance of the sensitivity of fertility rates could thus be masked by seasonal cycles in reproduction. This situation would not be expected to occur for populations under chronic irradiation conditions, since recovery could not occur.

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