# INSECTICIDE EFFECTS ON EARLY SUCCESSION IN AN OLD FIELD ECOSYTEM[1]

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*Abstract.* An ecosystem approach was used to assess the effects of soil contamination with an organophosphate insecticide on ecological succession in a 3-acre old field on the Piedmont of New Jersey. Diazinon was applied to one-half of the field in May 1967 and again in May 1968 at a rate of 12 lbs of active ingredient per acre. A latin square experimental design was used to analyze the effects of the insecticide on the density, diversity, and production of vegetation; the density and diversity of herb-stratum arthropods; and the trophic relationships that developed on treated and untreated areas.

In 1967, insecticide contamination produced a significant enrichment in both density and diversity of vegetation as well as a consistent trend toward greater plant biomass on treated areas. The vegetation changes represented a summation of small but consistent differences in major producers common to both treated and untreated areas. Plant differences were believed due to a phytotoxic effect of diazinon on *Convolvulus sepium*, which was significantly reduced on treated areas. Other plant species normally inhibited by *Convolvulus* subsequently flourished on treated areas.

Herb-stratum arthropod populations were similar on treated and untreated areas in 1967, despite the vegetation differences. Only a trend toward greater insect diversity on treated areas was present. The failure of indirect arthropod differences to develop was due to the similar availability of dominant producers and thus food web bases on treated and untreated areas. Radionuclide tracer studies indicated that ragweed (*Ambrosia artemisiifolia*) was the major food web base for resident consumers in the latter part of the growing season. The trophic transfer from ragweed was quite similar in treated and untreated areas. The lack of arthropod differences was thus attributed to similar availability of ragweed biomass in both areas.

Vegetation differences were absent in 1968 following a second treatment with diazinon. Moisture appeared to be a major factor influencing the impart of the insecticide during the two summers. Vegetation differences developed in June 1967 at a time when rainfall was almost absent. In 1968, however, considerable rainfall occurred during the same period. The increased rainfall stimulated a greater seedling development than in 1967, thus apparently overcoming the effects of the insecticide. Environmental factors such as soil moisture can therefore interact with pollutants and seriously influence the degree of ecosystem modification.

Experimental research is currently needed to assess the residual effects of organic insecticides on our natural ecosystems. Little is yet known about the ecological effects of insecticide residues, many of which are known to be quite persistent in nature (Edwards 1966, Nash and Woolson 1967, Woodwell *et al.* 1967). Past insecticide studies (Rudd 1964) have focused mainly on the effects on a single biotic component of an ecosystem. Only recently have integrated ecosystem approaches been attempted (Barrett 1968, Malone 1969) which stress both direct and indirect effects of insecticides on trophic interactions.

Concern has developed over the possible consequences of insecticide residues on secondary succession in abandoned farmland (Egler 1964, Rudd 1964). Malone (1969) used a high soil residue of diazinon, an organophosphate insecticide, to study the effects of an insecticide stress on early succession in an abandoned field in New Jersey. Malone found that diazinon residues induced floristic enrichment during the first year of succession. Changes in herb-stratum arthropod populations also resulted, some of which were suggestive of food chain alterations and thus represented indirect effects of the insecticide. Other indirect effects of insecticides have been reported (Edwards 1966, Barrett 1968), which further emphasize the need for an ecosystem approach to the pesticide problem.

The present study was designed to determine if the significant results obtained by Malone could be repeated under similar conditions and to isolate the causative mechanisms for any indirect insecticide effects on food web components. Diazinon was again used to study the effects of soil residues on secondary succession in an old-field ecosystem. Experimental treatments were replicated over two successive summers to enable temporal comparisons between different years as well as comparisons with Malone's study.

Past insecticide research has dealt only with the structural composition of experimental and control communities. Attempts to define causal mechanisms for indirect effects are thus usually speculative.

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Radioactive tracers, however, afford one means of identifying these causal mechanisms through analysis of the functional processes of ecosystems (i.e. food chains, energetics). Radionuclide tracer techniques were thus used in the present research to investigate possible insecticide effects on trophic relationships in both experimental and control areas. This method provides a direct measure of the influence of changes at one trophic level on other food web components.

## Materials and Methods

Diazinon is a short-lived (Malone *et al.* 1967), wide-spectrum (Mulla 1965, Harris and Mazurek 1966) organophosphate insecticide. It was selected for use in insecticide studies at Rutgers University (Malone *et al.* 1967) due to its future potential for agricultural usage and because it was believed that a single, moderately heavy application of a short-lived insecticide would induce responses characteristic of contaminated ecosystems yet permit the ecosystem to recover fairly rapidly.

The study was conducted in a 3-acre field (Fig. 1) adjacent to Hutcheson Memorial Forest in East Millstone, New Jersey. The field, located on the Piedmont Plateau, had a soil type of primarily silt loam (Ugolini 1964) with a slopeless topography. The field had been cultivated with orchard grass (*Dactylus glomerata*) since 1962. The patterns of secondary succession in fields of this area have been well documented (Bard 1952, Pearson 1959).

The entire 3-acre field was deeply plowed and disced twice during April 1967. After discing, the field was subdivided into paired treated and untreated subplots, each about 0.75 acres. Diazinon was then sprayed on both treated subplots on May 5, 1967 at a rate of 12 lbs active ingredient per acre. The insecticide was applied, carrier free, as a 50% wettable powder using a commercial spraying vehicle. Both treated and untreated subplots were disced to a depth of 5 cm on May 5 thereby creating an insecticide residue in the soil of the treated area. The field was then left to natural revegetation until April 1968 when the experiment was repeated. The field was deeply plowed again on April 16, 1968 and disced twice on April 30. Diazinon was applied to the same treated subplots on May 9 using the same formulation, rate and spraying apparatus. All subplots were disced and abandoned.

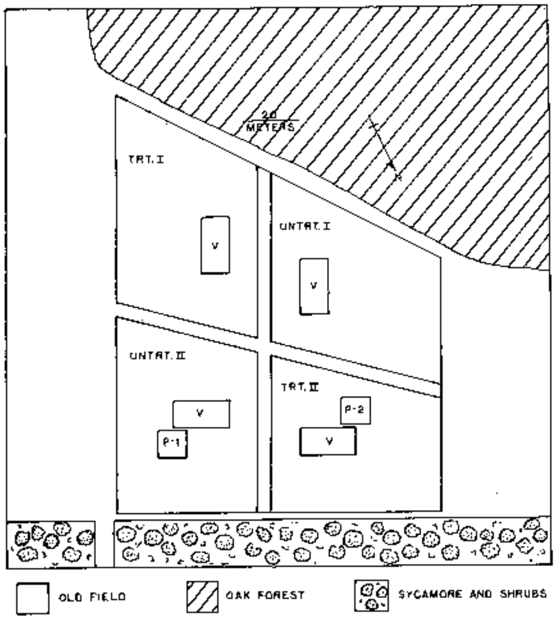

Fig 1. Diagram of 3-acre study area showing paired treated (Trt.) and untreated (Untrt.) subplots. Locations of 10–20 m vegetation sampling areas (V) and 100 m² tracer quadrats (i.e., P–1) are indicated.

Soil samples were collected periodically during both summers to determine the persistence of diazinon residues. Samples were collected at depths of 0–5 and 10–15 cm in treated areas to follow the distribution and vertical movements of the insecticide. Untreated samples were also collected periodically to check for lateral contamination. Each soil sample was composited from four equal portions (2 qt—1967, 1 qt—1968) collected at random within each subplot. Eight hundred grams of soil were removed from each composite and mixed with petroleum ether at a 1:1 ratio for diazinon extraction. Liquid aliquots were collected from the soil-ether mixture following a one-hour agitation on a roll mill tumbler. Aliquots were later analyzed for diazinon content using gas chromatographic facilities of the Department of Agricultural Chemistry at Rutgers University.

Vegetation was harvested from within 10 × 20 m quadrats (Fig. 1). The same quadrat locations were used both summers. Twenty, ¼ m² areas were harvested, five from each quadrat, at two-week intervals over the growing season. Sample locations were selected using a table of random numbers. All plants within each ¼ m² area were clipped at ground level, bagged and returned to the laboratory. Each sample was sorted by species, oven dried at 90° C for 24 hrs, and weighed for biomass estimations. Treated and untreated plant communities were compared throughout the growing season for changes in density, biomass and species diversity.

Arthropods associated with the herbaceous vegetation were sampled in 1967. A 10-sweep removal technique (Crossley and Howden 1961, Malone 1969) was used to sample the arthropods from 1 m² of vegetation. The sweep net had a diameter of 30 cm, a 1-mm mesh and a 93-cm handle. Samples were collected on three dates beginning in early July and at three-week intervals thereafter. Twenty sweep samples were obtained on each date, five from at random within each treated and untreated subplot.

Treated and untreated areas were then compared for significant differences in total insect density, density of major orders and species diversity.

All comparisons of plant and animal communities were made using a 2 × 2 latin square design for the analysis of variance (Steel and Torrie 1960). Significant differences were expressed graphically by using least significant intervals. These intervals represent an extension (± Lsd/2) of the least significant difference (Steel and Torrie 1960) and were computed at the .05 level.

Radionuclide tracer studies were conducted to determine any indirect effects of diazinon on trophic relationships in the old-field ecosystem. Ragweed (*Ambrosia artemisiifolia*) was labeled with $P^{32}$ in both treated and untreated areas to compare the trophic transfer from this dominant producer at its peak biomass level. The methodology followed similar tracer studies by Odum and Kuenzler (1963), Marples (1966) and Wiegert *et al.* (1967).

Two 10 × 10 m quadrats were set up, one untreated (P-1) and one treated (P-2), for conducting trophic transfer studies (Fig. 1). Each quadrat was subdivided into twenty-five, 4 $m^2$ sections in which eight ragweed plants were labeled. On August 7, 1967, 18 $\mu c$ of $P^{32}$ were added to each of 200 plants in the untreated quadrat while 24 $\mu c$ were used per plant on August 16 in the treated area. All plants were labeled using a "stem well" method (Wiegert and Lindeborg 1964).

Consumer populations were sampled from each quadrat on seven dates over a 42-day period. Herb-stratum arthropods were collected with a sweep net by taking ten sweeps while moving systematically through the quadrat. Arthropods associated with the ground or litter layer (i.e. crickets, ground beetles) were collected from under twelve 19 × 47 cm cryptozoan boards placed in a uniform grid within each quadrat. Arthropod samples were sorted by species in the lab and radioassayed intact using an organic quenched G.M. detector (Baird Atomic, model EWT-64) with a 1.4 mg/$cm^2$ end window and a decade scaler (Baird Atomic, model 135). Each species group was then dried at 100° C for 24 hr and weighed with a semi-micro analytical balance (± 0.1 mg) to obtain activity density (cpm/mg dry wt) estimations.

The uptake of $P^{32}$ by consumer species was estimated using trophic transfer indices (Wiegert *et al.* 1967). The formula

$$\text{Trophic Transfer Index} = \frac{\text{mean activity density consumer}}{\text{mean activity density plant foliage}} \times \text{Total consumer biomass (dry wt) sampled}$$

estimates the relative importance of consumer species in the isotope transfer along food chains. It represents the mean concentration factor of a consumer species times its population biomass. Samples of leaf and pollen tissue were also collected periodically to estimate the mean activity density of plant foliage. Plant samples were assayed in the same manner as arthropod species.

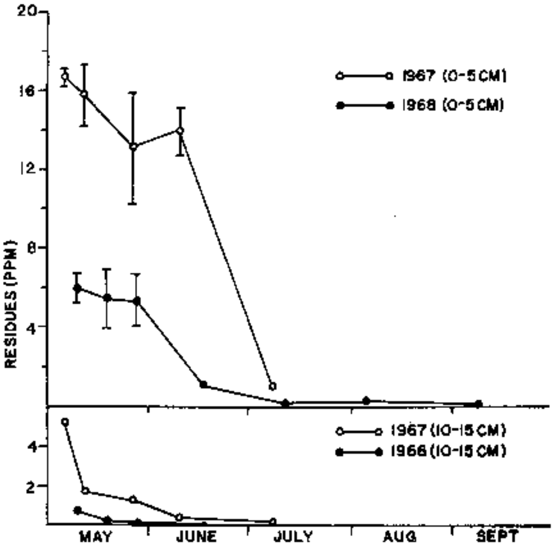

FIG. 2. Soil residue levels (ppm) of diazinon in treated areas during 1967 and 1968. Means (N = 4) plus one standard error are presented for (0–5) cm depths, while data points for (10–15) cm were averaged from single treated I and II estimates. Initial residue levels were determined within 6 hours post treatment.

## RESULTS

Diazinon was fairly short-lived in the soil during both summers (Fig. 2). Residue levels in the upper 5 cm decreased slowly at first, then dropped rapidly to below 1.0 ppm by two months post treatment. Initial residue levels, however, were only half as great in 1968, with a more rapid breakdown also occurring during the second summer. Diazinon was still detected in November 1968, but only at trace levels. Residues were also recorded initially from the 10–15 cm depth indicating some deeper mixing of the insecticide. These levels decreased rapidly, however, with no indication of diazinon leaching from the upper soil layers. No evidence of lateral contamination of untreated areas occurred either summer.

Differences were present in the plant communities that developed on treated and untreated areas in 1967. Plant density was significantly greater on treated areas over most of the growing season (Fig. 3). Plant density also peaked two weeks earlier in the treated areas. Total plant biomass was also consistently greater on treated areas (Fig. 4). Biomass differences were significant only in early June, however, due to the large variance associated with a ¼ $m^2$ sampling size.

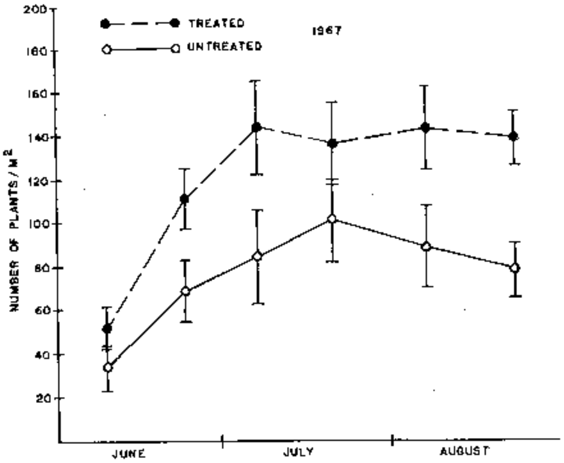

FIG. 3. Plant density during the 1967 growing season. Means (number/m²) and least significant intervals (see text) are presented with differences compared separately on each sample date using the analysis of variance.

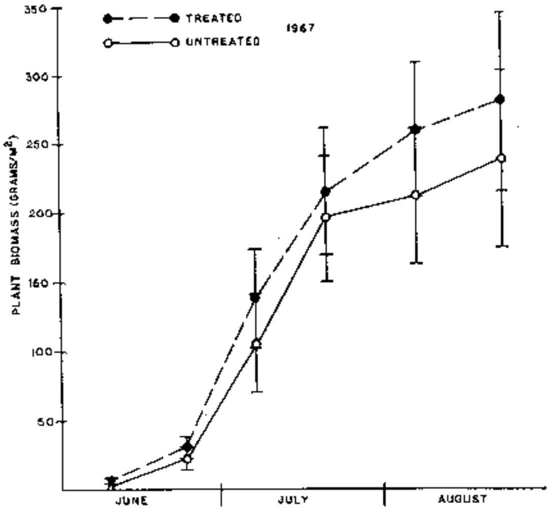

FIG. 4. Total standing crop biomass of vegetation during 1967. Means (g dry wt/m²) and least significant intervals are presented.

Plant diversity was compared using information theory (Shannon 1948, Lloyd *et al.* 1968). The Shannon formula $H' = -\Sigma p_i \log p_i$ was applied to the density data from each ¼ m² sample harvested on each sample date. Ten treated and ten untreated diversity indices were then analyzed for significant differences using the analysis of variance. Plant diversity was only slightly greater in treated areas during early vegetational development (Fig. 5). Diversity increased sharply during June but at a significantly greater rate in the treated areas. Plant diversity remained significantly greater on treated areas until mid-July when new species appearing on untreated areas increased diversity and made the differences nonsignificant. Diversity differences were again significant by late August.

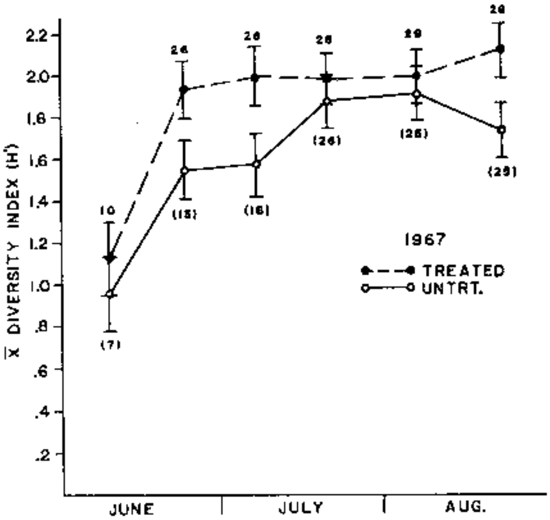

FIG. 5. Diversity of vegetation in 1967. Means of ten diversity indices, calculated using information theory (H') for each ¼ m² sample, are presented. Diversity indices were compared by analysis of variance with least significant intervals included. Total numbers of species recorded on each sample date in treated and untreated areas are indicated.

Plant species composition was quite similar in treated and untreated areas (Table 1) despite the differences in total community responses. Wild radish (*Raphanus raphanistrum*) and ragweed (*Ambrosia artemisiifolia*), the major producers in early and late summer respectively, reached their peak standing crop biomass at the same time in both areas. Other important producers were also present in both areas, with no major phenological differences in arrival at peak biomass. Nearly all plant dominants, however, were greater in density and biomass on treated areas (Table 1). Only hedge bindweed (*Convolvulus sepium*) was significantly more dense on untreated areas, with a much greater untreated biomass also.

Vegetation results were different in 1968 as compared with 1967. Temporal changes in total density, biomass and diversity of vegetation differed markedly from 1967 with no significant differences developing between treated and untreated areas. Greater numbers of seedlings germinated in the old field during 1968 (Fig. 6) with peak densities reached much earlier than 1967. Only in early June was plant density appreciably greater in treated areas. Plant biomass, which was more bimodal during 1968, was also quite similar on treated and untreated areas (Fig. 7). Plant diversity increased more rapidly during 1968 as species appeared earlier on both areas (Fig. 8). Only a slight trend toward greater plant diversity on treated areas was present the second summer. Plant species composition on treated and untreated areas was also similar in 1968 (Table 2) and involved the same species present during 1967.

TABLE 1. Mean biomass (g dry wt/m²) and density per m² of major plant species at their peak standing crop in both treated (Trt.) and untreated (Untrt.) areas in 1967. Statistical comparisons are included for species averaging at least 5 g/m² in either community. F values represent latin square analysis of variance comparisons between treated and untreated areas

| | Biomass | | | | | Density | | |
|---|---|---|---|---|---|---|---|---|
| | Trt. | | Untrt. | | | Trt. | Untrt. | |
| | g/m² | Date | g/m² | Date | F | No./m² | No./m² | F |
| *Raphanus raphanistrum* | 79.6 | 7/21 | 91.2 | 7/21 | 0.04 | 12.0 | 8.0 | 0.67 |
| *Ambrosia artemisiifolia* | 226.4 | 8/23 | 210.8 | 8/23 | 0.07 | 15.6 | 9.2 | 5.38* |
| *Convolvulus sepium* | 10.4 | 7/21 | 32.0 | 7/21 | 2.29 | 5.6 | 14.0 | 5.00* |
| *Chenopodium album* | 12.8 | 8/23 | 1.3 | 7/21 | 4.07 | 8.0 | 4.8 | 2.04 |
| *Acalypha rhomboidea* | 7.6 | 8/23 | 4.6 | 8/8 | 2.48 | 21.6 | 18.4 | 0.59 |
| *Rumex acetosella* | 15.6 | 8/8 | 5.2 | 7/21 | 2.62 | 24.8 | 4.4 | 4.40 |
| *Linaria vulgaris* | 9.2 | 8/23 | 2.8 | 8/8 | 1.64 | 11.2 | 4.4 | 2.77 |
| *Dactylis glomerata* | 16.4 | 8/8 | 1.4 | 8/23 | 1.47 | 1.2 | 0.4 | — |
| *Setaria viridis* | 6.4 | 8/8 | 2.9 | 8/23 | 0.46 | 3.6 | 3.2 | — |
| *Cyperus odoratus* (?) | 1.2 | 8/23 | 2.0 | 8/23 | — | 2.0 | 0.8 | — |
| *Digitaria sanguinalis* | 2.0 | 8/23 | 0.4 | 8/8 | — | 7.6 | 6.4 | — |

*Significant at .05.

TABLE 2. Mean biomass (g dry wt/m²) and density per m² of major plant species at their peak standing crop in both treated (Trt.) and untreated (Untrt.) areas in 1968. Statistical comparisons are included for species averaging at least 5 g/m² in either community. F values represent latin square analysis of variance comparisons between treated and untreated areas

| | Biomass | | | | | Density | | |
|---|---|---|---|---|---|---|---|---|
| | Trt. | | Untrt. | | | Trt. | Untrt. | |
| | g/m² | Date | g/m² | Date | F | No./m² | No./m² | F |
| *Raphanus raphanistrum* | 56.4 | 7/10 | 61.2 | 7/10 | 0.08 | 48.0 | 46.8 | 0.03 |
| *Ambrosia artemisiifolia* | 81.2 | 8/22 | 90.8 | 8/22 | 0.16 | 20.4 | 16.4 | 1.22 |
| *Convolvulus sepium* | 19.6 | 7/10 | 33.6 | 8/8 | 2.78 | 28.0 | 43.6 | 2.53 |
| *Acalypha rhomboidea* | 21.6 | 8/22 | 19.2 | 8/22 | 0.13 | 91.2 | 61.2 | 2.30 |
| *Rumex acetosella* | 21.6 | 7/10 | 6.8 | 8/8 | 2.48 | 46.4 | 24.8 | 1.33 |
| *Cyperus odoratus* (?) | 6.8 | 8/22 | 0.6 | 8/8 | 4.82* | 15.2 | 2.8 | 3.73 |
| *Polygonum pensylvanicum* | 1.0 | 8/8 | 14.0 | 8/22 | 1.18 | 1.2 | 3.6 | — |
| *Chenopodium album* | 4.4 | 8/8 | 0.8 | 7/25 | — | 18.4 | 6.8 | 4.56* |
| *Digitaria sanguinalis* | 3.3 | 8/22 | 4.8 | 8/22 | — | 7.2 | 8.0 | — |
| *Setaria viridis* | 1.0 | 8/22 | 3.4 | 8/8 | — | 4.0 | 6.0 | — |

*Significant at .05.

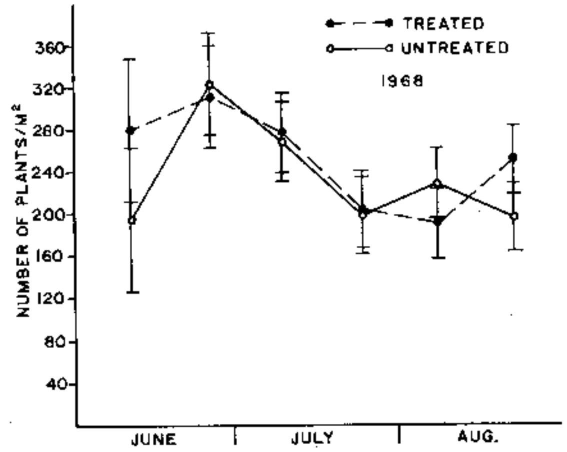

FIG. 6. Plant density during the 1968 growing season. Means (number/m²) and least significant intervals are presented.

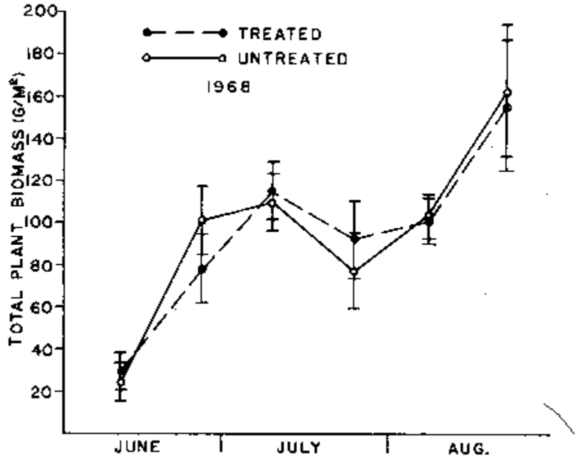

FIG. 7. Total above ground biomass of vegetation during 1968. Means (g dry wt/m²) and least significant intervals are presented.

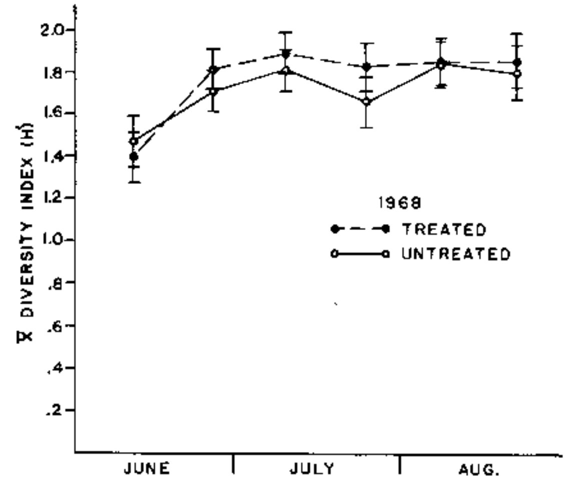

FIG. 8. Diversity of vegetation in 1968. Means of ten diversity indices are presented with least significant intervals included.

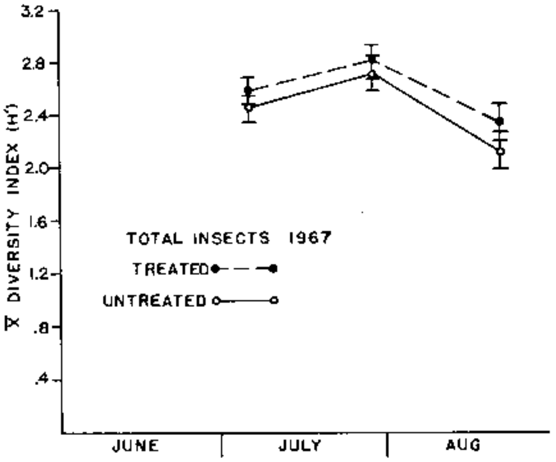

FIG. 9. Total insect diversity during 1967. Mean diversity indices (H') and least significant intervals are indicated.

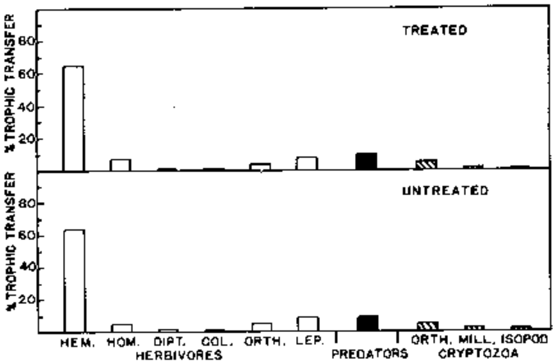

FIG. 10. Trophic transfer distribution among taxonomic components of the ragweed food web on untreated (P–1) and treated (P–2) areas. Histograms indicate the percentage of total trophic transfer (ΣTTI) that occurred by each taxon. Arthropod taxons include hemipterans (hem.), homopterans (hom.), dipterans (dipt.), coleopterans (col.), orthopterans (orth.), lepidopterans (lep.) and millipedes (mill.).

A few species, however, were again greater in density and biomass on treated areas in 1968, while hedge bindweed was still more prevalent on untreated areas.

Herb-stratum arthropod populations were similar on treated and untreated areas in 1967, despite the differences in producer populations. Total insect density increased greatly on both areas during July and August, with no significant differences developing (Table 3). The densities of major insect orders were also similar on treated and untreated areas throughout the growing season (Table 3). Insect diversity was calculated at the species level using the Shannon information formula (Fig. 9). A consistent trend toward greater insect diversity was correlated with the greater plant diversity in treated areas. The differences were insignificant, however, when compared by analysis of variance.

The radionuclide tracer studies were successful in determining the trophic transfer from ragweed in treated and untreated areas. Approximately 30 species of arthropods became labeled in each plot and thus were components of the ragweed food web. These species included all major consumers in the old field during the latter part of the growing season.

No major differences were present in the trophic transfer from ragweed on treated and untreated areas (Fig. 10). The major taxonomic components of each trophic level and their relative importance in trophic transfer were similar in both areas. Plant bugs (Miridae, Hemiptera) were the major ragweed consumers in both plots, with *Lygus pratensis, Reuteroscopus ornatus* and *Plagiognathus politus* accounting for 74.1% (P-2) and 74.5% (P-1) of all herbivore transfer. Meadow spittlebugs (*Philaenus spumarius*), red-legged grasshoppers (*Melanoplus femurrubrum*) and lepidopteran larvae were also important herbivores on both areas. Spiders and ladybird beetles (*Coleomegilla maculata*) were the major predators in both areas, while field crickets (*Nemobius fasciatus*) and ground beetles (*Harpalus pennsylvanica*) were the chief cryptozoan consumers. A detailed consideration of the ragweed food web will be presented in a subsequent paper.

## DISCUSSION

The impact of soil contamination with diazinon on the community developing during old-field succession was quite different when compared for three successive summers. In 1966, Malone (1969) found that diazinon contamination (14 lbs/acre) induced enrichment of density, diversity and net primary pro-

TABLE 3. Insect densities on treated (T) and untreated (U) areas during 1967. Mean densities/m² plus one standard error are presented with F values derived from latin square analysis of variance comparisons

| | | July 6 | | July 29 | | August 22 | |
|---|---|---|---|---|---|---|---|
| | | No./m² | F | No./m² | F | No./m² | F |
| Hemiptera | T | 11.5±3.0 | 2.88 | 24.8±2.5 | 5.29* | 108.4±19.1 | 0.36 |
| | U | 6.9±0.8 | | 34.0±3.0 | | 97.4±10.5 | |
| Homoptera | T | 15.4±2.0 | 0.85 | 14.3±1.8 | 1.07 | 24.7± 2.1 | 0.05 |
| | U | 17.6±1.8 | | 16.6±1.2 | | 24.0± 2.4 | |
| Coleoptera | T | 3.5±0.8 | 0.32 | 14.8±3.8 | 0.20 | 5.8± 1.0 | 0.15 |
| | U | 4.3±1.3 | | 17.0±3.7 | | 5.3± 0.9 | |
| Diptera | T | 15.1±2.5 | 1.25 | 18.1±2.2 | 1.31 | 13.3± 1.9 | 4.20 |
| | U | 12.7±1.5 | | 14.6±2.1 | | 8.6 ±1.2 | |
| Hymenoptera | T | 2.8±0.8 | 0.03 | 5.6±2.0 | 0.01 | 2.5± 0.6 | 0.07 |
| | U | 3.0±0.7 | | 5.4±1.6 | | 2.3± 0.6 | |
| Orthoptera | T | 0.0 | — | 0.4 | — | 0.4 | — |
| | U | 0.5 | | 0.1 | | 0.0 | |
| Lepidoptera | T | 0.6 | — | 0.7 | — | 1.3 | — |
| | U | 0.0 | | 0.5 | | 0.8 | |
| Total | T | 48.9±6.9 | 0.50 | 79.1±4.5 | 2.00 | 156.5±19.8 | 0.79 |
| | U | 45.0±3.7 | | 88.7±5.7 | | 138.9±11.6 | |

*Significant at .05.

duction of vegetation. Treated and untreated communities were distinctly different in their composition of dominant producers. In the present study, a significantly greater density and diversity of vegetation and a trend toward greater biomass occurred on treated areas in 1967. Species composition, however, was quite similar on treated and untreated areas. No significant differences developed in vegetational communities following the 1968 treatment. Trends persisted for certain plant species but were absent at the community level.

Residue levels, moisture and seed availability may have interacted to produce the decline in diazinon impact on producer populations over the three summers. Initial residue levels in the soil were inversely related with the extent of vegetation changes. Mean residue levels on day 0 were 155 ppm in 1966 as compared with 17 ppm and 6 ppm in 1967 and 1968, respectively. Although diazinon disappeared more rapidly in Malone's study in 1966, levels remained above those of the present study for over a month. The wide difference in residue levels may have caused differential toxic effects in the soil with different degrees of community changes resulting.

The time and extent of rainfall also varied considerably during the three summers (Fig. 11). Low rainfall during 1966 represents the fifth year of an extended drought in the Northeastern United States. This drought stress may have interacted with the high level of diazinon residues to augment vegetational differences induced by the insecticide (Malone 1969). Precipitation was greater during the 1967 growing season. Little rainfall resulted during late May and early June when seedling germination was most prevalent. Vegetation differences had thus developed before most precipitation had occurred. The reduced magnitude of the plant differences in 1967 may be partly a result of the increased precipitation that occurred during July and August. In 1968 most precipitation was from mid-May to mid-June with greater numbers of seedlings resulting during this period (Fig. 6). The 1967 seed crop may have contributed to the greater seed germination in 1968 despite the deep plowing in April. However, the interaction of low residues and increased precipitation during seedling germination in 1968 was apparently sufficient to prevent vegetation differences from developing.

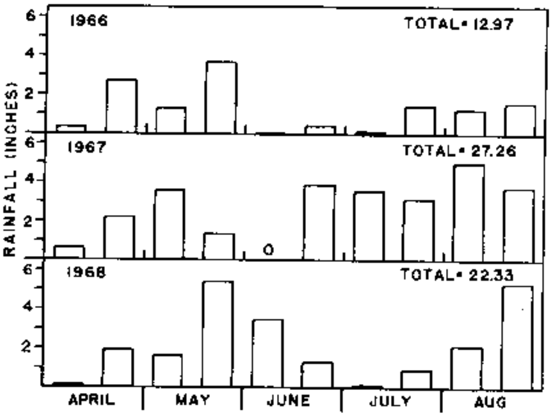

FIG. 11. Rainfall from April through August in 1966–1968. Histograms indicate total rainfall for half-month periods beginning the 1st and 16th day of each month. Data were obtained from records maintained at Hutcheson Memorial Forest in East Millstone, New Jersey.

Soil moisture thus appears to have had a major influence on the impact of diazinon contamination over the 1966–1968 summers. Lichtenstein and Schulz (1964) and Harris (1967) have found that soil moisture influences the toxicity or persistence of organophosphate insecticides in soil environments. Harris reported soil moisture variation produced up to a 100-fold difference in the toxicity of diazinon. Streu and Vasvary (1967) have shown that high soil moisture levels can offset the effects of soil treatments with organophosphate insecticides, including diazinon, on vegetation growth in turf grass communities. Vegetation differences induced by other stresses such as ionizing radiation have also been offset by increased soil moisture levels (Daniel and Platt 1968).

Several mechanisms have been proposed to explain the vegetative enrichment following soil contamination with organophosphate insecticides in agricultural (Tarjan 1964, Winchester and Burt 1964, Streu and Vasvary 1966, 1967) and old-field (Malone 1969) communities. These mechanisms include plant growth stimulation by insecticide control of phytophagous soil invertebrates, phytotoxic effects on seeds or seedlings of inhibitory plant species with subsequent flourishing of inhibited species, and direct enrichment by a fertilizer effect. In the present study, differential phytotoxicity appears to be a major causal mechanism for vegetative enrichment on treated areas. Hedge bindweed (*Convolvulus sepium*) formed a dense vegetative mat during early summer when most other seedlings were appearing. Growth forms of other species were observed to be altered depending on the degree of bindweed cover. Bindweed, however, was significantly reduced on treated areas in 1967. An increased density and biomass of most major producers was correlated with the reduced bindweed cover on treated areas. It seems probable then that the seeds, rhizomes or seedlings of bindweed were adversely affected by soil contamination with diazinon. Species normally inhibited by this early summer dominant then flourished on treated areas. In 1968, however, the increased moisture or lower residue levels were apparently sufficient to offset the inhibitory effects of hedge bindweed.

Other evidence supports this phenomenon. Organophosphate insecticides have been found to damage the seeds and seedlings of certain plant species (Bowling and Hudgins 1966, Bowling 1967), while diazinon itself is believed to have some phytotoxic properties (Edwards 1965). Research by J. A. Quinn (personal communication) at Rutgers University has also indicated inhibitory capacities of hedge bindweed on some of the same species that occurred in the present study. "Stresses" applied to other ecosystems have also upset interspecific plant relationships leading to increased growth of normally inhibited species. Moore (1967) found that plant diversification occurred when a pesticide caused the removal of a dominant overstory species in a forest community. Several studies concerning the effects of ionizing radiation on old-field vegetation (McCormick and Platt 1962, Woodwell and Oosting 1965, Daniel and Platt 1968) have indicated an increased abundance of radioresistant species by release from competition with radiosensitive species.

The failure of indirect arthropod differences to develop in 1967 is attributed to the similarity in dominant producers on treated and untreated areas. Differences in availability of major food web bases were not as significant as in Malone's study. Tracer studies showed no major differences in the trophic transfer from ragweed in treated or untreated areas. The importance of this dominant producer as a major food web base was verified by the tracer studies. Approximately 90% of all arthropods sampled in both treated and untreated areas were from labeled species groups and thus food web components of ragweed. This further explains the lack of herb-stratum arthropod differences in late summer, since ragweed biomass was similar in treated and untreated areas.

Pesticides and other pollutants are usually believed to induce simplification in natural ecosystems (Pimentel 1961, Cole 1964). Our studies on soil contamination with diazinon, however, have shown significant increases in producer diversity with the addition of a potential stress to an old-field ecosystem. Insecticides, by inducing simplification of phytophagous soil invertebrates or through differential phytotoxicity may actually remove a natural "stress" from many components of producer trophic levels. Resulting increases in producer diversity may then lead to increased consumer diversity through greater availability of food web bases. Additional integrated studies are thus needed for a more complete assessment of pollution effects on ecosystem diversity as well as functional ecosystem processes.

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