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Effects of Nutrient Enrichment on the Producer Trophic Level of a Six-Year Old-Field Community[1]

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ABSTRACT. **The effects of nutrient enrichment (i.e., application of sewage sludge and fertilizer) on a 6-year-old-field community were investigated. Vegetation was harvested in eight 0.1-ha plots comprising three treatments. Three plots were treated five times annually (May-September) with sludge; three plots were treated with an equivalent nutrient subsidy of urea-phosphate fertilizer; and two plots were left as untreated controls.**

Nutrient-enriched plots, dominated by the annuals *Ambrosia trifida, Ambrosia artemisiifolia,* and *Lactuca scariola,* exhibited lower species richness values but greater evenness values than the controls, which were dominated by the perennials *Solidago canadensis* and *Rubus frondosus.* Primary productivity values ($g \cdot m^{-2} yr^{-1} \pm$S.D.) for fertilizer, sludge, and control plots were 1737±304, 1384±222, and 1009±56, respectively. Fertilizer-treated plots exhibited significantly greater ($P < 0.05$) productivity than control plots.

Changes in plant species composition, diversity, and productivity suggest that nutrient-enriched plots are representative of an earlier seral stage of old-field succession as compared to controls. We conclude that continuous nutrient enrichment of old-field communities retards secondary succession when application is initiated immediately following agricultural practice.

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INTRODUCTION

The disposal of sewage sludge poses an ecological dilemma. Its high nutrient content can increase primary productivity, whereas its heavy metal content can adversely affect natural systems. An ideal site for sludge disposal has yet to be found. Evans (1973) suggested that the effects of sludge should be determined for various community types. Although the effects of sewage sludge disposal have been investigated on agricultural (Hinesly and Sosewitz 1969, Sopper and Kardos 1973) and forest (Sopper and Kardos 1973) communities, its effects on old-field communities have not been adequately determined.

Old-field communities may be the most efficient sites for sludge disposal. These communities are highly productive (Odum 1960), have closed inorganic nutrient cycles (Golley 1965), and should quickly assimilate sludge with minimal direct impact to man. This long-term study was designed to evaluate the effects of sewage sludge on an old-field community. Fertilizer was used to provide an equivalent and contrasting form of nutrient enrichment in which pollutants such as heavy metals were minimal (Anderson et al. 1982, Maly and Barrett 1984, Kruse and Barrett 1985).

Previous research on nutrient enrichment of old-field communities indicates that community composition, species diversity, and net primary productivity are each affected. The effect on community composition has varied with the duration of nutrient application. Short-term

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nutrient enrichment (i.e., one growing season) has resulted in a shift in dominance to later successional species (Mellinger and McNaughton 1975, Bakelaar and Odum 1978). Long-term subsidy, however, has resulted in a shift to earlier successional species (Maly and Barrett 1984). Both short-term and long-term nutrient enrichment have resulted in decreased species diversity (Bakelaar and Odum 1978, Maly and Barrett 1984) and increased net primary productivity (Hurd and Wolf 1974, Mellinger and McNaughton 1975, Reed 1977, Bakelaar and Odum 1978, Magdoff et al. 1980, Maly and Barrett 1984). Hence, changes in composition appear more dependent upon the duration of nutrient application and the seral stage at which enrichment began than are changes in diversity and productivity.

Decreased diversity and increased productivity support Odum's (1969, 1985) hypothesis that nutrient application to a community should result in a reversal of ecological succession to an earlier seral stage. The effects of nutrient application on community development when enrichment was initiated at the beginning of secondary succession have not been fully evaluated. This study evaluates the effects of contrasting types of nutrient enrichment in the sixth year of secondary succession. Both fertilizer and sewage sludge application were initiated during the first year of old-field succession in 1978.

MATERIALS AND METHODS

This study was conducted at the Miami University Ecology Research Center, Oxford, Ohio. The study area consisted of eight 0.1-ha plots comprising an old-field community in the sixth year of secondary succession. This design represents a completely randomized replicate system (Hurlbert 1984). The experimental design is depicted graphically and discussed in detail in Anderson and Barrett (1982) and Anderson et al. (1982).

Plots were plowed, disked, and fertilized (336 kg · ha^{-1}) with commercial fertilizer (N-P-K, 12-12-12) in 1977. All plots were planted with winter wheat (*Triticum aestivum* var. Ranger) in October, 1977. The wheat was not harvested in 1978, and the plots were permitted to go fallow. Hence, the communities entered the first year of secondary succession in 1979 (Anderson et al. 1982).

Plots were randomly divided into three treatment groups. Three replicate plots were treated with fertilizer; three were treated with municipal sludge; and two were left as untreated controls (Anderson et al. 1982, Anderson and Barrett 1982). The fertilizer was a urea-phosphate commercial fertilizer (N-P-K, 6-2-0) with no inert filler added. It was applied monthly (May to September) at a rate of 314 kg · $ha^{-1}mo^{-1}$. The sewage sludge was Milorganite, an anaerobically digested, heat-dried commercial sludge (N-P-K, 6-2-0). It was applied on the same days as was the fertilizer at a rate of 1,972 kg · $ha^{-1}mo^{-1}$ to give a N-P-K subsidy equivalent to the fertilizer.

All above-ground vegetation was harvested from four randomly selected 0.25-m^2 circular quadrats within each plot. Sampling began in late April and continued at three-week intervals through October. Vegetation was separated into litter, live, and standing dead plant material. Live vegetation was separated into species. All vegetation was oven-dried at 80 °C for 48 hours and weighed to the nearest 0.1 g · Community composition, species diversity, and primary productivity were determined.

All species that occurred at any time during the growing season were included in the analysis of community composition. A species was defined as important if it accounted for greater than 5% of the mean annual primary productivity per treatment, and was considered dominant if it accounted for more than 10% of the annual primary productivity.

Species richness was determined by calculating mean number of species per m^2 per treatment. Species apportionment was determined with Pielou's (1966) evenness index ($e = H'/\ln S$), where H' is the Shannon-Weiner function and S is the total number of species.

Net daily productivity (g · $m^{-2}day^{-1}$) was estimated by summing the increment of new plant biomass accumulated for each species since the previous sampling date. This sum was divided by the number of days between sampling dates. Annual productivity (g · $m^{-2}yr^{-1}$) was determined by summing peak biomass values for each species during the entire growing season.

Mean values of each index were calculated for each treatment. Results were tested for significance ($P < 0.05$) with analysis of variance (ANOVA) and Duncan's multiple range test.

RESULTS AND DISCUSSION

Community composition, species diversity, and primary productivity were affected by nutrient enrichment. Fertilizer-treated plots were dominated by *Ambrosia trifida, Cirsium discolor, Lactuca scariola,* and *Ambrosia artemisiifolia,* whereas sludge-treated plots were dominated by *A. artemisiifolia, L. scariola, A. trifida,* and *C. arvense.* Thus, nutrient-enriched plots were dominated mainly by annuals which accounted for 77% and 62% of the annual primary productivity for the fertilizer and sludge plots, respectively. In contrast, control plots were dominated by the perennials *Solidago canadensis* and *Rubus frondosus.* Perennials comprised approximately 70% of the annual primary productivity (Table 1).

Ambrosia species which dominated the nutrient-enriched plots usually have little importance after the fifth year of secondary succession, but are common dominants in 1- and 2-year old-fields (Bazzaz 1975, Abul-Fatih and Bazzaz 1979, Armesto and Pickett 1985). *S. canadensis,* the dominant species in the controls, is typically dominant in 5- through 7-year old-fields (Root and Wilson 1973, Bazzaz 1975, Armesto and Pickett 1985). Hence, the composition of the nutrient-enriched plots was representative of an earlier old-field stage of secondary succession.

Results indicate that succession in the nutrient-enriched plots has been maintained at this early developmental stage. For example, species composition of the nutrient-enriched plots is not substantially different from the first and second years of succession within these same plots as reported by Taylor (1979) and Carson and Barrett (unpublished). During the first two years, annuals (e.g., *A. artemisiifolia, Setaria faberii, Polygonum persicaria*) comprised more than 60% of the annual productivity (Taylor 1979, Carson and Barrett, unpublished). In contrast, annuals in the control plots contributed approximately 43% of the productivity in the first year of

TABLE 1

Percentage of mean annual net primary productivity ($g \cdot m^{-2}yr^{-1}$) for important plant species.

Species		Control	Fertilizer	Sludge
Solidago canadensis	(P)	35%	2%	—
Rubus frondosus	(P)	11%	4%	8%
Poa compressa	(P)	7%	—	4%
Poa pratensis	(P)	6%	—	2%
Cirsium arvense	(P)	6%	4%	10%
Ambrosia trifida	(A)	—	23%	10%
A. artemisiifolia	(A)	1%	10%	23%
Cirsium discolor	(B/P)	2%	12%	—
Lactuca scariola	(A)	5%	11%	12%
Chenopodium album	(A)	—	7%	—
Stellaria media	(A)	—	6%	7%
Setaria faberii	(A)	3%	6%	9%

A — indicates annual; B — indicates biennial; P — indicates perennial. Values of less than 1% are designated by dashes.

succession, but only 18% during the second year (Carson and Barrett, unpublished).

Those species best adapted to incorporating the increased nutrient subsidy into biomass should dominate an enriched community (Hurd and Wolf 1974, Grime 1979). In this study, the dominant annuals, particularly *A. artemisiifolia* and *A. trifida,* appear to be able to outcompete the perennials that normally dominate 6-year old-fields. This competitive advantage would explain the perennials' subdominant position.

The total number of plant species found in the fertilizer, sludge, and control plots during the entire growing season was 30, 39, and 46, respectively. Nutrient-enriched plots tended to have fewer species than the control plots during the growing season. Fertilizer plots had significantly ($P < 0.05$) fewer species than the controls in July (Fig. 1). Nutrient-enriched plots also tended to have lower mean species richness values than controls. Species apportionment was greater in nutrient enriched plots from late June through late August (Fig. 2). Low evenness values in control plots were attributed to *S. canadensis* which accounted for 61.8% of the total biomass in control plots on 29 June, and increased to 73.7% on 31 August. Species apportionment values were significantly ($P < 0.05$) higher in fertilizer plots than in sludge and control plots both in late June and in July.

Decreased species diversity is characteristic of early successional stages (Odum 1969). The nutrient-enriched plots appeared to represent an earlier old-field successional stage than did control plots. For example, species per area diversity results support the theory that succession in the nutrient-enriched plots has been maintained at an early stage of old-field succession.

Net daily productivity trends varied throughout the growing season (Fig. 3). Fertilizer and control plots had significantly ($P < 0.05$) greater productivity values than sludge plots in early June. Annual net primary productivity values for the fertilizer, sludge, and control plots ($g \cdot m^{-2} yr^{-1} \pm$ S.D.) were 1733 ± 304, 1384 ± 222,

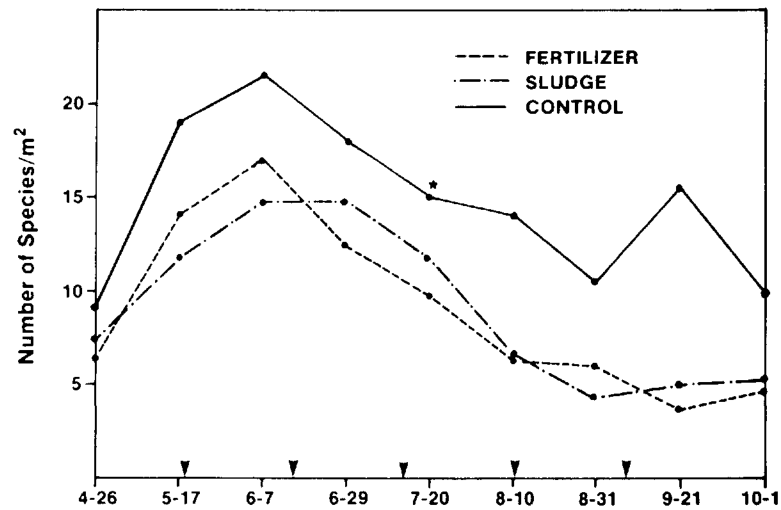

FIGURE 1. Mean number of plant species ($/m^2$) per treatment. Asterisk indicates significant difference between control and fertilizer-treated plots ($P<0.05$). Triangles indicate fertilizer and sludge application dates.

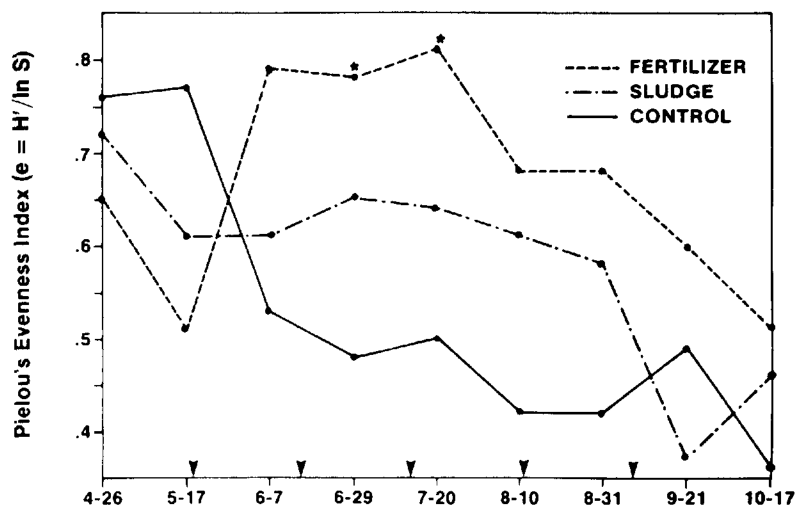

FIGURE 2. Mean plant species apportionment per treatment as determined by Pielou's evenness index. Asterisks indicate significant differences between control and fertilizer plots ($P<0.05$). Triangles indicate fertilizer and sludge application dates.

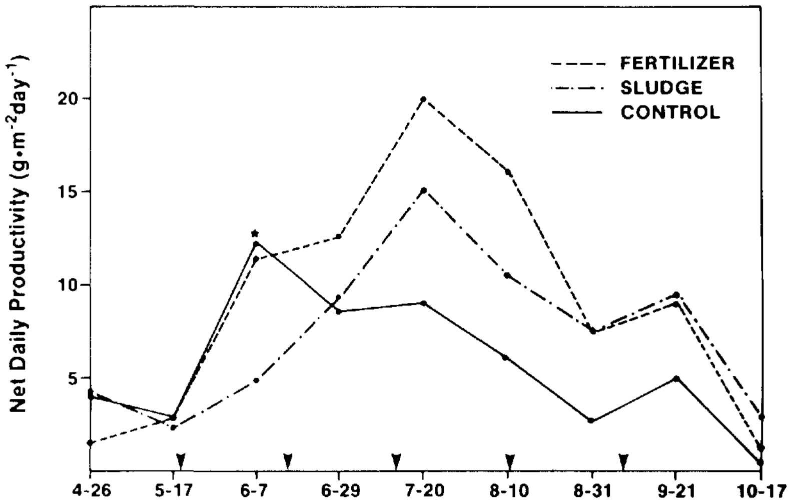

FIGURE 3. Mean net daily productivity (g · $m^{-2}day^{-1}$) per treatment. Asterisks indicate significant differences between sludge-treated plots and both control and fertilizer-treated plots ($P<0.05$). Triangles indicate fertilizer and sludge application dates.

and 1009 ± 56, respectively. Fertilizer plots exhibited significantly ($P < 0.05$) greater productivity than controls, but not the sludge plots. Increased productivity is also a characteristic of earlier successional stages (Odum 1969). Thus, our results again suggest that nutrient-enriched plots represented an earlier old-field successional stage than controls plots.

Although an equivalent N-P-K subsidy was applied equally to the fertilizer and sludge plots, the sludge plots tended to be intermediate in community composition, species diversity, and primary productivity between the fertilizer and contol plots. Taylor (1979) and Maly and Barrett (1984) also made this observation.

There are two possible explanations for this community response. First, one might expect that differences in dominant plant species between treatments (Table 1) would affect the microclimates (e.g., soil moisture content or soil temperature). Such differences should be reflected in functional community parameters such as the rate of litter decomposition. However, we found no significant differences ($P > 0.05$) regarding the amount of litter present between treatments at any time during the growing season. Thus, we have no evidence suggesting differences in the rate of litter decomposition between treatments.

A more plausible explanation for differences in community response relates to differences in nutrient availability. The sources of nutrient enrichment have different decomposition characteristics which affect both nitrogen availability and soil microorganisms. Not all of the nitrogen in sludge is available to plants. Hsieh et al. (1981) noted a significant amount of unrecovered N in digested sludge after incubation in soil. In contrast, most of the nitrogen in urea-phosphate fertilizer is released. Furthermore, the high amount of biologically active carbon in sludge stimulates populations of denitrifying bacteria. A significant amount of N can be lost via these bacteria (Kelling et al. 1977, Epstein et al. 1978, Gilbert et al. 1979, Hsieh et al. 1981). Successive fertilizer applications have been found to increase populations of nitrifying bacteria, with the rate of nitrification exceeding denitrification (Wagenet et al. 1977). Thus, the plant communities may not have been receiving equivalent nitrogen levels. Such differences probably accounted for the observed productivity differences between treatments.

In summary, it appears that long-term nutrient enrichment tends to retard normal community development as evidenced by changes in species composition, species richness, and primary productivity. It is from long-term studies of this nature that possible community types for sewage waste disposal can best be determined. It appears that old-field communities merit further research along these lines.

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