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STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF A RECLAIMED LANDFILL ECOSYSTEM IN PUTNAM COUNTY, TENNESSEE

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ABSTRACT

Estimates of standing crops of biomass and calcium (Ca) in primary producers, arthropods, leaf-litter, and avifauna, and of soil Ca concentration were made monthly or seasonally for a grassland ecosystem developed from a reclaimed solid waste landfill. These structural characteristics along with loss rates of leaf-litter biomass and Ca were compared with values reported for less disturbed ecosystems to evaluate the success of reclamation at the landfill. The reclaimed landfill was developed into a near-naturally appearing and functioning ecosystem. Structural and functional characteristics were similar to those reported for other ecosystems. Detritivores represented a substantial Ca pool and may be very important in Ca dynamics.

INTRODUCTION

The goal of land reclamation efforts in a disturbed area is to develop an aesthetic, relatively stable, and functional ecosystem. Standing crops of biomass and nutrients have been used to describe ecosystem structure (Wiegert and Evans 1964, Golley 1965, Menhinick 1967, Wiegert et al. 1967, Van Hook 1969, Rose 1979) while plant litter decomposition rates have been used as functional descriptors of ecosystems (Bocock and Gilbert 1957, Golley 1965, Ward and Wilson 1973, Douce and Crossley 1982). The purpose of this research was to quantify structural and functional characteristics of a reclaimed solid waste landfill and compare them to characteristics reported for less disturbed ecosystems. Specific objectives were to: 1) determine monthly or seasonal standing crops of biomass and Ca in primary producers, arthropods, detritus, and avifauna; 2) determine monthly concentrations of extractable Ca in soil; and 3) determine the rates of biomass and Ca loss from decaying leaf litter. Ca was used as a gauge for nutrient cycling because of its relative abundance (Deevey 1970) and importance as a plant macronutrient.

STUDY AREA

The 15.8 ha study area was a five to seven year old reclaimed landfill located on the Eastern Highland Rim in Putnam County, Tennessee. This area typically receives 125 cm of precipitation annually and has a mean annual temperature of 13°C (National Oceanic and Atmospheric Administration 1983).

Refuse at the study area was capped with local Mountainview silt loam which is well-drained, strongly acidic, and low in natural fertility. The area was then seeded with fescue (*Festuca arundinacea*) and sericaea lespedeza (*Lespedeza cuneata*), which remained dominant. Daisy fleabane (*Erigeron annuus*), red clover (*Trifolium pratense*), and white clover (*T. repens*) were also common.

METHODS

Biomass and Ca standing crops were estimated from monthly (March 1982–February 1983) samples of plants, leaf litter, soil, and arthropods. Aboveground living vegetation and leaf litter (including standing dead vegetation) were collected from ten 0.1 m^2 quadrats randomly located along 100 m transects. Plants were separated by species in the field. A soil core sample (2.3 $cm^2 \times 5$ cm deep) was collected from within each vegetation quadrat (10 samples per month).

Arthropods were sampled from both living vegetation and leaf litter. Ten samples from living vegetation, each representing a 1-m^2 area, were collected monthly using a 38 cm diameter sweep net (Menhinick 1967). Arthropods living in the leaf litter were collected using 30 × 30 cm cryptozoan drop boards (Tarpley 1967, Wiegert et al. 1967). A total of 120 drop boards were arranged in a 6 × 8 m grid

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system during February 1982. Beginning in March 1982, cryptozoans were collected from beneath 10 boards along a 72-m transect. Each board was assumed to sample a 1-m^2 area (Tarpley 1967). Arthropods were stored frozen and later identified to family level. Monthly samples were grouped by season: spring (March–May), summer (June–August), fall (September–November), and winter (December–February). Within seasons, arthropods were separated by feeding strategy (predators and parasites, herbivores, omnivores, or detritivores) according to Borror and DeLong (1970).

Plant, leaf litter, and arthropod biomass estimates were based on sample weights after drying for 24 h at 100°C. Vegetative matter was weighed to the nearest 0.1 g and arthropods to the nearest 0.2 mg.

Investigations of avifauna in the study area were limited to a representative species: eastern meadowlark (*Sturnella magna*). It was chosen for study because of its: 1) high relative abundance; 2) ease of direct observation; and 3) nearly exclusive use of grassland habitats. Meadowlark population size was determined monthly via direct observation. A male and female were collected near the study area and their digestive tracts cleared of material. They were then oven dried at 100°C for 48 h and weighed to nearest 0.1 g. Two meadowlark eggs were also collected and similarly dried and weighed.

Subsamples of dried vegetative, leaf litter, arthropod, and meadowlark samples were finely ground, ashed in a muffle furnace at 475°C for 8 h, and dissolved in 20% HCl acid solution (Perkin-Elmer 1982). Extractable Ca was removed from soil samples (Perkin-Elmer 1982). All samples were then analyzed for Ca using a Perkin-Elmer model 372 atomic absorption spectrophotometer with an air-acetylene flame.

Rates of leaf litter decomposition and subsequent Ca release were calculated from biomass and Ca concentration changes of litter contained in mesh bags (Ward and Wilson 1973, Douce and Crossley 1982). During February 1982, 120 samples of leaf litter (including standing dead vegetation) were collected from 0.1-m^2 quadrats located within the study area. These litter samples were oven dried for 214 h at 100°C, weighed to nearest 0.1 g, placed in 30 × 30 cm nylon mesh (3.2 mm^2 mesh size) bags, and returned to the study area in March. Beginning one month later, and continuing at monthly intervals for a year, 10 randomly selected decomposing litter samples were removed for analysis. The litter was oven dried for 24 h at 100°C, weighed to nearest 0.1 g, and analyzed for Ca content as described for vegetative samples.

Methods for calculation of Student's t-test, simple correlation, analysis of variance, Duncan's multiple range test, and summary statistics were found in Glass and Stanley (1970). Annual means were averages of monthly or seasonal means.

RESULTS AND DISCUSSION

Biomass

Standing crops of plant biomass varied monthly and ranged from 7.9 g/m^2 (N = 10, SE = 2.8) during March to 215.6 g/m^2 (N = 10, SE = 49.2) during August. Annually, plant biomass averaged 113.6 g/m^2 (N = 120, SE = 6.4). Fescue averaged 80% (N = 120, SE = 4.9) of plant biomass annually, with peak composition occurring during July. Maximum and minimum primary producer standing crops were similar to those found in a Tennessee fescue field (Van Hook 1969) and a Michigan old-field (Wiegert and Evans 1964). Sericea lespedeza biomass peaked during July as also noted by Menhinick (1967).

Standing crops of leaf litter exceeded that of live plants, as noted in other studies (Wiegert and Evans 1964, Golley 1965, Menhinick 1967, Van Hook 1969). Leaf litter biomass annually averaged 292.5 g/m^2 (N = 120, SE = 6.9), ranging from 205.8 g/m^2 (N = 10, SE = 62.5) in March to 461.4 g/m^2 (N = 10, SE = 62.5) in November. These trends were very similar to those observed in another Tennessee fescue field (Van Hook 1969).

Standing crops of arthropod biomass varied seasonally with herbivores being most prevalent during all seasons except winter, when detritivore standing crop was higher. The maximum total arthropod biomass (558.6 mg/m^2) was greater than that found (40 mg/m^2) in a lespedeza field (Menhinick 1967) but less than that found (968 mg/m^2) in a fescue field (Van Hook 1969). Total arthropod biomass was relatively low in winter (157 mg/m^2), but other studies (Menhinick 1967, Van Hook 1969) reported essentially no arthropods during winter.

Biomass of arthropods and their food sources peaked concurrently at the reclaimed landfill. These relationships between herbivores and plants, detritivores and leaf-litter, and predators (including parasites) and herbivores were also found in other ecosystems (Menhinick 1967, Van Hook 1969, Rose 1979). Leaf-litter biomass was significantly ($P < 0.05$) and linearly correlated ($r = 0.99$) with detritivore biomass, as was herbivore biomass with predator (including parasite) biomass ($r = 0.97$).

The estimated density of eastern meadowlark breeding pairs (3/15.8 ha = 8/100 acres) in this ecosystem approximated the averages reported for several other habitats (11/100 acres) and nonpasture grassy habitat (5.1/100 acres, Roseberry and Klimstra

1970). Based on an average weight of 42.4 g (N = 2, SE = 2.0), the annual average meadowlark biomass standing crop was 1.5 mg/m^2 (N = 12, SE = 0.3); meadowlark biomass was relatively low compared to arthropods.

Calcium Concentration

Concentrations of Ca in fescue varied ($P < 0.05$) monthly, ranging from 2.5 mg/g dry wt (N = 10, SE = 0.1) in January to 7.7 mg/g dry wt (N = 10, SE = 1.7) in September, with an annual average of 4.4 mg/g dry wt (N = 12, SE = 0.5). Sericea lespedeza Ca concentration was also highest ($P < 0.05$) in September $\bar{x}$ = 25.1, N = 4, SE = 8.6), while averaging 13.6 mg/g dry wt (N = 6, SE = 2.4) annually. Ca concentration increases in foliage as plants mature (Van Hook 1969, Rose 1979); this explains minimal Ca concentrations found in very young plants during late winter and peak levels found in old plants during September. The weighted annual average of Ca concentration in all plants was 5.3 mg/g dry wt (N = 12, SE = 0.6) and was within the broad range reported for various plants in other studies (Van Hook 1969, Rose 1979).

Calcium concentrations in leaf-litter varied ($P < 0.05$) monthly, ranging from 3.6 mg/g dry wt (N = 10, SE = 0.3) in February to 21.9 mg/g dry wt (N = 10, SE = 6.5) in April, with an annual mean of 10.4 mg/g dry wt (N = 12, SE = 1.7). This range was higher than that reported (3.34–5.25 mg/g dry wt) in a Tennessee fescue field (Van Hook 1969), and may have been caused by higher live plant Ca concentrations found in this study.

Leaf-litter Ca concentrations were generally higher than concentrations in live plants. Van Hook (1969) noted a similar relationship, probably attributable to the water insolubility of Ca in plants (Van Hook 1969, Ward and Wilson 1973). When plants die, Ca and other water insoluble materials are lost at slower rates than water soluble materials; thus Ca concentrations are greater in older leaf litter. The lack of significant ($P > 0.05$) correlation between monthly leaf-litter Ca concentrations and rainfall totals does not refute this explanation for higher Ca concentration in leaf-litter.

Soil extractable Ca concentration varied ($P < 0.05$) by month but was always considered high or very high (Jackson 1970). The annual average concentration (2.70 mg/g, N = 12, SE = 0.25) was very high. No significant ($P > 0.05$) correlations were found between monthly soil Ca concentrations and either rainfall totals, plant Ca concentrations, or litter Ca concentrations. Thus, rainfall did not appear to leach Ca out of plants or leaf-litter and into soil.

Annual average Ca concentrations (means of seasonal determinations, N = 4) for detritivores, predators and parasites, herbivores, and omnivores were 141.9 (SE = 3.0), 14.1 (SE = 1.9), 4.0 (SE = 1.5), and 3.0 (SE = 0.8) mg/g dry wt, respectively. Detritivores had greater ($P > 0.05$) Ca concentration than any other group; this has been attributed to their highly calcified exoskeleton (Reichle et al. 1969). Calcium concentrations in Polydesmida, Isopoda, and Chordeumida taxa were consistent with previously reported levels for these detritivores (Reichle et al. 1969).

Concentrations of Ca in omnivores and herbivores were similar to concentrations found by Reichle et al. (1969) and Clark (1958), but greater than those reported by Van Hook (1969). Mean predator (including parasite) Ca concentration was also greater than reported elsewhere (Reichle et al. 1969, Van Hook 1969, Rose 1979). Predator and herbivore Ca concentrations were positively correlated ($P < 0.05$, $r = 0.99$), but significant correlations were not detected between Ca concentrations in herbivores or detritivores and their food sources. Van Hook (1969) noted no increase in Ca concentration from herbivore to predator, but whole-body nutrient levels might be related to seasonal composition of food (Reichle et al. 1969).

Eastern meadowlark whole-body Ca concentration averaged 30.3 mg/g dry wt (N = 2, SE = 0.8). Total Ca concentration from meadowlark eggs was 137.7 mg/g dry wt (N = 2, SE = 1.2).

Calcium Standing Crops

Standing crops of Ca in plants varied ($P < 0.05$) by month, ranging from 46 mg/m^2 (N = 10, SE = 19) in March to 1431 mg/m^2 (N = 10, SE = 433) in September (Figure 1) and averaging 678 mg/m^2 (N = 12, SE = 161) annually. The peak value was double the highest level reported for another fescue ecosystem (Van Hook 1969). Fescue, sericea lespedeza, and other plants accounted for 67% (N = 12, SE = 7), 16% (N = 12, SE = 6), and 17% (N = 12, SE = 7), respectively, of the annual average Ca standing crop in live plants.

Standing crops of Ca in leaf-litter varied by month ($P < 0.05$) and were higher than in live plants (Figure 1). Calcium standing crops in leaf-litter averaged 2601 mg/m^2 (N = 12, SE = 402) annually, ranging from 1265 mg/m^2 (N = 10, SE = 140) in January to 5333 mg/m^2 (N = 10, SE = 888) in June. As with live plants, the maximum Ca standing crop found in leaf-litter was double the value reported for another fescue-dominated ecosystem (Van Hook 1969).

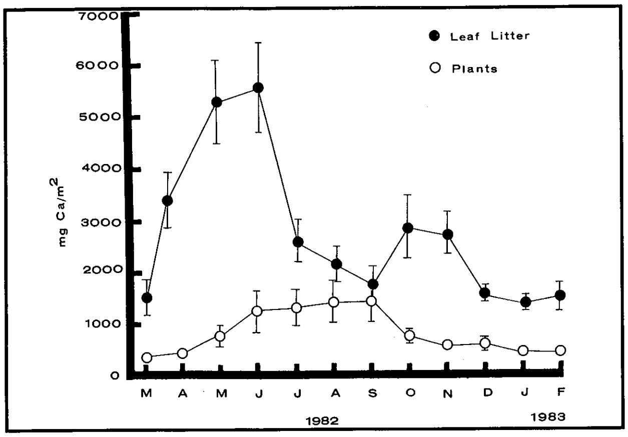

Figure 1. Monthly means (± SE) of Ca standing crops in live plants and leaf litter for March 1982–February 1983 at a reclaimed landfill, Putnam County, Tennessee.

Detritivores had a much greater Ca standing crop than other arthropod groups (Figure 2). Annually, Ca standing crops averaged 6.7 mg/m^2 (N = 4, SE = 2.6) in detritivores, while only averaging 0.2 mg/m^2 (N = 4, SE = 0.3), 0.5 mg/m^2 (N = 4, SE = 0.4), and 0.5 mg/m^2 (N = 4, SE = 0.2) in herbivorous, omnivorous, and predaceous (including parasitic) arthropods, respectively. However, as reported elsewhere (Van Hook 1969, Rose 1979), standing crops of Ca in arthropods represented <1% of the total Ca in the ecosystem (excluding soil). Detritivore and leaf-litter Ca standing crops were negatively correlated ($P < 0.05$, $r = -0.99$). A transfer in Ca from leaf-litter to detritivores may partially account for this negative relationship.

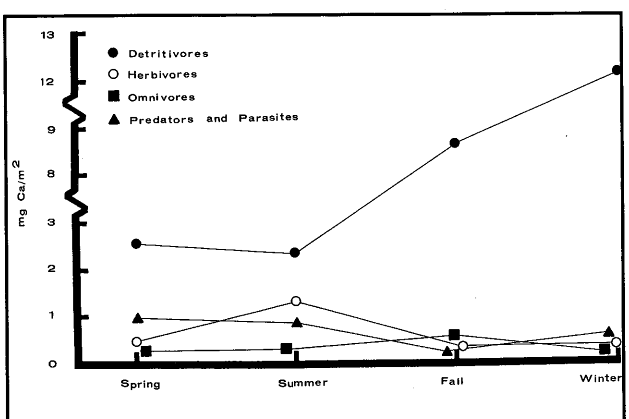

Figure 2. Seasonal estimates of Ca standing crops in arthropods for March 1982–February 1983 at a reclaimed landfill, Putnam County, Tennessee.

Calcium standing crops in meadowlarks were very low, averaging 0.05 mg/m^2 (N = 12, SE = 0.01) or about 0.001% of all Ca in the ecosystem (excluding soil). Peak egg standing crop was <0.01 mg Ca/m^2.

Leaf-litter Decay Rate

There was a significant ($P < 0.05$) negative linear correlation ($r = -0.87$) between time and percent leaf-litter biomass remaining in litter bags. Leaf-litter biomass decayed 7.1%/month (N = 12, SE = 1.13) and was within the broad range reported for several other ecosystems. Averaged decay rate in a Michigan old-field was 5%/month (Wiegert and Evans 1964) while fresh-cut oats lost 12%/month over 114 days (Ward and Wilson 1973). The estimated 41.4% litter remaining after one year was within the 25–80% range reported for forest ecosystems (Bocock and Gilbert 1957, Shanks and Olson 1961, Attiwill 1968) but lower than the 92% remaining in a tundra ecosystem (Douce and Crossley 1982). Cooler and drier climate may cause a slower decay rate in tundra ecosystems.

Calcium concentration of leaf-litter in litter bags remained relatively unchanged and averaged 7.3 mg/g dry wt (N = 12, SE = 0.6) annually. Calcium concentration changes in litter bag studies are infrequently reported. However, seasonal Ca concentrations in *Eucalyptus* forest litter did not vary significantly (Attiwill 1968).

Rate of Ca loss from leaf-litter was based on biomass and Ca concentration data. Excluding May, the only month of unexplainably high Ca concentration, there was significant ($P < 0.05$) negative linear correlation ($r = -0.85$) between time and percent leaf-litter Ca remaining in litter bags. The average rate of Ca loss was 7.4%/month (N = 11, SE = 0.6), similar to biomass loss rate (7.1%/month) and largely due to nonvarying monthly Ca concentrations.

CONCLUSIONS

The reclaimed landfill was developed into a near-naturally appearing and functioning grassland ecosystem. Ecological structure and functions at the reclaimed landfill were similar to those of less disturbed ecosystems. Comparisons between the study area and a Tennessee fescue field (Van Hook 1969) were most meaningful because of similarities in climate and dominant plant and animal taxa. Unfortunately, soil Ca information was not available for Van Hook's (1969) site. Soil Ca concentration appears to affect plant Ca levels, which in turn affects concentrations throughout the ecosystem. Because of the substantial Ca pool detritivores represented in this ecosystem, their role in Ca dynamics is probably substantial.

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