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The effects of termites and straw mulch on soil nitrogen in a creosotebush (*Larrea tridentata*) dominated Chihuahuan Desert Ecosystem

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The effects of organic matter (wheat straw) and subterranean termites on concentrations of soil nitrogen were measured on insecticide-treated plots to eliminate-termites and by adding straw mulch to insecticide-treated and insecticide-untreated plots. Soil nitrogen was significantly higher, 435 mg g^{-1} soil at 0–5 cm depth on plots with no termites than on plots with termites (340 mg g^{-1} soil). There were no differences in total soil nitrogen at soil depths of 5–10 cm. Soil nitrogen was higher in soils with termites than in soils with termites excluded on straw-amended plots. On the plots without straw amendments, total soil nitrogen was higher in soils without termites than in soils with termites present. Termites had no significant effect on total soil nitrogen under shrub canopies in comparison with intercanopy soils. The addition of straw mulch did not result in higher soil nitrogen content in soils without termites. Termites were more important as effectors of soil nitrogen than addition of organic matter in the form of wheat straw.

Keywords: chlordane; desert; soil nitrogen; straw; termites

Introduction

Soil nitrogen is an important factor limiting productivity in desert ecosystems when there is sufficient moisture for plant growth (Ettershank *et al.*, 1978, Floret *et al.*, 1982, Fisher *et al.*, 1988). Parker *et al.* (1982) reported that elimination of subterranean termites resulted in higher soil nitrogen content and shifts in species composition of the annual plant community in a creosotebush (*Larrea tridentata*) community in the Chihuahuan Desert. The soils of a Chihuahuan Desert piedmont slope and alluvial fan (bajada) have soil organic matter ranging between 0·4% and 1·2% (Nash & Whitford, 1995). Nash and Whitford (1995) reported a significant

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inverse relationship between termites and soil organic matter and Whitford *et al.* 1987) reported a positive relationship between soil organic matter and soil nitrogen. Therefore, addition of mulch should increase soil organic matter and soil nitrogen on soils where termites have been eliminated. Soils inhabited by termites may not exhibit changes in soil nitrogen if termites consume a significant fraction of the mulch. We hypothesized that added organic matter would result in increased soil nitrogen. We also hypothesized that soils with termites eliminated would accumulate higher soil nitrogen than soils inhabited by subterranean termites.

Methods and materials

The studies were conducted on creosotebush (*L. tridentata*) dominated ecosystems at mid-slope location on the Mt. Summerford watershed on the Chihuahuan Desert Rangeland Research Center of New Mexico State University. The watershed is approximately 40 km NNE of Las Cruces, N M. The mean soil organic matter content of the soils at the mid-slope locations is 0·4%. A long-term study of the effects of termite removal on ecosystem processes was initiated in 1977 by applying a soil soak with chlordane^{TM}. Chlordane (octachloro-4, 7-methanotetrahydroidane) was applied to the termite exclusion plots at a rate of 10 kg ha^{-1}. Chlordane is a highly recalcitrant molecule that binds to soil clay particles where it persists for years. One month after treatment, there were no differences in numbers of ant colonies on treated plots and untreated controls. One year after treatment, numbers of soil microarthropods returned to pretreatment levels. These measurements demonstrated that chlordane was adsorbed on soil particles and no longer had contact toxicity. Subterranean termites ingest soil, which allows the release of the toxin in the termite gut. There was no evidence of termite activity on the treated plots through 1990.

Plots were established in four blocks on the bajada slope. The experimental design consisted of four blocks, each containing four 30 m $\times$ 40 m plots in a split plot design in which the main plots were a 2 $\times$ 2 factorial (termites present and termites excluded; straw mulch and no straw mulch). The factors were randomly assigned to each plot in all blocks. In April 1981, one set of termite present and one set of termite-eliminated plots were amended with wheat straw. Between 1800 and 2000 kg ha^{-1} of straw was spread evenly over the entire area of the straw-mulch-amendment plots. A set of termite present and termite elimination plots had no straw mulch amendment.

On each sampling date five soil samples were collected from each location within a plot (under shrub canopies, shrub interspace, 0–5 cm and 5–10 cm depths) with a steel soil corer, 8 cm diameter in November 1981 and March and September 1982. Each set of five samples were bulked, mixed and sub-sampled for total nitrogen analysis. Total nitrogen was measured colormetrically following microKjeldahl digestion (Bremner & Mulvaney, 1982). The mean soil nitrogen values for the bulked samples were used in the analysis of variance. Treatment effects were analysed on the data from all sampling dates combined. Soil organic carbon was estimated by mass loss from 1·0 gram sub-samples of the ground, oven-dried soil samples prepared for nitrogen analysis. Soil samples were burned in a muffle furnace at 490°C and ash weight subtracted from sample dry weight to obtain soil organic matter. Significant interactions between treatments were examined by analysis of variance (ANOVA). F values were calculated from the error mean square values using two error terms to account for the whole unit error and sub-unit error associated with different degrees of freedom. Differences between means were tested by least significant difference (Steel & Torrie, 1980).

Results

In the first 6 months after straw mulch application, termites removed a large fraction of the straw on plots with termites present. By the second year of the study, most of the straw had disappeared on all plots except under shrub canopies where straw fragments were mixed with leaf litter.

Soil nitrogen was significantly higher ($P < 0{\cdot}05$) at the 0–5 cm depth on termite exclusion plots than in soils on plots with termites present. There were no differences in soil nitrogen at the 5–10 cm depth in soils on the termite-exclusion plots or soils with termites present (Fig. 1a). Soil nitrogen was significantly higher ($P < 0{\cdot}05$) on straw mulch — termite-present plots than on straw mulch — termite-exclusion plots (Fig. 1c). Soil nitrogen was significantly higher in soils on termite exclusion — no straw mulch plots than in soils on no straw mulch — termite-present plots. There

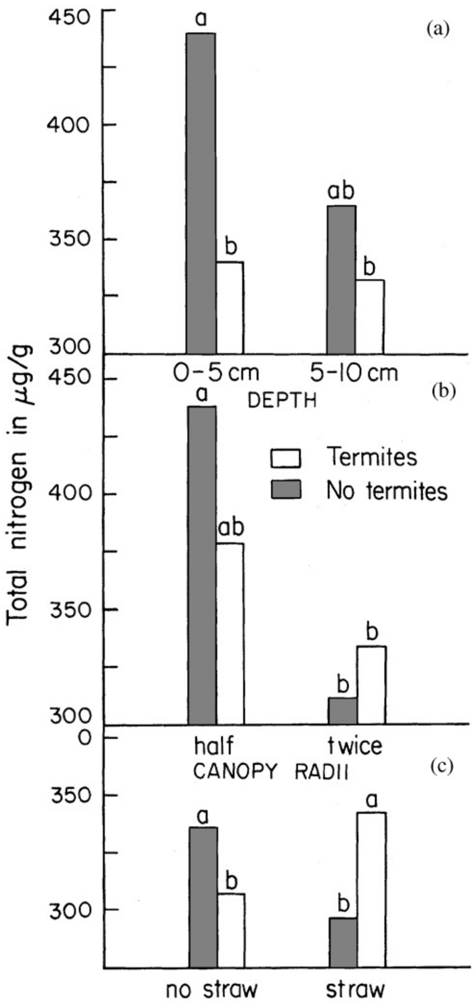

Figure 1. The interactions between soil depths, spatial location under creosotebush (*L. tridentata*) canopies or in intershrub spaces, and addition of straw mulch on plots from which termites were eliminated (no termites) and plots with termites present. Bars that are significantly different ($P < 0{\cdot}05$) are indicated by different letters.

were no significant differences in soil nitrogen in any of the treatments in soils from the small mounds associated with creosotebush shrubs (Fig. 1b).

Soil organic matter varied 1·4–2·1% with no significant differences among plots.

Discussion

These data support several of the generalizations about soil nitrogen in desert ecosystems, but require some modification of other generalizations. For example, the generalization that soil nitrogen is higher in surface soils than in deeper soils and the generalization that soil nitrogen is higher under shrub canopies than in intershrub spaces are confirmed by this study (Nishita & Haug, 1973, West & Klemmedson, 1978, Parker *et al.*, 1982). This study also confirms the hypothesis that soil nitrogen levels are higher in soils with low population numbers of subterranean termites or soils with no termites (Nash & Whitford, 1995).

The absence of a straw mulch effect on soil nitrogen is the opposite of that reported by Abd-El-Malek (1971). He applied straw mulch to cultivated–irrigated soils in Egypt. However, mulch that is tilled into the soil is decomposed differently than mulch that is spread on the soil surface. The absence of a spatial pattern in soil organic matter and the higher values of soil organic matter compared with those reported by Nash & Whitford (1995) suggests that the mass loss by ignition data obtained in this study was problematic. It is likely that the temperature of the muffle furnace was sufficiently high to drive carbon dioxide from the soil carbonates. We conclude that the soil organic matter data were compromised and cannot be included in the interpretation of the soil nitrogen patterns.

In our experiment, by the end of the first summer, most of the straw was fragmented into small (10–15 cm) pieces. The larger fragments were accumulated on the litter layer under the shrubs. The fragmentation of the straw was the result of abiotic breakdown. High temperatures and intense ultraviolet light cause the breakdown of organic matter in deserts (Pauli, 1964). Empirical studies of abiotic breakdown of organic materials showed that approximately 15% of the original mass of grass and shrub leaves was lost in a 90 day period as a result of abiotic decomposition (Vossbrinck *et al.*, 1979, MacKay *et al.*, 1994). Photooxidation of structural elements of wheat straw, weaken the straw sufficiently for rain drop impact or wind impact to cause the straw to shatter. This is consistent with the conceptual model proposed by Moorhead & Reynolds (1989).

In September and October, many straw fragments on plots with termites present were covered with termite foraging galleries. Organic matter eaten by termites is nearly completely metabolized (Lee & Wood, 1971). The nitrogen in materials eaten by termites is returned to the soil nitrogen pool by animals that prey on termites (Schaefer & Whitford, 1981). On termite-eliminated plots, small straw fragments that mixed with soil or that were buried provided an energy substrate for soil microflora. The organic matter processed by the microflora and micro/mesofauna contributes to the long-term increases in soil nitrogen. However, in this study, the increase in soil nitrogen was the result of relatively short-term elimination of termites (>5 years) compared to the 18 months during which mulch effects were evaluated.

The significant interactions between termites and straw mulch are the result of the foraging behavior of the subterranean termite, *Gnathamitermes tubiformans*. The higher soil nitrogen on plots with no straw mulch and no termites resulted from the decomposition and mineralization of annual plant roots (Parker *et al.*, 1984). Subterranean termites consume a large fraction of annual plant roots (Whitford *et al.*, 1988). The nitrogen in termite-consumed roots is cycled through termite predators and effectively removed from the soil patch of origin (Schaefer & Whitford, 1981). On plots with straw mulch and no termites, nitrogen was immobilized by microbial biomass growing on the straw at the mulch–soil surface interface. Microbial immobilization of nitrogen depletes nitrogen from the surface layers of soil (Whitford & Herrick, 1995). With termites present, straw mulch is consumed by subterranean termites that build foraging galleries and sheeting around the straw. When the galleries disintegrate with rainfall or wind, the nitrogen enriched gallery material contributes to the nitrogen content of the surface soil (Schaefer & Whitford, 1981).

This study supports the conclusion that subterranean termites are a major determinant of soil nitrogen levels in Chihuahuan Desert soils. Also, it is evident that surface application of organic mulch has no significant short-term effect on soil nitrogen. We also conclude that the soil nitrogen–termite pattern was a relatively long-term result and it is possible that surface applied straw mulch may have had an effect in the long-term, i.e. 5–10 years.

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