Journal of Arid Environments (1978) 1: 135–139

Effects of nitrogen fertilization on primary production in a Chihuahuan desert ecosystem

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In a Chihuahuan desert ecosystem, the growth responses to nitrogen amendment of a perennial shrub (creosotebush, *Larrea tridentata*) and a perennial grass (fluff grass, *Erioneuron pulchellum*) were made twice during the growing season: first during a period of average rainfall, then during a period of above average rainfall. Fluff grass exhibited a marked increase in biomass to 25 kg ha^{-1} and 100 kg ha^{-1} nitrogen fertilization. Creosotebush increased biomass production only at the higher level during both periods. These results suggest that productivity of a Chihuahuan desert system is partially nitrogen limited and that shallow-rooted plants utilized the available nitrogen at the 25 kg ha^{-1} fertilization level, thus making it unavailable to creosotebush.

Introduction

A basic premise accepted by most desert ecologists is that water is normally limiting, therefore increasing nitrogen will be effective only when soils are near field capacity or at least water supply is significantly increased. This is supported by the results of rangeland studies by Stroehlein *et al.* (1968) and Dahl (1963). Noy-Meir (1974) states, 'The overriding importance of water in desert ecosystems means that the cycling of organic material and nutrients is rarely limiting for primary and secondary production'. Noy-Meir (1974) also suggests that rapid growth pulses during rainy periods may exhaust nutrient pools faster than they can be renewed. Unfortunately, these premises and statements are largely suppositional and without empirical support.

Based on data accumulated at the Jornada Validation Site (US/IBP) we hypothesized that in years of 'average or above-average' rainfall, primary and secondary production are limited because carbon reserves in the soil quickly disappear. Skujins (1976) presented data which showed that the C : N ratio is important in desert soil because C is the energy source for nitrogen fixation and also denitrification.

We reasoned that the rapid breakdown of organic material would substantially reduce nitrogen fixation. Before we could test these hypotheses, we needed to determine the responses of the vegetation to enhanced nitrogen levels. Therefore, we conducted studies to evaluate the growth responses of the dominant perennial species in a Chihuahuan desert ecosystem to two levels of nitrogen amendment.

Materials and methods

A site was selected on the alluvial fan below Mt Summerford on the Jornada Experimental Range, 40 km NNE of Las Cruces, Dona Ana County, New Mexico. The area slopes gently eastward and supports a vegetation dominated by creosotebush (*Larrea tridentata* (Cov.)), with soaptree yucca (*Yucca elata* Englem.) as subdominant. The creosotebushes

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0140-1963/78/0102–0135 $01.00/0

are well spaced at densities of 4800 ha^{-1} (Whitford, 1977), with an herb-grass layer predominated by clumps of the perennial grass, *Erioneuron pulchellum* (H. B. K.). The soil is a sandy alluvium varying in depth from 30 to 100 cm over a calcium carbonate deposition layer (caliche). Rainfall occurs mostly during late summer, from convectional storms. The 100-year rainfall average at Las Cruces, New Mexico (mean $\pm$ one standard deviation), is 211 ± 77 mm (Houghton, 1972). Summer maximum temperatures reach 40 °C and freezing temperatures are recorded from October through mid-April on the site.

Fifteen 40×30 m plots were surveyed along an approximate contour line running west and east with 10 m barrier strips between, sited to avoid major arroyos (ephemeral water courses).

The area used for the trial was as homogeneous as could be found on the site. There is a distinct trend in soil composition from west to east along the line of the plots; on the western extreme the soils are shallower and more gravelly, with a cline to deeper, more loamy soil to the east. (This soil trend was reflected in significant differences between blocks in the analysis of variance.) Even the individual plots were somewhat variable; for this reason, the stratified random sampling scheme of Smartt & Grainger (1974) was adopted with each plot being divided into 12 subplots.

The plots were allocated at random to three treatments within five blocks. Due to the nature of the terrain, the three westernmost blocks (1 through 3) adjoin; block 4 is separated by a road; and block 5 is separated from 4 by a broad arroyo.

The treatments were:

(1) No treatments.

(2) Ammonium nitrate applied at the rate of 25 kg ha^{-1}.

(3) Ammonium nitrate applied at the rate of 100 kg ha^{-1}.

Two applications of the fertilizer were made by hand broadcast, on 16 March 1977 (prior to the expected onset of any rain), and on 11 July 1977 (after rain on 4, 7 and 8 July 1977).

Creosotebush samples were harvested on 14 June 1977 and 20 September 1977. The protocol followed was to select 12 points by the systematic random method of Smartt & Grainger (1974). (Briefly, this method ensures a spread of samples while retaining the statistical advantages of random samples.) Each 30×40 m plot was notionally divided into 12 subplots. One sample point was randomly situated in each subplot, at the intersection of one of three x-coordinates and four y-coordinates on the 30 and 40 m sides, respectively. The closest creosotebush was then selected and the canopy was visually divided into four quarters. One investigator haphazardly selected a terminal branch in a quarter; another investigator indicated if this branch was to be harvested by consulting a random GO–NOGO table. If the decision was NOGO, another branch was selected and the procedure was repeated until a GO was given. If GO, the terminal 25 cm of the branch was clipped and dropped into a paper bag, and the procedure repeated for each quarter. The four branches from each plant were stored in a single bag. This procedure was repeated for all plots. The bags were returned to the laboratory, and the current season's growth (indicated by its light green stems—Ludwig, pers. comm.) was clipped, re-bagged, oven-dried and weighed. Seed was hand-picked and weighed separately.

Only a relative estimate of creosotebush biomass production was made. To convert the biomass per branch to absolute terms would have required counting the number of shoots per shrub and accurately assessing the number of shrubs per unit area. This would have yielded but little further information on the primary question addressed in this investigation.

Since there was no growth of annuals or fluff grass (*E. pulchellum*) before 14 June 1977, no samples were taken during the first half of the growing season. Fluff grass was sampled on 30 August 1977, by a different procedure. An absolute estimate of the production was made. Plant density was obtained by the point quarter method (Greig-Smith, 1964) at points selected by the systematic random method described above. This was used to convert plant biomass to productivity per unit area (analysis of variance of the number of plants per plot showed that there was no significant difference between plots, so the data were combined to obtain a better overall estimate). At each point the distance to the nearest fluff grass plant in each quarter was measured and these four plants harvested by hand-pulling. The four plants at each point were bagged together. The bags were returned to the laboratory and oven-dried. Grass samples were then torn apart, all soil removed by dry-sieving and the grass weighed.

Selection of sets of sampling points and the GO–NOGO tables described above were constructed by APL programs written by one of us (G. E.). Data were analyzed as a factorial design using the ANOVA program on the NMSU IBM 360/65 computer.

Results

During the study period, rainfall was recorded (number of events, month, precipitation in mm; 80-year average for Las Cruces (Houghton, 1972) shown in parentheses) as follows: 1 April, 3·0 (5·1); 1 May 7·1 (7·6); 3 June, 9·1 (15·0); 11 July, 109·2 (37·8); 6 August, 78·7 (43·7); and 4 September, 16·5 (31·0); totals, 26 events, 223·6 mm rainfall. Thus, for the first growth period rainfall was near 'average' but above 'average' for the second growth period.

The only *a priori* hypothesis to be tested was that treatments would be different from controls. Therefore, differences were analyzed by least significant difference (Sokal & Rohlf, 1969). There was no difference in stem and leaf growth of creosotebush between controls and the 25 kg ha^{-1} nitrogen amendment on either sampling date (Table 1). However, the 100 kg ha^{-1} nitrogen addition resulted in marked increase in above ground biomass of *L. tridentata.* The ratio of seed production to vegetative production of creosotebush did not differ significantly between treatments.

Fluff grass, *E. pulchellum*, exhibited no visible growth between April and mid-July so was sampled only in September at which time there was a significant response to both levels of nitrogen amendment (Table 1). At no time during the growing season was there sufficient annual plant growth to warrant sampling.

Discussion

The most interesting data were the responses of the creosotebush and grasses to the two levels of nitrogen fertilization. In the creosotebush the lower level (25 kg ha^{-1}) resulted in no significant difference in production from the controls at either harvest date, before or after rains, while the higher level (100 kg ha^{-1}) gave a highly significant response ($P < 0{\cdot}01$). By contrast, added nitrogen produced a highly significant increment in production of grasses at both levels and the growth increment from the 100 kg ha^{-1} treatment was almost exactly double that of the 25 kg ha^{-1}. These data suggest that the shallower-rooted perennial grass (and probably the soil microflora and other plant species) extract a portion of the nitrogen supplement as it moves down through the soil horizon. Clearly (and fortuitously) this appears to be not less than the amount of the lower treatment (25 kg ha^{-1}) as there was no response in creosotebush production at this level. The effect of 25 kg ha^{-1} is seen instead in the increased biomass production of the fluff grass. Creosotebushes have a deeper root system with well-developed tap and lateral roots (Ludwig, 1977). At the higher nitrogen supplementation level (100 kg ha^{-1}), the requirements of the shallow-rooted plants are apparently satisfied and sufficient nitrogen moves down to the *Larrea* root zone to produce the response observed in the creosotebushes.

We know of no other studies of nitrogen fertilization in desert shrub ecosystems except the work in the Mojave desert by Hunter *et al.* (1976) who studied effects of irrigation and nitrogen fertilization. However, these authors note that their 'unwatered' plots did in fact receive extra water by percolation from adjoining irrigated plots, which makes comparisons with our study difficult. It is also difficult to make comparisons as their plots supported enormous numbers of annuals (527 m^{-2}) (Hunter *et al.*, 1975); whereas our plots had such low densities of annuals during 1977 that we did not collect data on them. Hunter *et al.*

Table 1. *The average production of creosotebush* (**Larrea tridentata**) *and fluff grass* (**Erioneuron pulchellum**) *in response to two levels of nitrogen fertilization*

Vegetative type	Harvest date	Average production on treatment			Significance of difference of means*
		1 (control)	2 (25 kg ha^{-1})	3 (100 kg ha^{-1})	
Creosotebush:	14 July 1977	10·03	10·30	12·25	$1 = 2 \ll 3$
total new growth	20 Sept. 1977	12·69	13·17	16·10	$1 = 2 \ll 3$
Creosotebush:	14 July 1977	9·28	9·79	11·21	$1 = 2 \ll 3$
twigs and leaves	20 Sept. 1977	11·11	11·44	13·76	$1 = 2 \ll 3$
Creosotebush:	14 July 1977	0·748	0·589	1·049	$1 = 2 \ll 3$
seeds	20 Sept. 1977	1·591	1·736	2·337	$1 = 2 \ll 3$
Fluff grass	30 Aug. 1977	573·5	863·7	1149·4	$1 \ll 2 \ll 3$

Production of creosotebush is expressed as weight in grams of new growth on the terminal 25 cm of four branches per bush. Production of fluff grass is the estimated standing crop in kg ha^{-1}.

* Terminology: $=$, no significant difference; $<$, $\ll$, significantly different at P = 0·05 and 0·01, respectively.

(1975) found that 100 kg ha^{-1} of supplemental nitrogen yielded creosotebush production of 93 ± 64 kg ha^{-1} ($\bar{x} \pm$ S.E.), based on two replicates, while 25 kg ha^{-1} N yielded 58 ± 7 kg ha^{-1} of plant growth and the control 2 ± 2 kg ha^{-1}. Their data show no buffering effect of shallow-rooted species as seen in the present study. This may be a result of differences in rainfall patterns and percolation transporting nitrogen from the surface to deeper in the soil.

These data provide empirical evidence that nitrogen is limiting in desert ecosystems. The growth response of creosotebush was the same in the first half of the growing season, which had 'average' rainfall, as in the last half, which had 'above-average' rainfall. The summer rains resulted in measurable growth of fluff grass which exhibited a marked response to nitrogen fertilization. It is possible that fluff grass sequestered nitrogen during the first half of the growing season even though there was no readily noticeable vegetative growth. These data support the idea expressed by Noy-Meir (1974) that rapid growth pulses may deplete nutrient pools. Consequently, if soil carbon reserves are increased thereby increasing nitrogen fixation, plant growth responses should be similar to those reported in this study. Experiments to test that hypothesis are in progress.

This research was supported in part by Grant no. DEB 77–16633 from the NSF.

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