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Nitrogen in Desert Grasses as Affected by Biosolids, their Time of Application, and Soil Water Content

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This study evaluated the interactive effect of biosolids, time of application, and soil water on plant N concentration and uptake by Bouteloua gracilis *(blue grama) and* Hilaria mutica *(tobosagrass) grown in pots. Biosolids were surface-applied to the soil of the pots either in the spring or the summer at rates of 0, 7, 18, 34, and 90 dry Mg ha*$^{-1}$*. All of the pots were irrigated weekly to achieve 40% or 80% of field capacity soil water. The maximum increase in* B. gracilis *tissue N concentration due to biosolids application with respect to control was 41% in plants grown under the higher irrigation regime and only 15% in those plants grown under the lower irrigation regime. In* H. mutica*, the higher irrigation level produced an average of 20% higher tissue N concentration than the lower irrigation level across all biosolids application rates. Both species had a much higher N uptake (3.5- to 6.3-fold) under the higher than under the lower irrigation regime due to the large increase in shoot biomass caused by the higher irrigation level, regardless of rate of biosolids. At low biosolids rates, soil* NO_3^-*-N was higher under the lower irrigation regime than under the higher irrigation regime due to the lower N uptake in plants. Spring application of biosolids produced higher soil* NO_3^-*-N levels than summer application only when irrigation level was high. The fertilizing effect of biosolids depended heavily on soil water availability.*

Keywords biosolids-irrigation interaction, blue grama, *Bouteloua gracilis*, Chihuahuan Desert, *Hilaria mutica*, nitrogen uptake, tobosagrass

Biosolids are nutrient-rich compounds whose application to semiarid rangelands enhances soil nutrient levels (Fresquez et al., 1990) in these environments where plant productivity is commonly water- and nitrogen-limited (Stephens & Whitford, 1993; Benton & Wester, 1998). Fresquez et al. (1990) reported an increase in forage production and N concentration in *Bouteloua gracilis* (H.B.K.) Lag. ex Steud. (blue

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grama) after applying biosolids to a semiarid rangeland. Likewise, Jurado & Wester (2001) reported an increase in *Hilaria mutica* (Buckl.) Benth. (tobosagrass) yield and N concentration following biosolids applications in the northern Chihuahuan Desert. Jurado & Wester (2001) also reported that dual applications of biosolids in winter and summer produced higher grass yields than dual applications in spring and summer. Also, in a year of average precipitation, the winter and summer applications caused a very substantial increase in leaf production and a decrease in N concentration with respect to the spring and summer applications, which was explained by a "dilution" effect. These results are important to determine a proper use of biosolids on rangelands and yet have not been adequately explained (Jurado & Wester, 2001).

Despite the widely accepted view that soil water content directly affects nutrient availability (Chapin, 1991; Schulze, 1991; Ivans et al., 2003), the interactive effect of biosolids and soil water content on N uptake of desert grasses has rarely been approached. The limited information available comes from field experiments in which yearly variation in rainfall produced inconsistent responses in tissue N of some short grasses (Pierce et al., 1998). In another field study, Jurado & Wester (2001) applied biosolids and supplemental irrigation to *H. mutica* plots and found that their effects on yield and tissue N were not interactive.

In this study, the objective was to determine the effect of biosolids applications on N concentration of two desert grasses and whether, or not, soil water content and season of biosolids application alter this effect. We hypothesized that the fertilizing effect of biosolids is directly enhanced by higher soil water content because of the strong relationship between water and nutrient absorption and because dry soils restrict soil microbial biomass and decomposition of organic amendments (Whitford et al., 1989).

Materials and Methods

This study was conducted in 1997 under a rain-out shelter (26 × 4.5 m) constructed in a semicylinder form with PVC tubes forming a frame and covered with greenhouse plastic film (Dura-Film 3, AT Plastic Inc.) that allows 92% light transmission. The rain-out shelter was located on the Sierra Blanca Ranch, about 10 km north of Sierra Blanca, Texas (Latitude 31° 16′ N, Longitude 105° 22′ W). The area is part of the Chihuahuan Desert with an annual average precipitation of 310 mm, occurring predominantly July through September. The mean annual temperature is 18°C, but temperatures of 38°C during the summer are common in the area (Jurado-Guerra, 2000).

One hundred and sixty plastic pots (total volume 14.7 L, 30 cm deep and 25 cm diameter) were used in the experiment. Eighty pots were filled with Armesa soil and the other 80 were filled with Stellar soil collected from the Sierra Blanca Ranch. Soil was collected from a 0- to 30-cm depth, air-dried, and passed through a 0.5 cm sieve to provide a homogeneous rooting medium. The Armesa taxadjunct fine sandy loam is a fine, loamy, mixed, thermic Ustic Haplocalcid (B. L. Allen and C. Moffet, pers. comm.). The Stellar taxadjunct loam is a fine mixed, superactive, thermic Vertic Paleargid with the surface horizon overlying an argillic and a calcic horizon (Casby-Horton, 1997). The names of the soil series used in this study are taxadjuncts or variants that may change in the future because the USDA Natural Resource Conservation Service has not officially correlated the soils of the area. Selected chemical characteristics of untreated Armesa and Stellar soils are presented in Table 1. These characteristics were obtained in soil samples from similar Armesa and Stellar soils, but not necessarily the exact locations where the soil was obtained for the pots. Organic matter was determined by the Walkley-Black procedure (Nelson & Sommers, 1996) and total N (TKN) by macro-Kjeldahl (Bremner, 1996). Available P was obtained by extraction with $NaHCO_3$ (Olsen & Sommers, 1982). Electrolytic conductivity and pH were determined in a solution extracted from a saturated paste.

TABLE 1 Baseline Chemical Analyses and Field Capacity for Untreated Armesa and Stellar soils, 0- to 30-cm Depth, on the Sierra Blanca Ranch in the Chihuahuan Desert, Sierra Blanca, Texas

Parameter	Armesa soil	Stellar soil
pH	7.53	7.54
EC (dS m^{-1})	0.46	1.66
OM (g kg^{-1})	7.00	8.50
TKN (mg kg^{-1})	496.75	881.67
P (mg kg^{-1})	2.60	4.27
Water at field capacity (v/v, g kg^{-1})	190.40	280.40

EC, electrolytic conductivity; OM, organic matter; TKN, total Kjeldhal nitrogen.

The more common plants growing on the Armesa soil are *B. gracilis*, *B. eriopoda* (Torr.) Torr. (black grama), *Muhlenbergia arenacea* (Buckl.) A.S. Hitchc. (ear muhly), *Scleropogon brevifolius* Phil. (burrograss), *Yucca elata* Engelm. (soaptree yucca), and *Ephedra trifurca* Torr. (Mormon tea). The predominant plants on the Stellar soil are *H. mutica*, *Sporobolus airoides* (Torr.) Torr. (alkali sacaton), and *Prosopis glandulosa* var. *glandulosa* Torr. (mesquite).

B. gracilis and *H. mutica* plants were collected from the same areas where the Armesa and the Stellar soils were obtained, respectively. The plants collected had roots with an average length of 10–15 cm and were reduced to four or five tillers prior to transplanting. *B. gracilis* plants were transplanted into pots containing Armesa soil and *H. mutica* plants were transplanted into pots containing Stellar soil. Transplanting was done in February, immediately after plant collection and the plants were irrigated regularly to ensure successful establishment. Potable water from the same source was used for irrigation of all plants. It was assumed that such water would not add significant amounts of N or other plant nutrients. However, we did not conduct a chemical analysis of the water. The pots were sealed on the bottom to prevent water loss via leaking. Half of the pots containing each species were treated with biosolids in March (spring application). The other half of the pots was treated in June (summer application). In both seasons of application, biosolids were surface-applied at rates of 0, 7, 18, 34, and 90 dry Mg ha^{-1}. No pots were treated more than once.

The biosolids that were used in this study were provided by a private contractor that land-applied anaerobically-digested biosolids from New York City to rangeland adjacent to the study area. Biosolids were Class B, of residential origin, and did not contain industrial residues. Class B biosolids have significantly low levels of pathogens and metals and are permitted for application on agricultural lands and reclamation sites, but are not permitted for lawns or home gardens. The chemical composition of the biosolids used in this study as well as the baseline soil data (Table 1) were analyzed by the Soil, Water, and Air Testing (SWAT) laboratory of New Mexico State University, Las Cruces, New Mexico. The chemical composition of biosolids was determined in samples that were obtained immediately after application of biosolids to the potted plants. These samples were kept frozen until they were analyzed in the SWAT laboratory. Selected chemical characteristics of the biosolids used in this study are shown in Table 2. A more detailed chemical composition of these biosolids is reported in Mata-González et al. (2002). Biosolids TKN was analyzed by macro-Kjeldahl (Bremner, 1996). The concentrations of P, K, Ca, Mg, S, and Na in biosolids were obtained using inductively coupled plasma-atomic

TABLE 2 Chemical Composition and Electrical Conductivity of the Biosolids Applied to the Soil in Individual Pots Containing *Bouteloua gracilis* and *Hilaria mutica* in Spring or Summer Applications in 1997 (No Pots were Treated More than One Time)

Parameter	Spring (March)	Summer (June)
TKN (g kg^{-1})	44.80	23.60
P (g kg^{-1})	20.20	19.80
K (g kg^{-1})	1.10	1.30
Ca (g kg^{-1})	24.40	22.30
Mg (g kg^{-1})	6.70	5.60
S (g kg^{-1})	12.10	13.30
Na (g kg^{-1})	0.80	0.90
EC (dS m^{-1})	5.64	6.66

TKN, total Kjeldahl nitrogen; EC, electrolytic conductivity.

emission spectrometry (EPA Method 200.7) (U.S. Environmental Protection Agency, 2001) after being digested with HNO_3 in a microwave. Electrolytic conductivity was determined in a solution extracted from a saturated paste.

Plants were subjected to two irrigation levels: 40% and 80% of soil field capacity. The amount of water that each soil holds at field capacity was multiplied by either 0.40 or 0.80 to obtain the amount of water to apply for each treatment. Previous studies (Wan et al., 1993; Mata-González et al., 2002) have used similar irrigation levels to represent contrasting conditions of soil water content without imposing excessive stress to plants. Field capacity (v/v) of each soil was determined with a pressure plate (Richards, 1965) and is shown in Table 1. After the spring application of biosolids, every pot, irrespective of season of biosolids application was weighed once a week and irrigated with the necessary amount of water to restore the appropriate levels of soil water.

The experimental unit was a pot containing one plant of either *B. gracilis* or *H. mutica*. A factorial experiment ($5 \times 2 \times 2$) was established by combining five biosolids application rates, two seasons of biosolids application, and two irrigation levels. As a result, 20 treatments were applied to each species and each experimental unit was replicated four times for a total of 160 pots. Each species was treated as a separate experiment and no attempt was made to statistically compare them. The experimental design was a randomized block consisting of four blocks confounded with replications. The blocks were designed to facilitate the measurement of other variables such as photosynthesis that are reported elsewhere (Mata-González et al., 2002).

At the end of the experiments (late August, 1997), the shoots of all plants were harvested by clipping at soil level, placed into a forced-air oven, dried at 75°C for 24 h, then weighed to determine dry matter production. Oven-dried shoot tissues were ground in a Wiley mill to pass through a 0.5 mm mesh screen. Nitrogen concentration in shoot tissue was determined by the macro-Kjeldahl method (Bremner, 1996). Nitrogen uptake, which represents the total amount of N in shoots, was obtained by multiplying the N concentration by the dry weight of shoots (Chapin & Van Cleve, 1989). After harvesting the shoots, soil samples were taken from every pot (top to bottom) with a 2-cm diameter probe and air-dried immediately. The dried soil samples were sieved to pass a 2-mm mesh screen, allowing us to separate and discard portions of the primary roots prior to chemical analysis. The NO_3^--N concentration from each soil sample was determined spectrophotometrically by Cd reduction after nitrate extraction with 2 M KCl (1 g soil:10 mL extractant ratio) (Mulvaney, 1996).

Before performing analyses of variance, data normality was tested by means of the Shapiro-Wilk's test. In order to assess sphericity, the Greenhouse-Geisser estimator of θ was calculated and used to modify the F test, assuming that sphericity was violated. It was found that violation of sphericity did not change the results of the analyses of variance in a critical manner; therefore, the unadjusted F tests were used. Treatment mean separation was performed with the general error term by using the protected Fisher's Least Significant Difference (LSD) test. Significant differences were declared at $P < 0.05$. The SAS package was used for all statistical analyses.

Results

In both species, tissue N concentration varied as a function of biosolids application rates and irrigation levels. The N concentration of *B. gracilis* shoot tissue increased as the rate of biosolids increased in plants irrigated at 80% field capacity (Table 3). Plants treated with 18, 34, and 90 Mg ha^{-1} had, respectively, 20%, 26%, and 41% more N than untreated plants. The N concentration in *B. gracilis* plants irrigated at 40% field capacity did not increase in a similar fashion. Only those plants treated with 90 Mg ha^{-1} had significantly more N (15%) than untreated plants. Plants treated with 0 and 7 Mg ha^{-1} of biosolids had higher N concentrations under the low irrigation level than under the high irrigation; whereas, plants treated with 18, 34, and 90 Mg ha^{-1} had no difference in N concentrations due to irrigation levels.

The N concentration of *H. mutica* increased ($P < 0.05$) in a curvilinear fashion as the rate of biosolids increased (Figure 1). However, this effect was not different between irrigation levels. Across all biosolids rates, plants receiving the higher irrigation level had 20% higher ($P < 0.05$) N concentration (15.3 g kg^{-1}) than plants receiving the lower irrigation level (13.0 g kg^{-1}).

Nitrogen uptake in both species was determined by an interaction between levels of biosolids application and irrigation. Regardless of rate of biosolids application, both species had a much higher N uptake (3.5- to 6.3-fold) at 80% than at 40% field capacity (Table 4). This result was due to a great increase in shoot biomass caused by the higher irrigation level. Even without biosolids application, the higher irrigation increased the N uptake about 4-fold in both species. When irrigation was high, N uptake in both species increased steadily as biosolids rate increased. This did not happen when irrigation was low. In both species and for both irrigation levels, N uptake did not differ significantly between plants receiving 0 or 7 Mg ha^{-1} biosolids.

Soil NO_3^--N levels at the end of the experiment varied as a function of the biosolids application rates and irrigation levels (Table 5). The increase in biosolids

TABLE 3 Nitrogen Concentration (g kg^{-1}) of *Bouteloua gracilis* Shoots as Affected by Rate of Biosolids Application and Irrigation Levels

	Irrigation level (% of field capacity)	
Biosolids rate (Mg ha^{-1})	40	80
0	10.4 Ab	8.8 Bc
7	11.1 Aab	9.7 Bbc
18	10.2 Ab	10.6 Ab
34	10.1 Ab	11.1 Aab
90	12.0 Aa	12.4 Aa

Different capital letters within a biosolids rate indicate significant difference between irrigation regimes at $P < 0.05$. Different lowercase letters within an irrigation regime indicate significant differences between biosolids rates at $P < 0.05$.

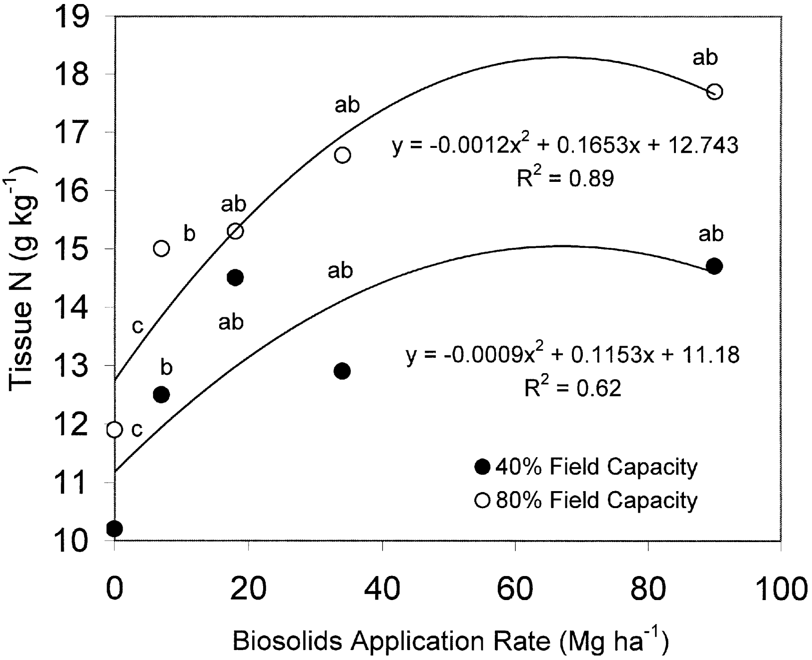

FIGURE 1 Nitrogen concentration in *Hilaria mutica* shoots as affected by biosolids application rate and soil water content (different letters within a soil water content indicate significant differences between biosolids rates at $P < 0.05$). Means are averaged across seasons of biosolids application.

rate was paralleled by an increase in NO_3^--N in both the Armesa and the Stellar soils irrigated at 80% field capacity. This increase was less pronounced in both soils irrigated at 40% field capacity. When no biosolids were applied to either soil, the higher irrigation resulted in very low soil NO_3^--N concentrations, but this effect was especially striking in the Stellar soil. Both soils treated with low biosolids application rates (0 to 18 Mg ha^{-1}) had higher NO_3^--N concentrations under the lower irrigation

TABLE 4 Nitrogen Uptake (mg plant^{-1}) of *Bouteloua gracilis* and *Hilaria mutica* Shoots as Affected by Rate of Biosolids Application and Irrigation Levels

Biosolids rate (Mg ha^{-1})	*B. gracilis*		*H. mutica*	
	Irrigation level (% of field capacity)			
	40	80	40	80
0	17.1 Bab	78.5 Ad	56.7 Ba	244.4 Ad
7	15.2 Bb	83.8 Acd	71.1 Ba	262.9 Acd
18	14.2 Bb	90.7 Ac	84.8 Ba	301.5 Abc
34	19.2 Bab	109.5 Ab	85.6 Ba	310.9 Ab
90	26.8 Ba	125.4 Aa	85.7 Ba	360.0 Aa

For each species,different capital letters within a biosolids rate indicate significant difference between irrigation regimes at $P < 0.05$. Different lowercase letters within an irrigation regime indicate significant differences between biosolids rates at $P < 0.05$.

TABLE 5 Soil NO_3^--N Concentration (mg kg^{-1}) in Armesa and Stellar Soils as Affected by Rate of Biosolids Application and Irrigation Level

	Armesa soil (*B. gracilis*)		Stellar soil (*H. mutica*)	
	Irrigation level (% of field capacity)			
Biosolids rate (Mg ha^{-1})	40	80	40	80
0	20.6 Ab	7.0 Bc	18.4 Ab	1.5 Bd
7	20.9 Ab	15.3 Ab	25.7 Ab	8.4 Bc
18	26.1 Aab	12.8 Bbc	29.8 Ab	14.4 Bc
34	23.4 Ab	16.5 Bb	26.4 Ab	28.0 Ab
90	32.1Ba	39.1 Aa	61.9 Ba	81.2 Aa

For each soil,different capital letters within a biosolids rate indicate significant difference between irrigation regimes at $P < 0.05$. Different lowercase letters within an irrigation regime indicate significant differences between biosolids rates at $P < 0.05$.

level than under the higher irrigation level. In contrast, when pots received 90 Mg ha^{-1} of biosolids, both soils had higher NO_3^--N concentrations under the higher irrigation than under the lower irrigation.

Season of biosolids application did not produce significant differences in N concentration or uptake for either species (data not shown). Season of biosolids application and irrigation level interacted to affect the concentration of NO_3^--N in both soils in a similar manner. Spring application produced higher soil NO_3^--N concentrations than the summer application, but only when the higher irrigation was applied (Table 6). In general, the lower irrigation resulted in higher soil NO_3^--N than the higher irrigation.

Discussion

The increase in plant N concentration as biosolids rate increased is in agreement with previous studies (Fresquez et al., 1990; Pierce at al., 1998; Zebarth et al., 2000; Jurado & Wester, 2001). In our study, however, this effect was only found under the higher irrigation regime in *B. gracilis*, and was substantially enhanced by higher irrigation in *H. mutica*. In both cases, irrigation determined the effect of biosolids. Consistent with this, Zebarth et al. (2000) reported that biosolids application only increased the tissue N concentration of dryland forage grasses during years of

TABLE 6 Soil NO_3^--N Concentration (mg kg^{-1}) in Armesa and Stellar Soils as Affected by Irrigation Level and Season of Biosolids Application

	Armesa soil (*B. gracilis*)		Stellar soil (*H. mutica*)	
	Irrigation level (% of field capacity)			
Biosolids rate (Mg ha^{-1})	40	80	40	80
Spring (March)	24 Aa	21 Aa	35 Aa	22 Ba
Summer (June)	25 Aa	15 Bb	26 Aa	9 Bb

For each soil, different capital letters within a season indicate significant difference between irrigation levels at $P < 0.05$. Different lowercase letters within an irrigation level indicate significant differences between seasons at $P < 0.05$.

average or above-average precipitation. Pierce et al. (1998) also reported that the effect of applying biosolids on tissue N concentrations of grasses such as *Agropyron smithii* (western wheatgrass), *Agropyron spicatum* (bluebunch wheatgrass), and *Oryzopsis hymenoides* (Indian ricegrass) varied in direct relation to changes in annual precipitation. In the northern Chihuahuan Desert, separate additions of nitrogen or water did not produce a significant increase in tissue N of *B. eriopoda;* only the combined addition of nitrogen and water increased N levels in this species (Stephens & Whitford, 1993). These results are supported by the well-established theory that adequate soil water increases ion diffusion to the root surface, which is usually the rate-limiting factor for plant nutrient absorption (Chapin, 1991; Schulze, 1991). Furthermore, limitations in soil water hinder the mineralization of organic amendments by restricting the size of soil microbial populations (Whitford et al., 1989).

In apparent contradiction with the above research, *B. gracilis* plants irrigated at 40% field capacity had higher N concentrations than those irrigated at 80% field capacity when biosolids rates were low. Under these conditions, the higher irrigation regime produced plants of greater size containing low N concentration due to the low soil N supply and to the increasing proportion of structural tissue. The lower irrigation regime produced smaller plants with more concentrated tissue N. This has been referred to as a "dilution" effect (Black and Wight, 1979) and observed in a number of studies (Jurado & Wester 2001; Mata-González et al., 2001; Irshad et al., 2002). The higher N concentration in *B. gracilis* with lower irrigation and lower biosolids rates was also coincident with higher photosynthetic rates (Mata-González et al., 2002). Therefore, our findings indicate that water stress primarily restricts shoot growth and secondarily N absorption and photosynthetic rates.

Nitrogen uptake of a plant represents the combined affect of N absorption and biomass accumulation. In *B. gracilis* and *H. mutica*, N uptake was highly favored by higher irrigation even in the absence of biosolids. In contrast, the effect of biosolids on N uptake was very limited under the lower irrigation level. This indicates that our plants were more limited by water than by N. Furthermore, our results indicate that the fertilizing effect of biosolids was restricted when water was less available to facilitate nutrient diffusion towards the root surface. This emphasizes the overriding importance of water in desert ecosystems and supports our premise that the fertilizing effect of biosolids is necessarily dependent on soil water levels because of the obligate relationship between water and nutrient uptake (Chapin, 1991; Schulze, 1991).

Field studies in the Chihuahuan Desert have reported that the effect of biosolids on *S. airoides* and *H. mutica* biomass was independent of supplemental irrigation (Benton & Wester, 1998; Jurado & Wester, 2001). In these studies the total amount of supplemental water per growing season was significant (75 mm), but was applied in small and frequent pulses of 15 mm. It is possible that the small irrigation events would not increase soil water content enough to promote higher N uptake and mineralization of biosolids. Studies have reported that small and frequent rainfall events, as compared to heavier events, are not effectively translated into higher photosynthesis (Yan et al., 2000) and growth (Stephens & Whitford, 1993) of Chihuahuan Desert plants. This is supported by studies in other desert environments reporting that at least 25 mm of rainfall are necessary to trigger increases in photosynthesis and growth (Beatley, 1974; Ehleringer et al., 1999). In spite of this, a recent study found that rain events of 5 and 15 mm were enough to facilitate absorption of N by typical Great Basin plants (Ivans et al., 2003).

In general, soil NO_3^--N concentration increased as rate of biosolids application increased in both the Armesa and the Stellar soils, which is consistent with the results of Fresquez et al. (1990). Biosolids typically have a low C:N ratio that permits N mineralization to exceed N immobilization by soil microflora, resulting in net N mineralization after land application (Benton & Wester 1998). In our experiment, however, the effect of biosolids application rate on soil NO_3^--N concentration was modified by the irrigation level.

At low biosolids application rates, the higher irrigation regime produced lower soil NO_3^--N concentrations than the lower irrigation regime in both soils. Soil NO_3^--N concentrations as measured in this experiment represented the residual concentrations after plant N uptake. Higher water availability produced larger plants with higher N demand (Chapin, 1991; Schenk, 1996) and caused a major impact on soil NO_3^--N depletion when low rates of biosolids were applied. Soil NO_3^--N is the dominant form of N available for plants in most types of soils (Schenk, 1996). Conversely, at the maximum application rate of biosolids, the higher level of irrigation produced higher soil NO_3^--N concentrations than the lower level of irrigation. Under these conditions, N supply by biosolids was probably high enough to limit the influence of plant N demand in determining the residual soil NO_3^--N concentrations. Supporting this, Devienne-Barret et al. (2000) reported that soil N levels could be minimally influenced by plant N uptake if soil N supply is high.

Seasons of biosolids application did not cause differences in tissue N concentration or plant uptake; therefore, soil NO_3^--N levels were only a function of biosolids mineralization because N losses by leaching were avoided and N losses by volatilization were expected to be low (Harmel et al., 1997). Higher NO_3^--N levels were found in soils treated with biosolids in the spring than in the summer, but only when irrigation was higher. When irrigation was lower, soil water content was restricted and the exposure time of biosolids was less important in determining N availability because decomposing agents were probably water-limited (Whitford et al., 1989). Therefore, the benefits of applying biosolids on the Chihuahuan Desert in the spring over applying them the summer can be realized only if significant winter or spring rains occur. A confounding factor in our study, however, was the different TKN levels that were found in spring-applied and summer-applied biosolids (Table 2).

The potential of biosolids to promote plant growth can be better expressed and predicted when water availability is not a restricting factor. It often seems that on semiarid rangelands, low water availability limits the potential benefit of biosolids for plant growth. One advantage of biosolids applications is their capacity for long-term nutrient release (White et al., 1997). Although the beneficial effect might be reduced in years of less than average precipitation, biosolids are not likely to cause adverse effects (Wester et al., 1996; Benton & Wester, 1998). In years of adequate precipitation, and in the long term, biosolids can increase soil nutrients and primary production. In addition, the beneficial effect of biosolids is not restricted only to its fertilizing effect. Jurado-Guerra (2000) reported a mulching effect of biosolids in desert grasslands that contribute to decreased soil water evaporation and moderation of extremes in soil temperatures. Increases in time-to-runoff, infiltration rates, and organic matter content were also reported as beneficial effects of biosolids application on Chihuahuan Desert soils (Rostagno & Sosebee, 2001).

The beneficial fertilizing effect of biosolids in desert grasslands might not be fully expressed in lower-than-average precipitation years. Yet, in the long-term, application of biosolids in semiarid to arid environments is a viable option for grassland improvement.

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