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Research Article

Residual Effects of Biosolids Application on Forage Production of Semiarid Grassland in Jalisco, Mexico

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Single application of biosolids increases forage production on semiarid grasslands. Residual effects of biosolids on forage production have been scarcely measured in semiarid grasslands. The objective was to evaluate the residual effects of biosolids application on forage production of blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths) and other grasses at a semiarid grassland in Jalisco, Mexico. The study was performed at shortgrass prairie in northeast Jalisco. Field plots were selected to include blue grama plants before rainy season in 2002. Aerobic biosolids were applied at 0 (control), 15, 30, 45, 60, 75, or 90 dry $\mathrm{Mg\,ha^{-1}}$ under a completely random design with five replications. Forage production was estimated by clipping at the end of the growing season during five years. Data analysis was performed with linear mixed model and repeated measures. Forage production was influenced by a rate × year × species interaction ($P = 0.0001$). Blue grama forage production increased with increasing biosolids rates during all years, with the magnitude of this response varying among years. Forage production of other grass species slightly decreased with biosolids application. Single biosolids application had a residual effect on forage production throughout five years in semiarid grasslands.

1. Introduction

Approximately half of the world native grasslands show moderate to strong degradation [1], while approximately 95% of the grasslands are overgrazed and show degradation in Mexico [2]. Studies in Mexico indicate that most of the shortgrass prairie in Jalisco [3], Zacatecas, and Chihuahua [4] show moderate-extreme to extreme rangeland health. Oak-bunchgrass and Halophyte grasslands also show deterioration, including high invasion of native shrubs and exotic grasses in Chihuahua [5].

Practices to recover degraded grasslands may include use of fertilizers, prescribed fire, shrub management, and soil and water conservation techniques. Fertilizer application to native grasslands has increased forage production [6, 7] although high fertilizer costs make this a low profitability technique. An alternative might be application of organic byproducts such as biosolids that are generated at wastewater treatment plants and can be used as fertilizer and soil amendments [8, 9].

Several studies have shown that surface-applied biosolids promote grass production at arid and semiarid grasslands [10–12]. Biosolids rates from 18 to 45 $\mathrm{Mg\,ha^{-1}}$ have been recommended for arid rangelands with good agronomic results in terms of grass forage production and soil fertility [13]. Also, residual effects have been observed on soil fertility [14–16] and on forage production of arid grasslands [10, 11]. However, limited information is available on the residual effects of biosolids application in semiarid grasslands. Then, the objective of this study was to evaluate the residual effects of biosolids application on forage production of blue grama and other grasses at a semiarid grassland in Jalisco, Mexico.

2. Materials and Methods

The study was conducted at the Vaquerias Experimental Station, INIFAP, located at km 8 of Ojuelos-Lagos de Moreno highway, Ojuelos, Jalisco, Mexico, at 21.77927°N, 101.61133°W at 2,150 m altitude. Climate is semitropical [17] with a mean annual temperature at 17°C and mean annual precipitation at 425 mm. Topography is flat to less than 3% slope. Soil is Haplic Calcisol [18], alluvial origin, sandy loam texture, and a cement phase ("tepetate") with a 50–100 cm soil depth. Dominant vegetation is composed of *Bouteloua-Lycurus* with huizache (*Acacia schaffneri* (S. Watson) F.J. Herm.) and prickly pear (*Opuntia* spp.) invasion [19].

Thirty-five field plots 1 × 1 m were selected at a native shortgrass prairie at regular range condition including blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths) plants with an initial mean forage production of 843 ± 101 kg ha^{-1} estimated by clipping before biosolids application. Square plots with a plywood frame were used to retain biosolids. Domestic, aerobic biosolids from the wastewater treatment plant at Aguascalientes city, Mexico, were applied one time only at 0 (control), 15, 30, 45, 60, 75, or 90 Mg ha^{-1} on a dry weight basis, with five replications in June 2002. Previous to biosolids application, four random 1 kg samples were taken to determine moisture content and the following chemical analysis (Table 1): pH ($CaCl_2$/electrometric pH meter); electrical conductivity (saturated paste/Solu-bridge); organic matter through Walkley and Black combustion method [20]; total nitrogen (Kjeldahl) [21]; phosphorus (Bray-1) [22]; potassium, calcium, and magnesium, extracted by ammonium acetate; aluminum, zinc, iron, copper, manganese, boron, lead, arsenic, chromium, and cadmium extracted by DTPA [23] and analyzed by Atomic Absorption Spectroscopy; sulfur was extracted with calcium chloride and determined by turbidimetric method and chloride by volumetric methods. Chemical analysis of biosolids (Table 1) showed that pH and electrical conductivity were lower, and organic matter, nitrogen, and phosphorus were slightly higher than values in other studies [10, 11]. Because of their N and P contents, biosolids have the potential to improve soil fertility and promote plant growth at different agricultural scenarios. Biosolids composition complies with the Official Regulation of SEMARNAT in Mexico and was rated "Excellent" in terms of metal content [24].

Chemical analyses of initial soil samples before biosolids application were done similar to biosolids and are shown as follows (mean ± SE): pH = 6.3 ± 0.03; electrical conductivity = 0.028 ± 0.001 dS m^{-1}; organic matter = 1.28 ± 0.03%; extractable nitrogen = 3 ± 0.3 mg kg^{-1}; extractable $P = 2 \pm$ 0.2 mg kg^{-1}; and extractable potassium = 352 ± 10 mg kg^{-1}.

Biosolids rates were randomly assigned to field plots [25]. Biosolids were surface-applied and uniformly distributed around the plots by hand at the beginning of the rainy season in June 2002. Plots were excluded to grazing during the study and kept under natural rainfall conditions. Precipitation was measured at a meteorological station close to the study site (Table 2). Forage production was estimated by clipping blue grama forage separated from other grasses including hairy grama (*Bouteloua hirsuta* Lag.), poverty three-awn (*Aristida divaricata* Humb. & Bonpl. Ex Willd.), common wolfstail (*Lycurus phleoides* Kunth), or *Bouteloua scorpioides* Lag. at 5 cm stubble height at the end of the growing season each year during four years. Forage production was determined by oven-drying forage samples at 60°C during 48 hr and is expressed on a dry weight basis.

Table 1: Chemical composition of aerobic biosolids from the wastewater treatment plant at Aguascalientes city (n = 4).

Parameter	Mean	Element (ppm)	Mean
pH (water 1 : 5)	6.6	Zinc	972
EC[†] (water 1 : 5) (dS m^{-1})	1.5	Boron	2
Organic matter (%)	35.2	Iron	8564
Nitrogen (%)	4.1	Copper	272
Phosphorus (%)	3.4	Lead	38
Potassium (%)	0.1	Arsenic	11
Calcium (%)	2.7	Chromium	60
Magnesium (%)	0.3	Cadmium	6
Sulfur (%)	1.0	Manganese	153
Aluminum (%)	1.0	Chloride	832

[†]Electrical conductivity.

Table 2: Annual, growing season (June to September), and mean precipitation (mm) on a semiarid grassland in Jalisco, Mexico.

Time	2003	2004	2005	2006	Mean
Annual	439	550	264	463	439
Growing season	367	369	186	297	319

Forage production data was analyzed with linear mixed models and year as repeated measures [26]. The first analysis included forage production of blue grama and other grasses from 2003 to 2004 to estimate changes of blue grama and other grasses production over time. The second analysis included total forage production (sum of blue grama and other grasses) from 2003 to 2006 to determine residual effect of biosolids on forage production. Several covariance structures including unstructured variance, compound symmetry, heterogeneous compound symmetry, and autoregressive were tested to select the best models. The models with unstructured variance were selected due to lower Akaike Information Criterion [26]. Significant effects were declared at a 5% probability level.

3. Results and Discussion

The analysis on forage production of blue grama and other grasses was affected ($P = 0.0001$) by a rate × year × species interaction (Table 3). Blue grama and other grasses forage production varied as a response to biosolids application and year of forage production (Figure 1). Blue grama forage increased from 2,533 ± 354 to 7,224 ± 354 kg ha^{-1} in 2003 and from 2,375 ± 227 to 5,385 ± 227 kg ha^{-1} in 2004, with 15 and 90 Mg ha^{-1} biosolids rates, respectively (Figure 1) showing a high residual effect. In contrast, forage production of other

Table 3: Statistical results of blue grama, other grasses, and total forage production data on a semiarid grassland in Jalisco, Mexico.

Effect	F value	Probability > F
(Blue grama and other grasses)		
Biosolids rate	33.4	0.0001
Year	20.1	0.0001
Species	1142.9	0.0001
Biosolids rate × year	3.9	0.0014
Biosolids rate × species	43.3	0.0001
Biosolids rate × year × species	6.3	0.0001
(Total forage production)		
Biosolids rate	61.3	0.0001
Year	116.7	0.0001
Biosolids rate × year	5.1	0.0001

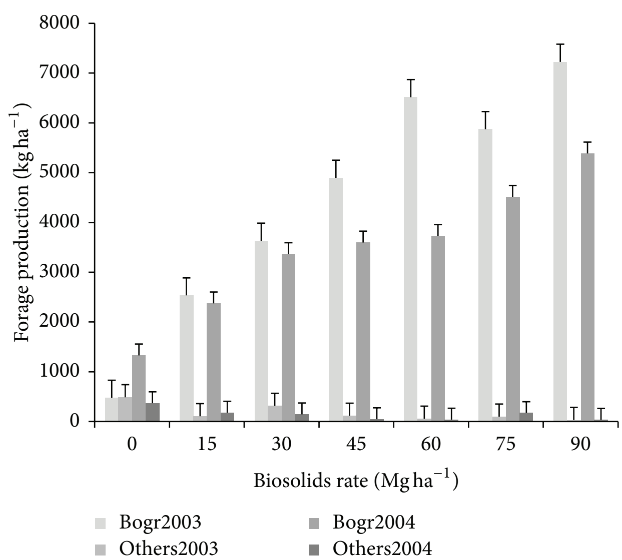

Figure 1: Forage production of blue grama and other grasses as affected by biosolids rate and year on a semiarid grassland in Jalisco, Mexico. Bogr2003 = blue grama forage production in 2003; Others2003 = forage production of other grasses in 2003; Bogr2004 = blue grama forage production in 2004; Others2004 = forage production of other grasses in 2004.

grasses was low and decreased from 106 to 30 kg ha^{-1} in 2003 and from 181 to 36 kg ha^{-1} in 2004 at the same rates (Figure 1). At control rate, forage production of blue grama (mean ± SE; 475 ± 148 kg ha^{-1}) was similar (P = 0.9797) compared to other grasses (488 ± 148 kg ha^{-1}) in 2003 and slightly higher (P = 0.0035) in 2004 (Figure 1).

Similar trends on increasing forage production of blue grama with biosolids and slighter effects of biosolids on other grasses such as galleta (*Hilaria jamesii* (Torr.) Benth.) and bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J.G. Sm.) have also been observed on arid grasslands in New Mexico [27]. However, blue grama forage production was lower in their study varying from 392 kg ha^{-1} at control rate to a maximum of 1,067 kg ha^{-1} at a biosolids rate of 90 Mg ha^{-1}, probably attributed to a lower mean annual precipitation of

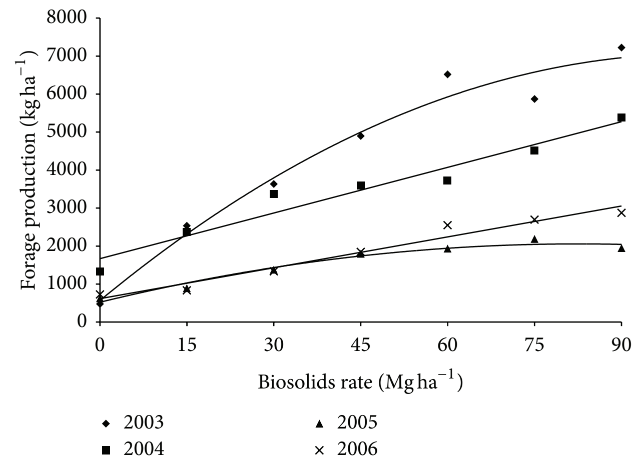

Figure 2: Total forage production as affected by biosolids rate and year on a semiarid grassland in Jalisco, Mexico (Y_{2003} = 569.05 + 125.88x − 0.6101x^2, r^2 = 0.97, P = 0.0290; Y_{2004} = 1,668.5 + 40.045x, r^2 = 0.94, P = 0.0001; Y_{2005} = 522.97 + 37.19x − 0.22x^2, r^2 = 0.96, P = 0.0369; Y_{2006} = 617.5 + 27.09x, r^2 = 0.96, P = 0.0001).

267 mm in their study site. Blue grama forage production was much higher in our study due to more favorable growing conditions such as a higher precipitation in the study site (Table 2). Another study showed variable effects of composted biosolids on plant cover in a shortgrass prairie dominated by western wheatgrass (*Pascopyrum smithii* (Rydb.) Love) and needle and thread grass (*Hesperostipa comata* (Trin & Rupr.) Barkworth) in a semiarid grassland in Colorado with 355 mm annual rainfall [28].

The residual effect of biosolids application on total forage production was affected (P = 0.0001) by a rate × year interaction (Table 3). Total forage production increased with biosolids application rates, and the effect was greater in 2003 and 2004 (Figure 2), showing a residual effect even four years after biosolids application. Increases of forage production varied from 5 to a maximum of 15 times at 15 to 90 Mg ha^{-1} rates, respectively, in 2003. However, the residual effect was lower in 2005 and 2006 attributed to a low precipitation during the growing season in both years (Table 2). Results of a similar study in New Mexico [27] showed increases of forage production up to 74% at the second year and up to 74% at the fourth year with 45 Mg ha^{-1} rate at an arid blue grama grassland in poor range condition. Research in Texas [10] showed a maximum increase of 92% on forage production of tobosa grass (*Pleuraphis mutica* Buckley) at the fourth year with single application of 36 Mg ha^{-1} rate and up to 80% with double annual applications of biosolids at 35 Mg ha^{-1} rate in arid grasslands [11]. The lower forage production in New Mexico and Texas can be attributed to low precipitation in their study sites with 267 and 310 mm of mean annual precipitation and lower than average at three out of four years during the study.

Also, forage production of winter grasses has increased with biosolids application at 40 to 120 Mg ha^{-1} rates after three years of application at a degraded native grassland in

Spain [29]. A later study [15] showed that forage production only increased at 80 and 120 Mg ha^{-1} rate after five years of application at the same site.

Our data showed the greatest forage production of grasses at native grasslands obtained under rainfed conditions, and they could be partially attributed to the precipitation observed during the years of study. Besides precipitation, the higher forage production with biosolids application could also be attributed to the plant growth nutrients provided by biosolids as shown by several studies [16, 27] and to the improvement on soil water infiltration and water availability with biosolids application [16, 30].

Soil fertility was evaluated during the first and second years after biosolids application in this study [16], showing beneficial effects on soil nutrients such as nitrogen and phosphorus. These beneficial results on soil fertility are partially responsible for the increases on grass forage production observed in this study. Improvement on soil fertility was more beneficial to blue grama, a dominant species in this grassland that had a better use of soil nutrients; meanwhile, other associated species were displaced as biosolid rates increased.

Residual effects of biosolids on soil fertility have been observed with increases on soil nitrogen and phosphorus after eight years of application of 45 and 90 Mg ha^{-1} rates on degraded native grassland of blue grama-galleta (*Hilaria jamesii* (Torr.) Benth.) in New Mexico [14]. Other authors also found residual effects on soil nitrogen and available phosphorus after five years with biosolids applications from 40 to 120 Mg ha^{-1} rates compared to control rate in native grassland in Spain [29]. Residual effects on soil available nitrogen and phosphorus after 12 years have also been observed in a shortgrass prairie with biosolids application from 5 to 30 Mg ha^{-1} rates in Colorado [31]. However, organic matter from biosolids decreased with time, and soil nitrogen availability has been shown to decrease from 5 to 1% in a seven-year period in desert grasslands in Texas [32].

Although biosolids application has shown favorable effects on forage production and consequently could have an impact on animal production, there are some limitations that make this practice not suitable for all grasslands. First, even though biosolids generation will increase due to increasing world population and to increasing environmental concerns for wastewater treatment, biosolids availability is still low in some remote and rural areas; second, high transportation and application costs [33, 34] make this practice more suitable for those grasslands closer to the wastewater treatment plants; and third, caution is advisable due to content of pathogens and heavy metals on biosolids. Despite this, land application of biosolids is still a recommended option to recycle organic matter and nutrients for plant growth in grasslands [13] and to restore degraded ecosystems [35].

4. Conclusions

Single biosolids application on the surface showed a residual effect on forage production even five years after application. The major effects on forage production were on blue grama at all biosolids rates. Other grasses such as hairy grama (*Bouteloua hirsuta* Lag.), poverty three-awn (*Aristida divaricata* Humb. & Bonpl. Ex Willd.), common wolfstail (*Lycurus phleoides* Kunth), and *Bouteloua scorpioides* Lag. showed no response to biosolids application. The residual effect on forage production is still very strong at 45 to 90 Mg ha^{-1} rates and is fading on biosolids rates from 15 to 30 Mg ha^{-1}. A biosolids rate of 45 Mg ha^{-1} is recommended, based on the residual effect on forage production during the years evaluated.

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