

Rangeland Restoration Using Biosolids Land Application

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ABSTRACT

Land application of aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure as an approach to restore disturbed rangelands was evaluated. While control plots yielded, on average, 84.1 lbs/acre of forage dry matter, dry forage yield on rangeland plots receiving aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure ranged from 129.0 to 664.1 lbs/acre. Field tests indicated an average moisture infiltration rate of 7.07 cm/hr for control plots compared to a maximum of 7.14, 9.98 and 9.56 cm/hr in plots receiving aerobically digested, anaerobically digested and beef cattle manure, respectively. The increase in forage yield and moisture infiltration underscored the value of biosolids land application in rangeland restoration activities.

INTRODUCTION

In the western United States (US), rangelands provide forage for livestock production, habitat for native flora and fauna and watersheds for rural agriculture. However, because of past grazing practices, these rangelands are in a variety of conditions ranging from severely degraded landscapes to fully functional ecosystems. Of all the range management practices available, proper stocking or control of forage utilization is the most important. Continued excessive defoliation, which is the major cause of range deterioration in the western US, has led to increased moisture runoff and soil erosion (Baker and Guthery, 1990; Fleischner, 1994; US Department of Agriculture Cooperative Extension Service, 1989). The adverse environmental effects associated with overgrazing are complex and addressing them requires a systematic and sustainable approach (Benton and Wester, 1998; Fleischner, 1994; Gass and Sweeten, 1992; McFarland, 2001).

Biosolids represent an inexhaustible resource that can be utilized to restore the vegetative vigor of arid and semiarid rangelands. Biosolids contain significant amounts of plant nutrients (nitrogen, phosphorus, potassium) as well as organic matter that support sustainable vegetative growth and forage productivity of rangelands. Land application of biosolids not only increases the potential economic value of rangelands by increasing their forage value but collection of land leasing and biosolids tipping fees from municipal wastewater treatment plants can be a significant source of financial revenue for ranchers who agree to utilize biosolids (Clapp *et al.*, 1994; Gass and Sweeten, 1992; McFarland, 2001; Parker, 1985).

Application of biosolids to disturbed rangelands poses little threat to groundwater resources in areas with adequate groundwater depths because evapotranspiration generally exceeds total precipitation (Evans *et al.*, 2001; Harris-Pierce *et al.*, 1995). Climatic variables including temperature, rainfall intensity and frequency are important in determining both the rate of rangeland recovery following biosolids land application as well as the types of vegetative species that will become established (Black and Wright, 1979; Jensen, *et al.*, 2000; National Research Council; 2002). The current study was focused on comparing the effects of land applying aerobically digested biosolids, anaerobically digested biosolids and beef-cattle manure to disturbed western US rangelands.

METHODOLOGY

Biosolids and beef cattle manure were surface applied at various rates on 1/3-acre test plots separated by buffer strips on private rangeland located in Skull Valley, UT. A control plot served as a treatment performance baseline and received no organic amendments (biosolids or beef cattle manure).

The agronomic rate for the surface application of biosolids and beef cattle manure was determined based on the assumption that a healthy rangeland would exhibit an annual nitrogen requirement of 150 lbs of nitrogen per acre (Natural Resources Conservation Service; 2000). The nitrogen-based agronomic rates for biosolids and beef cattle land application were estimated using Equation 1. Since an operational goal of the current study was to evaluate management practices that would reduce the overall costs of rangeland restoration activities, no tilling, irrigation and re-seeding occurred at the rangeland test sites. Moreover, to reduce energy and equipment operational costs, it was decided to evaluate the benefits of applying a large one-time application of biosolids and beef cattle manure to the disturbed rangeland sites. The organic amendments were surface applied at ten times (10X), five times (5X) and one time (1X) the estimated agronomic rate.

Environmental Sampling Design

A statistical inference approach was utilized to draw scientifically defensible conclusions regarding the benefit of land applying various organic amendments to restore disturbed rangelands. Application of statistical inference requires that field samples be selected at random. To facilitate the selection of random samples, each of the 1/3-acre test plots was divided into one hundred forty four (144) sections (i.e., subplots) having physical dimensions of 10 feet by 10 feet (i.e., 100 ft²). During field sampling, six (6) 10 feet by 10 feet subplots from each 1/3 acre test plot were sampled for forage and soil properties. The mean value for each parameter of interest was estimated using data from all subplots of a particular treatment.

$$\text{Agronomic Rate} \left(\frac{\text{tons}}{\text{acre}} \right) = \frac{\text{adjusted nitrogen fertilizer requirement} \left(\frac{\text{lbs N}}{\text{acre}} \right)}{\text{plant available nitrogen per ton of biosolids/manure} \left(\frac{\text{lbs N}}{\text{ton}} \right)} \quad (1)$$

$$= \frac{\text{ANR} \left(\frac{\text{lbs N}}{\text{acre}} \right)}{(\text{NO}_3) + K_v \cdot (\text{NH}_4) + K_{\min} \cdot (\text{N}_o)}$$

Where

ANR - Adjusted nitrogen fertilizer requirement (crop nitrogen requirement minus nitrate plus ammonia content found in soil) – (lbs N/acre)

NO₃ - nitrate concentration in biosolids (lbs N/ton)

NH₄ - ammonia concentration in biosolids (lbs N/ton)

N_o - organic nitrogen concentration in biosolids (total nitrogen content found in biosolids minus nitrate plus ammonia content)

K_v - volatilization factor (McFarland, 2001)

K_{min} - organic nitrogen mineralization rate (McFarland, 2001)

Forage Sampling

To estimate the effect of land application of the biosolids and beef cattle manure on forage growth, vegetation from each of the subplots as well as the control test plot were sampled. Forage yields were

determined by collecting forage using a standard gas powered lawn mower. The entire 100 ft² test plot sections were mowed during forage sampling. The harvested material was collected in plastic bags and weighed on site to obtain an estimate of the forage yield. For every test plot, the results from statistically analyzing the six (6) mowed 100 ft² sections was used to generate a mean wet-weight forage yield (lbs/acre). To convert wet weight to dry weight, three (3) forage samples taken from each treatment site were dried at 103 °C for two hours to establish a dry weight value. The estimated ratio of dry weight to wet weight was used to determine dry-matter forage yield values.

Estimating Forage Nutritional Value

In evaluating the impact of biosolids land application on forage nutritional value, three (3) parameters are of particular importance: crude protein, relative feed value and the animal stocking rate. Crude protein is a measure of the amount of nitrogen in a forage crop. Crude protein is estimated by multiplying the total nitrogen content by a constant, 6.25 (Stokes and Prostko, 1998; National Research Council, 1984). The value of the constant is based upon the assumption that forage protein contains approximately 16% nitrogen (by weight).

Relative feed value (RFV) is an index used to compare forage quality to the feed value of alfalfa (Belyea et al., 2005; Jeranyama et al., 2004; National Research Council, 1984). RFV is used to determine how well forage will be consumed and digested. Two important parameters whose value impacts the RFV level are the forage's acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents (National Research Council, 1984). ADF reflects the content of cellulose and lignin in forage and is closely related to digestibility. Equation 2 illustrates the relationship between ADF and digestible dry matter (DDM).

$$\% \text{ DDM} = 88.9 - (0.779 \bullet \% \text{ ADF}) \quad (2)$$

Where

DDM – digestible dry matter (%)

ADF – acid detergent fiber (%)

88.9 – empirical constant

0.779 – empirical constant

NDF is an estimate of the total fiber content and reflects the bulkiness of forage. The relationship between NDF and dry matter intake (DMI) is given by Equation 3.

$$\% \text{ DMI} = \frac{120}{\% \text{ NDF}} \quad (3)$$

Where

DMI – dry matter intake (%)

NDF – neutral detergent fiber (%)

120 – empirical constant

Once the value of DDM and DMI are estimated, the RFV can be estimated using Equation 4.

$$\text{RFV} = \frac{\% \text{ DDM} \bullet \% \text{ DMI}}{1.29} \quad (4)$$

Where

RFV – relative feed value

DDM – digestible dry matter (%)

DMI – dry matter intake (%)
 1.29 – empirical constant

In general, a healthy rangeland has forage with a RFV of between 110 and 125. However, for lactating animals, an RFV of at least 140 is desirable (National Research Council; 1984). It should be noted that RFV does not explicitly account for the protein content of the forage. Therefore, the protein content should be considered together with RFV when evaluating forage quality.

Stocking rate is an estimate of the number of animals that a parcel of land can nutritionally support during a grazing season. It is normally assumed that one animal unit (1,000 lb beef cow) has a daily feed requirement of twenty six (26) pounds of dry matter forage. Therefore, over a four month grazing season (120 days), one animal unit requires approximately 3,120 lbs of dry matter forage. From this forage matter requirement, the stocking rate can be determined.

Soil Sampling

Deep soil sampling consisted of taking soil samples at 0.75, 2, 3, 4 and 5 foot depths below the ground surface (bgs) in each of the six (6) test plot sections. Soil chemical parameters that were analyzed included: 1) nitrate, 2) ammonia, 3) available phosphorus, 4) electrical conductivity (EC), 5) sodium adsorption ratio (SAR) and 6) pH. All soil samples were collected in glass sampling vials and transported to the Utah State University (USU) Soils Testing Laboratory for chemical analysis using standard analytical methods (Gavlak et al., 2003; Keeney and Nelson, 1982).

Moisture Infiltration

Moisture infiltration was determined using minidisk infiltrometers (Figure 1). The minidisk infiltrometer consists of two chambers that maintain constant hydraulic communication. The minidisk infiltrometer, which has an outside radius of 1.6 cm, maintains a suction of two (2) cm water pressure. The volume of moisture, which was drawn from the bottom of the infiltrometer through a porous stainless steel sintered disk, was estimated in real-time as a change in pressure. Equation 5 was used to convert pressure change (recorded as a voltage) into a water depth.

$$\text{Vol.}(t) = \text{Vol.}_{\text{used}} - \left[(\text{Volts}(t) - \text{Volts}_{\text{min}}) \cdot \left[\frac{\text{Vol.}_{\text{used}}}{(\text{Volts}_{\text{max}} - \text{Volts}_{\text{min}})} \right] \right] \quad (5)$$

Where

Vol. (t) – depth of water infiltrated after a specific time
 Vol. _{used} – depth of water used in the minidisk infiltrometer
 Volts (t) – voltage at a specific time
 Volts _{max} – maximum voltage that the datalogger reads at the beginning of test
 Volts _{min} – voltage when minidisk infiltrometer is empty

At each subplot, four (4) minidisk infiltrometers were operated simultaneously. The four minidisk infiltrometers were connected to a datalogger in order to collect and generate a single (average) moisture infiltration rate.

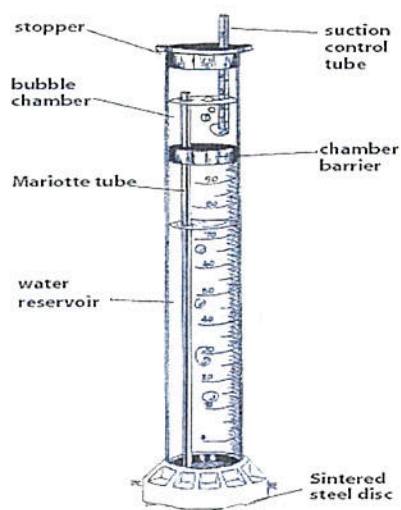


Figure 1 - Diagram of Minidisk Infiltrometer

RESULTS

Table 1 provides a summary of the soils data taken at three (3) separate locations within the rangeland test site. Evaluation of the background soils data indicated that the soils were alkaline, saline and sodic. Moreover, nitrate concentrations were significant throughout the soil profile, an observation that was consistent with the fact that the site was employed as a concentrated animal holding area.

Table 1 - Summary of Background Soils Analyses.

Sa mpl	De pt	p H	T ot	Nitr ate	Amm onia	E C	S A
A1	0.7	7	0.	26.7	6.86	1	6.
A2	2	7	0.	107.	9.00	2	15
A3	3	7	0.	135.	6.33	4	40
A4	4	7	0.	146.	9.44	4	54
A5	5	7	0.	146.	10.4	3	53
B1	0.7	8	0.	21.8	22.40	1	16
B2	2	8	0.	67.6	56.50	3	27
B3	3	7	0.	80.1	6.81	3	58
B4	4	7	0.	111.	7.45	4	39
B5	5	7	0.	156.	10.00	5	40
C1	0.7	8	0.	10.4	7.78	4	21
C2	2	8	0.	24.7	4.15	2	18
C3	3	8	0.	63.2	6.85	3	39
C4	4	7	0.	74.3	6.70	3	47
C5	5	7	0.	92.6	6.07	3	44

¹bgs – below ground surface, ²EC - electrical conductivity (deciseimens per meter), ³SAR – sodium adsorption ratio

Table 2 provides a summary of the average concentration of nitrogen species found in the organic amendments. Using the average nitrate and ammonia concentrations recorded in the surface soil (i.e., 0.75 foot depth), the plant available nitrogen (PAN) per acre of soil was estimated to be 98.6 lbs nitrogen/acre.

Table 2 - Average Concentration of Nitrogen Species in Organic Amendments.

Organic Amendment Type	Total N (%)	Nitrate (mg/kg)	Ammonia (mg/kg)
Aerobically Digested Biosolids	5.41	1.71	2,135
Anaerobically Digested Biosolids	5.85	13.40	12,500
Beef Cattle Manure	1.76	3.30	3,253

Given a rangeland nitrogen requirement of 150 lbs/acre, the nitrogen-based agronomic rates for the aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure were estimated to be 1.5, 0.8 and 4.3 tons/acre, respectively. Following 18-months after biosolids land application, all rangeland test plots were sampled for forage dry-matter yield, forage nutritional levels as well as specific soil chemical parameters at depths ranging 0.75 up to five (5) feet below the ground surface.

Forage Sampling

Land application of biosolids and beef cattle manure were observed to increase forage production above that which was recorded for the control plots in all cases (Table 3).

Table 3 - Average Forage Yields from Biosolids Land Treatment.

Organic Amendment Type	Application Rate (Multiple of Agronomic Rate)	Forage Yield $\pm$ std error (n = 6) (lbs/acre – dry weight)
Control	N/A	84.1 $\pm$ 45.6
Aerobically Digested Biosolids	1X	423.4 $\pm$ 237.4
Aerobically Digested Biosolids	5X	354.2 $\pm$ 225.1
Aerobically Digested Biosolids	10X	489.5 $\pm$ 172.7
Anaerobically Digested Biosolids	1X	612.3 $\pm$ 266.1
Anaerobically Digested Biosolids	5X	559.8 $\pm$ 160.9
Anaerobically Digested Biosolids	10X	376.0 $\pm$ 157.0
Beef Cattle Manure	1X	362.1 $\pm$ 87.1
Beef Cattle Manure	5X	129.4 $\pm$ 59.1
Beef Cattle Manure	10X	481.7 $\pm$ 233.3

Application of organic amendments at 1X the agronomic rate indicated that both biosolids and beef cattle manure resulted in significant increases in the dry matter forage yields relative to the control plots. Rangeland plots that had received beef cattle manure experienced a significant reduction in forage yields at 5X the estimate agronomic rate relative to the dry matter yield at 1X the agronomic rate. The reason for this remains unclear. This observation was particularly perplexing given that the dry matter forage yield for beef cattle manure increased when the application rate was increased from 5X to 10X the agronomic rate.

Given the limitations in achieving a perfectly homogeneous application of organic amendment over the test area, it is suspected that the inability to apply beef cattle manure evenly across the test site may have contributed to the confounding results. Visible observation of the test site confirmed the spotty accumulation of beef cattle manure within the 5X test plot. At 10X the estimated agronomic rate, adjustments were made to the surface application system that allowed a more even application. These results underscore the need to consider the physical consistency (i.e., workability) of the organic amendment as well as the type and effectiveness of the surface application equipment (particularly when the organic amendment surface application is not subsequently tilled into the soil).

Preliminary ecological analysis indicated that the dominant plant species found on the control test plots was an invasive species, *Bromus tectorum* or cheat grass, while the dominant vegetative species found on the test plots amended with biosolids and beef cattle manure was *Hordeum marinum gussoneanum* (seaside barley). Other minor plant species found on sites receiving biosolids and beef cattle manure included

Descurania brassicaceae, *Halogeton glomeratus* (saltlover) and *Kochia scoparia* (summer cypress) (Jensen, *et al.*, 2000).

Soil Sampling

Soil sampling results for sites amended with aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure are summarized in Tables 4, 5 and 6, respectively. Nitrate concentrations were observed to increase with increasing depth for all sites. Plant available phosphorus concentrations were found to have their largest values at the soil surface and decreased significantly with soil depth. The behavior of the electrical conductivity was similar to that of nitrate while soil ammonia concentrations remained relatively low for all application rates.

Table 4 - Soil Sampling Results from Sites Amended With Aerobically Digested Biosolids.

Biosolids Type	Depth (ft)	pH	Nitrate (mg/kg)	Ammonia (mg/kg)	Available Phosphorus (mg/kg)	EC ¹ (dS/m)	SAR ²
Aerobically Digested 1X	0.75	8.21	7.28	1.40	7.50	1.15	5.00
Aerobically Digested 1X	2	8.89	9.85	1.20	2.17	5.38	22.67
Aerobically Digested 1X	3	8.61	19.67	1.17	2.00	12.43	47.83
Aerobically Digested 1X	4	8.23	25.49	1.33	3.50	16.45	43.83
Aerobically Digested 1X	5	7.92	33.03	1.17	4.50	21.58	34.50
Aerobically Digested 5X	0.75	8.43	8.03	3.40	10.83	3.58	25.33
Aerobically Digested 5X	2	8.11	39.79	1.25	3.00	40.38	121.33
Aerobically Digested 5X	3	8.09	43.68	1.00	2.17	42.92	89.50
Aerobically Digested 5X	4	7.89	56.30	1.20	3.17	41.42	65.67
Aerobically Digested 5X	5	7.71	75.72	1.00	5.33	38.07	56.00
Aerobically Digested 10X	0.75	8.30	44.02	2.80	10.33	4.77	41.50
Aerobically Digested 10X	2	8.17	105.93	0.50	3.17	30.88	124.40
Aerobically Digested 10X	3	7.87	98.67	0.67	2.83	45.32	92.50
Aerobically Digested 10X	4	7.70	105.48	1.00	2.60	51.56	79.40
Aerobically Digested 10X	5	7.62	139.80	2.50	6.00	46.74	67.20

¹EC - Electrical Conductivity (deciseimens per meter)

²SAR - Sodium Adsorption Ratio

The behavior of the soil chemical parameters at rangeland test plots that received beef cattle manure was similar to that behavior found at those sites that had received aerobically digested and anaerobically digested biosolids (Table 6). As expected, nitrate concentrations increased both with depth and, in most cases, with increasing organic matter application rate.

Table 5 - Soil Sampling Results from Sites Amended With Anaerobically Digested Biosolids.

Biosolids Type	Depth (ft)	pH	Nitrate (mg/kg)	Ammonia (mg/kg)	Available Phosphorus (mg/kg)	EC ¹ (dS/m)	SAR ²
Anaerobically Digested 1X	0.75	8.28	42.03	1.00	14.00	5.51	33.17
Anaerobically Digested 1X	2	8.26	61.93	0.00	2.67	27.28	102.33
Anaerobically Digested 1X	3	7.90	103.20	1.00	2.67	41.60	79.83
Anaerobically Digested 1X	4	7.79	141.50	0.50	4.67	42.57	67.33
Anaerobically Digested 1X	5	7.70	195.17	0.25	4.67	46.38	63.17
Anaerobically Digested 5X	0.75	8.34	22.68	0.25	23.67	4.39	25.17
Anaerobically Digested 5X	2	8.58	67.35	0.50	8.17	19.66	96.67
Anaerobically Digested 5X	3	8.09	65.95	1.00	16.50	31.52	90.83
Anaerobically Digested 5X	4	7.89	93.60	1.67	12.00	37.55	67.83
Anaerobically Digested 5X	5	7.74	175.42	1.50	11.33	40.68	55.17
Anaerobically Digested 10X	0.75	8.41	19.17	2.00	9.00	5.34	31.67
Anaerobically Digested 10X	2	8.26	65.92	1.20	4.00	27.39	70.00
Anaerobically Digested 10X	3	8.08	84.10	2.20	4.17	28.82	55.50
Anaerobically Digested 10X	4	7.91	72.25	1.40	4.83	32.42	54.00
Anaerobically Digested 10X	5	7.77	76.52	2.50	7.50	31.07	47.83

¹EC - Electrical Conductivity (deciseimens per meter)²SAR - Sodium Adsorption Ratio**Table 6 - Soil Sampling Results from Sites Amended With Beef Cattle Manure.**

Organic Amendment Type	Depth (ft)	pH	Nitrate (mg/kg)	Ammonia (mg/kg)	Available Phosphorus (mg/kg)	EC ¹ (dS/m)	SAR ²
Beef Cattle Manure 1X	0.75	8.56	5.27	1.93	32.08	3.66	29.33
Beef Cattle Manure 1X	2	8.26	35.63	1.56	4.32	20.65	96.86
Beef Cattle Manure 1X	3	7.72	72.20	5.56	2.95	36.02	62.15
Beef Cattle Manure 1X	4	7.67	116.58	1.81	8.12	38.67	53.62
Beef Cattle Manure 1X	5	7.59	149.25	1.63	20.12	40.24	48.25
Beef Cattle Manure 5X	0.75	8.60	14.50	2.92	11.75	4.50	26.00
Beef Cattle Manure 5X	2	8.44	74.10	3.42	4.50	24.78	63.27
Beef Cattle Manure 5X	3	8.18	99.44	2.69	3.82	31.67	51.58
Beef Cattle Manure 5X	4	7.97	146.88	2.83	4.08	38.23	45.10
Beef Cattle Manure 5X	5	7.84	156.53	2.74	6.87	105.85	40.13
Beef Cattle Manure 10X	0.75	8.26	17.60	5.37	62.35	2.03	8.15
Beef Cattle Manure 10X	2	8.65	27.40	2.70	19.60	11.60	51.80
Beef Cattle Manure 10X	3	8.45	63.40	2.80	6.62	15.84	29.94
Beef Cattle Manure 10X	4	7.97	92.90	3.45	7.98	17.82	21.75
Beef Cattle Manure 10X	5	7.81	117.40	4.90	12.45	14.10	20.07

¹EC - Electrical Conductivity (deciseimens per meter)²SAR - Sodium Adsorption Ratio

The one exception was found in the soil nitrate levels associated with beef cattle manure application at 5X and 10X the estimated agronomic rate. At 10X the estimated agronomic rate, the soil nitrate concentrations were found to be, in general, less than the nitrate concentrations found in soils amended with beef cattle manure at 5X the estimated agronomic rate. It is unclear why lower nitrate levels were found in rangeland test plots amended with 10X the estimated agronomic rate that what were found in either the 1X or 5X beef cattle manure loadings. A possible explanation for this observation is the fact that, at 10X the estimated agronomic rate, the forage yield was significantly larger than that reported from rangeland test plots receiving 1X and/or 5X the estimated agronomic rate. A higher forage yield (and

presumably a higher nitrate plant uptake) could explain, at least in part, the smaller nitrate concentrations found at sites receiving 10X the estimated agronomic rate.

The impact of biosolids and beef cattle manure land application on forage quality is summarized in Table 7. Results confirmed that, while the average dry matter forage yield of control plots was 84.1 lbs per acre, the dry matter forage yield for aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure ranged from 129.0 to 664.1 lbs per acre.

Although the increase in dry matter forage yield as a result of biosolids land application was not surprising given the fertilizer and soil conditioning value of biosolids, the significant increase in forage quality was both surprising and compelling. Forage from the control plots was found to have a crude protein content of approximately 10.15%, which was lower than the crude protein content found in the forage collected from all biosolids amended rangeland plots. Forage grown on biosolids and beef cattle manure-amended rangelands reported maximum crude protein contents of 19.67%, 15.26% and 14.22% for aerobically digested, anaerobically digested and beef cattle manure biosolids land application sites, respectively.

Table 7 - Results from Forage Value Analyses.

Organic Amendment Type	Application Rate	Forage Dry (lbs/acre)	Crude Protein – Dry Mass Basis (%)	Relative Feed Value	Animal Stocking Rate*
Control	N/A	84.10	10.15	93.53	75.49
Aerobically Digested Biosolids	1X	423.40	19.40	114.04	15.34
Aerobically Digested Biosolids	5X	354.20	19.67	117.91	18.94
Aerobically Digested Biosolids	10X	489.50	15.85	100.32	13.15
Anaerobically Digested Biosolids	1X	612.25	15.26	112.58	10.68
Anaerobically Digested Biosolids	5X	559.84	13.62	108.85	11.58
Anaerobically Digested Biosolids	10X	376.03	14.33	109.62	17.33
Beef Cattle Manure	1X	362.15	12.45	103.35	17.84
Beef Cattle Manure	5X	129.45	13.67	109.74	50.26
Beef Cattle Manure	10X	481.66	14.22	120.34	13.86

*Assumes that one beef cow weighing 1000 lbs is grazing on the rangeland for 120 days.

The environmental and economic implications of enhanced forage quality and quantity as a result of biosolids or beef cattle manure land application are significant particularly in light of its impact on sustainable ranching activities. For example, in examining the animal stocking rate, to support one grazing animal (e.g., 1000 lb beef cow) for 120 days on rangeland having the same nutritional quality and dry matter yield as the control plot would require at least 75.5 acres of land. In comparison, for rangelands that have been amended with aerobically digested, anaerobically digested and beef cattle manure biosolids, the increase in forage nutritional value and quantity could potentially reduce the land needed to support the same animal over the 120-day grazing period to 9.7 acres, 10.7 acres and 13.9 acres, respectively. Increasing the number of grazing animals that can be supported on the same amount of land can significantly reduce the scope of any environmental impact (i.e., reduce the environmental foot print) while increasing the financial revenues for ranching activities.

Moisture Infiltration

Table 8 summarizes the moisture infiltration estimates from each of the test sites utilizing the minidisk infiltrometer. In general, none of the organic amendments were found to significantly affect the moisture infiltration rate of the rangeland test plots relative to the control. Because of soil heterogeneity, the variability in estimated soil moisture infiltration rates was large. Despite the large variations in measured moisture infiltration rates, rangeland sites amended with anaerobically digested biosolids appeared to yield the largest infiltration rates. This observation was consistent with the fact that; 1) because of its nitrogen content, anaerobically digested biosolids yielded the smallest agronomic rate (smallest amount of material

land applied) of the three organic amendments evaluated and 2) the rangeland sites receiving anaerobically digested biosolids were associated with the largest forage dry matter production.

Table 8. Moisture Infiltration Rates Measured on Rangeland Test Sites (n = 4).

Organic Amendment Type	Application Rate	Average Moisture Infiltration Rate (cm/hr)	Standard Deviation (cm/hr)
Control	N/A	7.07	2.93
Aerobically Digested Biosolids	1X	7.14	4.76
Aerobically Digested Biosolids	5X	6.02	3.46
Aerobically Digested Biosolids	10X	4.91	2.84
Anaerobically Digested Biosolids	1X	8.34	4.93
Anaerobically Digested Biosolids	5X	9.98	6.16
Anaerobically Digested Biosolids	10X	9.67	6.99
Beef Cattle Manure	1X	9.56	4.93
Beef Cattle Manure	5X	6.42	3.46
Beef Cattle Manure	10X	7.74	4.59

DISCUSSION

The land application of biosolids and beef cattle manure was found to be a technically effective and environmentally sound approach for restoring disturbed rangelands. Without supplemental irrigation, tilling or seeding, the land application of aerobically digested biosolids, anaerobically digested biosolids and beef cattle manure at rates much greater than the agronomic rate were demonstrated to lead to significant increases in forage yield when compared to control plots. While the control plots had an average forage yield of 84.1 lbs/acre (dry weight), a maximum forage yield of 664.1 lbs/acre (dry weight) was recorded on rangeland test plots that had received organic amendments.

When comparing nitrate soil concentrations that exist between biosolids types, rangeland test plots receiving aerobically digested biosolids consistently reported higher nitrate levels relative to those rangeland plots receiving anaerobically digested biosolids. There are several possible reasons for this observation including the fact that: 1) a greater fraction of the nitrogen added in the anaerobically digested biosolids was lost from the test plot through ammonia volatilization, 2) denitrification losses of nitrate were larger in rangeland test plots receiving anaerobically digested biosolids, 3) nitrate leaching losses may have been accelerated within the rangeland test plots that received anaerobically digested biosolids or 4) the organic nitrogen mineralization rate may have limited the production of nitrate in rangeland test plots amended with anaerobically digested biosolids.

In all rangeland test plots, the largest plant available phosphorus concentrations were found associated with the surface soil layer (i.e., 0.75 foot depth). This observation was not surprising since phosphorus tends to rapidly react with soil metals (e.g., calcium, iron, etc.) forming relatively insoluble complexes (McFarland, 2001). The accumulation of phosphorus in the surface soils has significant environmental implications. Effective phosphorus management from rangelands amended with biosolids and/or beef cattle manure will require implementation of procedures that minimize soil erosion (e.g., over land moisture flow) as this is the primary mechanisms by which phosphorus can become mobilized and potentially impact surface water quality.

CONCLUSIONS

The enhancement of forage quantity and quality on rangelands amended with biosolids and beef cattle manure underscore the value of land applying organic amendments to restore overgrazed rangelands. Like

beef cattle manure, biosolids represent a valuable and inexhaustible resource of organic matter and plant nutrients that can be utilized to restore the vegetative vigor of disturbed and/or marginal rangelands. Results from the current study demonstrated that land application of biosolids and beef cattle manure not only increases the forage quantity and quality but has the potential to improve the moisture infiltration capacity as well. In summary, the land application of biosolids has the following advantages in restoring disturbed rangelands:

- Reduction in the use of costly, petroleum-based, fertilizers and/or soil amendments
- Reduction in soil erosion (no tilling, greater plant root density)
- Improved soil aeration/moisture infiltration
- Reduction in water use (greater moisture retention capacity)
- Enhanced plant biodiversity

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REFERENCES

- Baker, D. L.; Guthery, F. S. (1990) "Effect of Continuous Grazing on Habitat and Density of Ground-Foraging Birds in South Texas" *Journal of Range Management*. 43: 2-5.
- Belyea, R. L.; Steevens, B.; Garner, G.; Whittier, J. C.; Sewell, H. (2005) "Using NDF and ADF to Balance Diets" University of Missouri Extension. Department of Animal Sciences. <http://muextension.missouri.edu/explore/agguides/dairy/g03161.htm>
- Benton, M. W.; Wester, D. B. (1998) "Biosolids Effects on Tobosagrass and Alkali Sacaton in a Chihuahuan Desert Grassland" *Journal of Environmental Quality*. 27:199-208.
- Black A. L.; Wright, J. R. (1979) "Range fertilization: Nitrogen and Phosphorus Uptake and Recovery over Time" *Journal of Range Management*. 32:348-353.
- Clapp, C.E.; Larson, W.E.; Dowdy, R. H. (Editors) (1994) *Sewage Sludge: Land Utilization and the Environment* Soil Science Society of America, Inc. Madison, Wisconsin
- Evans, R.; Rimer, R.; Sperry, L.; Belnap, J. (2001) Exotic Plant Invasion Alters Nitrogen Dynamics in Arid Grassland" *Ecological Applications*. 11(5):1301-1310.
- Fleischner, T. L. (1994) Ecological Cost of Livestock Grazing in Western North America" *Conservation Biology*. 8:629-644.
- Gass, W. B.; Sweeten, J. M. (1992) Benefits of applying sewage sludge on agricultural land. Bull. B-1637. Texas Agric. Ext. Service, College Station.
- Gavlak, R.; Horneck, D.; Miller, R. O.; Amacher, J. K. (2003) Soil, Plant and Water Reference Methods for the Western Region-2nd Edition.
- Harris-Pierce, R. L.; Redente, E. F.; Barbarick, K. A. (1995) "Sewage Sludge Application Effects on Runoff Water Quality in a Semi-arid Grassland" *Journal of Environmental Quality*. 24:175-182.
- Jensen, K.; Horton, H.; Reed, R.; Whitesides, R. (2000) *Intermountain Planting Guide* U. S. Department of Agriculture Forage and Range Research Laboratory – Logan, Utah
- Jeranyama, P.; Alvaro, D.; Garcia, D. (2004) "Understanding Relative Feed Value (RFV) and Relative Forage Quality (RFQ)" South Dakota State University. Extension Extra. <http://anserv.sdstate.edu/downloads/ExEx8149.pdf>
- Keeney, D. R.; Nelson, D. W. (1982) Nitrogen-inorganic forms. In A.L Page (eds.) *Methods of Soil Analysis*, part 2. Agron. Monogr. 9, 2nd ed. ASA and SSAA, Madison, WI. p. 643-698.

-
- McFarland, M. J. (2001) Biosolids Engineering McGraw-Hill, Inc. New York, N. Y.
- McFarland, M. J.; Vutran, M.; Vasquez, I. R.; Schmitz, M.; Brobst, R. B.; Olson, D.; Fisher, R. (2007) "Use of Aerobically Digested, Anaerobically Digested and Lime Stabilized Biosolids for Restoring Semi-arid Rangelands" *Proceedings from the Joint Residuals and Biosolids Management Conference* April 15-18, 2007 Denver, Colorado
- National Research Council (2002) Biosolids Applied to Land: Advancing Standards and Practice The National Academies Press – Washington, D. C.
- National Research Council (1984) Nutrient Requirements of Beef Cattle: Washington DC: National Academy of Sciences
- Natural Resources Conservation Service (2000) Soil Survey of Tooele Area, Utah: United States Department of Agriculture
- Parker, K. G. (1985) Some Important Utah Range Plants Utah Department of Agriculture Cooperative Extension Service - Utah State University, Logan, Utah
- Stokes, S. R.; Prostko, E. P. (1998) "Understanding Forage Quality Analysis", Texas Agriculture Extension Service, Texas A&M University System.
http://animalscience.tamu.edu/ANSC/publications/dairypubs/L5198_understandingforagequality.pdf
- Utah Department of Agriculture Cooperative Extension Service (1989) Rangeland Resources of Utah - Utah State University, Logan, Utah

INCREASE IN FORAGE COVER

LAND APPLIED BIOSOLIDS RESTORE DISTURBED RANGELANDS

MANY RANGELANDS in the western U.S. have experienced heavy livestock grazing that has led to substantial reductions in forage quality and quantity. Other environmental and ecological consequences associated with overgrazing on western rangelands include: 1) Reduction in moisture infiltration and retention; 2) Decreases in vegetative diversity and forage yield; and 3) Increased loss of topsoil.

Negative impacts from overgrazing are interrelated and addressing them requires a systematic and sustainable approach. For example, any rangeland restoration approach that has the net value of increasing forage cover will not only improve the land's grazing value but will also enhance moisture infiltration and reduce soil erosion.

Treated municipal sewage sludge or biosolids is a valuable and inexhaustible resource for restoring the vigor of disturbed rangelands. Biosolids represent a low cost source of organic matter as well as provide buffering capacity when land applied. Organic matter decomposition from land-applied biosolids releases chemically bound nutrients (nitrogen and phosphorus), making them available for assimilation by plants and soil microorganisms.

Biosolids land application on arid or semi-arid rangelands poses little threat to groundwater resources in areas with adequate groundwater depths because evapotranspiration generally exceeds total precipitation. Climatic variables including temperature, rainfall intensity and frequency are important in determining both the rate of rangeland recovery following biosolids land application as well as the types of vegetative species that will become established.

This current study was focused on evaluating the potential of land applying aerobically digested, anaerobically digested and lime-stabilized biosolids to improve the forage and soil quality at disturbed western U.S. rangelands.

METHODS USED ON TEST PLOTS

Biosolids were surface applied at various rates on one-third acre test plots separated by buffer strips on private rangeland located in Tooele County, Utah. The agronomic rate



Initiation of beef production starts with preparation of livestock for eventual grazing on rangeland. Preranging activities include the branding (above) and castration of bull calves as well as the branding of heifers.

To counter impacts of heavy grazing, organic matter decomposition from biosolids releases nutrients — making them available for plants and soil microorganisms.

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(tons/acre) for the surface application of biosolids was determined based on the assumption that a healthy rangeland would exhibit an adjusted nitrogen requirement of 150 lbs of nitrogen per acre. This nitrogen demand was based on the assumption that a healthy rangeland would be dominated by perennial grass species. Biosolids

were land applied on rangeland test plots at ten times (10x), five times (5x) and one time (1x) the estimated agronomic rate.

Each of the one-third acre test plots was divided into 144 sections (i.e., subplots) having physical dimensions of 10 feet by 10 feet (i.e., 100 ft²). During field sampling, six 10 feet by 10 feet subplots from each one-third acre test plot was sampled for forage and soil properties. The mean value for each parameter of interest was estimated using data from all subplots of a particular treatment. To minimize operational costs, after biosolids were surface applied on the rangeland plots, the plots were managed without any supplemental tilling, irrigation or re-seeding during the course of the field study.

To estimate the effect of land application of biosolids on vegetative growth, forage from each of the six test plot sections as well as the control test plot were sampled. Forage yields were determined by collecting forage using a standard gas powered lawn mower. The entire 100 ft² test plot sections were mowed during forage sampling. The harvested material was collected in plastic bags and weighed on site to obtain an estimate of the forage yield. For every test plot, results from statistically analyzing the six mowed 100 ft² sections was used to generate a mean wet-weight forage yield (lbs/acre). To convert wet weight to dry weight, forage samples from each treatment (including the control) were selected at random and dried at 103°C for two hours to establish a dry weight value. The estimated ratio of dry weight to wet weight was used to convert all wet weight values into dry-matter forage yield values.

ESTIMATING FORAGE NUTRITIONAL VALUE

In evaluating the impact of biosolids land application on forage nutritional value, three parameters are of particular impor-

tance: crude protein, relative feed value and specific animal stocking rate. Crude protein is a measure of the amount of nitrogen in a forage crop. Crude protein is estimated by multiplying the total nitrogen content by a constant, 6.25. The value of the constant is based upon the assumption that forage protein contains approximately 16 percent nitrogen (by weight).

Relative feed value (RFV) is an index used to compare forage quality to the feed value of alfalfa. RFV is used to determine how well forage will be consumed and digested. Two important parameters whose value impacts the RFV level are the forage's acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents. ADF reflects the content of cellulose and lignin in forage and is closely related to digestibility.

In general, a higher RFV reflects a greater digestibility of forage. A RFV value of between 110 and 125 reflects an adequate forage value for grazing cattle. However, for lactating animals, an RFV of at least 140 is desirable.

Stocking rate is the number of animals that a parcel of land (pasture, rangeland, etc.) can nutritionally support during a grazing season. It is normally assumed that one animal unit (1,000 lb beef cow) has a daily feed requirement of 26 pounds of dry matter forage. Therefore, over a four month grazing season (120 days), one animal unit requires approximately 3,120 lbs of dry matter forage. From this forage matter requirement, the stocking rate can be estimated.

BACKGROUND SOILS

Deep soil sampling consisted of taking soil samples at 0.75, 2, 3, 4 and 5 foot depths below the ground surface (bgs) in each of the six test plot sections. Parameters that were analyzed for each soil sample included the following: 1) nitrate; 2) ammonia; 3) available phosphorus; 4) electrical conductivity (EC); 5) sodium adsorption ratio (SAR); and 6) pH. Evaluation of the background soils data indicated that the nitrate concentrations were significant throughout the soil profile. This observation reflects a high level of historical animal grazing (nitrate source) in combination with a relatively limited amount of vegetative cover.

In addition to the high nitrate concentrations, soils analyses indicated that the biosolids land application site had an average EC and SAR significantly above 4.0 and 13, respectively. These findings confirmed that the biosolids land application site was both saline (high salt concentrations) and sodic (high sodium content). Using the average nitrate and ammonia concentrations found in the surface soil (i.e., 0.75 foot depth), the plant available nitrogen (PAN) per acre of soil was estimated to be 98.6 lbs nitrogen/acre.

Table 1 provides a summary of the average concentration of nitrogen species found in the aerobically digested, anaerobically digested and lime-stabilized biosolids used in



Lime stabilized (left) and aerobically digested biosolids (right) are stockpiled on disturbed rangeland prior to their surface application.

the field study. Using the average nitrate and ammonia concentrations found in the surface soil (i.e., 0.75 foot depth), the plant available nitrogen (PAN) per acre of soil was estimated to be 98.6 lbs nitrogen/acre.

Given an assumed rangeland nitrogen requirement of 150 lbs/acre, the nitrogen-based agronomic rates for the aerobically digested, anaerobically digested and lime stabilized biosolids were estimated to be 1.5, 0.8 and 8.8 tons/acre, respectively. Following 18-months after biosolids land application, all of the biosolids test plots were sampled for forage dry-matter yield, forage nutritional levels as well as specific soil chemical parameters at depths ranging up to 5 feet below the ground surface.

FORAGE SAMPLING

Biosolids land application was observed to increase forage production above that which was recorded for the control plots in all cases. Although lime stabilized biosolids applied at one times the agronomic rate were found to generate forage yields comparable to the levels recorded for test plots amended with either aerobically digested or anaerobically digested biosolids, when lime stabilized biosolids were added at higher multiples of the agronomic rate, the forage yield decreased significantly. Table 2 includes data on the application rates and forage yields.

The scientific explanation for the inverse relationship observed between forage dry matter yield and biosolids application rate for lime stabilized biosolids is unclear. Several possible explanations included the following: 1) Increased application of calcium-based salts was toxic to rangeland vegetation; 2) Large amount of biosolids applied to achieve the desired application rate physically obscured sunlight thereby reducing the emergence of rangeland forage; and 3) High pH of lime stabilized biosolids reduced the availability of plant micronutrients (e.g., metals).

Finally, ecological analysis indicated that the dominant plant species found on the control test plots was *Bromus tectorum* (cheat grass) while the dominant vegetative species found on the test plots amended with biosolids was *Hordeum marinum gussonianum* (seaside barley). Other minor plant species found on sites receiving biosolids included *Descurainia brassicaceae*, *Halogeton glomeratus* (saltlover) and *Kochia scoparia* (summer cypress).

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Table 2. Results from forage value analyses

Biosolids Type	Application Rate	Forage Dry (lbs/acre)	Dry Mass Basis (%)	Relative Feed Value	Animal Stocking Rate*
Control	not applicable	84.10	10.15	93.53	75.49
Aerobically digested	1X	423.40	19.40	114.04	15.34
Aerobically digested	5X	354.20	19.67	117.91	18.94
Aerobically digested	10X	489.50	15.85	100.32	13.15
Anaerobically digested	1X	612.25	15.26	112.58	10.68
Anaerobically digested	5X	559.84	13.62	108.85	11.58
Anaerobically digested	10X	376.03	14.33	109.62	17.33
Lime stabilized	1X	395.64	14.30	112.36	16.72
Lime stabilized	5X	180.79	16.57	105.57	36.09
Lime stabilized	10X	131.01	20.22	109.23	50.60

*Assumes that one beef cow weighing 1,000 lbs is grazing on the rangeland for 120 days.

the historical use of the site as an animal holding and feeding area. Moreover, the effect of large biosolids land application rates on soil nitrate concentrations was not surprising. As biosolids loading rates increased, the amount of nitrate detected in the soil increased. Any nitrate not utilized by rangeland forage was expected to leach below the root zone. In spite of the increase in nitrate concentrations, a large depth to groundwater (>80 feet in this case) and/or naturally poor groundwater quality are important site characteristics that can ameliorate any environmental and/or public health concern associated with nitrate leaching.

In all rangeland test plots, the largest plant available phosphorus

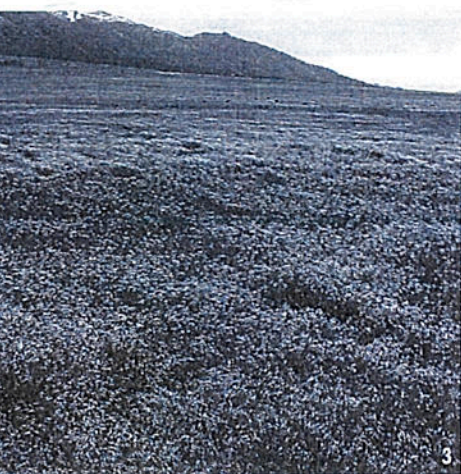
concentrations were found associated with the surface soil layer (i.e. top 0.75 foot depth). This observation was not surprising since phosphorus tends to rapidly react with soil metals (e.g., calcium, iron, etc.) forming relatively insoluble complexes. Accumulation of phosphorus in the surface soils has significant environmental implications. Effective phosphorus management from rangelands amended with biosolids will require implementation of procedures that minimize soil erosion (e.g., over land moisture flow) as this is the primary mechanisms by which phosphorus can become mobilized and potentially impact surface water quality.

Like nitrate, salt concentrations were found to increase with increasing depth. Since the salt concentrations are dependent on moisture movement including unsaturated moisture flow, the level of precipitation relative to evapotranspiration will determine the rate, extent and direction of salt movement within rangeland soils.

Finally, the enhancement of forage quantity and quality on rangelands amended with biosolids underscore the value of biosolids in supporting sustainable ranching practices. Land applied biosolids represent a valuable and inexhaustible resource that can be utilized to restore the vegetative vigor of disturbed and/or marginal rangelands. Results from the current study demonstrate that land application of biosolids not only increases the forage and, therefore, the economic value of rangelands to ranching interests but collection of land leasing and biosolids tipping fees from municipal wastewater treatment plants can be a significant source of financial revenue for ranchers who agree to utilize biosolids on their property. ■

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tions of enhanced forage quality and quantity as a result of biosolids land application are significant particularly in light of its impact on sustainable ranching activities. For example, in examining the animal stocking rate, to support one grazing animal (e.g., 1,000 lb beef cow) for 120 days on

rangeland having

the same nutritional quality and dry matter yield as the control plot would require at least 75.5 acres of land. In comparison, for rangelands that have been amended with aerobically digested, anaerobically digested and lime-stabilized biosolids, the increase in forage nutritional value and quantity could potentially reduce the land needed to support the same animal over the 120-day grazing period to 9.7 acres, 10.7 acres and 16.7 acres, respectively. Increasing the number of grazing animals that can be supported on the same amount of land can significantly reduce the scope of any environmental impact while increasing the financial revenues for ranching activities.

PROJECT OBSERVATIONS

Land application of biosolids was found to be a technically effective and environmentally sound approach for restoring disturbed western U.S. rangelands. Without supplemental irrigation, tilling or seeding, land application of aerobically digested, anaerobically digested and lime-stabilized biosolids at rates much greater than the agronomic rate were demonstrated to lead to significant increases in forage yield when compared to control plots. While the control plots had an average forage yield of 84.1 lbs/acre (dry weight), a maximum forage yield of 664.1 lbs/acre (dry weight) was recorded on rangeland test plots that had received land applied biosolids. Forage yields were found to increase with increasing biosolids application, a fact that seemed to suggest that the disturbed rangeland soils were nutrient limited.

Nitrate concentrations were found to be high in all plots including the control. The reason for the high nitrate concentrations in the control was unclear but suspicion falls on

Crude protein content in forage from biosolids amended rangeland varied from 15 to 20 percent, whereas the untreated control plot was about 10 percent.

SOIL SAMPLING

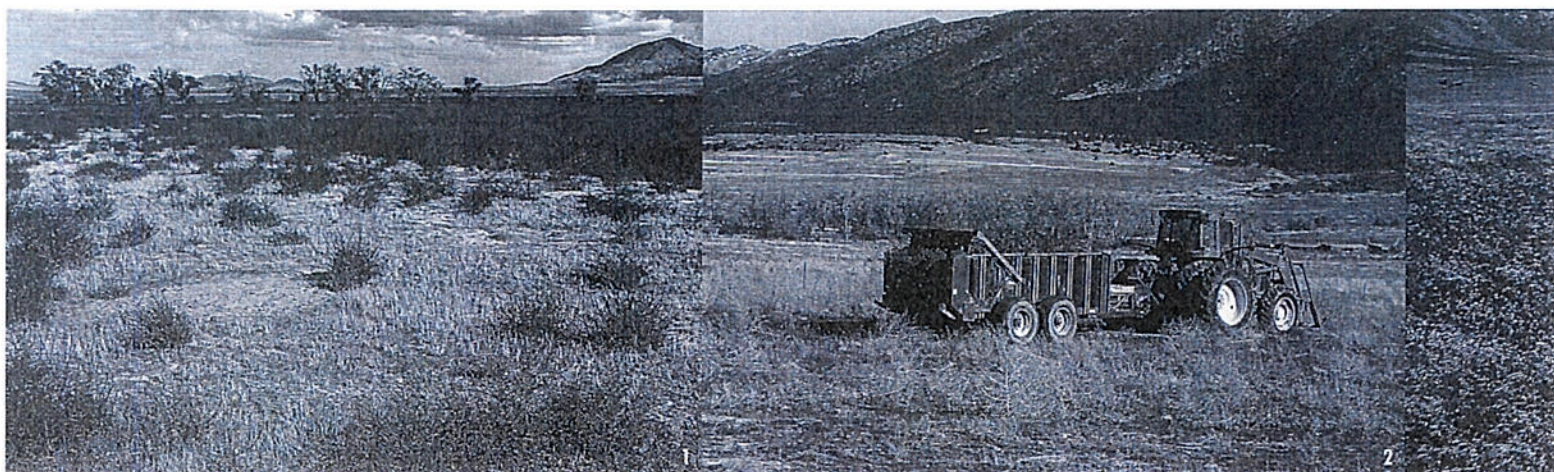
With respect to rangeland test plots receiving aerobically digested biosolids, nitrate concentrations were observed to increase with increasing depth for all treatments. Plant available phosphorus concentrations were found to have their largest values at the soil surface and decreased significantly with soil depth. These observations were not surprising since nitrate is relatively mobile and is easily transported through the soil matrix. On the other hand, phosphorus can readily interact with surface soil constituents (e.g., metals) and remain relatively immobile. The behavior of the electrical conductivity was similar to that of nitrate while soil ammonia concentrations remained relatively low for all application rates.

cally digested biosolids; or 4) Organic nitrogen mineralization rate may have limited the production of nitrate in rangeland test plots amended with anaerobically digested biosolids.

The behavior of the soil chemical parameters at rangeland test plots that received lime-stabilized biosolids was similar to that behavior found at those sites that had received aerobically digested and anaerobically digested biosolids. As expected, nitrate concentrations increased both with depth as well as with increasing biosolids land application rate.

ENHANCED FORAGE QUALITY

The impact of biosolids land application on forage quality is summarized in Table 2. Results confirmed that, while the average dry



Disturbed western rangelands are characterized by limited amounts of native grasses, high concentrations of invasive weeds and large areas of topsoil erosion (1). Biosolids are land applied using a manure-type spreader (2). View of vegetation established on disturbed rangeland by applying biosolids at five times the agronomic rate (3).

The behavior of the soil chemical parameters for those plots receiving anaerobically digested biosolids was similar to that observed at those rangeland plots that had received aerobically digested biosolids. The one notable exception was the behavior of nitrate particularly at the higher biosolids loading rates. The rangeland plots that had received anaerobically digested biosolids were found to have significantly less nitrate in the soil than the rangeland plots that had received aerobically digested biosolids.

There are several possible reasons for this observation including: 1) A greater fraction of the nitrogen added in the anaerobically digested biosolids was lost from the test plot through ammonia volatilization; 2) Denitrification losses of nitrate were larger in rangeland test plots receiving anaerobically digested biosolids; 3) Nitrate leaching losses may have been accelerated within the rangeland test plots that received anaerobi-

matter forage yield of control plots was 84.1 lbs per acre, the dry matter forage yield for aerobically digested, anaerobically digested and lime-stabilized biosolids ranged from 131.0 to 664.1 lbs per acre. Although the increase was not surprising given the fertilizer and soil conditioning value of biosolids, the significant increase in vegetative quality was both surprising and compelling. Forage from the control plots was found to have a crude protein content of approximately 10.15 percent, which was lower than the crude protein content found in the forage collected from all biosolids amended rangeland plots. Forage grown on biosolids-amended rangelands reported maximum crude protein contents of 19.67 percent, 15.26 percent and 20.22 percent for aerobically digested, anaerobically digested and lime-stabilized biosolids land application sites, respectively.

Beyond the difference in crude protein content, RFV for forage grown on rangeland test plots amended with land applied biosolids was substantially greater than the RFV of forage grown on the control plots. These results suggest that the forage grown on rangeland plots amended with land applied biosolids were both more nutritious (higher protein) and more digestible than the forage grown on the control plots.

The environmental and economic implica-

Table 1. Average concentration of nitrogen species in biosolids

Biosolids Type	Total N (%)	Nitrate (mg/kg)	Ammonia (mg/kg)
Aerobically digested biosolids	5.41	1.71	2135
Anaerobically digested biosolids	5.85	13.4	12,500
Lime stabilized biosolids	0.89	1.22	1175