Rangeland Restoration Using Biosolids Land Application

Michael J. McFarland[1*], Issaak R. Vasquez[1], MaiAnh Vutran[1], Mark Schmitz[2], Robert B. Brobst[3] and Linden Greenhalgh[4]

[1]Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, USA.
[2]Utah Department of Environmental Quality, Salt Lake City, Utah, USA.
[3]US Environmental Protection Agency Region 8, Denver, Colorado, USA.
[4] Utah State University Cooperative Extension, Tooele County, Utah, USA.
*To whom correspondence should be addressed. E-mail: farlandm@msn.com.

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 ft^2). 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.

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

$$= \frac{\text{ANR}\left(\frac{\text{lbs N}}{\text{acre}}\right)}{(NO_3) + K_v \bullet (NH_4) + K_{min} \bullet (N_o)}$$

Where

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

NO_3 - nitrate concentration in biosolids (lbs N/ton)

NH_4 - 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

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determined by collecting forage using a standard gas powered lawn mower. The entire 100 ft^2 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 ft^2 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 ºC 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).

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

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.

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

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.

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

Where
RFV – relative feed value
DDM – digestible dry matter (%)

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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.

$$\text{Vol.}(t) = \text{Vol.\_used} - \left[(\text{Volts}(t) - \text{Volts\_min}) \bullet \left[\frac{\text{Vol.\_used}}{(\text{Volts\_max} - \text{Volts\_min})} \right] \right] \quad (5)$$

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.

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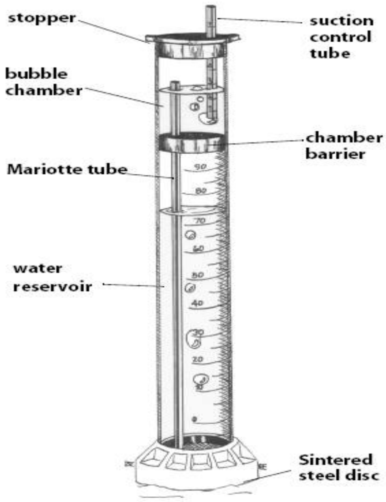

Figure 1 - Diagram of Minidisk Infiltrometer

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

[1]bgs – below ground surface, [2]EC - electrical conductivity (deciseimens per meter), [3]SAR – 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 ± std error (n = 6) (lbs/acre – dry weight)
Control	N/A	84.1± 45.6
Aerobically Digested Biosolids	1X	423.4 ± 237.4
Aerobically Digested Biosolids	5X	354.2 ± 225.1
Aerobically Digested Biosolids	10X	489.5 ± 172.7
Anaerobically Digested Biosolids	1X	612.3 ± 266.1
Anaerobically Digested Biosolids	5X	559.8 ± 160.9
Anaerobically Digested Biosolids	10X	376.0 ± 157.0
Beef Cattle Manure	1X	362.1 ± 87.1
Beef Cattle Manure	5X	129.4 ± 59.1
Beef Cattle Manure	10X	481.7 ± 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

[1]EC - Electrical Conductivity (deciseimens per meter)
[2]SAR – 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.

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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

[1]EC - Electrical Conductivity (deciseimens per meter)
[2]SAR – 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

[1]EC - Electrical Conductivity (deciseimens per meter)
[2]SAR – 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

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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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