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Impact of Land-Applied Biosolids on Forage Quality and Water Movement During Rangeland Restoration Activities

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IMPACT OF LAND-APPLIED BIOSOSLIDS ON FORAGE QUALITY AND WATER MOVEMENT DURING RANGELAND RESTORATION ACTIVITIES

by

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ABSTRACT

Impact of Land-Applied Biosolids on Forage Quality and Water Movement During Rangeland Restoration Activities

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The land application of biosolids to provide nutrients and organic matter is widely practiced in agricultural applications. However, the potential benefit of applying biosolids to disturbed rangelands has not been adequately evaluated. Thus the main goal of the current study was to evaluate the potential economic and environmental benefits of applying biosolids to disturbed rangeland with the main focus on evaluating the impact on forage quality and quantity as a function of biosolids type and application rate. Three types of biosolids (aerobically, anaerobically, and lime stabilized biosolids) were surface applied with no subsequent tilling at various loading rates (1, 5, 10, and 20 times nitrogen plant requirement) in Skull Valley, Utah. It was demonstrated that forage quality (crude protein and in vitro digestibility) and quantity (biomass) can be improved by biosolids land application. Also, the analyses of the soil and forage for 16 specific metals indicated no measurable accumulation except for a statistical increase of sodium compared with the control. No negative impact on soil moisture infiltration (e.g., drainage) properties were seen. The economic analysis of biosolids land application on disturbed rangeland associated with improvements in forage quality indicated that use of biosolids for land restoration would be profitable. The highest potential financial return was observed when anaerobically digested biosolids were land applied at 20 times the agronomic rate.

Finally, despite the numerous benefits associated with biosolids land application, there remain a number of human health and environmental concerns regarding its use on publicly accessible lands that should be addressed in future studies. These concerns are primarily associated with the accumulation of heavy metals and recalcitrant organics (e.g. polychlorinated biphenyls, dioxins, brominated biphenyls, and pharmaceuticals and personal care products) that may be associated with the biosolids.

(93 pages)

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Issaak Vasquez

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CHAPTER 1

INTRODUCTION

The national regulatory framework for controlling water quality in the United States was established by the 1948 Federal Water Pollution Control Act (FWPCA). The 1948 FWPCA has been amended many times resulting in today's regulation which is simply known as the US Clean Water Act (CWA). The CWA is the comprehensive federal law that contains the basic national framework for water pollution and water quality control in the United States (McFarland 2001). Under the CWA, biosolids, which are treated sewage sludge from municipal wastewater treatment plants (WWTPs), may be beneficially used (e.g., land application) if they meet certain quality standards. These standards are defined in the CWA by the 40 Code of Federal Regulations (CFR) Part 503 rule (Desai 2006). The 40 CFR Part 503 rule states that biosolids that meet the pollutant (e.g., heavy metal), pathogen and vector attraction requirements for beneficial use may not be land applied at rates above the agronomic rate *except* when used to reclaim marginal or disturbed land. This rule stipulates that biosolids that contain regulated pollutants at concentrations above the ceiling concentrations can not be beneficially used (e.g., land applied). Also, the pathogens concentrations in biosolids must achieve either Class A or B before the material can legally be land applied. Class A and B biosolids have low levels of heavy metals. They differ because Class B biosolids has detectable, yet low, levels of known human pathogens, while the pathogen levels of Class A biosolids are not detectable. Finally, the vector attraction reduction standard requires that biosolids be treated (chemically and/or biologically) to reduce microbially activity or physically incorporated into the soil (tilling or injection of biosolids) as part of the land application requirements.

Rangelands in the western United States have experienced heavy livestock grazing during the past century, which has led to a substantial reduction in total plant cover and density. These western rangelands are categorized as disturbed rangelands because its forage productivity has decreased considerably as consequence of land disturbances. Any rangeland restoration approach that has the net effect of increasing plant cover over time will have the beneficial impact of promoting moisture infiltration and reducing soil erosion. Moreover, many rangeland soils have been significantly depleted of organic matter and, in many cases, supplemental organic matter is needed to improve rangeland productivity.

Since treated sewage sludge (or biosolids) is rich in organic matter and nutrients, it is believed that they will help in restoring the vigor of disturbed rangelands. Biosolids represent a low cost source of organic matter when land applied to affected soils. In addition, organic matter decomposition from land-applied biosolids releases chemically-bound nutrients (e.g., proteins), making them available for assimilation by plants and soil microorganisms.

The overarching goal of the current study is to determine the potential economic and environmental benefits of land applied aerobically digested, anaerobically digested and lime-stabilized biosolids to disturbed alkaline rangelands located in Tooele County (Skull Valley), Utah. There are very few studies available that have evaluated the impact of sludge processing methods on biosolids quality and its effectiveness in restoring deteriorated rangeland. Moreover, the impact of applying biosolids at rates as high as 20 times agronomic rate based on nitrogen needs of the plants has never been documented.

From a regulatory standpoint, biosolids can be applied on undisturbed sites at rates much higher than the agronomic rates. The state of Utah wants to document the environmental impact of applying biosolids at large rates to disturbed rangelands. Since the various types of biosolids have different allocations of the various nitrogen forms (e.g., nitrate, ammonia, organic nitrogen), a rangeland's response to these biosolids quality differences are of particular importance to state regulators.

It is important to note that since the selected land application site is disturbed land, the study is not limited to the agronomic rate as the ceiling application rate for biosolids. In fact, the range of biosolids application rates is established at 1 to 20 times the estimated agronomic rate (based on the vegetation crop nitrogen requirement).

For the specific case of lime stabilized biosolids, the application rate was limited to 10 times the agronomic rate because higher rates were considered to be unpractical. For example, since the nitrogen content in the lime stabilized biosolids was relatively low, the biosolids application rate required to achieve a nitrogen loading twenty times the agronomic rate would have resulted in producing a biosolids layer several inches in thickness. After discussions with agricultural specialists, it was surmised that, without tilling, the resulting surface application would have physically impeded plant emergence. An additional concern expressed by local agricultural specialists was the potential toxicity of large inorganic salt additions (as lime) on the already disturbed rangeland. Given the potential negative physical and chemical impacts associated with adding large amounts of lime to soils already high in salt content, application of lime stabilized biosolids was limited to no more than 10 times the agronomic rate.

Because the focus of this study is to evaluate the impact of both biosolids quality and quantity on soil moisture transport, biomass yield, and biomass quality, the parameters whose values will be monitored throughout the study include: hydraulic conductivity, water drop penetration time, forage minerals, crude protein and energy analyses.

The principal goal of this study is to document and quantify various effects of applying different types and amounts of biosolids during the restoration of disturbed semiarid rangelands. The specific research objectives include the following:

1) To characterize qualitative and quantitative the effect of biosolids application on soil water transport properties by evaluating water drop penetration time and soil hydraulic conductivity for a range of biosolid types;
2) To clarify the effect of biosolids in increasing the forage value of disturbed rangelands, biomass yield and quality (protein and energy content) will be documented and evaluated;
3) To evaluate the impact of biosolid type and application rate on rangeland forage crop production;
4) To analyze the effect of mineral concentrations on the forage after biosolids application, and see if they are a possible threat for the cattle consumption;
5) Optimize biosolids application for a sustainable range management by accounting for the economic benefit associated with the improvement in forage quality/quantity.

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CHAPTER 2

EFFECT OF BIOSOLIDS ON RANGELAND FORAGE QUALITY

Abstract The productivity and quality of rangeland of western Utah could be improved with the addition of nutrients and organic matter. Land application of biosolids has been promoted as a potentially cost effective approach to supplying these necessary nutrients and organic matter. However, few studies have directly evaluated the potential of land applied biosolids to improve marginal rangelands. To address this deficiency, a 2-year field study was conducted in Skull Valley, Utah to evaluate the effectiveness of land application of manure and biosolids in improving the forage quality of marginal rangelands. Manure (a common fertilizer on rangelands) and three different types of biosolids were compared with a control plot on which no amendments were applied. Biomass and forage samples were collected and measured respectively for each treatment. The crude protein (CP, %) and the in-vitro true digestibility (IVTD, %) were measured. Although the IVTD analysis did not show a statistical improvement in forage grown on biosolids amended rangelands, improvements in CP associated with biosolids land application were found to be statistically significant. Based on improvements in CP and IVTD, modeling results demonstrated that the estimated daily gain in weight for a 136.4 kg (300 lb) beef cow was considerably higher for animals grazing on forage from biosolids amended sites compared to the control. Finally, the increase in vegetative yield (e.g., biomass production) was found to be statistically significant greater on sites amended with biosolids, which led to a considerable improvement in stocking rate.

Introduction

Biosolids are the final solid products of waste water treatment plants (WWTP) (USEPA 1991). Biosolids can be directed to beneficial use such as land application for agricultural, (USEPA 1994), and the production and sale of biosolids products like soil substitute products, alkaline-stabilized soil additives, heat-dried pellets, compost among others (McFarland 2001).

Forage quality directly affects a rangeland's ability to support the nutritional needs of livestock. Good forage quality can be achieved by applying fertilizer. Fertilizer applications in the form of manure have been shown to increase the biomass of rangeland (Bell et al. 2006). Few studies have compared the benefit of applying manure and biosolids on a rangeland (Mata-Gonzalez et al. 2006). The present research program, which attempts to increase knowledge about the subject, is focused on comparing the impact of land applying manure and three types of biosolids (aerobically digested, anaerobically digested, and lime stabilized biosolids) on disturbed rangelands. Owing to the types of pathogen treatment processes used in generating the material, the three biosolids were characterized as Class B. Class B biosolids differ from Class A biosolids in that they have detectable, yet low, levels of known human pathogens. Even though lime stabilized biosolids are readily available, few field studies have been conducted using them (Mata-Gonzalez et al. 2006).

It is well known that higher water application to sites where biosolids were applied will lead to higher responses in forage biomass and the absorption of nitrogen (Mata-Gonzalez et al. 2004). In the present study, none of the test sites were irrigated although the mean precipitation rate for this area is approximately 382.5 mm/year.

In this study, a control plot (where organic amendments were not applied) was used to establish a performance baseline. We initially determined the application rate needed to just meet the plant's needs based on nitrogen. This application rate is defined as the agronomic rate. For the current study, biosolids and manure application rates were limited to 1, 5, 10, and 20 times the agronomic rate. For the specific case of the lime-stabilized biosolids, the 20 times agronomic rate was not applied because the amount of biosolid was considered to be too high to allow unfettered emergence of rangeland vegetation. Since the nitrogen content in the lime stabilized biosolids was low, the amount of biosolids needed to achieve an application rate equivalent to 20 times the agronomic rate would result in a surface application layer of several inches. Without incorporation, surface application of lime stabilized biosolids would result in a soil amendment layer of several inches. The physical limitations associated with vegetation emerging from such a layer as well as the high inorganic salt additions led to a number of concerns expressed by agricultural specialists affiliated with the project. It was determined that to limit the potential negative impacts of land applying lime stabilized biosolids, its maximum application rate would be 10 times the estimated agronomic rate. A unique characteristic of the current study compared with other reported field results (Martin and Jack 2002; Jurado and Wester 2001) is that this is one of the few studies that established biosolids application rates based on multiples of the estimated nitrogen-based agronomic rates. Even though some other studies based their application rate on estimated agronomic rate (Tiffany et al. 2000[b]), they did not apply more than twice the rate needed by plants. Some other researchers applied manure and biosolids in laboratory-size pots to determine the reaction of two specific species (Mata-Gonzalez et al. 2006). In this research program, however, a field demonstration study was conducted.

The main objective of this study was to determine the influence of manure and biosolids at different application rates on forage quality. Among the parameters that were analyzed were the dry biomass, the CP and the IVTD. The stocking rate was calculated, and the daily gain in weight of a 136.4 kg (300 lb) cow was estimated based on the CP and IVTD analysis.

Materials and Methods

Field studies were conducted on a series of rangeland test plots in Skull Valley, in Tooele County, at the coordinates lat 40° 27’ 06’’ N and long 112° 44’ 42’’ W. The predominant surface texture of the soil is sandy loam. The mean annual air temperature fluctuates from 7 to 10°C (USDA-NRCS 2000). The average mean precipitation is 382.5 mm/year (GIS Climate Search 2006). The average mean precipitation at the site of study was calculated by extrapolating the values from nearby stations to the study site using the inverse distance weighting method (Gao 2006). Table 2.1 shows the precipitation in millimeters per month over the mentioned periods.

Table 2.1 Extrapolated mean precipitations for stations “Grantsville 2 W” and “Johnson Pass” over a period of 51 and 34 years, respectively, expressed in mm per month

Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Grantsville 2 W	17.0	21.6	32.4	38.0	32.9	21.6	19.2	19.2	24.1	27.4	24.8	20.9
Johnson Pass	38.8	39.7	44.6	44.1	52.4	24.7	29.0	25.8	29.3	34.6	36.3	34.2
Working Site	***30.5***	***32.8***	***40.0***	***41.8***	***45.0***	***23.6***	***25.3***	***23.3***	***27.3***	***31.9***	***31.9***	***29.2***

Treatments

Biosolids (aerobically digested, anaerobically digested and lime stabilized) were obtained from three different municipal wastewater treatment plants (WWTP) located along the Wasatch Front, Utah while the beef cattle manure was obtained from the Ensign Ranches of Utah, Inc. feedlot. The biosolids and beef cattle manure were applied in December 2004, and rates were determined based on the plant nitrogen requirement. The agronomic rate was determined from Equation 1 (McFarland 2001).

$$\text{Agronomic Rate}\left(\frac{\text{metric ton}}{\text{ha}}\right) = \frac{\text{adjusted nitrogen requirement (ANR)}\left(\frac{\text{kg - N}}{\text{ha}}\right)}{\text{plant available nitrogen per ton of biosolids/manure}\left(\frac{\text{kg - N}}{\text{metric ton}}\right)}$$

$$= \frac{\text{ANR}}{\left[(NO_3) + K_v(NH_4) + K_{min}(N_o)\right]10} \qquad (1)$$

where:

ANR	Adjusted nitrogen requirement (kg N/ha)
NO_3	nitrate concentration in biosolids/manure (kg N/metric ton)
NH_4	ammonia concentration in biosolids/manure (kg N/metric ton)
N_o	organic nitrogen concentration in biosolids/manure (total nitrogen content found in biosolids/manure minus nitrate plus ammonia content)
K_v	volatilization factor (0.5 if biosolids/manure are not tilled into soil)
K_{min}	organic nitrogen mineralization rate (assumed to be 0.3) (McFarland 2001)

The ANR was determined based on the estimation that a healthy rangeland in this area would exhibit a nitrogen demand of approximately 168.5 kg nitrogen per ha (150 lbs-N/acre) as detailed below. It is known that, on average, the plant biomass at the rangeland test site is approximately 1123 kg/ha (1000 lbs/acre) (USDA-NRCS, 2000). Also, it was assumed that the nitrogen content of the biomass was around 15% (Desai 2006). From this, the total nitrogen needed by the plant is approximately 168.5 kg-N per ha (150 lb/acre). Soil analysis indicated that there was already approximately 112 kg-N per ha (100 lb-N per acre) of available nitrogen. From this, the nitrogen that needed to be applied at the site was around 56.1 kg-N per ha (50 lb-N/acre). Table 2.2 shows the different rates applied for each of the soil treatments based on the nitrogen analysis on biosolids and background soil.

Sixteen 0.13-ha test plots were established for the field demonstration study. To facilitate the selection of random samples, each of the 0.13-ha subplot was divided into approximately 144 sections having physical dimensions of 3 by 3 m (10 by 10 ft).

On May 8th, 2006, 6 out of the 144 plots were selected randomly in each subplot. A random generator was used to select the random plots. The wet biomass was harvested in each of the six plots. In addition, forage samples were taken for three out of the 6 sections, and the dry matter, crude protein and neutral detergent fiber were analyzed by the Utah State University Analytic Laboratories. The sampling and analysis was repeated on May 15th, 2007, but for this year, four forage samples were analyzed per subplot. The five parameters calculated on this study are described in the following sections:

Table 2.2 Application rates for the three different biosolids and manure

Agronomic Rate	Metric tons per hectare			
	Manure	Central Valley (Anaerobically Digested)	Snyderville (Aerobically Digested)	Tooele (Lime Stabilized)
1	11.8	2.9	3.4	19.7
5	59.2	14.3	17.2	98.6
10	118.3	28.6	34.4	197.3
20	236.6	57.1	68.8	†394.5

† 20 times agronomic rate for Tooele biosolid was not applied because it was considered to be impractical to plant growth because of its thick layer.

Dry Biomass (kg/ha). The dry herbage biomass was calculated by multiplying the average wet weight of herbage biomass in each subplot by the average of the dry matter obtained in each subplot. The dry matter obtained for the 2006 and 2007 years had 3 and 4 samples respectively per subplot.

Stocking Rate. Stocking rate is defined as the amount of land per animal unit (Holechek and Rex 1995). An animal unit is defined as a 454.5 kg (1,000-lb) cow with a calf (USDA-NRCS 2008). Stocking rate was calculated using the following procedure:

* *Calculation of total usable forage.* The total usable forage is the amount of forage that the cattle will eat on a specific unit of land. It is expressed by Equation 2.

$$\text{Total Usable Forage} = \left[\text{Dry Biomass}\left(\frac{\text{kg}}{\text{ha}}\right)\right](\text{Percent Allowable Use}) \qquad (2)$$

The percent allowable use can be classified as heavy, moderate, or light. Moderate gives the higher net return per unit of land, so economically it is more profitable in the long term to use a moderate percent allowable use on the range.

Different analyses had been done for estimating the percent allowable use. A simple classification can be used, such as consumption from 45 to 60% on humid regions, from 35 to 45% on a semiarid rangeland, and from 25 to 35% on more arid region (mean annual precipitation below 300 mm) (Holechek and Rex 1995). According to the mean annual precipitation of this study site, this rangeland is classified as semiarid rangeland, and a value of 45% was taken as percent allowable use.

* *Calculation of Forage Demand per Cow per Number of Days.* The forage demand that a single cow will require is given by the following equation:

$$\text{Forage Demand} = (\text{DMI}) * (\text{number of days the pasture will be grazed}) \qquad (3)$$

The dry matter intake or DMI is expressed in kg/day/cow. The number of days the pasture will be grazed was considered for one month (30 days). The DMI was calculated for a 454.5 kg (1000 lb) cow weight, and the approach used for calculating this for beef cattle is expressed in Equation 4 (Belyea et al. 2005).

$$\text{Dry Matter Intake} = \frac{(\text{Weight of Beef Cow}) * (1.08\%)}{\text{NDF}\,\%} \tag{4}$$

The NDF value used in Equation 4 represents the average neutral detergent fiber. For the years 2006 and 2007, three and four samples were analyzed respectively for each subplot. The NDF was determined using an Ankom 200 fiber analyzer.

* *Calculation of Stocking Rate.* The stocking rate was calculated using Equation 5, and it is expressed in numbers of hectares per animal per month.

$$\text{Stocking Rate} = \frac{\text{Forage Demand}}{\text{Total Usable Forage}} \tag{5}$$

Crude Protein. Nitrogen was measured at the Utah State University Analytic Laboratories by combustion using a LECO TruSpec CN carbon-nitrogen analyzer. For the year 2006, three sub-samples were taken randomly from each subplot and the CP was calculated in each sub-sample. For the year 2007, four sub-samples were taken randomly from each subplot. The crude protein (CP) was estimated by multiplying the percent nitrogen (dry basis) of the vegetation by 6.25 (Schroeder 1994). Higher CP denotes better forage quality.

In-Vitro True Digestibility. One of the most accurate methods to measure forage digestibility is by the IVTD test (Van Soest 1982). The IVTD is a lab methodology that simulates the digestion that occurs in the cow's rumen, and is performed in anaerobic conditions. Rumen fluid is collected and the forage samples are incubated anaerobically at 39^{o}C. During the time of incubation, the forage samples are digested by the microbial population that are in the rumen. The IVTD experiment was done in the Skaggs Nutrition Laboratory, and a Daisy incubator was used (Ankom model). Dried samples were used for this experiment, and Equation 6 was used for calculating the IVTD:

$$\text{IVTD}\,(\%) = 100 - \left[\frac{(\text{Final WT - Bag WT})*100}{\text{Sample WT}}\right] \tag{6}$$

Bag WT = weight of each sample bag.
Sample WT = sample weight before the experiment.
Final WT = weight of the bag plus the undigested fibrous residue.

Increased Weight. The two main factors that influence the daily gain in weight per day in beef cattle are the CP and the digestibility of the forage. A simple estimation of the daily weight gain of a 136.4 kg (300 lb) cow was analyzed to determine the influence of these two factors. The lowest daily gain between the CP and the IVTD for a specific subplot was considered as the daily weight gain of the cow. Also, cattle maximum daily gain was no more than 1.14 kg (2.5 lbs) because of water limitation. Table 2.3 was used to obtain the daily gain of a 136.4 kg cow (National Research Council 1984).

Table 2.3 Cattle daily gain in weight for a 136.4 kg cow

Daily Gain (lbs/day)	CP (%)	IVTD (%)
0.5	9.5	52.5
1.0	11.3	56.0
1.5	12.9	59.5
2.0	14.6	63.5
2.5	16.3	67.5
3.0	18.0	72.0
3.5	20.3	78.5

Statistics

The experimental design was based on a pseudo-replication method because of budget and time constraints. The main factors that might affect the final results were not affected by the lack of a replicated design. For example, temperature and water content were assumed to be the same for all treatments. Therefore, these factors should not affect the outcomes of the experiment.

Basically two statistical methods were used in this experiment. Since it was an unbalanced design, a fixed-effect analysis of variance with one treatment factor by using contrast statements to isolate comparisons of interest was used. This methodology was used for the analysis of the CP (%), and IVTD (%).

The dry biomass and the stocking rates were obtained from the multiplication of at least two collected or measured samples. For this reason, a fixed-effect analysis of variance with one treatment factor was not performed for these cases, and a normal Z-test was considered a better fit in this case. The standard error was determined, and it was calculated using a statistic for propagation of measurement error (Berthouex 2002).

In both statistical analysis, each subplot was compared with the control, and the subplots were considered to be statistically significant different if the level of confidence was 95% or more.

Results and Discussion

Dry Biomass (kg/ha)

Figure 2.1 shows that the biomass harvested in 2006 is highly variable, which is reflected in the low statistical difference of the treatments with the control. It is believed that this high variability is because it was harvested just one year after biosolids application, which did not allow a consistent effect of the biosolids. On the other hand, Figure 2.2 shows better uniformity, and a more consistent trend for the biomass. Hatched subplots represented by bars shows their biomass production to be significantly higher than that of the control plot. In general, it can be seen that higher dry biomass will be obtained for higher agronomic rates. This result was expected because of the higher nitrogen content for higher application rates. These results are consistent with other studies where higher rates of biosolids application resulted in an increase in biomass (Walter et al. 2000; Martinez et al., 2003). This does not seem to be the case for the lime-stabilized treatment, where, for higher agronomic rates, lower biomass yields were obtained. Sodium absorption ratio (SAR), pH, electrical conductivity (EC), and mineralogical analysis of the soil did not seem to explain the inverse relationship between biomass production and increasing application of lime stabilized biosolids. Related studies show that heavy applications of manure were unsuitable for rangelands where Blue grama is the predominant species (Stavast et al. 2005), however, in the present study, the predominant specie is *Bromus tectorum*, and no adverse effect were seen for high manure applications on this species.

Stocking Rate

The stocking rate was calculated based on the dry biomass and on the NDF obtained for each subplot. Figures 2.3 and 2.4 show the stocking rate for the years 2006 and 2007, respectively. The lower the number of hectares needed per animal unit month, the more productive the site. Even though the subplots are not significantly different than the control, all the subplots are more productive than the control. No much difference in the productivity obtained by the manure with the biosolids can be seen. In addition, some subplots were 5 times more productive than the control. This trend can be confirmed for the years 2006 and 2007.

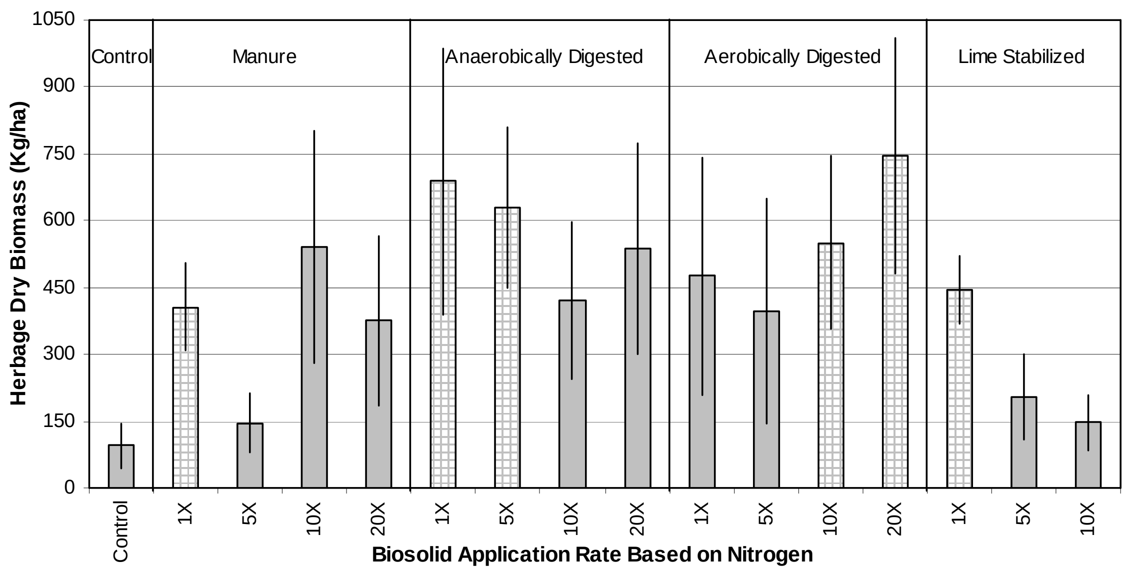

Fig. 2.1. Herbage biomass vs. biosolid application rate for year 2006. Error bars indicate standard error.

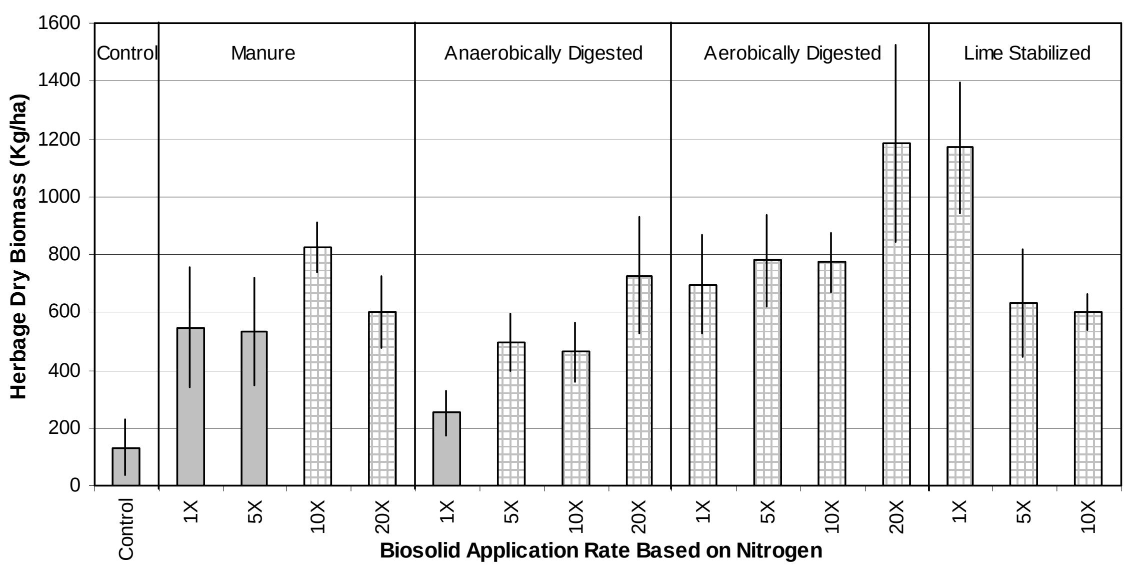

Fig. 2.2. Herbage biomass vs. biosolid application rate for year 2007. Error bars indicate standard error.

As mentioned before, we have speculated that, for 2007, a more uniform biomass was obtained because more time had passed since biosolids land application. It is anticipated that, for the future years, productivities similar to that observed in year 2007 will be seen.

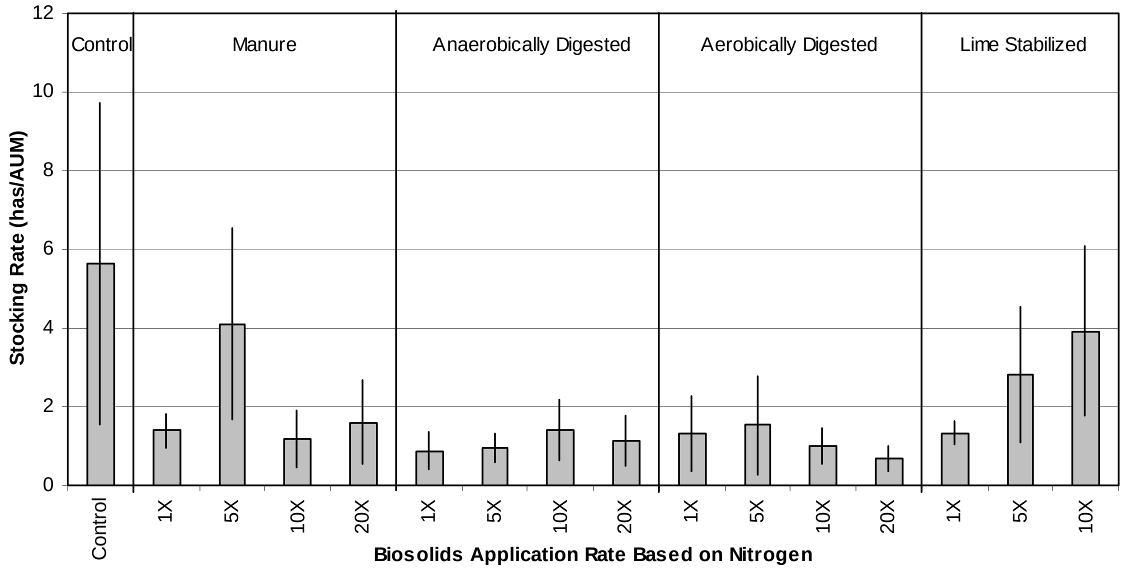

Fig. 2.3. Stocking rate vs. biosolid application rate for year 2006. Error bars indicate standard error.

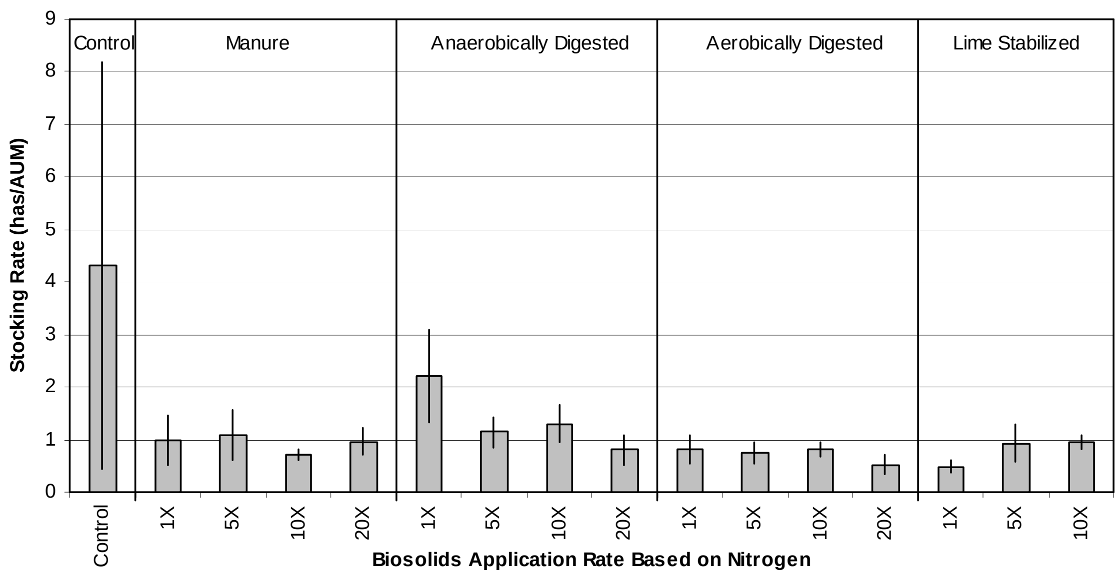

Fig. 2.4. Stocking rate vs. biosolid application rate for year 2007. Error bars indicate standard error.

Crude Protein

The improvement in CP compared with the control was consistent for the years 2006 (Figure 2.5) and 2007 (Figure 2.6). These results are consistent with previous studies that showed that biosolids application increased the CP content compared with the control (Tiffany et al. 2000[a], Martin and Jack 2002; Jurado et al. 2006). All treatments were significantly higher in CP content compared with the control. The CP is directly related to the nitrogen content in the forage, so higher nitrogen content will lead to a higher CP content. Since the treatments receive a high nitrogen loading compared to the control, it was anticipated that the forage that grew on biosolids amended soils would have a high nitrogen content. Some studies have shown higher nitrogen content in the forage for treatments where biosolids were applied (Pierce et al. 1998). This increase in nitrogen availability will lead to higher CP content in the forage associated with the biosolids amended sites compared to the control. The subplots represented by hatched bars show statistically higher CP than the control. In general, higher agronomic rates resulted in the same response in crude protein, with the exception for rangeland test sites receiving lime stabilized biosolids.

In-Vitro True Digestibility

The IVTD data seen in Figures 2.7 and 2.8 shows how digestible the forage is for the different treatments. The subplots represented by hatched bars were statistically significantly different than the control. A previous study showed that IVTD improves with biosolids application (Jurado et al. 2006). In contrast with this study, a significant difference could not be seen when the digestibility of the different biosolids treatments are compared with the control for years 2006 and 2007. The reason for this result may be because the samples were taken in the early part of the growing season. A previous study compared in vitro organic matter digestibility (IVOMD) of forage grown with biosolids amendments with a control area where no biosolids were applied. This earlier study revealed that there was no significant difference in the IVOMD for early season's forage compared to the control. This study also illustrated that, during the latter part of the growing season, the statistical difference of the IVOMD was significant when the control was compared with the biosolids treatments (Tiffany et al. 2000 [a]).

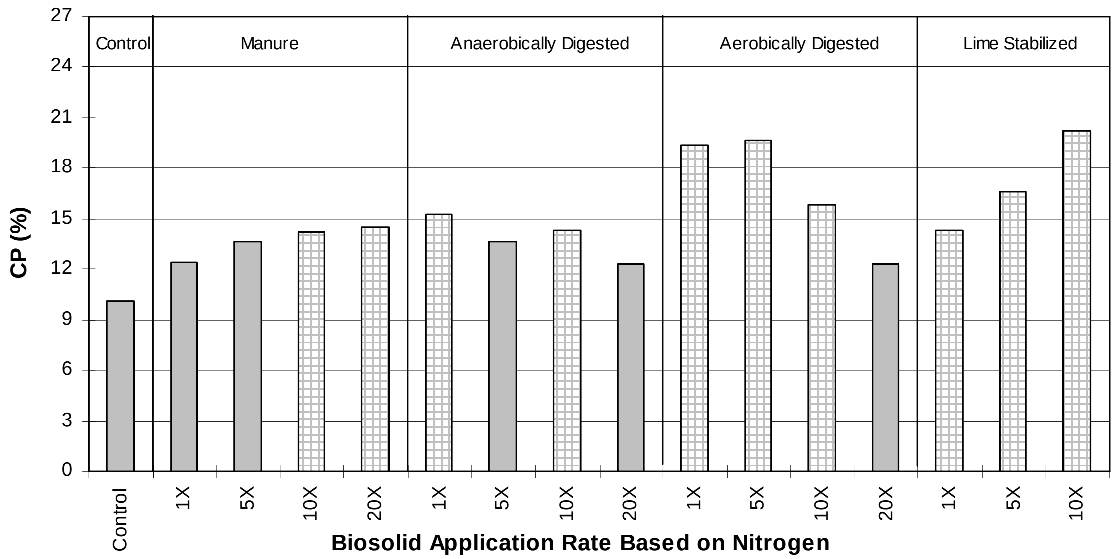

Fig. 2.5. Crude protein vs. biosolid application rate for year 2006.

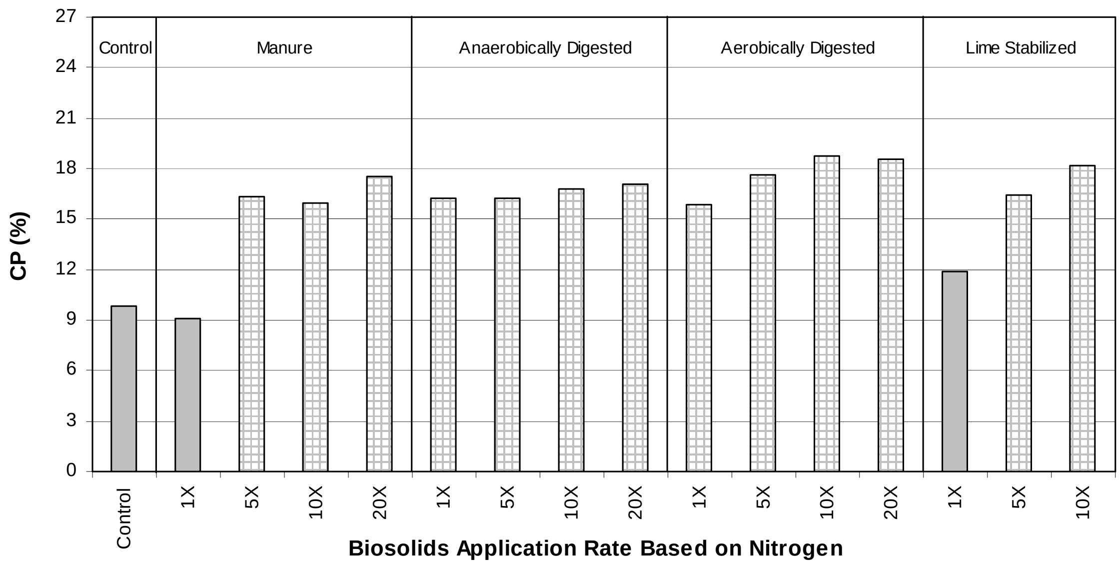

Fig. 2.6. Crude protein vs. biosolid application rate for year 2007.

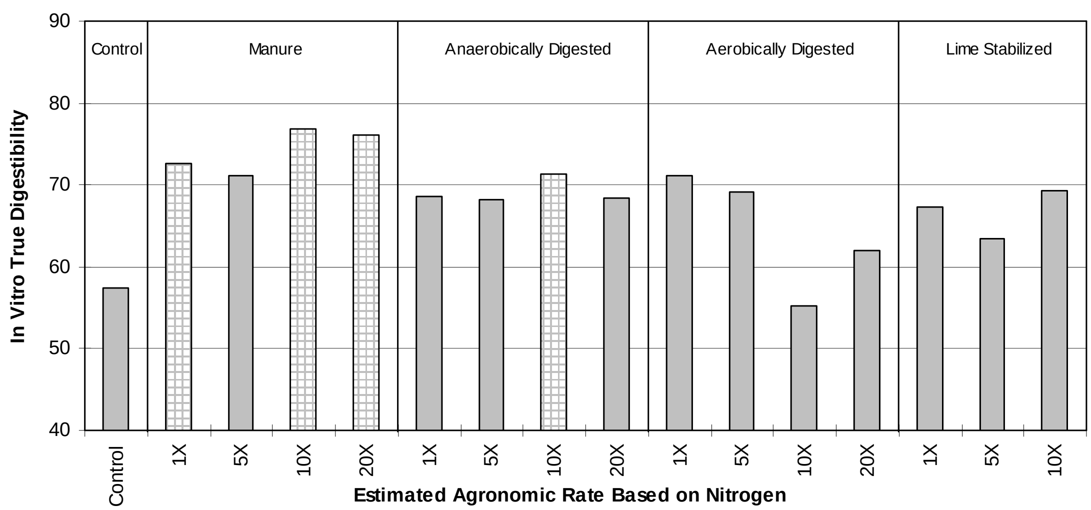

Fig. 2.7. In vitro true digestibility vs. biosolid application rate for year 2006.

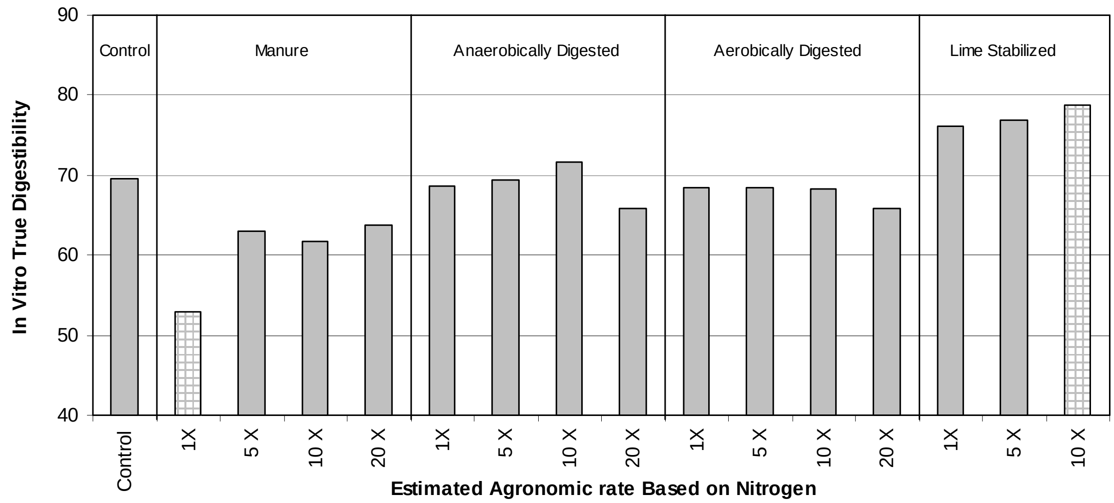

Fig. 2.8. In vitro true digestibility vs. biosolid application rate for year 2007.

Increased Weight

Figures 2.9 and 2.10 depict the estimated average daily gain in weight of a 136.4 kg beef cow for the years 2006 and 2007. From these figures, it can be seen that the forage quality, IVTD and CP, increase significantly with increasing daily weight gain in most of the treatments compared with the control. This gain of weight was consistent for years 2006 and 2007. It is important to mention that these types of estimations of daily gain based on CP and IVTD have not been reported in other studies using biosolids and/or manure soil treatments.

Conclusions

The application of biosolids and manure, in general, resulted in higher biomass growth, which increased stocking rates, and improved the carrying capacity of a rangeland compared with the control area. For lime stabilized biosolids, application at one time the agronomic rate was found to result in greater productivity than at higher applications.

Forage quality was also improved with increasing biosolids application rates. This was documented by comparing the increase in CP values in forage grown on biosolids-amended soils to forage grown on control plots. The digestibility for the treatments compared to the control did not show consistent improvement. Finally, improvements in forage quality were found to directly benefit the daily gain in animal weight.

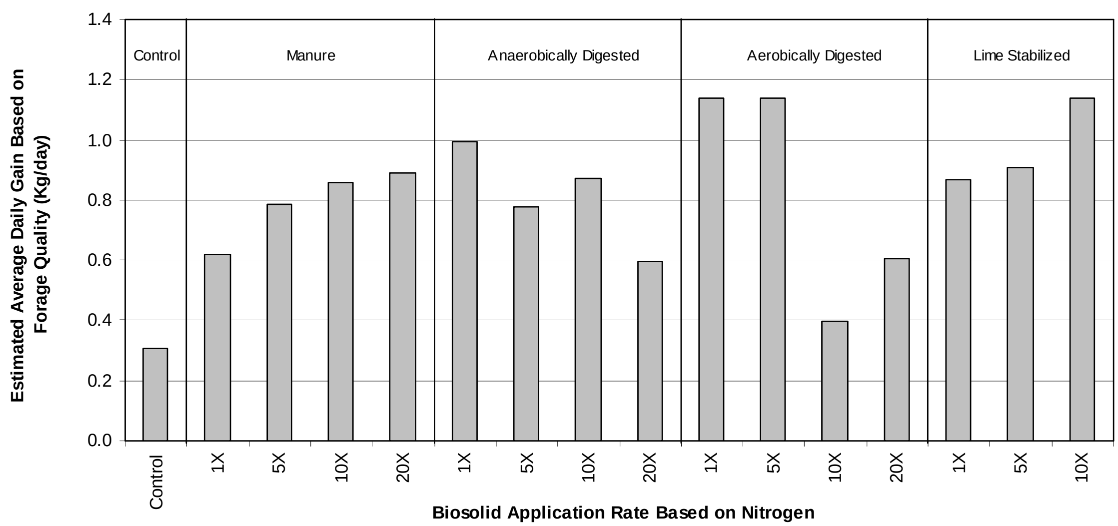

Fig. 2.9. Estimated average daily meat gain vs. biosolid application rate for year 2006.

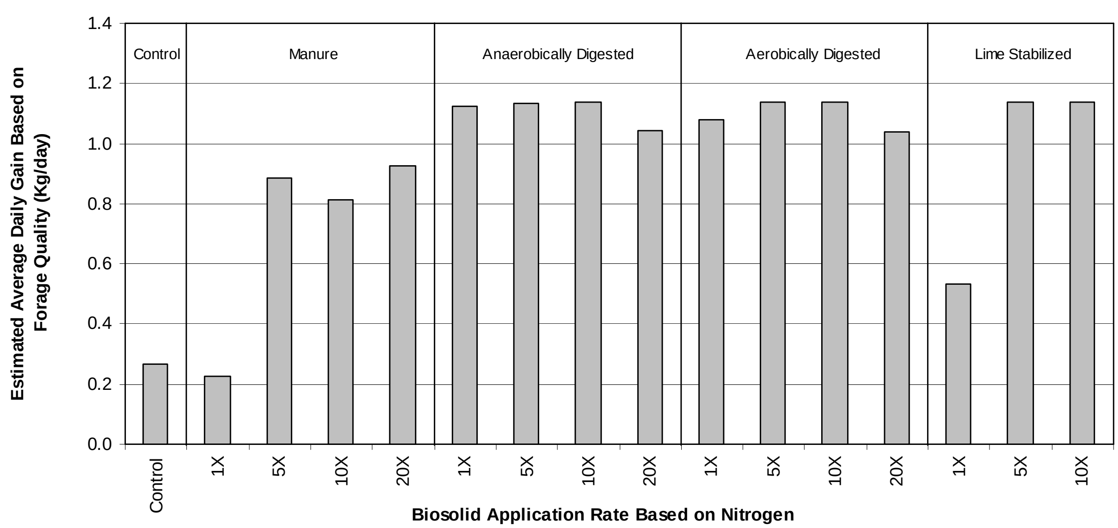

Fig. 2.10. Estimated average daily meat gain vs. biosolid application rate for year 2007.

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CHAPTER 3

SOIL AND RANGELAND FORAGE MINERALOGICAL ANALYSIS POST APPLICATION OF MANURE AND THREE BIOSOLIDS' TYPE

Abstract

Manure and biosolids can be land applied to disturbed rangelands to improve soil fertility. The primary focus of the field study was to quantify how the application of soil amendments (biosolids and beef cattle manure) might impact metal accumulation within the soil and to evaluate and document the possible adverse impact of metal accumulation on as well as in rangeland forage. The present research study was conducted from 2004 through 2007 in Tooele County, Utah. Cattle manure and three types of biosolids (aerobically digested, anaerobically digested, and lime stabilized biosolids) were land applied at rates up to 20 times the nitrogen-based agronomic rate. The results of these soil treatments were compared with a control area on which no amendments were applied. Soil analysis, one year later after the amendments application, showed a statistical increase in the sodium and a statistical decrease in the potassium concentration compared to the control. The analysis of the other minerals do not show a statistically significant increase compared to the control site. The forage analysis demonstrated that, of all the metals species investigated, only the forage molybdenum concentration grown in sites amended with cattle manure might be a problem during land restoration activities. The molybdenum concentration one year later after its application was found to be higher than 6 mg/kg, which exceeds the levels recommended by the US National Research Council. Moreover, forage grown on the different rangelands amended with biosolids

and manure indicated that sodium and copper supplements were necessary to ensure livestock health.

1. Introduction

Biosolids are the final solid products from the treatment of municipal wastewater (USEPA, 1991). Because of its abundance of organic matter and large concentration of nutrients, biosolids can be utilized in restoring vegetation on disturbed lands as well as for other agricultural purposes (USEPA, 1994).

Although biosolids land application has been demonstrated to have significant potential for restoring disturbed land, there is considerable concern regarding soil mineral accumulation that could potentially yield negative environmental effects. In New Mexico, a post sludge application study reported that soil macro-minerals and micro-minerals increased for higher sludge application (Fresquez et al., 1990). In addition, several studies have reported that, in the long term, the mineral concentration in the soil following biosolids land application increases but without toxic levels ever being reached (Lane, 1988; Julia et al., 2003).

Many studies have reported that biosolids application can improve the nutritional quality of native grasses (Pierce et al., 1998; Adjei and Rechcigl, 2002; Mata-Gonzales, 2006). Rangeland forage quality is vital because it directly affects the land's ability to support the nutritional needs of wildlife and livestock. The amount of macro-minerals, micro-minerals and other minerals contained in the rangeland vegetation is an indicator of forage quality. A surplus or deficit in mineral content in rangeland vegetation could adversely impact forage quality, leading to animal illness or, in extreme cases, death (Linn and Martin, 1999).

In Georgia, a forage analysis taken before and after biosolids application showed that the mineral concentrations are lower than the recommended maximum tolerable levels for beef cattle (Julia et al., 2003). A similar study in Florida reported that biosolids land application at rates equivalent to 2 times the agronomic rate resulted in no toxic mineral concentration being achieved in the vegetation (Tiffany et al., 2000). In New Mexico, a study reported that the nutrient levels in forage will be better at rates of 22.5 and 45 mt/ha than at 90 mt/ha after biosolids application. They were measured within the first 5 growing seasons after biosolids application (Fresquez et al., 1991).

In the present study, three different types of biosolid and beef cattle manure were land applied to increase forage productivity on disturbed rangeland. Both biosolids and manure were added at rates equivalent to 1, 5, 10 and 20 times the estimated rangeland agronomic rate based on nitrogen (USEPA, 2000). In addition to biosolids and manure test plots, a control area was used to establish a performance baseline. However, it was determined that, because of its relatively low nitrogen content, the application rate for lime stabilized biosolids was excessive in terms of the mass of biosolids actually applied. In other words, application of lime stabilized biosolids at 20X the agronomic rate would have resulted in a biosolids layer too thick for effective plant emergence. Owing to this concern, the maximum lime stabilized biosolids application rate was limited to 10X the estimated agronomic rate.

2. Experiment

Field studies were conducted on a series of rangeland test plots in Skull Valley, in Tooele County, UT at the coordinates lat 40° 27’ 06’’ N and long 112° 44’ 42’’ W. The predominant soil surface texture in the study site is sandy loam. The site’s mean annual air temperature fluctuates from 7 to 10°C (USDA-NRCS, 2000), and the average mean precipitation is 382.5 mm/year (GIS Climate Search, 2006). The mean precipitation at the site of study was calculated extrapolating the values of “Grantsville 2 W” and “Johnson Pass” stations to the study site using the “Inverse Distance Weighting” Method (Gao, 2006). Table 3.1 shows the precipitation in millimeters per month over the mentioned periods.

2.1. Treatments

Biosolids (aerobically digested, anaerobically digested and lime stabilized) were obtained from three different municipal wastewater treatment plants (WWTP - Central Valley, Snyderville, and Tooele, respectively). In addition, beef cattle manure was also land-applied, which was obtained from the Ensign Ranches of Utah, Inc. feedlot. Manure application was selected because it is a commonly used fertilizer. Biosolids and beef cattle manure were surface-applied on 0.13-ha (1/3-acre) test plots separated by buffer strips. A control area, where no soil amendment was applied, was used as a treatment performance baseline.

Table 3.1
Extrapolated mean precipitations for stations “Grantsville 2 W” and “Johnson Pass” over a period of 51 and 34 years respectively

Name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Grantsville 2 W	17.0	21.6	32.4	38.0	32.9	21.6	19.2	19.2	24.1	27.4	24.8	20.9
Johnson Pass	38.8	39.7	44.6	44.1	52.4	24.7	29.0	25.8	29.3	34.6	36.3	34.2
Working Site	***30.5***	***32.8***	***40.0***	***41.8***	***45.0***	***23.6***	***25.3***	***23.3***	***27.3***	***31.9***	***31.9***	***29.2***

The biosolids and beef cattle manure were applied in the middle of December 2004, and rates were determined based on the plant nitrogen requirement. The agronomic rate was determined from Equation 1 (McFarland, 2001).

$$\text{Agronomic Rate}\left(\frac{\text{metric ton}}{\text{ha}}\right) = \frac{\text{adjusted nitrogen requirement (ANR)}\left(\frac{\text{kg - N}}{\text{ha}}\right)}{\text{plant available nitrogen per ton of biosolids/manure}\left(\frac{\text{kg - N}}{\text{metric ton}}\right)} \tag{1}$$

$$= \frac{\text{ANR}}{\left[(NO_3) + K_v(NH_4) + K_{min}(N_o)\right]10}$$

where:

ANR	Adjusted nitrogen requirement (kg N/ha)
NO_3	nitrate concentration in biosolids/manure (kg N/metric ton)
NH_4	ammonia concentration in biosolids/manure (kg N/metric ton)
N_o	organic nitrogen concentration in biosolids/manure (total nitrogen content found in biosolids/manure minus nitrate plus ammonia content)
K_v	volatilization factor (0.5 if biosolids/manure are not tilled into soil)
K_{min}	organic nitrogen mineralization rate (assumed to be 0.3) (McFarland, 2001)

The ANR was determined based on the estimation that a healthy rangeland in this area would exhibit a nitrogen demand of approximately 168.5 kg nitrogen per ha (150 lbs-N/acre) as detailed below. It is estimated that, on average, the total plant biomass at the test site is approximately 1123 kg/ha (1000 lbs/acre) (USDA-NRCS, 2000). Assuming that the nitrogen content of the biomass is approximately 15% (Desai, 2006), the total nitrogen needed by the plant is approximately 168.5 kg-N per ha (150 lb/acre).

Soil analysis indicated that there was already approximately 112 kg-N per ha (100 lb-N per acre) of available nitrogen. From this estimation, the nitrogen required by the rangeland vegetation was approximately 56.1 kg-N per ha (50 lb-N/acre). Table 3.2 shows the different rates-of land applied biosolids.

Table 3.2
Application rates for the three different biosolids and manure

Agronomic Rate	Dry Metric Tons per Hectare			
	Manure	Central Valley (Anaerobically Digested)	Snyderville (Aerobically Digested)	Tooele (Lime Stabilized)
1	11.8	2.9	3.4	19.7
5	59.2	14.3	17.2	98.6
10	118.3	28.6	34.4	197.3
20	236.6	57.1	68.8	† 394.5

† 20 times agronomic rate for Tooele biosolid was not applied because it was considered to be impractical to plant growth because of its thick layer.

The mineralogical analyses of the biosolids based on the dry weight before being land applied are summarized in Table 3.3.

Table 3.3
Metal content of biosolids (mg/kg) before application on the site

Pollutants	Anaerobically Digested Biosolid (Central Valley)	Aerobically Digested Biosolid (Snyderville)	Lime Stabilized Biosolid (Tooele)
Arsenic	21	2	Non detect
Cadmium	2	0.98	0.261
Copper	560.9	99	51
Lead	65.6	41	5
Mercury	3.2	1	0.185
Molybdenum	16.4	1.8	1.3
Nickel	38.5	2.1	2.8
Selenium	21.9	2	Non detect
Zinc	877.3	200	54

Sixteen 0.13-ha test plots were established for the field demonstration study. To facilitate the selection of random samples, each of the 0.13-ha subplot was divided into 144 sections having physical dimensions of 3 by 3 m (10 by 10 ft). A random generator was used to select the random plots. At the time of field sampling, 6 out of the 144 subplots were selected randomly for each treatment. Each one of the six sections in each treatment has a dimension of 3 by 3 m.

On May 8th, 2006, soil samples at a depth of 0.23 m (0.75 ft) were obtained in each one of the randomly selected subplots and analyzed for its mineral concentrations. In addition, forage samples were taken for three out of the six subplots, and its mineral concentrations were analyzed by the Utah State University Analytic Laboratories. The forage collection and mineral analysis were repeated on May 15th, 2007, but for this year, four forage samples were analyzed per subplot. The forage minerals were determined by the wet acid digestion procedure using nitric acid and 30% hydrogen peroxide (Gavlak et al., 2003). The soil was digested by using the EPA 3050 method. In this method, the soil was digested using concentrated nitric acid supplemented with 30% hydrogen peroxide. The soil was then saturated and allowed to sit at least 4 hours (Edgell, 1988). After this, the liquid was extracted and the minerals were analyzed by an ICP spectrophotometer.

2.2. Statistics

Because of limited budget, the field experiments were considered a pseudo-replication design. Since it is an unbalanced design, it was decided to use a fix-effect analysis of variance with one treatment factor to isolate comparisons of interest. This methodology was used to compare whether the subplots for the different treatments are statistically different from the control. The subplots were considered to be significant different if the level of confidence was 95% or more. A light and dark color over the subplots means that they are statistically significant lower and higher than the control. The values that were below the method detection limit (MDL) were represented by “<”. The MDL was based on the dry weight. The numbers that follow the “±” symbol represent the standard error.

3. Results and Discussion

3.1. Soil Analyses

Six out of the nine regulated metals by EPA were analyzed (Table 3.4, trace elements). Of the three regulated metals that were not measured by the commercial laboratory, e.g., As, Se and Hg, As and Se detection was confounded by the presence of high levels of Fe. Adjustment of the inductively coupled plasma (ICP) instrument to compensate for the high iron concentrations would have been prohibitively expensive. Similarly, Hg detection required that the ICP set up and operational conditions be varied significantly compared to what was used for the detection of the other six heavy metals. Given the costs associated with targeting Hg, As and Se on the ICP, it was decided to focus the study’s limited resources in quantifying the levels of Cd, Cu, Pb, Mo, Ni, and Zn. The mineral concentrations for most of the treatments are not statistically different than the control. The sites where organic amendments were applied did not show significant increases in the metal concentrations in the surface soils as was expected. Because of a number of environmental processes e.g., soil erosion (wind and/or moisture induced), leaching etc., a complete mass balance on metal species could not be performed. Despite the absence of a mass balance, it was expected that, in an alkaline soil, many of the heavy metals associated with biosolids would simply accumulate at the soil surface. However, the initial metal concentrations found in the biosolids were low (Table 3.3). This finding coupled with the fact that biosolids adds dry matter to the soil profile suggests the possibility that application of high quality biosolids can effectively "dilute" the existing background metal concentrations. These results are consistent with previous studies that reported that biosolids application did not result in an accumulation of heavy metals in soil in soil (Lane, 1988).

There was a statistically significant increase and decrease of sodium and potassium, respectively, because of the application of the different soil amendments. Many reasons could lead to the increase and decrease of these metals. The decrease in potassium could be due to the increase in plant uptake on these sites receiving biosolids. This increasing uptake is due to the significant increase in biomass on the sites where the biosolids were applied. The increase in sodium could be due to the increase in evapotranspiration because of the significant increase of biomass in the amended sites. The increase in evapotranspiration leads to a greater salt movement to the soil surface. In general, the macro-minerals and micro-minerals in the treatments do not show a linear increase for higher agronomic rates which contrast with a study in New Mexico (Fresquez et al., 1990).

Table 3.4
Trace elements, micro-minerals and macro-minerals present in the soil for the different treatments

Trace Elements (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
Cd	2	<	<	<	<	<	<	<	<
Cu	2	9.2±0.7	<	9.8±0.2	10.6±0.6	11.6±0.6	22.4 [a]	4.2 [a]	<
Pb	10	* 13.3	<	10.6±0.1	<	<	27.3 [a]	14.1 [a]	10.5 [a]
Mo	2	46.2±2.0	<	46.6±1.0	38.8±2.0	48.9±2.3	57.3 [a]	<	<
Ni	8	30.8±5.3	<	20.8±0.7	22.1±1.9	19.5±0.4	40.3±31.2	8.1 [a]	16.6 [a]
Zn	2	51.5±2.2	<	52.3±1.2	55.6±10.1	53.5±2.3	60.0±7.6	56.2±5.7	44.3±2.1

Trace Elements (mg/kg)	MDL (mg/kg)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
Cd	2	<	<	<	<	<	<	<	<
Cu	2	<	10.2±1.5	2.6 [a]	<	<	<	4.1 [a]	<
Pb	10	<	<	12.1 [a]	10.2 [a]	<	<	11.7 [a]	10.0 [a]
Mo	2	<	<	<	<	<	<	<	<
Ni	8	12.7 [a]	<	<	<	22.2 [a]	11.6 [a]	16.3 [a]	20.0 [a]
Zn	2	47.4±3.20	54.20±4.00	51.2±0.8	45.5 [a]	36.4±1.1	52.4±3.5	48.1±2.9	47.7±1.2

Macro Minerals (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
K	0.01	1.24±0.06	0.73±0.05	1.35±0.03	0.77±0.16	1.43±0.12	0.77±0.10	0.68±0.02	0.70±0.02
Ca	0.01	4.85±0.26	5.09±0.53	4.36±0.38	10.14±1.12	5.27±0.25	5.08±0.32	5.03±0.33	5.31±0.31
Mg	0.01	1.15±0.05	1.19±0.08	1.20±0.04	1.30±0.05	1.29±0.06	1.21±0.07	1.22±0.06	1.48±0.04
Na	0.01	0.04 [a]	0.17±0.06	0.17±0.05	0.26±0.06	0.13±0.03	0.12±0.06	0.16±0.03	0.15±0.03

Macro Minerals (mg/kg)	MDL (mg/kg)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
K	0.01	0.81±0.05	0.86±0.03	0.90±0.01	0.82±0.05	0.59±0.03	0.97±0.05	0.83±0.04	0.83±0.03
Ca	0.01	4.55±0.54	5.29±0.28	5.98±0.25	6.91±0.52	4.92±0.20	4.55±0.52	4.74±0.33	5.28±0.27
Mg	0.01	1.42±0.09	1.54±0.05	1.73±0.02	1.51±0.08	1.24±0.06	1.47±0.08	1.40±0.04	1.45±0.04
Na	0.01	0.17±0.03	0.16±0.05	0.26±0.06	0.11±0.04	0.04±0.00	0.20±0.02	0.16±0.02	0.19±0.04

Micro Minerals (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
Co	2	* 2.8	<	<	3.9±1.2	3.9±1.2	10.8±5.4	2.9 [a]	2.8 [a]
Fe	100	13789±604	13062±995	15502±508	14212±1272	14347±330	13898±855	14743±633	14512±419
Mn	1	335.0±15	288.3±18	337.3±11	286.0±51	349.6±21	854.1±513	342.4±17	281.0±79

Micro Minerals (mg/kg)	MDL (mg/kg)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
Co	2	4.7 [a]	6.4±0.30	5.7±0.1	2.7 [a]	<	<	4.7 [a]	3.7 [a]

Table 3.4 (Continued)

Fe	100	13708±854	14272±457	14998±292	13267±925	12910±374	15680±682	13883±725	13603±445
Mn	1	383.8±26	373.6±11	391.2±22	358.4±28	329.5±15	365.4±15	333.7±11	346.9±9

[a] At least one of the six values is below detection limit. The maximum detection limit was used for calculating the average.

In the soil analysis, a high variability was seen. One example of this variability can be seen in the Cu concentration for the case of lime stabilized biosolids. In this soil treatment, Cu concentrations decreased with higher biosolids applications. This observation could be due to a high variability in the soil background horizons. In general, all the metal concentrations after biosolids application with exception of molybdenum are below average background levels (Frink, 1996; Lindsay, 1979). The high molybdenum concentrations are high not because of the treatments applications, but because the soil itself has high background concentration of this metal.

3.2. Forage Analyses

Cattle require the consumption of a certain amount of micro and macro-minerals to remain healthy. The excess intake of these minerals can be harmful and, in extreme cases, result in death. The maximum mineral concentrations for beef cattle diets (i.e. Maximum Tolerable Levels) recommended by the National Research Council (National Research Council, 1984) are shown in Tables 3.5. Tables 3.6 and 3.7 represent the different minerals analyzed on the rangeland forage for the different treatments on the years 2006 and 2007, respectively.

Table 3.5
Macro-minerals, micro-minerals and trace elements recommended on forage for cattle consumption

Macro minerals	Recommended Levels (%)	Maximum Tolerable Levels (%)
K	0.5 to 0.7	3
Ca	0.4	2
Mg	0.05 to 0.25	0.4
Na	0.06 to 0.10	10
Micro minerals	**Recommended Levels (mg/kg)**	**Maximum Tolerable Levels (mg/kg)**
Co	0.07 to 0.11	5
Cu	10	115
Fe	50 to 100	1000
Mn	20 to 50	1000
Mo	---	6
Trace Elements	**Maximum Tolerable Levels (mg/kg)**	
Al	1000	
As	50	
Cd	0.5	
Pb	30	
Sr	2000	

Table 3.6
Trace elements, micro-minerals and macro-minerals present in the forage for the different treatments for 2006 year

Trace Elements (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
Al	6	104±15	71±16	96±12	72±22	52±12	77.6 [a]	121±34	61.1 [b]
As	5	<	<	<	<	<	<	<	<
Cd	0.5	<	<	<	<	<	<	<	<
Pb	1.5	<	10.5 [b]	<	<	1.6 [b]	<	<	<
Sr	1.5	39.3±2.5	25.5±1.5	33.8±6.1	38.2±2.0	33.1±1.9	38.2±2.2	38.4±0.9	29.9±1.6

Trace Elements (mg/kg)	MDL (mg/kg)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
Al	6	142±48	121±42	256±101	128±31	132±40	70±16	129±21	261±154
As	5	<	<	<	<	<	<	<	<
Cd	0.5	<	<	<	<	<	<	<	<
Pb	1.5	<	<	<	2.4 [a]	2.0±0.3	<	<	<
Sr	1.5	29.1±2.2	31.8±3.4	35.2±1.5	39.9±2.7	33.3±4.1	33.4± 1.1	34.5±2.2	43.1±7.1

Table 3.6 (Continued)

Macro minerals (%)	MDL (%)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
K	0.0025	1.55±0.20	1.93±0.28	1.99±0.36	2.05±0.11	2.24±0.15	1.86±0.16	2.65±0.38	2.30±0.16
Ca	0.0005	0.40±0.03	0.23±0.01	0.29±0.04	0.35±0.05	0.25±0.02	0.40±0.03	0.37±0.04	0.33±0.03
Mg	0.0005	0.13±0.01	0.11±0.01	0.12±0.01	0.13±0.01	0.11±0.01	0.15±0.00	0.13±0.00	0.12±0.00
Na	0.0005	0.020±0.00	0.005±0.00	0.009±0.00	0.004±0.00	0.015±0.01	0.028±0.01	0.028±0.00	0.023±0.00

Macro minerals (%)	MDL (%)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
K	0.0025	2.39±0.19	2.13±0.36	1.82±0.14	1.76±0.24	2.81±0.11	2.91±0.19	2.10±0.20	1.75±0.27
Ca	0.0005	0.30±0.03	0.34±0.04	0.49±0.06	0.42±0.02	0.38±0.05	0.30±0.02	0.32±0.03	0.48±0.04
Mg	0.0005	0.11±0.01	0.11±0.00	0.13±0.01	0.13±0.01	0.11±0.01	0.12±0.01	0.12±0.01	0.15±0.00
Na	0.0005	0.015±0.01	0.011±0.01	0.017±0.01	0.008±0.00	0.012±0.01	0.013±0.00	0.123±0.04	0.037±0.01

Micro minerals (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
Co	0.5	<	<	<	<	<	<	<	<
Cu	0.5	8.5±0.7	8.2±1.5	7.3±0.6	6.6±0.2	6.9± 0.1	8.4±0.1	9.8±1.5	11.8±0.7
Fe	0.5	131±17	101±15	128±12	107±23	87±14	111±18	170±42	106±1
Mn	0.0005	56.0±4.7	36.4±1.2	46.6±10.6	47.4±4.1	39.1±4.2	59.4±1.8	39.1±4.5	32.3±1.0
Mo	7.5	<	10.7 [a]	14.7±0.5	16.4 [a]	<	<	<	<

Micro minerals (mg/kg)	MDL (mg/kg)	Anaerobically Digested Biosolid				Aerobically Digested Biosolid			
		1X	5X	10X	20X	1X	5X	10X	20X
Co	0.5	<	<	<	<	<	<	<	<
Cu	0.5	6.8±0.5	6.4±0.4	8.1±1.1	8.2±0.9	11.7±1.0	9.3±0.9	9.3±0.9	8.5±1.0
Fe	0.5	177±49	154±41	296±100	160±31	173±40	115±12	168±23	305±155
Mn	0.0005	35.9±4.5	44.1±6.7	57.1±8.2	58.4±8.0	53.9±10.4	40.2±1.7	42.3±6.4	65.7±1.9
Mo	7.5	<	<	<	<	7.97 [b]	<	<	<

[a] One of the three values is below the detection limit. The average of the other two values is being displayed.

[b] Two of the three values are below the detection limit. Just the value that is not below detection limit is being display.

Table 3.7

Trace elements, micro-minerals and macro-minerals present in the forage for the different treatments for 2007 year

Trace Elements (mg/kg)	MDL (mg/kg)	Control	Manure				Lime Stabilized Biosolid		
			1X	5X	10X	20X	1X	5X	10X
Al	6	173±68	285±177	167±82	87±19	142±44	148±72	99±17	161±15
As	5	<	<	<	<	<	<	<	<

Table 3.7 (Continued)

Cd	0.5	<	<	<	<	<	<	<	<
Pb	1.5	<	<	<	<	<	<	<	<
Sr	1.5	36.9±3.8	26.8±0.6	32.5±1.7	44.6±3.1	40.7±4.5	28.4±3.5	36.7±2.7	36.7±1.9

Trace Elements (mg/kg)	**MDL (mg/kg)**	**Anaerobically Digested Biosolid**				**Aerobically Digested Biosolid**			
		1X	**5X**	**10X**	**20X**	**1X**	**5X**	**10X**	**20X**
Al	6	260±142	268±140	47±8	137±63	161±92	117±22	93±16	134±51
As	5	<	<	<	<	<	<	<	<
Cd	0.5	<	<	<	<	<	<	<	<
Pb	1.5	<	<	<	<	5.8 [a]	10.3 [b]	<	21.6 [b]
Sr	1.5	32.2±4.0	32.5±2.7	37.2±1.2	38.2±1.7	58.2±14.7	56.9±11.0	30.6±1.8	48.3±19.9

Macro nutrients (%)	**MDL (%)**	**Control**	**Manure**				**Lime Stabilized Biosolid**		
			1X	**5X**	**10X**	**20X**	**1X**	**5X**	**10X**
K	0.0025	1.32±0.09	1.22±0.00	2.54±0.15	2.26±0.35	2.58±0.03	1.45±0.12	1.83±0.14	2.11±0.19
Ca	0.0005	0.33±0.04	0.33±0.05	0.31±0.04	0.30±0.02	0.32±0.04	0.32±0.07	0.34±0.07	0.43±0.05
Mg	0.0005	0.13±0.01	0.14±0.01	0.13±0.01	0.14±0.01	0.15±0.01	0.11±0.01	0.13±0.01	0.14±0.01
Na	0.0005	0.16±0.06	0.01±0.00	0.10±0.05	0.13±0.07	0.04±0.01	0.03±0.01	0.17±0.08	0.08±0.02

Macro nutrients (%)	**MDL (%)**	**Anaerobically Digested Biosolid**				**Aerobically Digested Biosolid**			
		1X	**5X**	**10X**	**20X**	**1X**	**5X**	**10X**	**20X**
K	0.0025	2.06±0.16	1.90±0.12	1.68±0.12	1.95±0.10	1.99±0.22	2.02±0.32	2.35±0.05	2.35±0.16
Ca	0.0005	0.35±0.06	0.33±0.05	0.33±0.02	0.34±0.04	0.70±0.36	0.55±0.17	0.25±0.02	0.56±0.31
Mg	0.0005	0.14±0.01	0.13±0.01	0.14±0.01	0.14±0.00	0.21±0.07	0.17±0.03	0.12±0.00	0.17±0.05
Na	0.0005	0.07±0.03	0.05±0.02	0.02±0.01	0.07±0.04	0.09±0.02	0.26±0.10	0.05±0.02	0.03±0.01

Micro nutrients (mg/kg)	**MDL (mg/kg)**	**Control**	**Manure**				**Lime Stabilized Biosolid**		
			1X	**5X**	**10X**	**20X**	**1X**	**5X**	**10X**
Co	0.5	<	<	<	<	<	<	<	<
Cu	0.5	7.5±1.0	7.9±1.1	9.5±0.9	8.2±1.1	8.4±0.2	7.3±0.9	9.2±0.6	10.7±0.3
Fe	0.5	202±71	297±162	206±96	122±13	200±45	167±63	113±11	158±16
Mn	0.0005	86.8±1.2	79.3±3.9	63.8±6.2	80.3±6.3	55.5±7.3	77.9±7.0	54.2±4.0	44.9±3.0
Mo	7.5	<	<	<	<	<	<	<	<

Micro nutrients (mg/kg)	**MDL (mg/kg)**	**Anaerobically Digested Biosolid**				**Aerobically Digested Biosolid**			
		1X	**5X**	**10X**	**20X**	**1X**	**5X**	**10X**	**20X**
Co	0.5	<	<	<	<	3.5 [b]	2.3 [b]	<	1.1 [b]
Cu	0.5	8.9±0.6	9.3±1.1	7.4±0.2	10±1.7	26.7±16.6	20.1±11.3	8.8±0.3	33.8±24.6
Fe	0.5	298±149	274±147	85±11	185±64	135±34	152±32	118±26	620±481
Mn	0.0005	55.6±11.6	59.1±12.2	64.2±7.5	80.0±8.5	106.7±45.2	72.2±25.0	39.9±5.7	88.4±58.7
Mo	7.5	<	<	<	<	<	<	<	<

[a] Two of the four values are below the detection limit. The average of the other two values is being displayed.

[b] Three of the four values are below the detection limit. Just the value that is not below detection limit is being display.

All the biosolids soil treatments resulted in forage mineral concentrations below the maximum tolerable levels for beef cattle consumption. These results are consistent with other prior studies (Tiffany et al., 2000; Gaskin et al. 2003).

Some forage calcium deficits are shown in most of the treatments and a supplement of this mineral will be required for healthy livestock production. A sodium supplement is also required for all the treatments.

Forages were normally high in potassium concentration relative to cattle requirements. This excess potassium is removed in the kidneys. With high potassium excretion, there is an obligatory loss of sodium also from the kidneys. Consequently, all ruminants require supplemental sodium when consuming forage based diets. Regardless of treatments, all forages were deficient in copper for cattle, consequently supplementation of this mineral is necessary. The manure treatments increased molybdenum to a level higher than the maximum tolerable level. Excess molybdenum interferes with copper metabolism. Supplementing copper to about 110% of the molybdenum requirement can potentially neutralize this problem (Weidmeier, personal comm.., 2007).

3.3. Implications

The current research study attempted to determine the impact of applying three different types of biosolids at rates equivalent to up to 20 times agronomic rate, and compare them with manure applications. The mineral concentrations in the soil for the different treatments were compared with a control plot to see if they represent a possible risk to livestock health. Also, the concentration of minerals in the forage were analyzed, and compared to standard values to determine if they show a possible risk to cattle health. This study demonstrated that biosolids application can be applied at rates as high as 20 times the agronomic rate without posing a significant risk to livestock.

4. Conclusions

From the soil analyses, high levels of minerals in the top layer of the soil were not observed. In part, this is because the low concentration of some minerals in the biosolids. Even in the cases where the biosolids mineral concentrations were high, the forage mineral concentrations remained comparable to the control. This may be because the minerals were made unavailable through chemical reactions within the soil environment and/or because they were diluted by the low mineral concentration of the control. In addition, it is believe that leaching problems to the groundwater will not be a problem of concern because of the low mean precipitation reported at the site.

Based on the forage analyses, it is recommended that sodium and calcium supplements to livestock diet be considered for all the treatments (control and other treatments). Also, a copper supplement for cattle is recommended to make up for the deficiencies found in the forage. Levels higher than the tolerable levels in molybdenum concentrations were found in the manure treatments for the 2006 year.

A major concern associated with the treatment of rangeland soils with biosolids would be the accumulation of minerals in the forages such that there would be imbalances and/or toxicity. With the exception of molybdenum, this does not appear to be the case. The problem of excess molybdenum can easily be overcome by supplementing with copper.

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CHAPTER 4

ECONOMIC ANALYSIS OF APPYING BEEF CATTLE MANURE AND BIOSOLIDS TO RESTORE DISTURBED RANGELANDS

Abstract

This study, which took place in Skull Valley, Utah during the Years 2006 and 2007, was focused on determining the economic benefits of land applying biosolids to restore the forage productivity on disturbed rangeland. A control area where no amendments were applied, and the effect of applying beef manure and three types of biosolids (aerobically digested, anaerobically digested, and lime stabilized) were analyzed. Two economic analyses were applied to each treatment. The first was based on the assumption that the land would be leased with the objective to graze cattle after the soil amendment application. The other economic analysis was based on the value associated with improvements in forage quality. For this second analysis, the quality and quantity of the forage were compared to standard alfalfa quality. From these analyzes, if the land were leased for grazing purposes, then the application of soil amendments is not economically profitable. On the other hand, if the forage quality obtained through biosolids land application is taken into account, it is profitable to apply soil amendments for specific rates. Application of aerobically digested biosolids at 20 times the nitrogen-based agronomic rate is the treatment that gave the highest return (73.1 $/ha/year) compared to the control.

1. Introduction

If they meet certain qualities in terms of pollutants and pathogens, the solid residuals from the processing of municipal wastewater are legally considered biosolids (USEPA, 1991). Because of their nutritional and soil conditioning properties, biosolids can be utilized as soil amendments (USEPA, 1994)

Increasing its forage production and quality are examples of rangeland improvement. A rangeland's ability to support the nutritional needs of livestock is directly influenced by its forage quality. By applying different types of amendments, improved forage quality and productivity can be achieved. For example, amendment applications in the form of manure have been shown to increase the biomass of rangeland (Bell et al., 2006).

Few studies have compared the benefits to forage productivity by applying manure versus biosolids (Mata-Gonzalez et al., 2006). In addition, even though lime stabilized biosolids are readily available; few studies have been carried out using those (Mata-Gonzalez et al., 2006). For the present study, manure and three types of biosolids (aerobically digested, anaerobically digested, and lime stabilized biosolids) were applied at the site as amendments.

In this study, a control area (where amendments were not applied) was used as a reference. It was determined that the application rate would be based as a multiple of the forage nitrogen amendment requirement needs. For this field demonstration study, land applications rates of 1, 5, 10, and 20 times the agronomic rate were applied. For the specific case of lime stabilized biosolids, the application rate was limited to 10 times the agronomic rate because higher rates were considered to be unpractical. For example, since the nitrogen content in the lime stabilized biosolids was relatively low, the biosolids application rate required to achieve a nitrogen loading twenty times the agronomic rate would have resulted in producing a biosolids layer several inches in thickness. After discussions with agricultural specialists, it was surmised that, without tilling, the resulting surface application would have physically impeded plant emergence. An additional concern expressed by local agricultural specialists was the potential toxicity of large inorganic salt additions (as lime) on the already disturbed rangeland. Given the potential negative physical and chemical impacts associated with adding large amounts of lime to soils already high in salt content, application of lime stabilized biosolids was limited to no more than 10 times the agronomic rate.

There are many studies that have reported the application of biosolids or wastewater on the soil (Pedro and Wester, 2001; Tiffany et al., 2001; Martin and Jack, 2002; Mata-Gonzalez et al., 2004). Some analyze the nutritive values of the forage (Martin et al. 2002), and others analyze the mineral composition post application in the forage and soil (Fresquez et al., 1991; Pierce et al., 1998; Gaskin et al., 2003). This study, in contrast, focused on an economic analysis.

The main objective of this study was to quantify the economic value of the improvement of the forage in the different treatments with respect to the control. To achieve this, two economic analyses were performed. The first one considered forage quality for the different treatments and quantified them based on the quality of a standard alfalfa crop. The other analysis took into consideration the improvement in the stocking rate, which is the number of animal unit months (AUM) that can be supported per hectare.

2. Materials and Methods

Skull Valley, in Tooele County test site has the following coordinates: lat 40° 27' 06'' N and long 112° 44' 42'' W. The mean annual air temperature at the site fluctuates from 7 to 10°C, and the predominant surface texture of the soil is sandy loam (USDA-NRCS, 2000). The average mean precipitation was calculated to be 382.5 mm/year (GIS Climate Search, 2006). This calculation was done by extrapolating the values from nearby stations to the study site using the inverse distance weighting method (Gao, 2006). Table 4.1 shows the precipitation in millimeters per month over the mentioned periods.

2.1. Treatments

The beef cattle manure was obtained from the Ensign Ranches of Utah, Inc. feedlot, while the biosolids (aerobically digested, anaerobically digested and lime stabilized) were obtained from three different WWTP (Snyderville Basin, Central Valley and Tooele WWTP, respectively). The beef cattle manure and the biosolids were applied on December 14, 2004. The rates of application were based on plant nitrogen requirement. Equation (1) was used to determine the agronomic rate (McFarland, 2001).

$$\text{Agronomic Rate}\left(\frac{\text{metric ton}}{\text{ha}}\right)=\frac{\text{adjusted nitrogen requirement (ANR)}\left(\frac{\text{kg - N}}{\text{ha}}\right)}{\text{plant available nitrogen per ton of biosolids/manure}\left(\frac{\text{kg - N}}{\text{metric ton}}\right)} \qquad (1)$$

Table 4.1
Extrapolated mean precipitations for stations "Grantsville 2 W" and "Johnson Pass" over a period of 51 and 34 years, respectively, expressed in mm per month

Name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Grantsville 2 W	17.0	21.6	32.4	38.0	32.9	21.6	19.2	19.2	24.1	27.4	24.8	20.9
Johnson Pass	38.8	39.7	44.6	44.1	52.4	24.7	29.0	25.8	29.3	34.6	36.3	34.2
Working Site	***30.5***	***32.8***	***40.0***	***41.8***	***45.0***	***23.6***	***25.3***	***23.3***	***27.3***	***31.9***	***31.9***	***29.2***

$$= \frac{ANR}{\left[(NO_3) + K_v(NH_4) + K_{min}(N_o)\right]10}$$

where:

ANR	Adjusted nitrogen requirement (kg N/ha)
NO_3	nitrate concentration in biosolids/manure (kg N/metric ton)
NH_4	ammonia concentration in biosolids/manure (kg N/metric ton)
N_o	organic nitrogen concentration in biosolids/manure (total nitrogen content found in biosolids/manure minus nitrate plus ammonia content)
K_v	volatilization factor (0.5 if biosolids/manure are not tilled into soil)
K_{min}	organic nitrogen mineralization rate (assumed to be 0.3) (McFarland 2001)

The ANR was determined based on the estimation that a healthy rangeland in this area would exhibit a nitrogen demand of approximately 168.5 kg nitrogen per ha (150 lbs-N/acre) as detailed below. It is known that in average the plant biomass at Skull Valley, in the site where the experiment was done, is approximately 1123 kg/ha (1000 lbs/acre) (USDA-NRCS, 2000). Also, it was assumed that the nitrogen content of the biomass was approximately 15% (Desai, 2006). From this value, the total nitrogen needed by the plant was estimated to be approximately 168.5 kg-N per ha (150 lb/acre). Soil analysis indicated that there were already approximately 112 kg-N per ha (100 lb-N per acre) of available nitrogen. From this estimate, the nitrogen needed at the site was approximately 56.1 kg-N per ha (50 lb-N/acre). Table 4.2 shows the different rates applied for each one of the rangeland soil amendments based on the analysis previously described.

Sixteen 0.13-ha test plots were established for the field demonstration study. To facilitate the selection of random samples, each of the 0.13-ha subplot t was divided into approximately 144 sections having

Table 4.2
Application rates for the three different biosolids and manure.

Agronomic Rate	Dry Metric tons per hectare			
	Manure	Central Valley (Anaerobically Digested)	Snyderville (Aerobically Digested)	Tooele (Lime Stabilized)
1	11.8	2.9	3.4	19.7
5	59.2	14.3	17.2	98.6
10	118.3	28.6	34.4	197.3
20	236.6	57.1	68.8	† 394.5

† 20 times agronomic rate for Tooele biosolid was not applied because it was considered to be impractical to plant growth because of its thick layer.

physical dimensions of 3 by 3 m (10 by 10 ft). A random generator in excel was used to select the random subplots.

2.2. Forage Samples

On May 8th, 2006, 6 out of the 144 subplots were selected randomly from each treatment plot. The wet biomass was harvested in each of the six subplots. In addition, forage samples were taken for three out of the six sections, and analyzed by the Utah State University Analytic Laboratories. This experiment was repeated on May 15th, 2007, but for this year, four forage samples were analyzed per subplot. In the lab, the dry matter (DM, %), crude protein (CP, %), and in vitro true digestibility (IVTD, %) were measured.

The dry biomass was obtained by multiplying the wet biomass by the dry matter. The CP was estimated by multiplying the percent nitrogen (dry basis) of the vegetation by 6.25 (Schroeder, 1994). The nitrogen was measured at the Utah State University Analytic Laboratories by combustion using a LECO TruSpec CN carbon-nitrogen analyzer. The IVTD experiment was done in the Skaggs Nutrition Laboratory, and an

Ankom Daisy II In Vitro Incubator was used. Dried samples were used for this experiment. The following equation (2) was used for calculating the IVTD:

$$\text{IVTD}(\%) = 100 - \left(\frac{[\text{Final WT} - \text{Bag WT}] * 100}{\text{Sample WT}} \right) \tag{2}$$

Bag WT = It is the weight of each sample bag.
Sample WT = It is the sample weight before the experiment.
Final WT = It is the weight of the bag plus the undigested fibrous residue.

2.3. Economic Analysis

To conduct a reasonable economic analysis, two scenarios were investigated, which were based on the following assumptions: 1) land leasing and 2) forage quality. It is assumed in the economic model that the manure and the biosolids are available for free. The manure can be obtained by the ranchers for free, and the WWTP pays a tipping fee to the ranchers to accept their biosolids. The WWTP transports their biosolids to the rangelands without charge, but the ranchers are responsible for spreading the material once it is delivered. The only cost associated with the handling of the soil amendment that is taken into account is the spreading of the amendments onto the rangelands. It is known that 30 metric tons can be applied in 1 hour, and the cost of spreading amendments for 1 hour is approximately 60 dollars. It was assumed that the application of the manure and biosolids is in its wet form. It was also assumed that a loan for spreading the amendments will be taken out at a discount rate of 8%. This assumption was based on data taken from the St. Louis Federal Reserve Board Bank for prime rates (Federal Reserve Bank of St. Louis, 2007). It was assumed that the positive effect of the amendments will be for a period of time of five years, and after this time more amendments will be applied. The productivity of the rangelands for the years 2006 and 2007 was averaged and it was assumed to remain constant for 5 years.

2.3.1 Leasing of Land

Some rangeland owners rent their land in the form of grazing leases. In Utah, the cost for grazing in 2006 was around 14 dollars per animal unit month (AUM) according to the National Agriculture Statistics Service (2007). The amendment application increases the stocking rate of the lands. The increasing stocking rate enhances the financial returns of the range, but at the same time, the amendment applied will increase costs. The net return that the control produced was subtracted from each treatment net return. This subtraction represent the extra net return obtained because the application of the treatments. The estimated cost for applying each amount of amendment in each treatment was calculated, and this value was brought annually during the five years. The five year time period was chosen because it was assumed that the forage productivity and quality will last at least five years before more soil amendments are needed. From these assumptions, the net annual benefit was calculated taking into account the extra income and the annual cost.

2.3.2 Forage Quality

This analysis was based on the cost of hay mid bloom alfalfa. According to the CP and the IVTD, the average cost for the years 2006 and 2007 was approximately \$137.5/metric ton (\$125/US-ton) according to the USDA Agricultural Marketing Service (USDA Agricultural Marketing Service, 2006 and 2007). The CP and IVTD for hay mid bloom alfalfa are 17% and 60%, respectively (National Research Council, 1996). As mentioned before, the dry biomass (kg/ha), the CP (%) and the IVTD (%) are known for each treatment. The CP and the IVTD produced for each treatment were estimated in kilograms per hectare (kg/ha). These two calculated values were used to estimate the amount of dry biomass needed to achieve the minimum required of CP and IVTD representative to the alfalfa. This representative biomass was transformed into a net economic return for each treatment. The next calculations are the same as mentioned for the leasing of land's case.

3. Results and Discussion

On average, the control area will bring a net return of 2.9 $/ha/year and 9.1 $/ha/year if the rangeland is used for leasing of land or forage quality purposes, respectively. Figure 4.1 shows the net annual benefit for the different treatments minus the net return obtained from the control for the mentioned methodologies. For the two methodologies, the leasing of land is not economically profitable. On the other hand, the methodology of forage quality is profitable in some cases (Fig. 4.1). Figure 4.1 can be seen in a more detail by looking at Table 4.3.

4. Implications

Many field studies have demonstrated that soil amendments like manure or biosolids can improve rangeland's productivity. However, a benefit-cost analysis has never been conducted to determine at what point the application of biosolids can be profitable for the ranchers. This study was focused on developing a more comprehensive economic understanding of how profitable land application of biosolids can be for a rangeland.

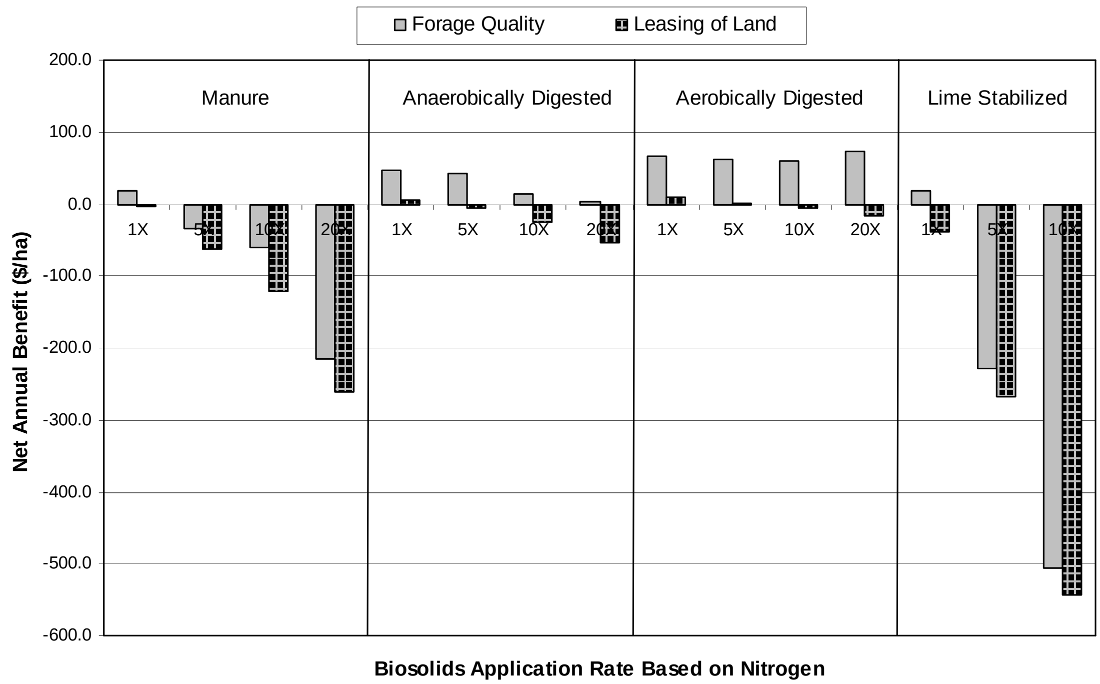

Fig. 4.1. Net benefit comparing two methodologies.

Table 4.3
Net benefit comparing two methodologies

Type of Analysis	Manure				Anaerobically Digested Biosolid			
	1X	5X	10X	20X	1X	5X	10X	20X
Forage Quality	18.0	-33.3	-59.8	-215.1	46.5	41.8	14.3	2.6
Leasing of Land	-4.2	-62.0	-121.7	-260.6	5.0	-5.6	-25.0	-52.9

Type of Analysis	Aerobically Digested Biosolid				Lime Stabilized Biosolid		
	1X	5X	10X	20X	1X	5X	10X
Forage Quality	66.5	62.6	60.5	73.1	17.7	-228.0	-506.5
Leasing of Land	9.2	1.9	-5.4	-15.3	-37.9	-267.4	-542.8

5. Conclusions

Application of amendments and soil conditioners are important to enhance rangeland productivity. The economic benefits that the application of manure and three types of biosolids may produce on a rangeland were analyzed. Two economic scenarios were analyzed in order to determine under what conditions land application of soils amendments become economically beneficial for rangeland purposes. From this analysis, the following conclusions were obtained:

If the enhanced economic value associated with forage quality were included, then the application of soil amendments is profitable under certain conditions. The application of manure and lime stabilized biosolids will generate an added return over the control just for one time the agronomic rate (18 and 17.7 $/ha/year, respectively). The anaerobically digested biosolid application is profitable for all land application rates investigated. However, the higher economic benefit is obtained for one time agronomic rate (46.5 $/ha/year). For the case of the aerobically digested biosolids, it is also profitable for all land application rates investigated. However, 20 times agronomic rate resulted in the highest return (73.1 $/ha/year). From all the treatments and all the rates; the treatment that brings the largest economic benefit is aerobically digested biosolid for 20 times the agronomic rate.

If the rangeland will be used with the purpose of land leasing following land application of soil amendments to increase stocking rate, then the application of amendments is not profitable. Under these circumstances, it will be better to use the land without any soil amendment land application.

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CHAPTER 5

BIOSOLIDS APPLICATION INFLUENCE ON INFILTRATION, UNSATURATED HYDRAULIC CONDUCTIVITY, AND WATER DROP PENETRATION TIME

ABSTRACT

In December 2004, three types of biosolids were applied on a rangeland located in Skull Valley, Utah. The impact of biosolids application on the soil properties (first two years after biosolids application) was analyzed. Soil properties analyzed were the unsaturated hydraulic conductivity, cumulative infiltration, infiltration rate, and water drop penetration time. The study used three types of biosolids (aerobically digested, anaerobically digested, and lime stabilized biosolid) which were applied at 1, 5, 10, and 20 times the agronomic rate based on the nitrogen requirement. The results demonstrated that there is no statistical difference between the control (where no amendment was applied) and the other soil treatments regarding unsaturated hydraulic conductivity values at any biosolids/manure application rate. The infiltration test analysis showed a similar result, with no statistical difference observed between the control and the other treatments. In addition, the water drop penetration time indicated that all the treatments are classified as wettable soils.

Biosolids are the final solid products from the treatment of the municipal wastewater (USEPA, 1991). Biosolids can be beneficially used or land applied for agriculture (USEPA, 1994) as a soil conditioner and fertilizer because they are rich in organic mater and nutrients. The western rangelands in Utah suffer from high overgrazing. The land application of biosolids may be used to improve forage quality.

Both environmental regulators and land owners must fully understand the impact of biosolids land application on soil properties if potential environmental problems are to be avoided.

Some researchers had shown that the application of biosolids can modify the physical properties of soil (Khaleel et al., 1981; Kuntal et al., 2006). These physical properties change according to the type of the soils where the biosolids are applied (Aggelides and Londra, 2000). Infiltration rates can significantly increase after biosolids application (Moffet et al., 2005; Tsadilas et al., 2005). In addition, some other researchers had shown that unsaturated hydraulic conductivity decreases as rates of biosolids addition increased (Gupta et al., 1977). Other studies have demonstrated that no tilling results in higher infiltration rates compared to tilled plots (Bruggeman and Mostaghimi, 1993). In the current study, untilled plots were evaluated.

The objective of this field study was to document the change in unsaturated hydraulic conductivity, water drop penetration time (WDPT), cumulative infiltration, and infiltration rates associated with biosolids land application on disturbed rangelands.

MATERIAL AND METHODS

This field study was conducted at Skull Valley, Tooele County, UT, at test sites located at the following coordinates 40° 27’ 06’’ N, 112° 44’ 42’’ W. The predominant surface texture of the soil is sandy loam. Its mean annual air temperature fluctuates from 7 to 10°C (USDA-NRCS, 2000). The average mean precipitation at the site is 382.5 mm/year. This precipitation value was calculated using two of the closest weather stations to the study site which are “Grantsville 2 W” and “Johnson Pass” stations over a period of 51 and 34 years, respectively (GIS Climate Search, 2006). The average mean precipitation at the site was calculated extrapolating the values of these stations to the study site using the "Inverse Distance Weighting" method (Gao, 2006). Table 5.1 shows the precipitation in millimeters per month over the mentioned periods.

Treatments

Biosolids were surface-applied on 0.13-ha (1/3-acre) test plots separated by buffer strips. A control area where no amendments were applied served as a treatment performance baseline.

Biosolids were taken from three different WWTPs. The biosolids applied were anaerobically digested, aerobically digested, and lime stabilized biosolids that came from Central Valley, Snyderville Basin, and Tooele City WWTPs, respectively. These treatments were applied in the middle of December 2004, and land application rates were determined based on the plant nitrogen requirements, background nitrogen concentrations and nitrogen content of biosolids. These parameters are used to establish the rangeland's agronomic rate as depicted in Eq. [1] (McFarland, 2001).

$$\text{Agronomic Rate}\left(\frac{\text{metric ton}}{\text{ha}}\right) = \frac{\text{adjusted nitrogen requirement (ANR)}\left(\frac{\text{kg - N}}{\text{ha}}\right)}{\text{plant available nitrogen per ton of biosolids/manure}\left(\frac{\text{kg - N}}{\text{metric ton}}\right)} \qquad [1]$$

Table 5.1. Extrapolated mean precipitations for stations "Grantsville 2 W" and "Johnson Pass" over a period of 51 and 34 years, respectively, expressed in mm per month.

Name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Grantsville 2 W	17.0	21.6	32.4	38.0	32.9	21.6	19.2	19.2	24.1	27.4	24.8	20.9
Johnson Pass	38.8	39.7	44.6	44.1	52.4	24.7	29.0	25.8	29.3	34.6	36.3	34.2
Working Site	***30.5***	***32.8***	***40.0***	***41.8***	***45.0***	***23.6***	***25.3***	***23.3***	***27.3***	***31.9***	***31.9***	***29.2***

$$= \frac{ANR}{\left[(NO_3) + K_v (NH_4) + K_{min} (N_o)\right]10}$$

where:

ANR	Adjusted nitrogen requirement (kg N/ha)
NO_3	nitrate concentration in biosolids/manure (kg N/metric ton)
NH_4	ammonia concentration in biosolids/manure (kg N/metric ton)
N_o	organic nitrogen concentration in biosolids/manure (total nitrogen content found in biosolids/manure minus nitrate plus ammonia content)
K_v	volatilization factor (0.5 if biosolids/manure are not tilled into soil)
K_{min}	organic nitrogen mineralization rate (assumed to be 0.3) (McFarland, 2001)

The ANR was determined based on the estimation that a healthy rangeland in this area would exhibit a nitrogen demand of approximately 168.5 kg nitrogen per ha (150 lbs-N/acre). It is known that, on average, the plant biomass in this area is approximately 1123 kg/ha (1,000 lbs/acre) (USDA-NRCS, 2000). Also, it was assumed that the nitrogen content of the biomass was approximately 15% (Desai, 2006). From these values, the total nitrogen needed by the plant is approximately 168.5 kg-N per ha (150 lb/acre). Soil analysis indicated that there was already approximately 112 kg-N per ha (100 lb-N per acre) of available nitrogen. Given the available background nitrogen levels, the nitrogen that needed to be applied at the site was around 56.1 kg-N per ha (50 lb-N/acre). Table 5.2 summarizes the different rates applied for each one of the treatments based on the analysis described above.

To facilitate the selection of random samples, each of the 0.13-ha subplots was divided into approximately 144 sections having physical dimensions of 3 by 3 m (10 by 10 ft). After this, a random generator was used to select the random plots.

Table 5.2. Application rates for the three different biosolids and manure.

Agronomic Rate	Dry Metric tons per hectare		
	Central Valley (Anaerobically Digested)	Snyderville (Aerobically Digested)	Tooele (Lime Stabilized)
1	2.9	3.4	19.7
5	14.3	17.2	98.6
10	28.6	34.4	197.3
20	57.1	68.8	† 394.5

† 20 times agronomic rate for Tooele biosolid was not applied because it was considered to be impractical to plant growth because of its thick layer.

On 12 and 13 July 2006, three test plots were selected randomly in each subplot. Four unsaturated hydraulic conductivity tests were performance around each selected spot. A total of twelve tests per subplot were measured. On 13 July 2006, the WDPT experiment was tested over the same three chosen test plots. Ten water drops around each chosen test plot were tested.

On 15 and 16 May 2007, a double ring infiltration experiment was conducted. Random test plots were chosen for each test. The infiltration test was done for the control and for twenty times the agronomic rate for Central Valley and Snyderville treatments. Six tests were run for the Central Valley treatment. For the control and for the Snyderville site, four tests were run for each plot.

Statistics

The experimental design was based on a pseudo-replication method because of budget and time constraints. The main factors that might affect the final results were not affected by the lack of a replicated design. For example, temperature and water content were assumed to be the same for all treatments. Therefore, these factors should not affect the outcomes of the experiment.

Basically two statistical methods were used in this experiment. Since it was an unbalanced design, a fixed-effect analysis of variance with one treatment factor by using contrast statements to isolate comparisons of interest was used. This methodology was used to compare if each subplot from the different treatments are statistically different than the control. The subplots were considered to be significantly different if the level of confidence was 95% or more. This methodology was used for the unsaturated hydraulic conductivity and for the analysis of the cumulative infiltration as well as infiltration rate.

For the analysis of the cumulative infiltration and the infiltration rate tests, specific times were chosen. The cumulative infiltration was recorded for each infiltration test. In each test, the cumulative infiltrations were recorded for different times. Specific times were chosen, and the cumulative infiltration that did not match for the chosen times were interpolated. As mentioned above, the same statistical analysis used for the unsaturated hydraulic conductivity was used for this case for each specific time. The control was compared with the Central Valley and with the Snyderville treatments for plots that received biosolids at rates equivalent to twenty times the agronomic rates for each specific chosen time.

A statistical analysis was not used for the WDPT test because the average time that each drop took for infiltrating the soil for all the subplots was less than 1 second. All the subplots soils were characterized as wettable because each drop of water takes less than 5 seconds to infiltrate.

Unsaturated Hydraulic Conductivity Test

For measuring the unsaturated hydraulic conductivity, a minidisk infiltrometer was used. This device had a suction of 4 cm with an outside radius of 1.27 cm. This minidisk infiltrometer has an air-inlet tube above the base.

The data needed for using this method is the volume of water infiltrated as a function of time as can be seen in Eq. [2] (Equation 4 Zhang et al., 1997a).

$$I = C_1 t^{1/2} + C_2 t \qquad [2]$$

The parameters C_1 (m $s^{-1/2}$) and C_2 (m s^{-1}) are related to the sorptivity and the hydraulic conductivity of the soil. I and t represent the water infiltrated and the elapsed time, respectively. The hydraulic conductivity was found using Eq. [3].

$$K(h_o) = C_2/A(h_o) \qquad [3]$$

The "A" value was computed from Eqs. [4] and [5]: (Zhang et al., 1997b)

$$A = \frac{11.65\left(n^{0.1}-1\right)\exp\left[2.92(n-1.9)\alpha h_o\right]}{\left(\alpha r_o\right)^{0.91}} \qquad n \geq 1.9 \qquad [4]$$

$$A = \frac{11.65\left(n^{0.1}-1\right)\exp\left[7.5(n-1.9)\alpha h_o\right]}{\left(\alpha r_o\right)^{0.91}} \qquad n < 1.9 \qquad [5]$$

where:

r_o,	radius of the porous disk (1.27 cm)
h_o	suction head (-4 cm)
n and α	van Genuchten parameters (1.89 and 0.075, respectively)

The parameters n and α change according to the soil texture. The soil texture measured in all the treatments was Sandy loam. The n and α were classified according to this soil texture classification (Van Genuchten parameters were taken from Carsel, and Parrish, 1988).

For the calculation of unsaturated hydraulic conductivity, four minidisk infiltrometers were operated simultaneously. An innovative methodology developed at Utah State University was applied for running the minidisk infiltrometer (Madsen and Chandler, 2007). Infiltration information from each of the minidisk infiltrometers were recorded in real-time by a data logger HOBO U12 (On-Set Computer Corporation, Boston, MA). Figure 5.1 shows 3 minidisk infiltrometers connected to a HOBO U12 data logger

Variations on the volume on water in the minidisk were registered by the variation of voltage. The different voltages were downloaded onto a laptop computer where they were converted to volume of water infiltrated using Eq. [6].

$$\text{Vol.(t)} = \text{Vol.\_used} - \left[(\text{Volts\_t} - \text{Volts\_min}) * \left(\frac{\text{Vol.\_used}}{\text{Volts\_max} - \text{Volts\_min}} \right) \right] \qquad [6]$$

where:

Vol.(t) = Calculated volume infiltrated at a specific time.
Vol._used = Volume used in the minidisk infiltrometer.
Volts_t = Voltage at a specific time.

Fig. 5.1. Three minidisk infiltrometers connected to a HOBO U12 data logger.

Volts_max = Maximum voltage that the data logger reads at the beginning.
Volts_min = Minimum voltage that the data logger reads when the minidisk infiltrometer is empty.

Once the volume infiltrated is known, the water infiltrated is determined by dividing the volume by the cross section area of the minidisk infiltrometer. The infiltrated water and the time recorded were used in Eq. [2], and the parameter C_2 was found. A total of 12 readings were obtained for each subplot.

Infiltration Test

For these tests, a 30 cm-ring infiltrometer diameter was used. To achieve a vertical infiltration, a circular soil berm was built around the ring infiltrometer using a shovel and water was poured in it. Also, a metallic ruler and a stop watch were used for the measurements. Each infiltration test was run for approximately 2½ hours. Four tests were run for the control and Snyderville Basin (i.e., aerobically digested) biosolids test sites while six for tests were conducted on those rangeland soils that received Central Valley (i.e., anaerobically digested) biosolids.

Water Drop Penetration Time

Water drop penetration time is the time that it takes for a drop of water to completely penetrate the soil. This methodology basically measures the hydrophobicity of the soil (Mainwaring et al., 2005). For performing this test, a standard medicine dropper was used. Table 5.3 shows the seven different classification levels for water repellency that have been established according to the time that a drop takes to infiltrate into the soil.

RESULTS AND DISCUSSION

Unsaturated Hydraulic Conductivity

Previous research has shown that unsaturated hydraulic conductivity decreases as the rates of biosolids application increases (Gupta et al., 1977). Fig. 5.2 indicates that there is no statistical difference in hydraulic conductivity between the control and each subplot.

Table 5.3. Repellency classification of the soils (Dekker et al., 2001)

Class	Description	Time
0	Wettable	< 5 s
1	Slightly Water Repellent	5 - 60 s
2	Strongly Water Repellent	60 - 600 s
3	Severely Water Repellent	600 - 3600 s

Table 5.3 (Continued)		
4	Extremely Water Repellent (> 1 hr)	1 - 3 h
5		3 - 6 h
6		> 6 h

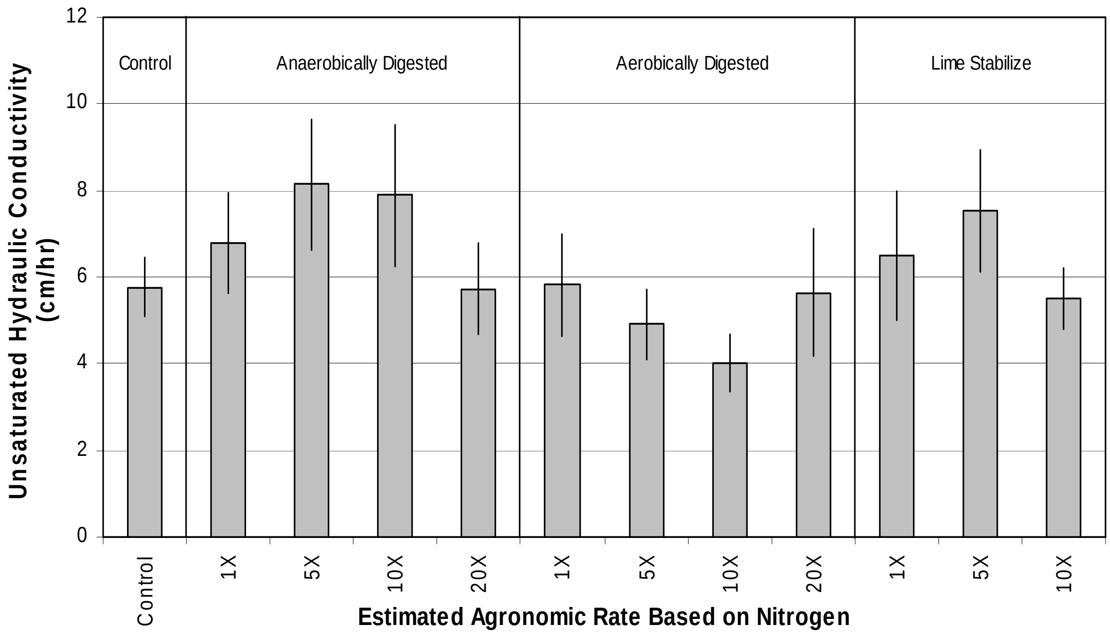

Fig. 5.2. Unsaturated hydraulic conductivities vs. estimated agronomic rate based on nitrogen.

Infiltration Test

Cumulative Infiltration Test

Figure 5.3 shows the average of the cumulative infiltration tests measured in the control as well as those sites that have received aerobically digested (e.g., Snyderville Basin) and anaerobically digested (e.g., Central Valley) biosolids. The statistical analysis applied at each specific chosen time shows that there is no significant statistical difference in cumulative infiltration between the control and the other treatments.

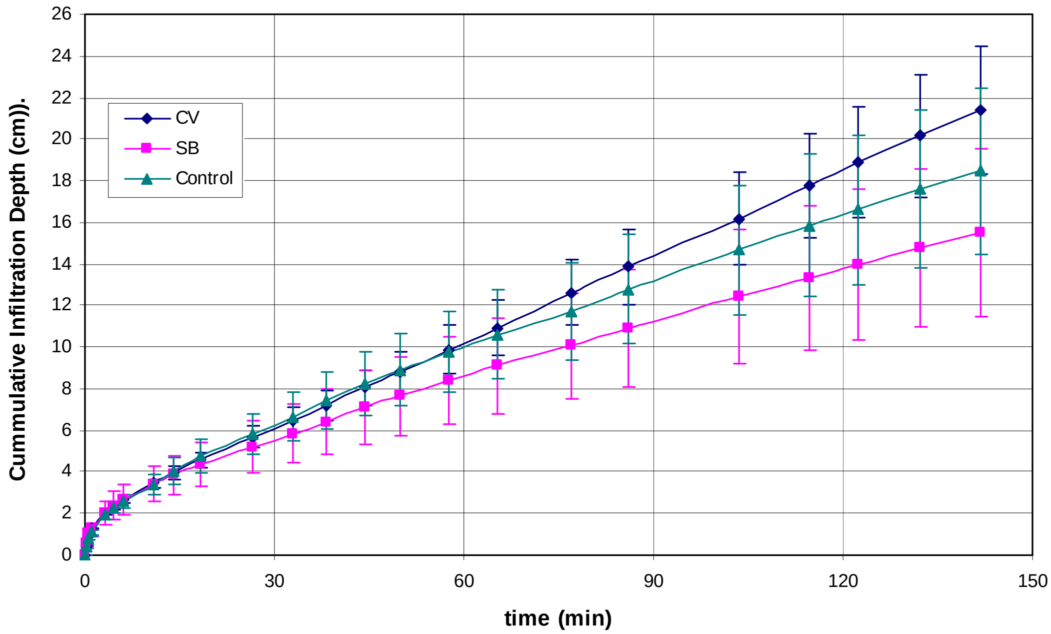

Fig. 5.3. Cumulative infiltration depth vs. time with its respective standard errors.

Infiltration Rate

Some studies have reported that infiltration rate can significantly increase with the application of biosolids (Moffet et al., 2005; Tsadilas et al., 2005). Figure 5.4 shows the average of the different infiltration rates for the control as well as rangeland test sites that have received Snyderville (e.g., aerobically digested) and Central Valley (e.g., anaerobically digested) biosolids. The statistical analysis applied for each specific time shows that there is no significant difference between the control and the other two treatments at the 95% confidence level. One possible reason for this is that the soil below the biosolids is highly impermeable and it decreases the infiltration rate.

Water Drop Penetration Time

Table 5.4 shows that the WDPT is lower than 1 second on average for the control and for the other treatments. The repellency classification for the control and for all the other treatments is classified as "Wettable."

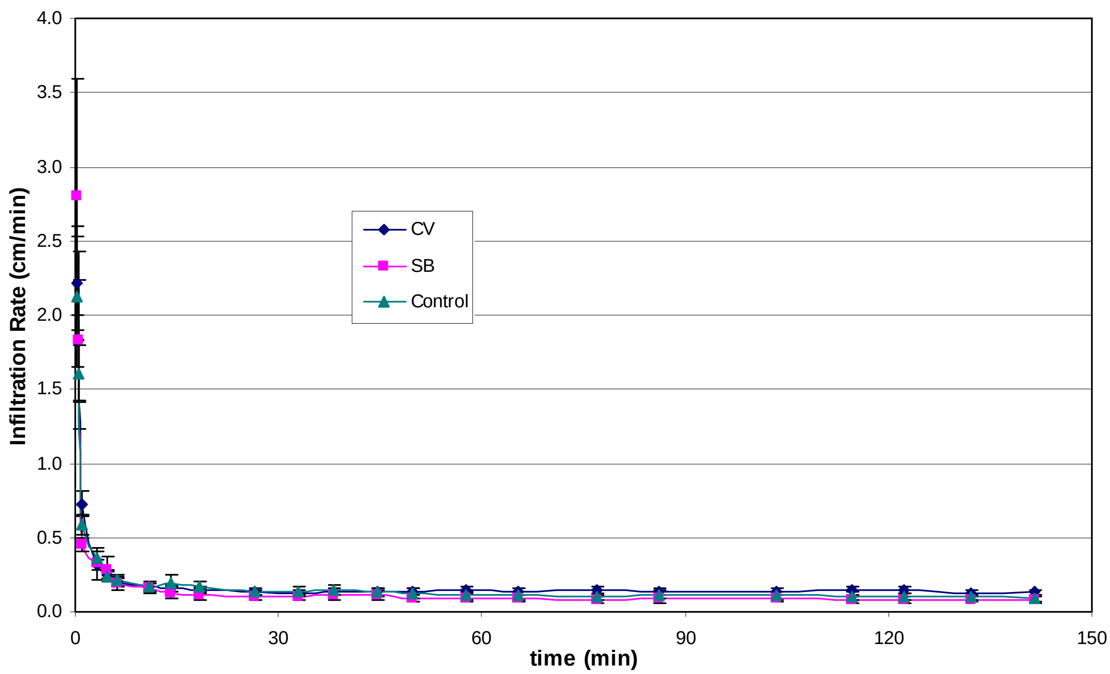

Fig. 5.4. Infiltration rate vs. time with its respective standard errors.

Table 5.4. Water drop penetration time for all the treatments with respective standard errors.

Control	T 1X	T 5X	T 10X
0.65 ± 0.07	0.62 ± 0.07	0.41 ± 0.03	0.64 ± 0.05
SB 1X	SB 5X	SB 10X	SB 20X
0.51 ± 0.05	0.32 ± 0.02	0.55 ± 0.04	0.51 ± 0.03
CV 1X	CV 5X	CV 10X	CV 20X
0.76 ± 0.09	0.39 ± 0.03	0.40 ± 0.02	0.51 ± 0.06

CONCLUSIONS

Three tests were applied to determine whether soil properties have changed as a result of biosolids land application. The different soil moisture parameters that were evaluated as part of the field included the unsaturated hydraulic conductivity, the water drop penetration time and the infiltration. From evaluating these three parameters, the following conclusions were obtained:

The unsaturated hydraulic conductivity test indicated that there is no statistical difference between the control and those sites that received biosolids at the 95% confidence level. The infiltration test analysis (cumulative infiltration and infiltration rate) also indicated that there is no significant difference (at the 95% confidence level) between the control and sites that received Snyderville Basin (e.g., aerobically digested) and Central Valley (e.g., anaerobically digested) biosolids at rates equivalent to 20 times the estimated agronomic rate. From the WDPT test, the repellency soil classification for the control and those soils that received land applied biosolids was wettable. This finding indicates that all the treatments are classified as non-hydrophobic soils.

The soil properties were analyzed one and two years after biosolids applications. It is entirely possible that more significant changes could occur if the same tests were applied after a longer period of time.

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CHAPTER 6

SUMMARY AND CONCLUSIONS

This dissertation presents the analysis of the environmental and economic benefits of utilizing biosolids on disturbed rangeland. The land application of three types of biosolids was analyzed. Each biosolids type was applied at rates equivalent to 1, 5, 10 and 20 times the agronomic rate based on nitrogen needs of the vegetation. Among the studies performed are forage quality analyses, soil and forage mineralogical analyses, economic analyses, and soil property changes after biosolids application. From this study, the following conclusions were obtained:

The land application of biosolids results in higher biomass growth, which increased the stocking rates or the animal carrying capacity of a rangeland compared with the control area. Higher application rates increased the carrying capacity. Forage quality was improved, which could be seen in higher CP values compared to the control. The forage quality, based on the CP and IVTD, makes a direct impact on the daily gain in livestock weight. This impact is reflected in a higher daily weight gain by livestock utilizing the forage grown on biosolids-amended rangelands as compared to the control.

The application of biosolids did result in a significant Na increase and K decrease. The other soil mineral concentrations did not show significant statistical differences compared with the control. These results suggest that the application of biosolids on the environment had a minimal impact, even when applied at rates equivalent to as high as 20 times the estimated agronomic rate.

Some copper, calcium and sodium supplement may be needed to ensure a healthy cattle diet. Forage analyses indicated that all the minerals levels were below the maximum tolerable levels for cattle consumption. These results suggest that the risk to livestock health due to an increase in mineral concentration in vegetation is minimal when biosolids land application is utilized in rangeland restoration activities. The land application of beef manure could be problematic because it results in a significant increase in soil molybdenum. The problem of excess molybdenum, however, can easily be overcome by supplementing with extra copper.

Land application of biosolids to enhance forage production increases the profitability of the rangelands. The highest cost-benefit analysis was calculated for each one of the soil treatments. The highest financial return was obtained for lime stabilized biosolid at 1X agronomic rate (17.7 $/ha/year), aerobically digested biosolid at 20X agronomic rate (73.1 $/ha/year), and anaerobically digested biosolid at 1X agronomic rate (46.5 $/ha/year).

If the rangeland were leased by ranching interests, application of biosolids may not profitable. The collection of tipping fees can be a significant source of financial revenue for land owners and can make biosolids land application profitable with or without the enhancement of forage production.

The application of biosolids had no significant impact on a number of important soil parameters including unsaturated hydraulic conductivity, cumulative infiltration, infiltration rate and the WDPT. Finally, the increase in vegetative density will help to reduce the soil erosion of the rangelands.

APPENDIX

Inverse Distance Weighting Method

This methodology is used when there is not available data on the study site. In order to obtain the data in the required site, data from the closest stations are used. The stations that are closer to the working site will have more influence or more weight into the working site. The following lines show the procedure used to calculate the data in the working taking the precipitation from the 2 closest stations to the working site:

$$P\ (x,y) = \sum_{i=1}^{n=2} W_i * P_i$$

P(x,y) = precipitation at the working site.

i = stations

P_i = Precipitation of station i

W_i = It is the weight for the individual location

$$W_i = \frac{\left(\frac{1}{d_i}\right)^R}{\sum_{K=1}^{n=2}\left(\frac{1}{d_K}\right)^R}$$

For this study R was considered equal to “1”.

d_i = distance from station I to the working site

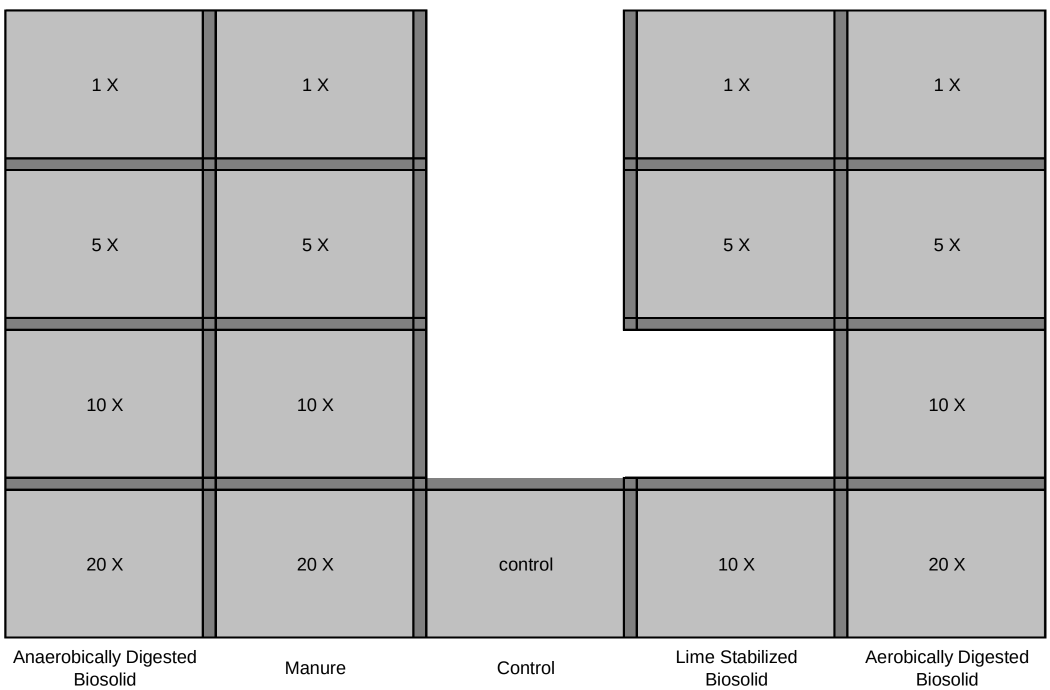
$\sum_{K=1}^{n=2}\left(\frac{1}{d_K}\right)^R$ = Addition of the inverse distance of each station to the working site.

Pseudo Replication Design

Pseudo replication design is a form on non-independent replication in an experiment that may be due to sub-sampling on experimental units or measuring experimental units over time.

Unbalance Design

An experimental design is balanced if all combinations of factor levels have equal numbers of observations. All other designs are unbalanced. For the present study, it is considered an unbalance design because basically there are 5 different treatments and they do not have the same number of sub treatments as it can be seen in the following figure:



Most of the treatments have 4 different sub treatments, but the control and lime stabilized biosolids have one and 3 sub treatments respectively.

Statistic for Propagation of Measurement Error

The propagation of measurement errors for calculating the standard error was used for calculated for the dry biomass and for the stocking rate. The following procedure was done for the calculation of the standard error of the dry biomass for manure 1X the agronomic rate.

Calculating the Dry Biomass (DB) as kg per ha for the Manure 1X;

$$\mathrm{DB} = \mathrm{WB} * \mathrm{DM} \pm \mathrm{S}_{\overline{\mathrm{DB}}}$$

DB = Dry Biomass (lbs/ft^2)
WB = 0.0233 lbs/ft^2 (Wet Biomass)
DM = 0.3563 (Dry Matter)
$S_{\overline{DB}}$ = Standard Error of the Dry Biomass

$$\mathrm{DB} = \left(0.0233\,\frac{\mathrm{lbs}}{\mathrm{ft}^2}\right) * (0.3563) * \left(\frac{1\,\mathrm{ft}}{0.3048\,\mathrm{m}}\right)^2 * \left(\frac{10\,000\,\mathrm{m}^2}{1\,\mathrm{ha}}\right) * \left(\frac{1\,\mathrm{kg}}{2.2\,\mathrm{lbs}}\right)$$

$$\mathrm{DB} = \left(0.0233\,\frac{\mathrm{lbs}}{\mathrm{ft}^2}\right) * (0.3563) * \left(48\,926.9\,\mathrm{ft}^2\text{ - kg/ha - lbs}\right)$$

DB = 406.8 kg/ha

$$\mathrm{DB} = 406.8\ \pm \mathrm{S}_{\overline{\mathrm{DB}}}$$

The original equation taking into account the change of units will be:

$$\mathrm{DB} = 48\,926.9 * \mathrm{WB} * \mathrm{DM}$$

Calculating the Standard Error of the DB:

a) Calculating the total variance:

$$\mathrm{S}^2_{\mathrm{DB}} = \left[\frac{d(\mathrm{DB})}{d(\mathrm{WB})}\right]^2 * \mathrm{S}^2_{\mathrm{WB}} + \left[\frac{d(\mathrm{DB})}{d(\mathrm{DM})}\right]^2 * \mathrm{S}^2_{\mathrm{DM}}$$

$$\frac{d(DB)}{d(WB)} = 48\,926.9 * DM = (48\ 926.9)*(0.3563) = 17\ 432.9$$

$$\frac{d(DB)}{d(DM)} = 48\,926.9 * WB = (48\ 926.9)*(0.0233) = 1\ 141.6$$

S^2_{DB} = Variance of the Dry Biomass
$S^2_{WB} =$ 0.00005
$S^2_{DM} =$ 0.0020

$$S^2_{DB} = (17\ 432.9)^2 * 0.00005 + (1141.6)^2 * 0.0020$$
$$S^2_{DB} = 19126.1$$

b) Calculating the Standard Error:

$$S_{\overline{DB}} = S_{DB}\left(\frac{1}{n_{WB}} + \frac{1}{n_{DM}}\right)^{1/2}$$

$S_{\overline{DB}}$ = Standard Error of the Dry Biomass
S_{DB} = Standard Deviation of the Dry Biomass
$n_{WB} =$ 6 (number of samples taken for the wet biomass)
$n_{DM} =$ 3 (number of samples taken for the dry matter)

$$S_{\overline{DB}} = \sqrt{19126.1}\left(\frac{1}{3} + \frac{1}{6}\right)^{1/2}$$
$$S_{\overline{DB}} = 97.8$$

So, the total dry protein for the control will be:
$DB = 406.8 \pm 97.8$ kg/ha

Fix effects analysis of variance with one treatment factor

The fixed-effects analysis of variance model is applied when there are several treatments to the subject of the experiment and when we want to see if there is any change with the response variable. By this methodology, the range of response variable values generated in the population as a whole by the treatment can be estimated. Vita

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JOB OBJECTIVE

Get involved in projects about Irrigation, Environment and/or Water Resource Engineering projects.

EDUCATION

Ph.D. in Environmental Engineering, *Utah State University, Logan UT.*

- Maintained a 3.81 out of 4.0 GPA while working 20 hours per week.
- Period of study: From 01/05, and expected graduation is in May 2008.

M.S. in Irrigation Engineering, *Utah State University*, *Logan UT.*

- Maintained a 3.9 out of 4.0 GPA while working 20 hours per week.
- Period of study: From 08/03 to 12/04

Bachelor of Science in Agricultural Engineering, *Agrarian National University of La Molina,* 2001. Lima - Peru.

- Second best in graduating class; graduated in 4.5 years from a 5 year program.

PROFESSIONAL EXPERIENCE

Graduate Research Student, Utah Water Research Laboratory 05/06 – Present. Logan, UT.

- Impact of Land-Applied Biosolids on Forage Quality and Water Movement During Rangeland Restoration Activities. Used as dissertation for Ph.D.
- Analyzing advantages and disadvantages of applying biosolids on degraded rangelands.
- Knowing the influence of the application of 3 different types of biosolids applied at different rates on a rangeland.
- The effect on the forage quality and in the macronutrients will be analyzed.
- The economic impact is being taken into consideration.

Graduate Student Assistant, International Irrigation Center, USU, 02/05 – 04/06. Logan, UT. It was a part time job.

- Worked on technology transfer on irrigated agriculture and water management for irrigation purposes for participants from different countries.
- Experience in courses and conference arrangements (travel, accommodations, and organization) in the United States.

Graduate Research Student,
Biological & Irrigation Engineering Department, 04/04 – 12/04. Logan, UT.

- Analysis of the float method under uniform and non-uniform flow conditions in rectangular channels. Used as thesis for M.S. Degree.

Agrarian National University of La Molina. 06/01 – 12/01. Lima, Peru

- Evaluating the use of PVC tubes channels and concrete channels in high altitude places. Used as thesis for B.S. Degree.

Assistant Engineer, Agro Industrial Enterprise Laredo (sugar enterprise) Peru, 03/99 to 06/99. It was a full time job.

- Management of irrigation, farming operations, and personnel in different areas of the mentioned enterprise (8000 has).

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PAPERS AND PRESENTATION (Completed)

1. Absalon Vasquez, Issaak Vasquez, (2006) "The Economic Value of Water" Universidad Nacional Agraria La Molina. (Publication)

2. Issaak Vasquez, M. Vutran, M. J. McFarland, M. Schmitz and R. B. Brobst (2007) "Enhancing Rangeland Forage Quality through Biosolids Land Application" Water Environment Association of Utah (WEAU) Annual Conference April 18 – 20, 2007 St. George, UT

3. M. Vutran, Issaak Vasquez, M. J. McFarland, M. Schmitz and R. B. Brobst (2007) "Application of Biosolids to Disturbed Western Rangelands" Water Environment Association of Utah (WEAU) Annual Conference April 18 – 20, 2007 St. George, UT

4. M. J. McFarland, M. Vutran, Issaak Vasquez, M. Schmitz, R. B. Brobst, D. Olson and R. Fisher (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

5. M. J. McFarland, M. Vutran, Issaak Vasquez, M. Schmitz and R. B. Brobst (2007) "Land Application of Biosolids to Restore Disturbed Western Rangelands" Submitted to the *Journal of Compost Science and Utilization*

PAPERS (Pending)

1. Issaak Vasquez. "Analyzing the Effect of Biosolids on Rangeland Forage Quality".
2. Issaak Vasquez. "Analyzing the Effect of Biosolids on Forage Nutrients".
3. Issaak Vasquez. "Analyzing the Economic Impact of Biosolids on a Rangeland".