UTILIZING LONG-TERM ORGANIC AMENDMENTS TO IMPROVE SOIL HEALTH IN SEMI-ARID, GRAZED GRASSLANDS

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ABSTRACT

Determining soil health changes associated with long-term land application of organic amendments, such as biosolids, is important for understanding and improving overall environmental health. In 1991, a single application of biosolids were surface applied (treatment rate: 0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}) to a semi-arid grazed grassland. In 2002, a repeated application of biosolids were surface applied at the same rate to ½ of all plots. In 2018, soil samples were obtained from 0-15 cm depths in all plots. The Soil Management Assessment Framework (SMAF) was used to provide a foundation for quantifying soil health by utilizing soil physical, biological, chemical, and nutrient health indicators, in conjunction with soil management practices, climatic conditions, and taxonomy. Results showed that there was no significant changes in soil physical and nutrient health indices. However, biological soil health was positively affected by increasing application rate or the repeated application as compared to the single application. Chemical soil health was greater with lower biosolids application rates and the single compared to repeated applications. When all indices were combined, overall soil health was "best" at all biosolids application rates except the 30 Mg ha^{-1} rate. A 'sweet spot' exists when applying organic amendments to land by which the material is not under or over-applied, causing no changes or deficiencies, or causing excesses in various soil characteristics.

INTRODUCTION

Biosolids are nutrient-rich organic materials that are a byproduct of municipal wastewater treatment. Once treated and processed, these residuals are often recycled and applied to agricultural lands as an amendment to improve various soil properties and encourage plant growth. The controlled land application of biosolids completes a natural cycle in the environment and is preferable to taking up space in a landfill or other disposal facilities. Paramount to any land application program is the understanding of how biosolids may affect soil health.

Soil health is an assessment of how well soil performs all of its functions now and how those functions are being preserved for future use (Doran et al., 2000). Soil health cannot be determined directly by measuring only a single outcome such as crop yield or water quality. Instead, soil health is evaluated from physical, biological, chemical, and nutrient indicators. Years of scientific research support that fact the organic amendment applications, like biosolids, have a positive impact on disturbed lands, which may then directly or indirectly affect the overall soil health (USEPA, 2017). The objective of this study was to determine the long term effects on soil health properties in response to single or repeated, low to excessive biosolid applications, on semi-arid (over) grazed grasslands.

MATERIALS AND METHODS

Experimental Site Design

This study was conducted on long-term experimental research plots within the Meadow Springs Ranch, Larimer County, CO (40 53'46"N, 104 52'28"W). The ranch (1,750 m elevation) is owned by and located north of the City of Fort Collins, which uses it for the city's land-based biosolids recycling program. The study site is a semi-arid, shortgrass steppe rangeland community dominated by perennial grasses. In 1991 plots (15x15 m) were originally established (Harris-Pierce 1994) and arranged in a randomized, complete block design with four replicates and application rates equal to 0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}. In 2002, each plot was divided in half (7.5x15 m) and a second application equaling the first application was applied to the eastern ½ of each plot (Sullivan et al., 2006). In September 2018, a hydraulic Giddings probe was used to collect four soil cores (0-15 cm depth) from each plot. Three cores were composited and then placed in Ziploc bags, while the fourth core was used for bulk density and soil water content determination. Composite soils were passed through an 8mm sieve, a representative sub-sample (~150 g) of 8 mm sieved field moist was stored in a Ziploc bag at 4º C, another sub-sample (~300 g) of the 8 mm sieved soil was passed through a 2 mm sieve and allowed to air dry, and the remaining 8 mm sieved soil was also allowed to air dry. Once dry, a small sub-sample (~5 g) of the 2 mm sieved air dry soil was powder ground.

Soil Health and Laboratory Soil Analysis

The Soil Management Assessment Framework (SMAF) is an assessment tool that provides a foundation for quantifying soil health by utilizing 11 soil indicators, in conjunction with soil management practices, climatic conditions, and taxonomy (Andrews et al., 2004). These soil indicators include: 1) soil physical health indicators: bulk density and water stable aggregates; 2) soil biological health indicators: soil organic carbon, microbial biomass carbon, potentially mineralizable nitrogen, and beta-glucosidase activity; 3) soil chemical health indicators: pH and electrical conductivity (EC); and 4) soil nutrient health indicators: plant-available potassium and phosphorus. The SMAF utilizes clay content, determined by the soil texture analysis, in the background due to the influence clay content has on most other indicators for soil health quantification. Once all information has been entered into the SMAF, individual indicators are grouped into physical, biological, chemical, nutrient, and overall soil health indices (SHI). To create an output that reflects the specific limitations and needs of the soil to function at its fullest potential, the SMAF takes into account the soil's quantified properties, climatic conditions, how it is utilized, and the management practices performed.

Statistical Analysis

The Meadow Springs Ranch site is a split-plot design (with time) containing four replicates. Utilizing SAS 9.4 (SAS Institute, Inc., 2012), we performed ANOVA using PROC GLM and if significant differences were present (at an α of 0.05) within treatments or time, we determined mean separation using Tukey adjusted pairwise comparisons. The interaction between treatment and time was also taken into consideration.

RESULTS AND DISCUSSION

Soil Physical and Nutrient Health Indices

There was no significant change in physical soil health indices between treatments, application times, or interactions of treatment and time (data not shown). In fact, soil physical health was maximized in this system. There was no significant change in nutrient soil health indices between treatments, application times, or interactions of treatment and time. A trend did exist, however, with nutrient soil health tending to decrease with increasing biosolids application (Figure 1).

Soil Biological Health Indices

There was a significant change ($p < 0.05$) in biological soil health indices between treatments (Figure 2), application times (Figure 3), and interactions of treatment and time. This result is likely due to the combination of all four biological health indicators. There was a significant change ($p < 0.05$) in soil organic carbon between treatments, application times, and interactions of treatment and time. There was no significant change in microbial biomass carbon or potentially mineralizable nitrogen between treatments, application times, and interactions of treatment and time; but there was a positive trend with increasing application rate. There was no significant change in beta-glucosidase activity between treatments, application times, and interactions of treatment and time; but there was a negative trend with increasing treatment rate. When this aforementioned data is combined, it affected the soil biological health index as described above.

Soil Chemical Health Indices

There was a significant change ($p < 0.05$) in chemical soil health indices between treatments (Figure 4) and application times (Figure 5), but no significant interactions existed. Specifically, a significant change existed ($p < 0.05$) in pH between treatments, but not between application times and interactions of treatment and time. There was a significant change ($p < 0.05$) in EC between application times, but not between treatments and interactions of treatment and time.

Overall Soil Health Index and Conclusions

There was a significant change ($p < 0.05$) in the overall soil health index (Figure 6) between treatments. However, there was no significant change in overall soil health indices between application times and interactions of treatment and time. The end result is that a 'sweet spot' exists whereby biosolids over-application has detrimental effects on soil health. Based on the overall soil health index, it is suggested to apply no more than 21 Mg biosolids ha^{-1}, at least when applying repeated applications over time. More research is obviously required to better match what the city of Fort Collins, CO and other municipalities perform.

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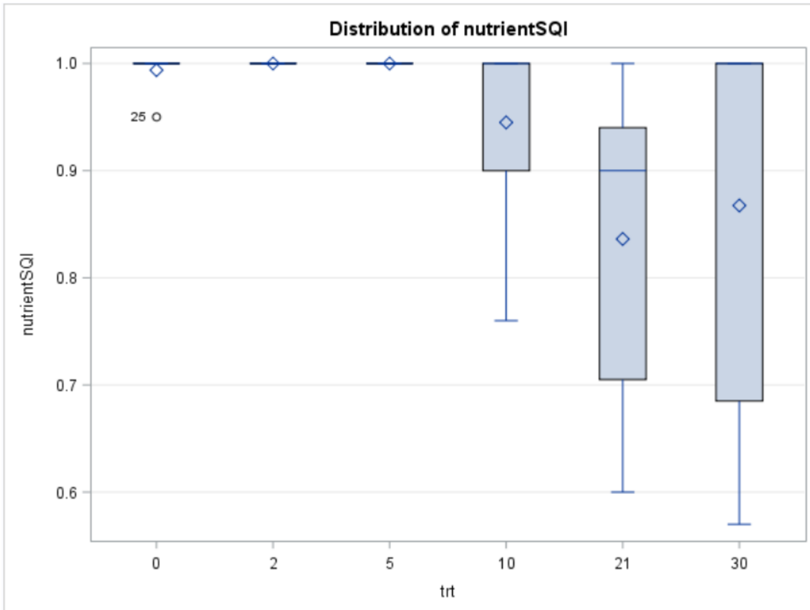

Figure 1. Changes in the soil nutrient health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Although no significant differences existed between treatments, a trend existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

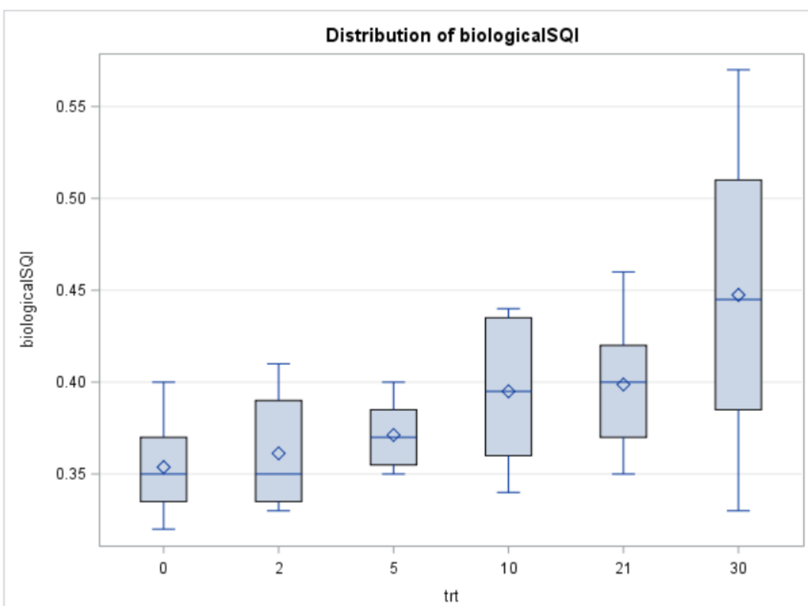

Figure 2. Changes in the soil biological health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

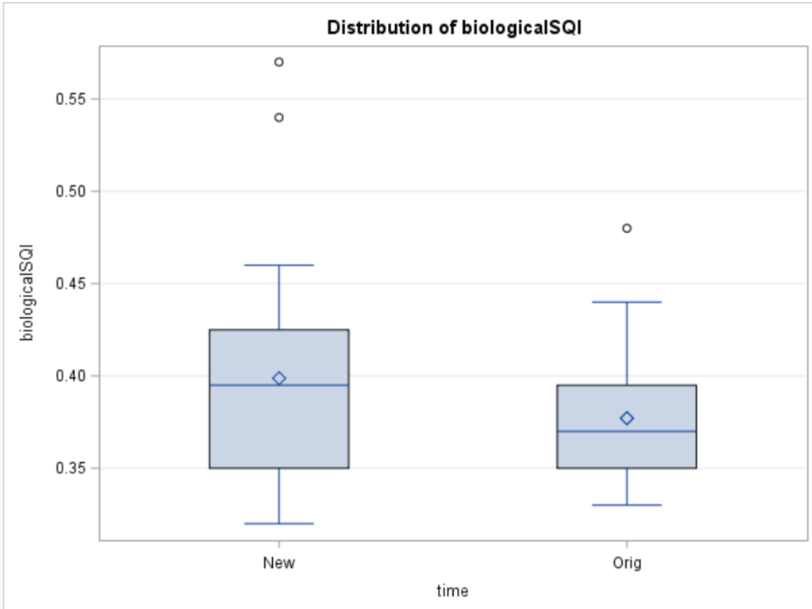

Figure 3. Changes in the soil biological health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') based on original (i.e., one time biosolids application) or new (i.e., repeated biosolids application). The new biosolids application had significantly greater (α<0.05) biological soil health as compared to the original application. Diamonds = mean, while horizontal dark lines = median (n=24).

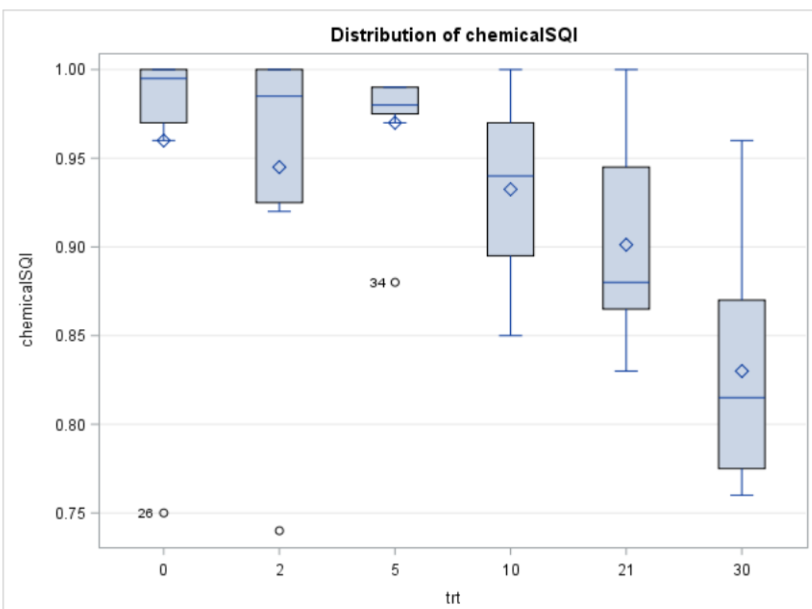

Figure 4. Changes in the soil chemical health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).

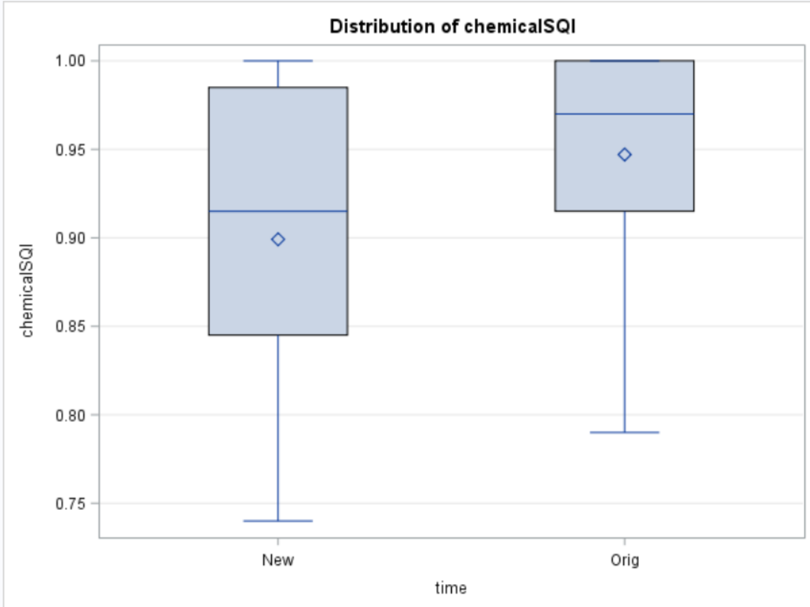

Figure 5. Changes in the soil chemical health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') based on original (i.e., one time biosolids application) or new (i.e., repeated biosolids application). The new biosolids application had significantly lower (α<0.05) chemical soil health as compared to the original application. Diamonds = mean, while horizontal dark lines = median (n=24).

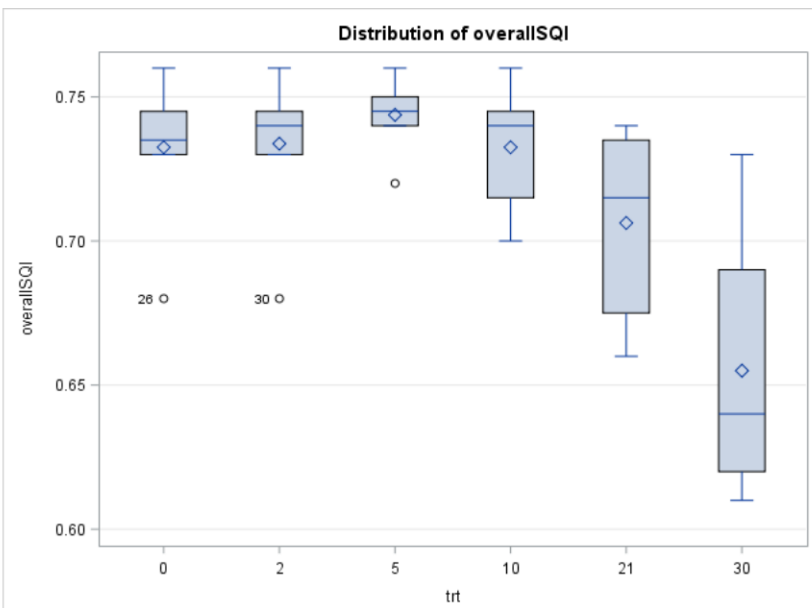

Figure 6. Changes in the overall soil health index (scored from 0 to 1, with 0 being 'worst' and 1 being 'best') with increasing biosolids application rate. Significant differences (α<0.05) existed with increasing biosolids application rate. Diamonds = mean, while horizontal dark lines = median (n=8).