Evaluating Temperature Constraints for Municipal Biosolids Application to a Desert Grassland Soil

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ABSTRACT

Arid and semiarid regions of Texas and the United States are becoming locations of choice for year-round application of municipal biosolids (sewage sludge) to minimize application-time lost to cold or wet conditions. We determined carbon losses from surface applied municipal biosolids (1.8 lbs wet biosolids ft^{-2}) to a clay loam soil in sealed, forced-air chambers for 29 days after application. Experimental conditions, three temperatures (41, 73 or 100°F) and two initial soil-water contents (5 or 15 % water), were similar to those experienced at a commercial application site near Sierra Blanca, Texas. All treatments had an initial, nonmicrobial degassing peak. From 4 hours through day 2, carbon loss as measured by CO_2 evolution increased significantly ($P < 0.05$) with temperature. By day 29, 0.41, 0.55 and 0.73 % of carbon was lost for the 41, 73 or 100°F treatments, respectively. Carbon loss from the 41°F temperature treatments and temperature differences in carbon loss were significant only through day 2. We conclude, therefore, that biosolids may be applied throughout the year without restricting temperature or water parameters beyond the current USEPA or Texas Natural Resource Conservation Commission regulations.

KEYWORDS: Municipal biosolids, Desert grassland, Sewage sludge.

Current U.S. Environmental Protection Agency policies and regulations encourage beneficial use of waste substances such as biosolids (municipal sewage sludge) (U.S. Environmental Protection Agency, 1995). These regulations state that biosolids cannot be applied to a "site that is flooded, frozen, or snow-covered. . .or that enters a wetland or waters of the United States" (U.S. Environmental Protection Agency, 1993). This policy favors application of biosolids in warm southwestern U.S. desert areas (Aguilar and Loftin, 1994; White et al., 1997). One such commercial application site is located near Sierra Blanca, Texas. At this location 3 dry tons of biosolids per acre are applied, annually (Mooney 1992).

Concerns have been raised as to temperature effects at time of application on plant utilization and degradation of surface-applied municipal biosolids in the desert. Benton and Wester (1998) reported tobosagrass (*Hilaria mutica*) and alkali sacaton (*Sporobolus*

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airoides) respond more to dormant-season application of biosolids than growing-season application at Sierra Blanca, Texas in the first growing season. Loftin (1995) reports that grassland response to biosolids application is dependent upon water availability. Staley and Konopka (1985) report the rate of microbial decomposition depends on the physical, chemical and biological characteristics of the habitat. Sommers et al. (1981) list these factors to be temperature, O_2 supply, water potential, pH, inorganic nutrients and C:N ratio of the material along with management factors.

Although it may be assumed that decomposition requires microorganisms, the rate of decomposition may not be directly related to increasing microbial populations. Macalady et al. (1998) stated that CO_2 evolution rate is not necessarily influenced by microbial growth. Microbial habitats are unlikely to be in a steady state (Staley and Konopka 1985). Instead, habitats occur as a series of transient states due to the fluctuations in the chemical and physical environment.

Climate preeminently influences biotic and abiotic decomposition of organic matter in the Chihuahuan Desert (Moorhead and Reynolds, 1991). Moorhead and Reynolds (1989) stated that abiotic factors account for 50-75% of the total annual degradation of creosotebush (*Larrea tridentata*) surface litter in the northern Chihuahuan Desert. Miller and Pepper (1988) suggested that high pH levels, high temperature and low moisture would be advantageous to soil microbes under desert conditions. In addition, a fast growth rate to take advantage of ephemeral conditions would favor microbial growth in these environments. Other microbial advantages to cope with limited nutrient supplies would be the ability to utilize a wide range of nutrients for carbon, energy, and nitrogen sources.

Anderson and Domsch (1975) reported that litter decomposition for mixed microbial populations with complex substrates can be determined quantitatively by measurement of total respiration. Huffman et al. (1996) reported CO_2 evolution peaks at day 5 with wheat (*Triticum aestivum*) residue that was high in cellulose. The initial peak observed by Huffman et al. (1996) would be expected to occur more quickly with biosolids, because cellulose is more resistant to decomposition than many of the components of biosolids. Similar CO_2 evolution peaks have been shown in other studies for ryegrass (Jenkinson, 1966) and soils (Heilmann and Beese, 1992) over a shorter time scale. Therefore, the exact timing of this initial CO_2 evolution peak was likely to depend on soil type and environmental conditions prevalent at the time of the study.

Current interests in beneficial applications in the Texas and southwestern U.S. deserts suggest a need for specific information regarding the influence of temperature and soil-water content on the fate of surface-applied biosolids. The objective of this project was to evaluate the influences of temperature and initial soil water on the loss of carbon from surface applied biosolids to a desert grassland soil. Specific objectives were to (1) quantify the CO_2 evolution from surface-applied biosolids as a function of temperature and soil water, and (2) determine the influence of temperature and soil water on microbial population numbers in biosolids and soil.

MATERIALS AND METHODS

Soil used in this study was from a commercial application site in a Chihuahuan Desert grassland near Sierra Blanca, Texas that received New York, New York domestic biosolids. Temperature chambers contained two soil and one control chamber, which were 10 inch long × 6 inch wide × 7 inch high. A 6.6-lb soil sample from the top 2

inches of a calcareous clay loam (fine, mixed, thermic superactive Vertic Paleargids) was placed into each soil chamber. On the "inlet" side of each temperature chamber, ambient air was pumped by diaphragm pumps set to deliver a flow rate of 0.0175 $ft^3 hr^{-1}$. Bacterial air vents (No. 4210, Gelman Sciences, Ann Arbor, MI) were installed in-line between the pumps and the sample chambers. Individual CO_2 samples could be obtained on the "outlet" side without opening the temperature chamber.

Temperature chambers were operated at 41, 73 and 100°F to simulate winter, spring/fall or summer application temperatures. Copper/constantan thermocouples connected to a data logger (Campbell Scientific CR-5A Digital Recorder, Logan, UT) monitored soil-air interface temperatures. Water content was monitored four times per day using Time Domain Reflectometry (TDR-Trase system, Soil moisture Equipment Co., Santa Barbara, CA). Carbon dioxide samples were evaluated in an infrared CO_2 analyzer (Beckman Model 865, equipped with a Hewlett-Packard 3390A Integrator, Avondale, PA). The analyzer was calibrated with a 515 ppm CO_2 gas standard. Integrated sample values were compared to a calibration curve peak height to obtain CO_2 concentrations from each sample. Chambers were allowed to equilibrate within the temperature chambers for a period of 5 to 7 days. Sufficient water was added to bring gravimetric soil water levels to 5% (~permanent wilting point) and 15% (~field capacity).

After stabilization, nylon mesh fabric (390 × 390 mesh per $inch^2$) was placed over the entire soil surface. Approximately 0.77lbs of the biosolids (~1.8 lbs per ft^2) were applied evenly across the soil surface/mesh fabric of each soil chamber. Biosolids averaged 72% water on a wet basis with 2.08% carbon on a dry basis. CO_2 samples were taken immediately after biosolids application and daily thereafter for a total of 28 days.

Soil and biosolids subsamples were taken for microbial population size determination initially and at day 29. All samples were stored at -4°F until replicate plating could begin. The microbial population enumeration procedure for soils (Wollum, 1982) was extended to biosolids. Wollum (1982) reported shaking times of 10 min. for soils. Post-experimental biosolids subsamples, however, were often dried into hydrophobic "clumps." Pretrial studies indicated a 20-min. shaking time improved the disaggregation of these clumps.

Soil and biosolids were plated using dilutions ranging from 10^{-3} to 10^{-8}. Dilutions were made as needed with no more than five dilutions being necessary for any subsample. Aliquots of 0.06 in^3 were drawn from each dilution and spread onto Triptic Soy Agar plates using a bent glass spreader. Subsample plates were incubated at the temperature at which the sample was treated during the experiment. The temperature chambers used in the experiment were subsequently used as incubators for plating. All plates were incubated for 48 hours and microbial colonies counted using a Quebec counter. The CO_2 evolution and plating experiments were replicated three times. Data were analyzed using Analysis of Variance procedures and significances evaluated at the 5% level using Duncan's new multiple range test.

DISCUSSION OF RESULTS

Soils and biosolids used in this study were collected from a commercial application site. Experimental temperatures and initial soil-water contents were similar to those encountered at that location. The actual temperature chamber design precluded maintaining soil water at a constant level. For both the 73°F-wet and 100°F-wet treatments, soil water decreased throughout the experiment, presumably as a result of evaporation (Fig.

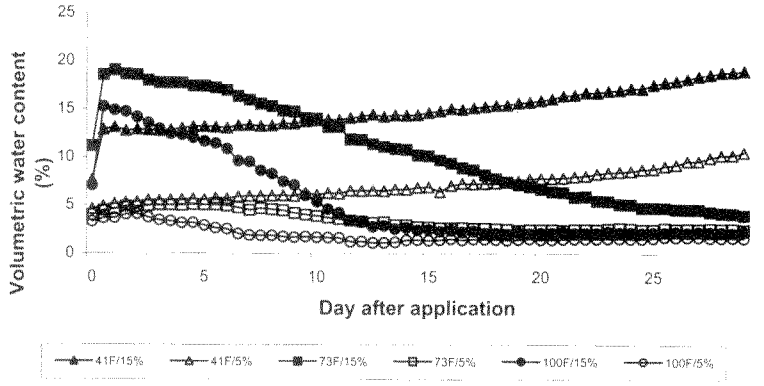

Figure 1. Volumetric soil-water content for each temperature-water content treatment as a function of time.

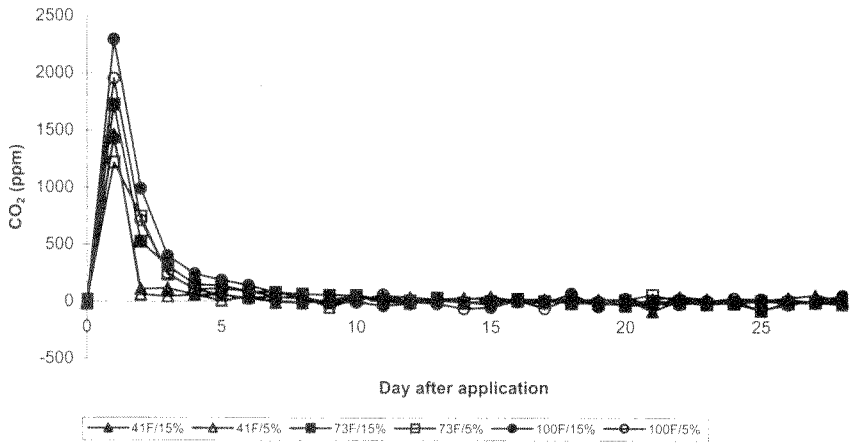

Figure 2. Daily CO_2 evolution for each temperature-water content treatment as a function of time.

1). Soil water increased in both the 41°F-wet soil treatment and the 41°F-dry soil treatment presumably due to condensation within the chambers. The 100°F-dry and 73°F-dry treatment water contents were relatively constant (± 2% water) throughout the experiment. Thus, in the context of the entire 29 day study, initial water contents were not independent variables, but were dependent upon temperature. Cumulative CO_2 evolution from this experiment as a function of initial water content could not be statistically compared across treatments due to changes in soil water.

Daily CO_2 evolution values, however, were compared since soil water was assumed not to change during the daily sampling period of approximately 30 min. Immediately after biosolids application, all treatments showed an increase of CO_2 above preapplication levels (Fig. 2). There were no temperature or water treatment effects at this sampling time. While these first experimental CO_2 samples were taken immediately after application,

it was unlikely that biosolids had reached either 41°F or the 100°F. Thus, initial biosolids CO_2 evolution occurred with the biosolids at or near ambient temperature (73°F). Theoretically, initial CO_2 evolution should increase with increasing temperature.

Four hours after application, biosolids temperatures were assumed to be the same as the soil. At this time (Fig. 2), the 100°F treatment had significantly greater CO_2 evolution (2180 ppm CO_2 above background) than either the 73°F or 41°F treatments (1270 and 1500 ppm CO_2 above background, respectively). On day 1, CO_2 evolution values for the 73°F treatment were not significantly different from either the 41°F or 100°F treatments. By day 2, CO_2 evolution values for the 41°F treatment were significantly less than either the 73°F or 100°F treatments. Through day 2, CO_2 evolution differences were significantly ($P < 0.05$) related to temperature alone. From day 2 through the remaining 29 days of the study, there were no significant daily temperature effects on carbon loss. The CO_2 peaks for all temperatures decreased quickly to levels near background (<100 ppm CO_2 above background) by day 5 (Fig. 2). CO_2 evolution data may be inconclusive since only one series of CO_2 samples was taken per day. Increased sampling was impractical due to time and budgetary constraints.

Cumulative CO_2 evolution could not be statistically compared across different water treatments due to changes in soil-water contents. Actual CO_2 evolution amounts, however, indicate a greater loss of CO_2 as the temperature increased. The wet initial soil treatments evolved more CO_2 than the dry initial soil treatments. Quantities of CO_2 evolved for the 41, 73 and 100°F temperatures of the wet treatments were 30.9, 43.4 and 61.4 mg CO_2 lost during the 29 d experiment, respectively. Quantities of CO_2 evolved for the 41, 73 and 100°F temperatures of the dry treatments were 30.2, 38.0 and 48.1 mg CO_2 lost during the 29-day experiment, respectively. The average carbon lost across both initial water treatments were 8.34, 11.1 and 14.9 mg carbon lost during the 29 day experiment at the 41, 73 and 100°F temperatures, respectively. These values are 0.41, 0.55 and 0.73 % of carbon applied for the 41, 73 and 100°F temperature treatments, respectively. Again, with the confounding of the water treatments, these results cannot be statistically compared.

All temperature and water treatments lost carbon as indicated by CO_2 evolution. Biosolids CO_2 evolution likely occurred as a result of two distinct phenomena: (1) the physical degassing of the biosolids and (2) microbial decomposition of the biosolids. We believe that physical degassing of the biosolids is responsible for the initial CO_2 evolution peak in the cold temperature treatments. Although we were unable to separate physical and microbial phenomena, Jenkinson (1966) demonstrated that, in fumigated soils, this initial peak was primarily due to the decomposition of lysed microbial cells. The materials used in this experiment were not fumigated (autoclaving the biosolids resulted in visually altered material), but biosolids may be assumed to consist largely of components similar to those of lysed cells (U.S. Environmental Protection Agency, 1983). Huffman et al. (1996) reported a similar initial peak in a study investigating wheat residue application. Macalady et al. (1998) stated that CO_2 evolution is based on microbial populations and not necessarily influenced by microbial growth.

Soil and biosolids microbial populations differed in pre-application and post-application numbers. Replicated plating results indicated no soil or biosolids microbial colony forming units for either the pre-application or post-application cold treatments (Table 1). Initial soil microbial numbers were significantly less at 41°F than for the warmer temperatures while initial biosolids microbial population numbers were not significant with respect to temperature. Final soil microbial numbers were significantly different with respect to temperature with microbial population numbers increasing with temperature.

Table 1. Initial and final (29d) microbial population numbers for the soil and biosolids as a function of temperature (Initial only) and temperature and initial soil-water content.

	Temperature			ANOVA results
Parameter	41°F	73°F	100°F	Pr>F
	CFU × 10^6 g^{-1}			
Initial soil	0.0a*	1.45b	1.10b	0.0017
Initial biosolids	0.0a	1.06a	1.20a	0.5148
Final soil	0.01	3.308b	7.578c	0.0001
Final biosolids	0.0a	142.3a	591.9b	0.0057

*Similar letters within rows are not significantly different using Duncan's new range test.

The 41°F microbial population numbers were not significantly different from the 73°F population, but both differed significantly from the 100°F population numbers. Although the 73°F microbial population numbers were less than the 100°F numbers (142.3 × 10^6 colony forming units per gram (CFU g^{-1}) vs. 591.9 × 10^6 CFU g^{-1}), replication to replication variability in both the 73°F and 100°F treatment numbers precluded significant differences.

Replicated plating data support the concept that CO_2 evolution, after the initial phase of degassing, was due to microbial metabolic activity. As experimental temperatures increased, microbial population numbers for both biosolids and soil increased. Increased microbial populations in biosolids may be just that—aerobic microbes indigenous to the biosolids that are increasing in population number as a result of the application process (i.e., removed from anaerobic shipping containers used to transport the biosolids and applied to an oxygen-rich environment). Soil microbial numbers may increase not as a direct result of biosolids addition, but result indirectly from an influx of nutrients in the solution leached from the biosolids to the soil.

CONCLUSIONS

Temperature at which biosolids are surface applied to the soil influences total carbon loss. The CO_2 peak obtained immediately after biosolids application was not influenced by temperature or water. This peak was consistent with peaks reported by Jenkinson (1966) and Huffman et al. (1996). Carbon loss increased significantly as temperature increased from 4 h after application through day 2. Beyond day 2, carbon loss was not significantly related to temperature levels. Average carbon lost across both initial water treatments were 0.41, 0.55, and 0.73% of the carbon applied during the 29-day experiment at the 41, 73 and 100°F temperatures, respectively. Since temperature differences in carbon loss were significant only for 2 days, and there was carbon loss even for the 41°F temperature treatment, we concluded that biosolids may be applied throughout the year without restricting temperature or water parameters beyond the current USEPA or Texas Natural Resources Conservation Commission regulations.

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