Final Report

BENEFICIAL REUSE OF DIAMOND GRINDING SLURRY WASTEWATER

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16. Abstract

This project assessed the effect of land application of diamond grinding slurry (DGS) by characterizing the DGS, applying it in a controlled greenhouse trial, and applying it to plots in a field trial. The characterization involved collecting several samples and analyzing them for a wide range of constituents including nutrients, sediment and metals. The results showed that while the DGS had relatively high levels of pH, calcium, magnesium, and solids, levels of the 30 or more contaminants that define wastes as hazardous were not found. The greenhouse trial involved incorporating DGS into three different soils in pots at three application rates and growing bahiagrass in a controlled environment. The results documented that applying DGS at recommended rates for soil pH correction resulted in no detrimental effects on the growth of bahiagrass for the three soils involved. Further, application of DGS at twice the recommended rate did have a significant detrimental effect on bahiagrass growth for the two more sandy soils involved in the greenhouse trial. The field trial involved applying DGS at two rates to small plots of bermudagrass and monitoring runoff and vegetative growth on the plots. Application of DGS at recommended rates showed no detrimental effects to the soil or bermudagrass and other vegetative growth. Further, runoff from plots with DGS application contained a much greater concentration of calcium in the first storm after DGS application compared to runoff from a control (no application of DGS) plot, but the difference decreased dramatically by the second storm. The pH and lead levels in runoff from plots receiving the recommended rates of DGS application were similar to corresponding levels in runoff from the control plot.

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DISCLAIMER

SUMMARY

The overall purpose of this project was to assess the effect of land application of diamond grinding slurry (DGS) on vegetated areas. The assessment was conducted by characterizing the DGS, applying it in a controlled greenhouse trial, and applying it to plots in a field trial. The characterization involved collecting several samples and analyzing them for a wide range of constituents including nutrients, sediment and metals. Analysis results showed relatively high levels of pH and concentrations of nitrogen, phosphorous, solids, calcium, and magnesium. Concentrations of more than 30 compounds used to identify waste as hazardous were less than levels identified as hazardous. Incorporating DGS into soil in a controlled greenhouse trial documented that, when applied at recommended rates, the DGS caused no detrimental effects on the growth of bahiagrass for the three Piedmont soils involved. However, incorporating DGS at twice the recommended rate did have a significant detrimental effect on bahiagrass growth for the two more sandy soils involved in the greenhouse trial. The field trial was designed to assess the effects of surface-applying DGS to vegetated areas under uncontrolled more natural temperature and moisture conditions. The results showed that applying DGS at recommended rates (equivalent to liming needs) resulted in no detrimental effect on the growth of bermudagrass and associated vegetation during a 3-month period. Runoff from plots with DGS application contained a much greater concentration of calcium in the first storm after DGS application compared to runoff from a control (no application of DGS) plot, but the difference decreased dramatically by the second storm. The pH and lead levels in runoff from plots receiving the recommended rates of DGS application were similar to corresponding levels in runoff from the control plot. Overall data from the characterization and greenhouse and field trials showed that surface application of DGS (at rates recommended to correct soil acidity) to areas with bermudagrass or bahiagrass do not appear to present a significant concern to the soil, vegetation, or surface water.

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INTRODUCTION

Grinding of concrete road surfaces, accomplished using diamond-impregnated grinding wheels, is often used to smooth and/or provide grooves in the road surface. During the grinding process, water is used to cool the grinding wheels, minimize dust, and carry the loose concrete particles away from the machine thereby generating large volumes of a water-concrete slurry referred to as diamond grinding slurry (DGS). Currently, the disposal or reuse of DGS in the USA varies by State. For example, some states including North Dakota have allowed the application of DGS in the highway corridor below the road shoulder (DeSutter et al., 2011a), while other states including California and North Carolina have required collection and disposal of DGS offsite often in wastewater treatment plants and/or landfills. North Carolina and Nebraska are in the process of allowing land application of DGS only after a permit is obtained. The costs of disposal methods vary, but it is likely that land application near the place of origin would be the least expensive and potentially most beneficial method of disposal/use.

Currently, land application of DGS is limited by vegetation and environmental concerns. The DGS typically has a high pH and hence its application to land can increase the soil pH considerably and potentially limit the growth of vegetation. Shanmugam (2004) documented and increase in soil pH from 6.3 to as much as 9.4 along one roadside in the state of Washington following the application of DGS, but the effects on vegetation were not reported. DeSutter et al. (2011b) reported that DGS applied at 83 Mg/ha to two North Dakota soils was generally beneficial to the growth of smooth Brome grass, but cautioned that applications at greater rates may be harmful to growth.

Environmental concerns about the effects of surface land application of DGS on vegetation and soil as well as nearby surface and ground water also currently limit DGS slurry application. Because highway surfaces can potentially have metals, polycyclic aromatic hydrocarbons (PAHs), and other contaminants deposited on them, it is reasonable to assume that at least some of these could be present in DGS. Although diamond grinding has been routinely done for many years, only recently have there been limited efforts to characterize the DGS. There is one published article in the scientific literature (DeSutter et al., 2011a) and several technical reports (e.g. Yonge and Shanmugam, 2005; Homes and Narver, 1997) that characterized DGS. Both the article and the technical reports state that DGS application at rates consistent with recommended liming requirements did not increase trace metal levels significantly above those in soils located outside the application area. Further, DeSutter et al. (2011b) found that none of the 16 PAHs associated with the production and use of asphalt or the processing, use, and disposal of fuels used for transportation were detected above laboratory reporting limits. While these data indicated no detrimental effects of DGS applied at relatively low rates to soils or vegetation, there was no data on the effects of DGS application on runoff and ground water quality.

The purpose of this project was primarily three fold: characterize DGS from several sites, document the effect of DGS application on three soils and one grass in a greenhouse trial, and monitor the effect of DGS on runoff from a field application area (field trial).

METHODOLOGY AND PROCEDURES

Characterization of DGS: Properly characterizing DGS requires first collecting a representative sample which was difficult for several reasons including the often large volume of slurry, the inconsistency of solids concentration in the slurry; and the rapid settling of the much of the solids in the slurry. On most projects many thousands of gallons of DGS are generated. Ideally, at least 5-7 samples would be collected and analyzed from this large volume of slurry and then the results combined for an overall representative characterization; however, due to the cost of analyses, often only one or two samples get analyzed. This was the case in this project also. Two large samples of DGS were collected by NC DOT personnel and provided to NCSU during this project: one from Booker Dairy Road (5 gallons) and one from the I-540 (50 gallons) toll road.

Samples for laboratory analysis were collected by first agitating the bulk sample using a large paint mixer (figure 1) and then by quickly plunging a laboratory container into the DGS and removing a sample for analysis. Samples were analyzed for a suite of parameters as shown in Table 1. Analyses were conducted by state certified labs using standard methods (Eaton et al., 1995).

Greenhouse trial: Soils were collected from three sites, two in the Piedmont, and one in the Coastal Plain physiographic regions of North Carolina. At each site about 40 L of soil was collected from within 150-mm of the surface at 5-6 locations in a grassed area. The first site was along US 70 in front of the Central Crops Research Station in Johnston County where the soil was mapped as Norfolk Loamy sand. The second site was a residential lot in eastern Wake County where the soil was mapped as Durham loamy sand. The third site was at NCSU's Lake Wheeler Field Lab in Wake Country where the soil was mapped as Cecil sandy loam. After passing the soil through a 4 mm diameter sieve and thoroughly mixing, subsamples were analyzed by the Soil Testing Laboratory of NCDA&CS Agronomic Division (NCDA) with the results shown in Table 2. This lab provides agricultural lime application rate recommendations for various crops including grasses based on the pH and buffer acidity values of each soil. The lime application recommendations were converted into equivalent gallons of DGS based on this material's agricultural lime equivalent (ALE) values, as shown in Table 1. The Lake Wheeler soil also received 1.0 g of $CaH_4(PO_4)_2$, which was equivalent to 1000 lb P_2O_5/acre, to raise its plant-available soil phosphorus (P) to a level similar to the two other soils. The intent of this P supplement was to eliminate differences in soil P as a variable in the plant growth phase of the trial.

Treatments for each soil consisted of the DGS application rate equivalent to the NCDA lime recommendation for Bahiagrass, and three additional rates above and below the recommended rate (Table 3). The highest rate of DGS, equivalent to 2.5 times the recommended liming rate, corresponded to the water holding field capacity of the Johnston county soil and therefore prevented the use of a higher application rate of DGS, since leaching was to be avoided. Two additional reference treatments were included for each soil, a control without lime or DGS and agricultural lime applied at the NCDA recommended application rate. Thus, comparisons between soils were based on multiples of the recommended lime rates, instead of absolute quantities of DGS. Lime and DGS were thoroughly mixed with 1 L of soil and placed in a new pot prior to planting the vegetation. While in reality the DGS would most likely be surface-applied, this application method was difficult to replicate and repeat on such a small scale. Also, the pots were less than 100-mm deep, so application was to the top soil layer (figure 2). There were three replicates of each treatment combination arranged in a randomized complete block design.

The pots were placed in a climate-controlled greenhouse. Bahiagrass seed variety 'Pensacola' was planted in the pots and maintained at 90% water-holding capacity from March 19, 2014 to June, 13, 2014. Aboveground Bahiagrass biomass (figure 23) was harvested, dried in air-forced ovens at 65 degrees C, weighed, ground and analyzed for nutrients by the Plant Analysis Lab of the NCDA&CS Agronomic Division. Soil samples were also collected from each pot and analyzed by the NCDA.

Field trial: Because all of the results were not available at the time of the final report on hydrodemolition runoff water (HRW) treatment options and the field trial was essentially the same as the DGS, the results for the HRW will be included here with those for DGS. In order to assess potential effects on vegetation under natural conditions, 10 plots (nominally 0.61 x 0.91 m; 2ft x 3ft) were established on an area of NC State University's Lake Wheeler field laboratory near Raleigh, NC. Runoff collection systems were installed on five of the plots to begin to assess the effect of DGS and HRW application on runoff from vegetated areas. The soil on the plots was mapped as Cecil sandy loam. The soil likely had been altered in the recent past as there was a demonstration stream channel immediately next to the area. Analysis of soil samples from the area documented a soil pH of 5.0-5.2 (Table 4). There was an established, although relatively thin, stand of bermudagrass on the area with other vegetation mixed in. The 10 plots were delineated with the longer dimension up and down slopes ranging from 4-8%, while the cross slope was less than 1%. Plastic landscape edging was installed around the perimeter of 6 plots and a runoff collection system was added to the downslope end in order to collect samples of storm-event runoff (figure 3). One replicate of each treatment (no DGS or HRW, recommended rate, and 1.5 x recommended rate) was included in the 5 plots with runoff collection systems. The collection system consisted of a PVC pipe sealed to the downslope end of the landscape edging, which conveyed runoff to a 19-L bucket placed inside a shelter (figure 4). The plots and collection systems were installed on 6/17/14 and then not used for monitoring until 7/9/14 to allow time for the soil and vegetation around borders to stabilize or recover from being disturbed during installation. Several storm events occurred during this period producing runoff that was discarded. A recording rain gage was installed on-site on 7/9/14 to monitor rainfall.

About 56 L of DGS from a section of I-540 was obtained by NC DOT personnel and delivered to the Lake Wheeler Field laboratory in a drum. About 35 L of DGS was obtained from the drum by plunging a collection container into the agitated slurry and retrieving the container. An equal volume of HRW was obtained from a highway bridge reclamation project as outlined in the final report for RP2012-16. Samples of HRW and DGS were obtained by suspending the solids via a large paint stirrer and plunging a laboratory container into the slurry, retrieving, and capping the container. The samples were then analyzed by the NCDA (Table 1).

The recommended application rate of agricultural lime was computed from soil sample analysis results as 1880 kg/ha or 0.84 ton/ac using the average soil pH of 5.1 and the buffer acidity of 1.4. The recommended DGS application rate was then computed using the average agricultural lime equivalent (ALE) of the 2 samples of DGS slurry analyzed (19,434 L/metric ton or 4,655 gal/ton) and the lime application rate from the soil analysis. On 8/11/14 two plots each received no DGS application, recommended rate of DGS (3,920 gal/ac), and 1.5 x recommended rate of DGS. The 1.5 times the recommended rate was used because it is difficult to apply the

DGS uniformly under field conditions due to the high solids content and the bulk application methods; hence, it is likely that up to 1.5 times the target rate would often be applied. The DGS was applied to the surface of the plots via a custom-made flange device (figure 5) on 8/11/14 which was during the time Bermudagrass was rapidly growing. More specifically, the application device was moved back and forth across the plot while being inverted so the DGS and HRW flowed out over the flange and onto the plot vegetation and soil. Application of DGS and HRW did not appear to be heavy as observation showed that none of the grass was matted or there was little evidence of solids on the ground (figure 6); however, DGS and HRW adhered to the grass and other vegetation turning it from green to gray. The soil moisture had been replenished from the recent rains occurring at the time; thus, soil moisture was not, at least initially, be a limiting factor to vegetative growth.

After each rain event occurring between 7/9/14 and 11/1/14 the site was visited and the pH of the runoff was measured using a portable pH meter. The volume of runoff in the containers from each runoff plot (figure 7) was determined either by comparing the water level to previously calibrated levels in the buckets or by pouring the water into a known volume container until the bucket was empty. During this process a sample of water was retained for laboratory analysis. These samples were transported immediately to the laboratory for analysis of total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate+nitrite nitrogen (NOx-N), lead (Pb), zinc (Zn), manganese (Mn), and copper (Cu) as shown in Table 1. Vegetation was cut to the same height on 7/28/14. Photos were taken to document the condition of the plots at this time (example in figure 8).

On 11/7/14 soil samples were collected from the top 51 mm of at least three locations within each plot and submitted to NCDA lab for analysis. The vegetation on each plot was clipped to the same height as at the start of the trial and dried and weighed to determine growth during the period.

RESULTS

Characterization of DGS: The analysis results from five DGS samples are shown in Table 1. The data for the Booker Dairy Road (BDR) and NC 147 DGS was provided by NC DOT while for the I-540 samples, the DGS was provided in bulk by the NC DOT, but the laboratory sample was collected by NCSU personnel and analyzed by NCDA. The first two I-540 samples were from DGS used in the Field trial whereas the last sample was from DGS used in the Greenhouse trial. The greenhouse trial sample was also filtered and the filtrate and solids analyzed separately.

The total suspended solids (TSS) concentrations for the BDR and NC 147 DGS was very high, which was expected. A sample of DGS from BDR analyzed by NCSU had a TSS concentration of 322,000 mg/L. Concentrations of TSS this high are subject to considerable uncertainty as only small volumes of DGS can be filtered in the laboratory. The pH of samples varied from 6.18 to 11.58. It is not known how or when the pH for the NC 147 DGS was measured, but this value was unusually low for DGS, whereas the other values were more typical. Concentrations of ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), and total phosphorus (P) varied considerably between sources of DGS. They also varied between the filtrate and the solids with the solids having a much greater concentration of all three. These data highlight the variability of DGS and the difficulty in obtaining representative samples due to the contribution of the solids to the concentrations of the two nitrogen forms and P.

Concentrations of chloride (Cl) were somewhat high for the 2 samples analyzed; however, neither result exceeded the NC regulatory limit for water supply (250 mg/L), freshwater (230 mg/L), and groundwater (250 mg/L).

Concentrations of calcium (Ca), magnesium (Mg), and sodium (Na) varied considerably between samples (Table 1). Concentrations in the I-540 DGS were much greater than corresponding levels in soils at the field trial plots. Levels of Ca, Mg, and Na were much greater in the DGS solids than in the filtrate, especially for Ca and Mg. The concentration of Na is a concern in soils as at too high levels it can hurt soil productivity; however, the high Ca and Mg levels help counteract the effects of the Na such that the sodium adsorption ratio (SAR) is much less than 2.0 (Table 1) for all DGS samples indicating there should be no restrictions on the application rate from a Na build-up perspective.

With respect to solids in samples, the very limited data reported here suggested that the inclusion of solids greatly increased turbidity, TSS, TP, Ca, Mg, and Pb compared to DGS for which solids had settled or been filtered out. In contrast, pH and NO_3-N were similar with or without solids. This indicates that for many pollutants of concern, the DGS must be agitated in some way to suspend the solids and then be sampled immediately to obtain a representative sample that includes the solids. The concentration of Pb in solids was greater than the maximum regulatory level (5 mg/L) allowed using the Toxicity Characteristic Leaching Procedure (TCLP); however, the procedure used by NCDA was for total recoverable Pb. The fact that the concentrations in the slurry and the filtrate were much less than in the solids, indicated that the Pb was closely associated with the DGS solids and thus was unlikely to leach out of the solids. While there was no TCLP analysis of this DGS to confirm the potential for leaching, analysis of the other two DGSs using the TCLP showed low leaching potential (Table 1).

Samples of the BDR and NC 147 DGS were also analyzed for arsenic; phenols; benzene; carbon tetrachloride; chlordane; chlorobenzene; chloroform; m-Cresol (4-Methylphenol); o-Cresol (2-Methylphenol); p-Cresol (4-Methylphenol); cresol; 2,4-D; 1,4 Dichlorobenzene; 1,2-Dichloroethane; 1,1-Dichloroethelyne; 2,4-Dinitrotoluene; endrin; hexachlorobenzene; heptachlor & hydroxide; hexachloro-1,3-butadiene; hexachloroethane; lindane; methoxychlor; methyl ethyl ketone; nitrobenzene; pentachlorophenol; pyridine, selenium; tetrachloroethylene; toxaphene; trichloroethylene; 2,4,5-Trichlorophenol; 2,4,6-Trichlorophenol; 2,4,5-TP (Silvex); Vinyl chloride; bromodichloromethane; dibromochloromethane; bromoform; o-Xylene; total Xylenes; 1,2,3 Trichloropropane; 1,2,4 Trimethylbenzene; 1,2 Dibromo-3-chloropropane; Naphthalene; and 1,2,3 Trichlorobenzene. Chloroform was the only one in the above list that was found at a level greater than the detection limit. The above compounds are included in a list of pollutants that govern the disposal of solid and hazardous waste according to the Resource Conservation and Recovery Act (USEPA, 2010).

Greenhouse trial: The mass of Bahiagrass dry matter harvested from each pot is shown in Table 4. There were significant differences in the dry matter when averaged across soils or treatments (DGS application rate), as well as the soil-treatment interaction (Table 4). Observation indicated that the Lake Wheeler soil had a higher clay content, which was confirmed by measurements documenting that it retained about 50% more water by volume at field capacity than the other soils. However, plant wilting on hot, sunny days was more prevalent in this clayey soil. None of the soils presented a significant yield difference between the control treatment and the recommended lime application with either agricultural lime or DGS (treatment 1 DGS). Therefore, Bahiagrass growth in the unlimed “Control” treatments was not limited by the native levels of soil acidity in these three soils.

One of the objectives of the greenhouse trial was to investigate how much DGS could be applied to soils without detrimental effects on plant/Bahiagrass growth. Dry matter yields in both the sandier Johnston and Residential soils receiving 2.5 times the recommended lime rate (2.5 DGS) were reduced significantly (Table 4) when compared to the recommended rate (1 DGS). The rate of 2 DGS on the Residential soil also had a significant yield reduction relative to the 1 DGS rate. In contrast to the sandy soils, there was no yield difference among any of the treatments in the more clayey Lake Wheeler soil. Although growth in general was lower in the clayey soil, detrimental effects from high DGS applications were not as evident as for the sandier soils.

Lime application rate recommendations for Bahiagrass target reaching a soil pH of 6.0. Analyses of soil from each pot show that this pH value was approached in all pots receiving the recommended amount of agricultural lime (Table 6). The DGS application rate equivalent to the recommended agricultural lime application rate (1 DGS) exceeded the targeted pH value for each soil, and averaged a pH of 6.6 across the three soils. All soil acidity was neutralized when this DGS rate was doubled (treatment 2 DGS) in all three soils. In addition to a liming effect, soil data (Tables 6 and 7) also showed that DGS applications increase the supply of Ca, Mg, K, and S in soils as well as increasing their cation exchange capacity (CEC).

Plant tissue nutrient data show that the increased supply of K with DGS applications also increased K concentration in the plants (Table 8). The simultaneous decrease in Mg concentrations with increasing DGS applications is consistent with the antagonistic effects that are often observed between plant K and Mg levels. However, Mg levels appear to remain adequate for optimal plant growth.

Plant Mn and Zn levels decreased with increasing rates of applied DGS (Table 9). This is probably due to the elevated pH above 7 with DGS applications of 2 and 2.5 times the lime equivalent rate. At such high pH values the plant-availability of Mn and Zn are markedly reduced. It is difficult to determine the extent to which reduced Mn and Zn contributed to reduced plant growth at the high DGS applications, because there were changes of several nutrients occurring simultaneously among the DGS treatments. Additional controlled single-variable studies would be needed to pinpoint plant Mn and Zn deficiency levels for Bahiagrass. Nevertheless, these two plant nutrients should be monitored whenever DGS application rates increase soil pH to values of 7 or higher.

Field trial: Rainfall and runoff monitoring data for five of the 10 field trial plots are shown in Table 10. There were seven storms that produced measureable runoff prior to the DGS and HRW application. For each storm, the greatest volume of runoff occurred for the control (plot 1) and the least for either plot 2 or 5. Differences in soil and/or vegetation likely caused the variability in runoff. This trend continued for the four storms occurring after DGS and HRW application. All storm producing measureable runoff had an accumulation of at least 25.4 mm. Other smaller storms occurred during the monitoring period, but they were not included because they produced no runoff. The combination of relatively few storms and the high variability precludes making definitive conclusions about the effect of DGS and HRW application on runoff volume; however, it appears that the DGS and HRW had no dramatic effect on runoff volume.

From a runoff quality perspective, the pH of runoff for storms producing measureable runoff is shown in figure 9. The pH of the runoff from plots 2&3 (recommended application rate of DGS and HRW) was less or nearly equal to the pH of runoff from the control for both storms following DGS and HRW application. Hence, at recommended application rates it appeared that the DGS and HRW had no significant effect on the pH of runoff. Conversely, the pH of runoff from plots 3&4 (high application of HRW and DGS) increased to greater than 8 following DGS and HRW application on 8/11/14 (figure 9). However, the pH of runoff from all plots including plot 1, which had no DGS or HRW application, also increased for the 8/12/14 storm thereby confounding the results. The pH of runoff from all plots decreased for the 10/15/14 storm compared to the 8/12 storm indicating that if there was an initial effect it did not persist. Paired t-tests suggested that the pH of runoff from plot 4 was significantly greater than that for plot 1, but the pH of runoff from plot 3 was not significantly different. Hence, the data show that when applied at recommended rates neither DGS nor HRW appear to increase the pH of runoff significantly.

The concentrations of pollutants in runoff from the five instrumented field plots are shown in Table 11. Mean concentrations of nutrients and solids (TSS) were sometimes greater, but mostly less, in post-application runoff samples as compared to pre-application samples. The small number of runoff-producing storms (2) and the large and intense first post-application storm limit the representativeness of the data; however, the data show that the application of DGS and HRW did not dramatically increase concentrations of nutrients and sediment in runoff. Concentrations of Ca, Cu, Zn, Mn, and Pb varied with Ca and Pb having the highest mean concentrations (Table 11). Concentrations of Ca and Pb for each storm monitored are shown in figures 10 and 11. For the first storm after HRW and DGS application (8/12/14), concentrations of Ca in runoff increased with increasing HRW and DGS application rate. The application of DGS at 1.5 times the recommended rate (DGS1.5) resulted in a concentration of Ca in runoff of 53 mg/L, which was more than 10 times that of runoff from the control plot. Concentrations of Ca in runoff decreased by more than 50% on plots with DGS and HRW application from the first to second storm. Concentrations of Pb in runoff from plots receiving DGS and HRW application were similar or less than that of the control plot (figure 11). In fact, the increase in the concentration of Pb in runoff from plots DGS and HRW1.5 compared to the control (Cont) was greater before application of DGS and HRW than after application indicating that the effect of applying DGS and HRW was insignificant.

The mean masses of nitrogen, phosphorus, and sediment in runoff from storm events are shown in Table 12. The average mass/storm of each constituent for each plot increased from pre-application to post-application, even the control which received no DGS or HRW. This was likely due to the large and intense storm occurring just after DGS and HRW application on 8/12/14. Thus, the more appropriate comparisons are between runoff from the control and the application plots. Mean mass/storm of TKN, NOx-N, and TP in runoff from plots with DGS and HRW application were less or only slightly greater than the control. Mass/storm of NH_3-N in runoff for the DGS plot was much greater than the control for some unknown reason. The mass/storm of TSS was much greater in the runoff from the DGS, HRW1.5, and DGS1.5 plots than the control. The increase was expected as solids in the DGS and HRW washing off the vegetation and into the runoff. Because there were no replications and only two storms producing runoff, there was no way to determine if the differences between the control and the application plots were statistically significant.

Mass/storm of Cu in runoff was negligible before and after application of DGS and HRW (Table 12). Mean mass of Ca, Zn, Mn, and Pb increased from pre- to post-application for each plot even the control. There was a much larger increase in Ca in runoff from plots with DGS and HRW application as compared to the control. While there are no studies that show high levels of Ca are harmful, studies do show that different Ca:Mg ratios in surface water effect the toxicity of Cu to aquatic organisms. However, because there was no Cu measured in the runoff from the plots, the Ca:Mg ratio was not an issue. The mass of Pb in runoff for each storm was less in the four plots with DGS and HRW applications than in the control. Although limited by the number of storms and the lack of replications, these data indicated little, if any, effect of HRW or DGS application on lead in runoff.

Analyses of soil samples are shown in Table 4. Results labelled pre-trial A and B were for samples collected prior to the field trial whereas those labelled ‘control’ were collected after the trial from plots receiving no DGS or HRW. There was considerable variability in these results, which to some extent was expected. The reason for the high variability was unknown, but may be related to past construction of a stream channel next to the trial area for which soil was excavated and moved around. A two sample t-test using the combined pre-trial and control sample results and the results from samples collected from HRW and DGS application areas found that the only significant differences were for pH and Ca. The same test was then conducted using results from only plots that received the recommended rates of DGS and HRW and they were still significantly different. These results were expected given the high levels of Ca in the DGS and HRW. The pH for soils receiving the DGS and HRW ranged from 5.8 to 6.7 which, at the high end, was greater than the target set by NCDA for bermudagrass (pH=6.0), still within the range reported in Carolina Lawns: A Guide for Maintaining Quality Turf in the Landscape (www.turfgrass.ncsu.edu) for optimal growth (pH=6.5-7.0). Thus, these data show no detrimental effect of the application of DGS and HRW to soils or to the suitability of the soil for growing bermudagrass, which agrees with the results of the greenhouse trial for growing bahiagrass.

The dry mass of vegetative growth on all 10 plots between 7/28/14 and 9/12/14 is shown in figure 12. Observation indicated that the between 20 to 50% of the vegetation in the plots was bermudagrass. For replication 1 (plots 1-5) it appeared that the growth/yield for the high application rate of DGS (DGS1.5) was much less than the other plots, but this trend did not carry over to replication 2. The only consistent trend is that the yield for the high application rate of DGS (DGS1.5) was less than the control for both replications, which may indicate a negative effect of the high application rate. This result agrees with the greenhouse trial which also found that a higher than recommended application rate of DGS had a negative effect on bahiagrass growth for some soils. This was consistent with DeSutter et al. (2011b) who reported that application of DGS at a moderate rate was generally beneficial to the growth of smooth brome grass. Thus, the data shown that at recommended rates the application of DGS and HRW had no negative effects on bermudagrass and other vegetation growth and that even if the application exceeded the recommended rates by 50%, the bermudagrass and other vegetation would not be killed.

SUMMARY AND CONCLUSIONS

This project assessed the effect of land application of DGS by characterizing the DGS, applying it in a controlled greenhouse trial, and applying it to plots in a field trial. The characterization involved collecting several samples and analyzing them for a wide range of constituents including nutrients, sediment and metals. The greenhouse trail involved incorporating DGS into three different soils in pots at three application rates and growing bahiagrass. The field trial involved applying DGS at two rates to small plots of bermudagrass and monitoring runoff and vegetative growth on the plots. From the data and observations collected during this project the following conclusions can be drawn:

- Collecting a representative sample of DGS requires great care due to the large volumes involved and the high concentration of solids
- The concentrations of most constituents analyzed for in the DGS were much greater in the filtered (solids) compared to the filtrate indicating that a representative sample must be representative of the solids in the DGS
- Contaminants in the two DGSs analyzed during this project were found at levels not considered harmful. Further, analysis for a suite of 30 compounds that are used to identify waste as being hazardous under the Resource Conservation and Recovery Act (USEPA, 2010) documented that the DGS was not hazardous.
- Application of DGS to soils at rates recommended to correct low pH in soils caused no detrimental effect to the growth of bahiagrass in a controlled greenhouse trial
- Application of DGS to soils at rates recommended to correct low pH in soils raised the pH to or slightly above target levels in a controlled greenhouse trial
- Application of DGS at twice the recommended rate had a significant detrimental effect on the growth of bahiagrass for the two more sandy soils involved in the greenhouse trial
- Application of DGS to field plots of bermudagrass and other vegetation at rates equivalent to lime recommendations resulted in no detrimental effect to growth over a 6-week period
- Runoff from field plots on which DGS and HRW was applied had a higher pH and Ca concentration than runoff from a control plot for the first storm after application, but levels were similar for the 2nd storm. Overall, levels of contaminants in runoff from plots with DGS and HRW applied did not appear to present a significant environmental concern to surface waters.
- Overall the data show that application of DGS and HRW to bermudagrass and bahiagrass at rates recommended to correct soil acidity do not appear to present a significant concern to the soil or vegetation of the application area or adjacent surface water; however, further study is needed, particularly of the effect on adjacent surface waters, to confirm this initial conclusion.

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LIST OF TABLES

Table 1. Sample Analysis Results for DGS.

Parameter	Units	Booker[a] Dairy Road	NC147[a]	I-540[b]	I-540[b]	I-540 Greenhouse[b]		
						Slurry	Filtrate	Solids
Turbidity	NTU	129000	97000	na	na	na	na	na
TSS	mg/L	302000	587000	na	na	na	na	na
pH	s.u.	na	12.29	11.04	11.58	10.64	10.49	9.94
BOD_5	mg/L	55.5	12.8	na	na	na	na	na
NH_3-N	mg/L	<0.02	0.50	na	na	0.59	0.63	12.4
NO_3-N	mg/L	0.35	3.0	na	na	0	0	0
TKN	mg/L	119	20.3	70.8	63.7	579	59.0	2640
TP	mg/L	21.4	43.7	102	48	65.8	9.98	740
TDS	mg/L	1930	870	na	na	na	na	na
Total Organic Carbon	mg/L	ND[c]	90.9	na	na	na	na	na
Chloride	mg/L	32.5	170	na	na	na	na	na
Calcium	mg/L	502	947	10100	15900	5790	117	78500
Magnesium	mg/L	0.157	64.2	1110	413	681	11.2	8080
Sodium	mg/L	ND[c]	963	144	138	123	66.0	756
Sulfur	mg/L	na	na	347	474	207	53.6	2180
Iron	mg/L	na	na	1640	1250	1050	3.24	13300
Manganese	mg/L	na	na	72.3	19.8	40.9	0.10	517
Zinc	mg/L	na	na	8.98	9.31	5.4	0.15[d]	69.0[d]
Copper	mg/L	na	na	10.6	2.30	5.6	0.15[d]	62.0[d]
Boron	mg/L	na	na	2.23	1.87	1.0	0[d]	12.2[d]
Cadmium	mg/L	0.07	na	na	na	0.07	0[d]	0.77[d]
Lead	mg/L	ND[c]	na	na	na	0.50	0.04[d]	5.77[d]
Sodium Adsorption Ratio		ND[c]	0.42	na	0.02	0.02	na	na
ALE[e]		na	na	7220	2090	19600	na	na

[a] Data obtained from Robin Maycock of NC DOT.

[b] DGS obtained by NC DOT from I-540 and sampled by NCSU (analysis by NCDA).

[c] Not detected.

[d] Analysis by NCDA laboratory for total recoverable.

[e] Quantity of DGS that provided equivalent liming effect of 1 ton of agricultural grade limestone.

Table 2. Analysis Results for the Three Soils Used in the DGS Greenhouse Trial.

Soil	Humic Matter	pH	Buffer Acidity	Exchangeable Ca	Mg	K	Na	CEC	P	S	Cu	Mn	Zn
	%		--------------- $\text{cmol}_c\ L^{-1}$ soil --------------						----- mg dm^{-3} soil ------				
John	0.51	5.0	1.6	1.4	0.6	0.20	0.1	3.8	79	13	4.1	8.5	7.4
Wake	0.41	5.2	1.6	1.3	0.5	0.19	0.3	3.6	38	12	1.1	25.3	1.9
LW	0.04	5.0	1.4	1.7	1.0	0.38	0.1	4.5	4	254	2.7	2.7	1.3

Table 3. Agricultural Lime and DGS Application to Each Soil in the Greenhouse Trial.

Treatment	Soil Johnston (John)	Wake	Lake Wheeler (LW)
	weight of lime (g) or volume of slurry (ml) per pot[a]		
Control (no lime or slurry)	0	0	0
Reference ag lime (g/pot)	1.10	1.00	0.89
0.5 DGS (ml/pot)	46	41	36
1 DGS (ml/pot)[#]	92	82	73
2 DGS (ml/pot)	184	164	146
2.5 DGS (ml/pot)	230	205	182

[a] Weight of one liter of soil in kg for each pot, based on weight/volume ratios, are 1.24 for Johnston, 1.17 for Residential and 0.99 for the Lake Wheeler soil.

[#] Corresponded to the volume of slurry with lime neutralization potential equal to that of the recommended agricultural lime rate, based on the NCDA soil test and DGS analysis.

Table 4. Analysis of Soil Samples Collected From the Field Trial Site.

Plot	Humic Matter %	pH	P	K	Ca	Mg	S	Na	Mn	Cu	Zn
			******************* mg/dm³ *******************								
Pre-trial											
A[a]	0.04	5.0	4	147	340	124	254	8	2.7	2.7	1.3
B[a]	0.04	5.2	4	84	354	136	168	7	3.9	3.7	1.2
Post-trial											
Control	0.22	5.4	20	84	647	189	46	17	5.7	1.6	2.8
Control	0.46	5.7	20	105	1074	269	32	17	15.2	1.3	5.9
Mean	0.19	5.3	12	105	604	180	125	12	6.9	2.3	2.8
HRW	0.41	6.3	22	80	1716	223	38	19	10.3	1.9	4.8
HRW	0.18	6.1	13	122	1130	165	100	17	5.8	1.6	2.1
HRW1.5	0.32	6.7	22	91	2501	178	69	21	7.9	1.9	3.8
HRW1.5	0.32	6.2	15	80	1514	195	52	20	7.9	1.6	3.1
DGS	0.18	5.8	10	87	803	170	73	16	4.4	1.7	1.8
DGS	0.27	6.2	19	97	1297	199	75	24	10.5	1.7	3.3
DGS1.5	0.18	6.3	11	133	1047	176	100	18	6.2	1.8	2.0
DGS1.5	0.22	5.8	10	89	753	137	66	17	5.9	1.3	1.8

[a] Soil samples were collected from the area where the plots were later established.

Table 5. Bahiagrass Dry Matter Yield for the Three Soils.

	Soil			Treatment
Treatment	Johnston	Residential	L. Wheeler	Mean
	-------------------- plant top dry weight (g/pot) --------------------			
Control	5.68	5.55	3.68	4.97
Ag Lime	5.80	4.94	2.89	4.54
0.5 DGS	5.38	5.03	3.30	4.57
1 DGS	4.93	5.03	4.43	4.80
2 DGS	3.19	3.42	2.91	3.17
2.5 DGS	2.22	1.60	3.58	2.47
Soil Mean	4.53	4.26	3.46	
Least Significant Difference $_{0.05}$:[a]				
Soil		0.63		
Treatment		0.89		
Soil x Treatment		1.54		

[a] F-test protected Least Significant Difference (LSD) at the 0.05 probability level.

Table 6. Effect of Lime and DGS Application Rates on Soil Acidity and Exchangeable Cations.

Soil	Treatment	pH	Buffer Acidity	Ca	Mg	K	CEC
			------------------- meq/100 cm^3 soil				---------------------
Johnston	Control	5.1	2.10	1.49	0.39	0.04	4.00
	Ag Lime	5.9	1.30	3.41	0.53	0.12	5.37
	0.5 DGW	5.9	1.33	3.34	0.57	0.04	5.27
	1 DGW	6.7	0.67	5.38	0.80	0.06	6.87
	2 DGW	7.7	0	8.99	1.03	0.12	10.13
	2.5 DGW	7.9	0	11.44	1.27	0.22	12.90
	Mean	*6.5*	*0.90*	*5.68*	*0.77*	*0.10*	*7.42*
Residential	Control	5.5	1.83	2.14	0.59	0.05	4.63
	Ag Lime	6.0	1.40	3.69	0.51	0.06	5.70
	0.5 DGW	6.0	1.30	3.88	0.70	0.07	6.00
	1 DGW	6.5	0.80	5.70	0.76	0.07	7.37
	2 DGW	7.7	0	9.94	1.04	0.12	11.07
	2.5 DGW	8.0	0	12.20	1.25	0.22	13.67
	Mean	*6.6*	*0.89*	*6.26*	*0.80*	*0.10*	*8.07*
L. Wheeler	Control	5.3	1.63	3.43	0.95	0.08	6.10
	Ag Lime	6.1	0.90	4.64	0.98	0.10	6.60
	0.5 DGW	6.0	0.97	4.58	1.03	0.10	6.67
	1 DGW	6.7	0.43	6.25	1.05	0.08	7.87
	2 DGW	7.5	0	9.21	1.25	0.15	10.60
	2.5 DGW	7.7	0	10.66	1.29	0.13	12.10
	Mean	*6.6*	*0.66*	*6.46*	*1.09*	*0.11*	*8.32*
LSD $_{0.05}$	*Soil*	*NS*	*0.07*	*0.18*	*0.05*	*NS*	*0.22*
	SoilxTmt	*0.2*	*0.18*	*0.45*	*0.12*	*NS*[a]	*0.54*
		---------- Treatment Means Averaged Across Soils ----------					
	Control	5.3	1.86	2.36	0.65	0.06	4.91
	Ag Lime	6.0	1.20	3.92	0.67	0.09	5.89
	0.5 DGW	6.0	1.20	3.93	0.76	0.07	5.98
	1 DGW	6.6	0.63	5.78	0.87	0.07	7.37
	2 DGW	7.7	0	9.38	1.11	0.13	10.60
	2.5 DGW	7.8	0	11.43	1.27	0.19	12.89
LSD $_{0.05}$	*Treatment*	*0.1*	*0.11*	*0.44*	*0.10*	*NS*	*0.31*

[a] Non-significant effect at 0.05 probability level.

Table 7. Effect of lime and DGW application rates on Mehlich-3 extractable soil P, S, Mn and Zn from three soils from North Carolina.

Soil	Treatment	P	S	Mn	Cu	Zn
		---------------------- mg/dm^3 soil ----------------------				
Johnston	Control	84	41	6	1.5	6.5
	Ag Lime	94	47	7	1.5	5.6
	0.5 DGW	79	39	7	1.4	5.2
	1 DGW	78	54	10	1.8	5.2
	2 DGW	70	52	13	2.2	5.7
	2.5 DGW	72	62	15	2.7	6.8
	Mean	*79*	*49*	*10*	*1.8*	*5.8*
Residential	Control	49	34	54	2.1	2.4
	Ag Lime	51	34	39	2.1	2.1
	0.5 DGW	50	33	41	2.0	2.2
	1 DGW	45	45	37	1.9	2.0
	2 DGW	41	48	38	2.5	2.6
	2.5 DGW	41	87	36	2.8	2.7
	Mean	*46*	*47*	*41*	*2.2*	*2.3*
L. Wheeler	Control	91	169	3	4.4	1.9
	Ag Lime	62	170	5	4.9	2.0
	0.5 DGW	63	176	5	5.1	2.1
	1 DGW	72	182	7	5.3	2.3
	2 DGW	78	172	9	5.5	2.6
	2.5 DGW	79	210	9	5.2	2.5
	Mean	*74*	*180*	*6*	*5.1*	*2.2*
LSD $_{0.05}$	*Soil*	*10*	*20*	*1*	*0.2*	*0.2*
	SoilxTmt	*NS*[a]	*NS*	*3*	*0.4*	*0.4*
		---------- Treatment Means Averaged Across Soils ----------				
	Control	75	81	21	2.7	3.6
	Ag Lime	69	84	17	2.8	3.2
	0.5 DGW	64	83	18	2.8	3.2
	1 DGW	65	94	18	3.0	3.1
	2 DGW	63	90	20	3.4	3.6
	2.5 DGW	64	120	20	3.6	4.0
LSD $_{0.05}$	*Treatment*	*NS*	*NS*	*2*	*0.2*	*0.2*

[a] Non-significant effect at 0.05 probability level.

Table 8. Effect of lime and DGW application rates on macronutrient content of harvested Bahiagrass in three soils from North Carolina.

Soil	Treatment	N	P	K	Ca	Mg	S
		----------------------------- % of dry matter -----------------------------					
Johnston	Control	0.64	0.16	1.12	0.31	0.44	0.41
	Ag Lime	0.66	0.11	0.98	0.44	0.36	0.33
	0.5 DGW	0.63	0.12	1.14	0.44	0.34	0.37
	1 DGW	0.69	0.11	1.24	0.43	0.25	0.31
	2 DGW	0.92	0.08	1.51	0.53	0.19	0.39
	2.5 DGW	1.30	0.06	1.61	0.46	0.17	0.30
	Mean	*0.81*	*0.11*	*1.27*	*0.44*	*0.29*	*0.35*
Residential	Control	0.68	0.07	1.34	0.29	0.29	0.40
	Ag Lime	0.71	0.07	1.38	0.46	0.26	0.36
	0.5 DGW	0.70	0.07	1.48	0.47	0.26	0.38
	1 DGW	0.71	0.07	1.39	0.49	0.27	0.35
	2 DGW	0.94	0.05	1.36	0.57	0.23	0.39
	2.5 DGW	1.13	0.05	1.33	0.69	0.27	0.42
	Mean	*0.81*	*0.06*	*1.38*	*0.50*	*0.26*	*0.38*
L. Wheeler	Control	0.63	0.19	1.54	0.45	0.23	0.44
	Ag Lime	0.52	0.14	1.43	0.40	0.14	0.30
	0.5 DGW	0.50	0.14	1.44	0.40	0.14	0.33
	1 DGW	0.54	0.13	1.42	0.51	0.17	0.39
	2 DGW	0.53	0.07	1.34	0.51	0.11	0.38
	2.5 DGW	0.58	0.08	1.32	0.76	0.14	0.53
	Mean	*0.55*	*0.12*	*1.41*	*0.51*	*0.15*	*0.40*
LSD $_{0.05}$	*Soil*	*0.07*	*0.01*	*0.06*	*0.05*	*0.03*	*0.03*
	SoilxTmt	*0.16*	*0.03*	*0.15*	*0.13*	*0.07*	*0.08*
		---------- Treatment Means Averaged Across Soils ----------					
	Control	0.65	0.14	1.33	0.35	0.32	0.42
	Ag Lime	0.63	0.11	1.26	0.44	0.25	0.33
	0.5 DGW	0.61	0.11	1.35	0.44	0.24	0.36
	1 DGW	0.65	0.10	1.35	0.48	0.23	0.35
	2 DGW	0.80	0.07	1.40	0.54	0.17	0.39
	2.5 DGW	1.00	0.06	1.42	0.64	0.19	0.42
LSD $_{0.05}$	*Treatment*	*0.10*	*0.02*	*0.09*	*0.07*	*0.04*	*0.04*

Table 9. Effect of lime and DGW application rates on micronutrient content of harvested Bahiagrass in three soils from North Carolina.

Soil	Treatment	Mn	Zn	Cu	B
		-------------------- ppm ---------------------			
Johnston	Control	328	51	5.6	7.8
	Ag Lime	130	31	4.9	6.3
	0.5 DGW	115	28	5.2	6.9
	1 DGW	54	23	5.0	6.6
	2 DGW	38	21	8.8	4.8
	2.5 DGW	42	22	9.0	4.0
	Mean	*118*	*29*	*6.4*	*6.1*
Residential	Control	709	21	4.8	6.1
	Ag Lime	432	18	5.4	7.6
	0.5 DGW	247	22	4.8	8.0
	1 DGW	305	20	5.0	8.1
	2 DGW	186	14	6.5	6.7
	2.5 DGW	188	14	6.0	8.6
	Mean	*344*	*18*	*5.4*	*7.5*
L. Wheeler	Control	169	19	6.4	6.1
	Ag Lime	32	15	5.2	4.0
	0.5 DGW	41	13	4.9	4.4
	1 DGW	21	13	5.7	5.2
	2 DGW	31	11	6.8	4.5
	2.5 DGW	39	14	6.7	6.1
	Mean	*55*	*14*	*6.0*	*5.0*
$LSD_{0.05}$	*Soil*	*50*	*3*	*0.8*	*0.8*
	SoilxTmt	*123*	*7*	*NS*	*1.9*
		----- Treatment Means Averaged Across Soils -----			
	Control	402	30	5.6	6.7
	Ag Lime	198	21	5.2	6.0
	0.5 DGW	134	21	5.0	6.4
	1 DGW	127	19	5.2	6.6
	2 DGW	85	16	7.4	5.3
	2.5 DGW	90	17	7.2	6.2
$LSD_{0.05}$	*Treatment*	*71*	*4*	*1.1*	*NS*

Table 10. Rainfall and Runoff from 5 Field Plots Receiving HRW and DGS.

	Storm Parameters			********** Plot Runoff **********				
				Control	HRW	DGS	HRW1.5	DGS1.5
Date	Rain	Dur.	Int.	(P1)[1]	(P2) [1]	(P3)[1]	(P4)[1]	(P5)[1]
	in	hr	in/hr	ml	ml	ml	ml	ml
Pre-application of DGS&HRW								
7/10/14	1.00	2.5	0.40	2150	80	490	790	na
7/15/14	1.42	na	na	1120	0	10	300	na
7/21/14	0.20	4.0	0.05	165	10	10	0	0
7/24/14	1.92	4.0	0.48	5000	10	850	2100	20
7/27/14	0.22	1.5	0.15	10	0	0	0	0
8/2/14	1.52	2.0	0.76	13248	750	3010	1750	10
8/9/14	1.37	24	0.06	20	0	0	0	0
DGS&HRW applied								
8/12/14	1.72	3.2	0.54	18925	18925	18925	18925	9463
9/4/14	2.65	na	na	650	0	0	10	0
9/8/14	1.96	20	0.10	900	0	0	0	0
10/15/14	1.31	8	0.16	18925	7449	8300	5600	1575

[1] Treatment with plot number in parenthesis.

Table 11. Average Pollutant Concentrations in Storm Runoff Samples.

Analyte	Control(P1)[1]	HRW(P2)[1]	DGS (P3)[1]	HRW1.5 (P4)[1]	DGS1.5 (P5)[1]
	mg/L	mg/L	mg/L	mg/L	mg/L
Pre-application of DGS&HRW					
TKN	1.80	5.27	4.40	2.33	na
NH_3-N	0.45	2.25	2.00	0.65	na
NOx-N	0.31	0.13	0.13	0.10	na
TP	0.53	0.81	0.73	0.46	na
TSS	14.2	70.0	136.0	165.0	na
Ca	2.60	na	2.45	5.30	na
Cu	<0.002	na	<0.002	<0.002	na
Zn	<0.002	na	0.01	0.01	na
Mn	<0.002	na	<0.002	<0.002	na
Pb	0.40	na	0.57	0.58	na
Post-application of DGS&HRW					
TKN	1.94	2.63	2.58	1.44	1.75
NH_3-N	0.19	0.47	1.66	0.23	0.44
NOx-N	0.12	0.11	0.10	0.17	0.11
TP	0.49	0.56	1.03	0.51	1.03
TSS	21.54	25.52	36.78	46.1	328.5
Ca	3.05	7.95	12.5	18.65	30.55
Cu	<0.002	<0.002	<0.002	<0.002	<0.002
Zn	0.02	0.03	0.02	0.01	0.02
Mn	0.01	0.01	0.01	0.01	0.06

Pb	0.67	0.61	0.65	0.65	0.71

Table 12. Average Storm Nutrient and Sediment Loads From Field Trial Plots.

Analyte	Control(P1)[1] mg/storm	HRW(P2)[1] mg/storm	DGS (P3)[1] mg/storm	HRW1.5 (P4)[1] mg/storm	DGS1.5 (P5)[1] mg/storm
Pre-application of DGS&HRW					
TKN	14.3	3.95	10.3	4.39	0.00
NH_3-N	3.47	1.69	4.52	1.19	0.00
NOx-N	1.96	0.10	0.19	0.20	0.00
TP	4.07	0.61	1.64	0.88	0.00
TSS	338	53	145	328	0.00
Ca	24.13	na	5.32	10.66	0.00
Cu	0.00[2]	na	0.00[2]	0.00[2]	0.00
Zn	0.00[2]	na	0.03	0.02	0.00
Mn	0.00[2]	na	0.00[2]	0.00[2]	0.00
Pb	3.98	na	1.16	1.11	0.00
Post-application of DGS&HRW					
TKN	41.0	29.3	31.7	19.8	8.7
NH_3-N	4.14	4.32	20.5	2.48	3.03
NOx-N	2.63	1.39	1.26	1.82	1.28
TP	10.3	6.07	11.4	4.92	12.9
TSS	465	299	520	603	5630
Ca	70.2	126	205	265	527
Cu	0.00[2]	0.00[2]	0.00[2]	0.00[2]	0.00[2]
Zn	0.38	0.19	0.17	0.06	0.11
Mn	0.09	0.07	0.04	0.03	1.00
Pb	14.67	8.50	8.91	7.84	8.91

[1] Treatment with plot number in parenthesis.

[2] Concentrations were less than the reportable limit.

LIST OF FIGURES

Figure 1. Bucket of DGS and large paint mixer.

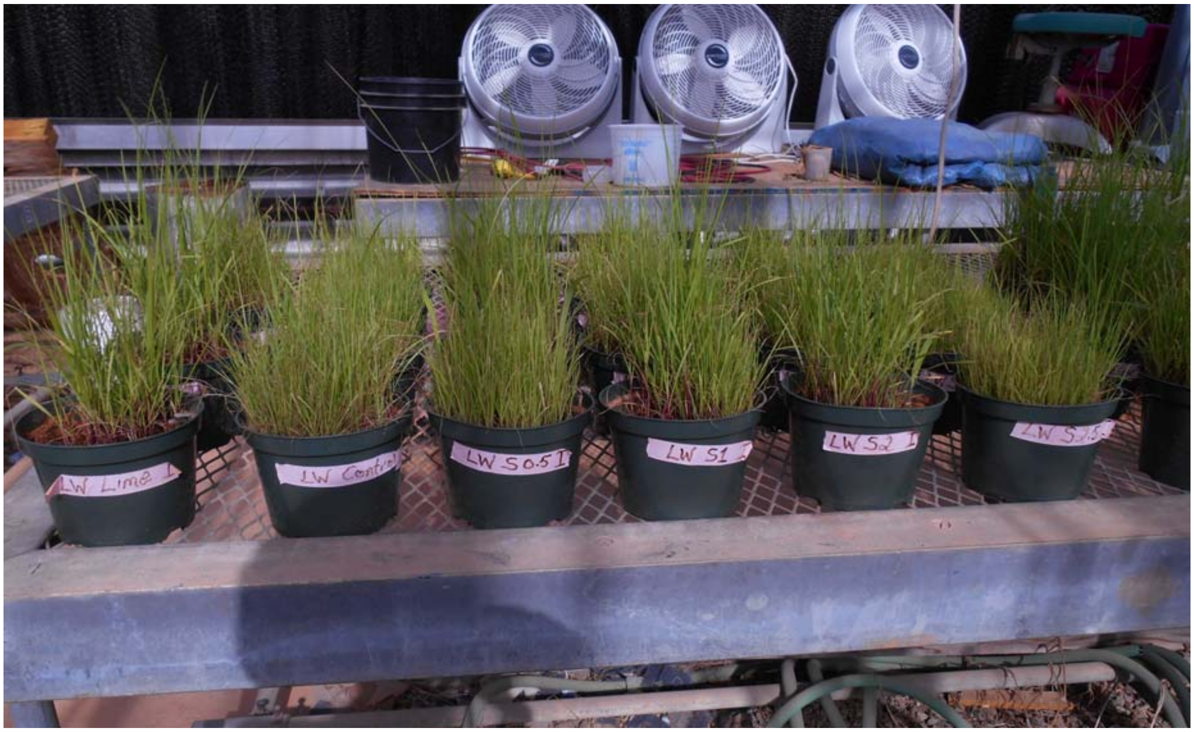

Figure 2. Pots of Bahiagrass in greenhouse trial.

Figure 3. Plots at the field trial.

Figure 4. Runoff conveyance system for plots at the field trial.

Figure 5. Application device for DGS and HRW.

Figure 6. Coated vegetation after DGS application.

Figure 7. Buckets of runoff following 10/14/2014 storm.

Figure 8. Vegetation on plots.

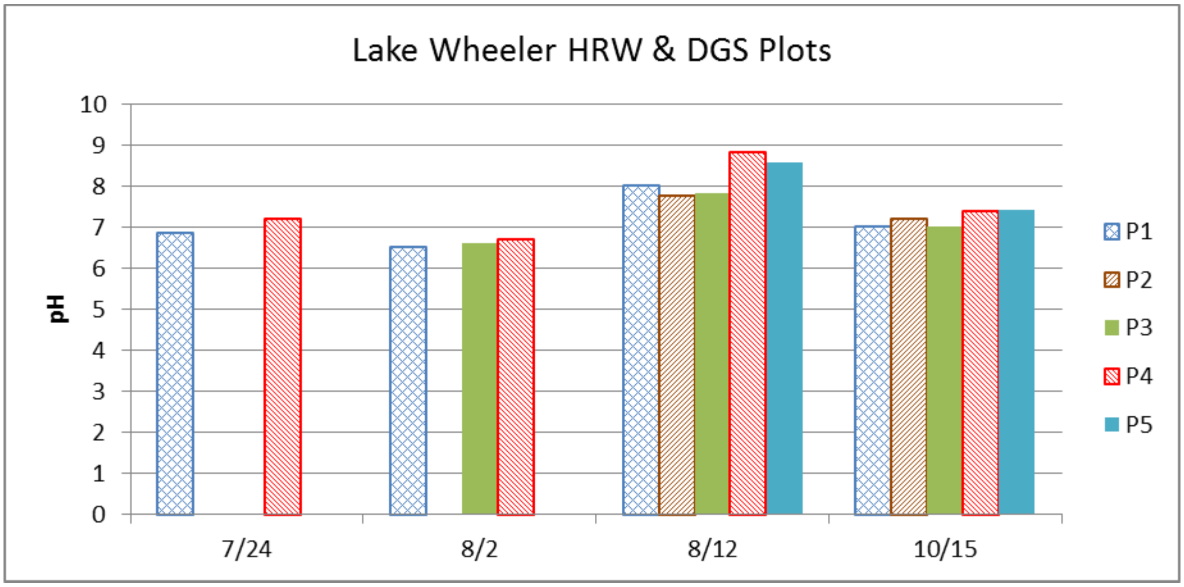

Figure 9. The pH of runoff from field trial plots (P1, P2.

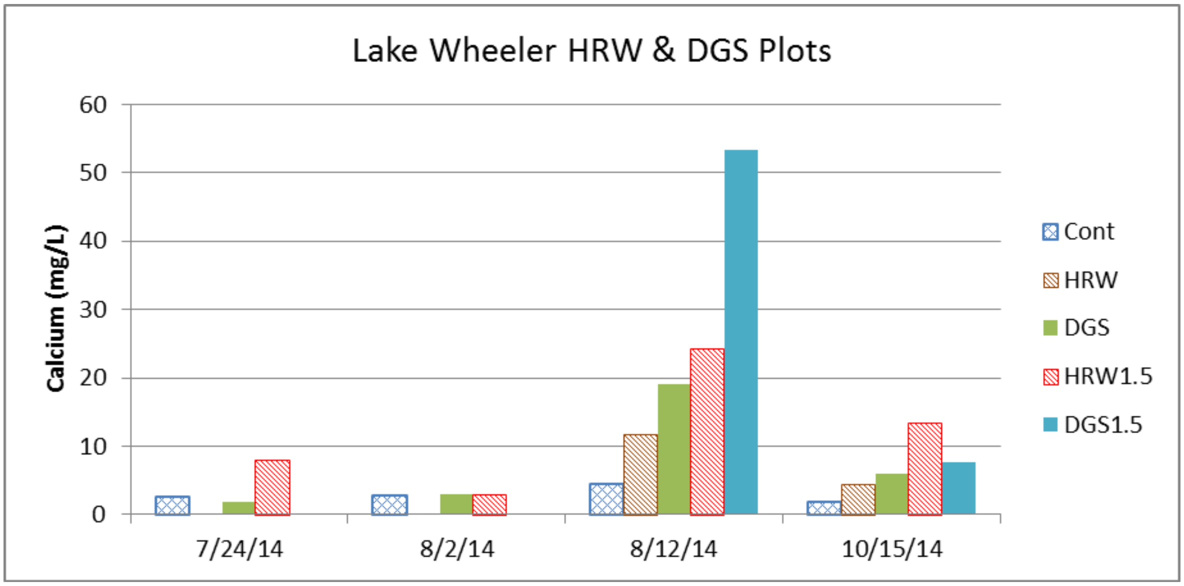

Figure 10. Concentration of calcium in runoff from field plots (DGS&HRW applied 8/11/14).

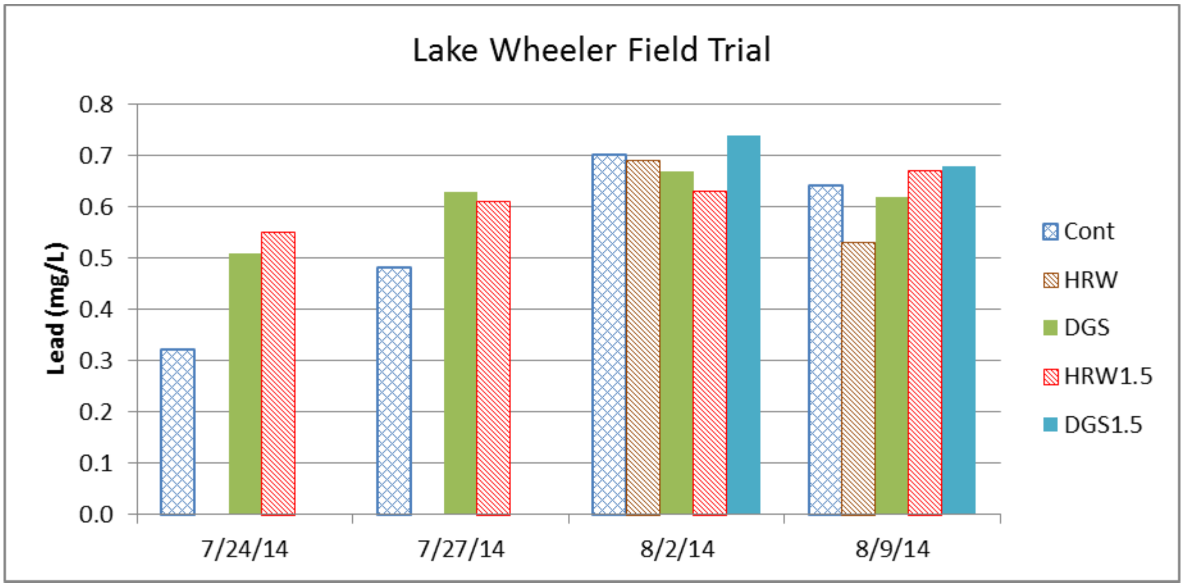

Figure 11. Concentration of lead in runoff from field trial plots (DGS&HRW applied 8/11/14).

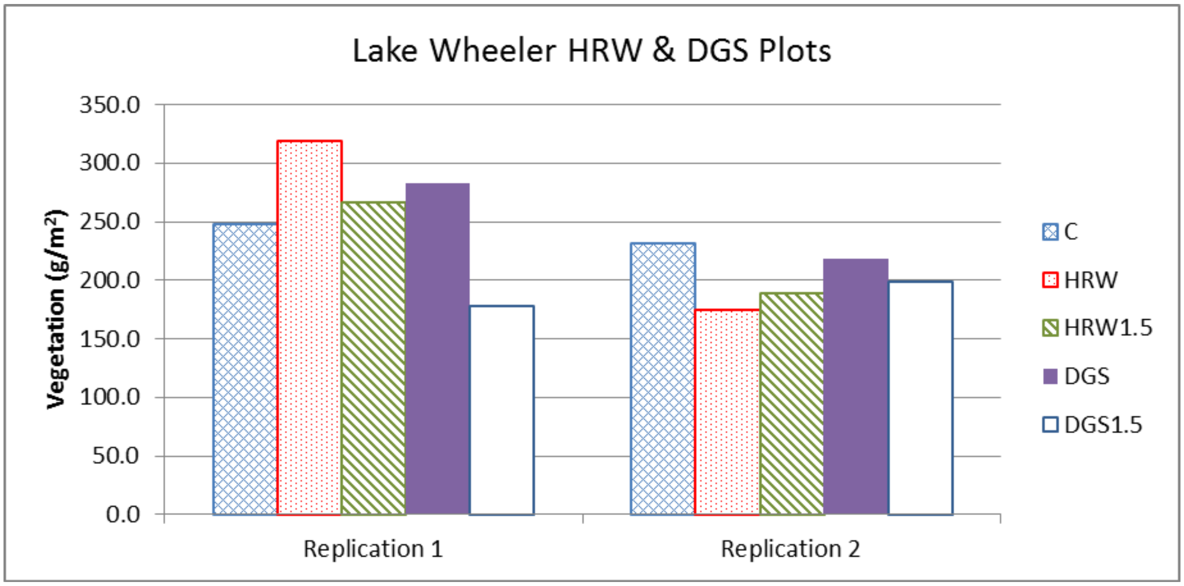

Figure 12. Mass of vegetative growth in field trial plots.