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Evaluation of Concrete Grinding Residue (CGR) Slurry Application on Vegetation and Soil Responses along Nebraska State Highway 31

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FINAL REPORT

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Summary

Diamond grinding is a concrete pavement restoration technique that corrects irregularities such as faulting and roughness on old concrete pavements and extends the life of pavement. Cooling water used during the diamond grinding of concrete pavement highways generates slurry consisting of water, concrete and aggregate residue (CGR). Recently, disposal of CGR in Nebraska changed from unregulated roadside discharge to a National Pollutant Discharge Elimination System (NPDES) permit (NDEQ, 2010). The permit is designed to control pollutant levels being land applied as a result of the spreading of CGR slurry. According to NPDES permit, the CGR primary pollutant is its alkalinity and the amount of CGR that can be roadside applied is restricted to 5 dry tons/acre or the agronomic liming rate whichever is lower.

The Nebraska Department of Roads (NDOR) is concerned that existing agronomic rate calculation methods were developed to *minimize* the active ingredient (lime) application, as such, there is also need to evaluate maximum discharge rate of CGR for cost efficiency. Therefore, this research was established to evaluate rates that will maximize the CGR discharge rate without adverse effects on roadside vegetation and soil.

We conducted a two-year study to evaluate the effect of CGR application on soil chemical properties, existing vegetation, and rainfall runoff. The study was conducted on roadsides of NE State HWY 31 at mile post 36 (MM36) in 2013 and mile post 34 (MM34) in 2014 on loam and silt loam soils, respectively. CGR slurry rate was 0, 10, 20, 30, and 40 dry tons per acre, with 40 dry tons/acre considered to be the maximum CGR rate that would be applied to roadside foreslope. Vegetation, soil, and runoff were evaluated before CGR application and one month and one year after CGR application at both mile posts. The CGR effective calcium carbonate equivalent (ECCE) ranged from 13 to 28%. The results showed that application of CGR slurry at 5 dry tons/acre, as limited by the NPDES permit[1], on medium to fine textured roadside soil does not have adverse effects on existing vegetation, soil chemical properties, and water quality. Moreover, the results indicated that a uniform application (i.e. uniform spread) of CGR of up to 40 dry tons/acre on loam and silt loam soils did not negatively affect existing vegetation, soil chemical properties, and runoff volume and chemistry. The highest CGR

[1] Part III C 3 b 3, p 6 of Permit Number NEG500000 “The application rate shall be limited to the agronomic rate or a maximum of five dry tons per acre whichever is lower”

application increased soil calcium, sodium and pH in short term (one month) but did not persist after one year of CGR application. While CGR discharge of up to 40 dry tons/acre can safely be applied in a uniform layer one time to roadsides with medium textured soils, there needs to be caution applying these high rates to coarser soils (sandy soil). Such soils may respond differently due their lower ability to retain cations or buffer pH changes. In addition, this study evaluated the CGR application after one time application based on the premise that grinding extends the life of pavement and with high likelihood that regrinding will not occur again on the same highway segment. As such, the findings of our study on soil, vegetation, and runoff water quality, should not be extended for multiple and frequent application of CGR application at the same location. This study showed that it is plausible to apply CGR slurry at rates up to 40 dry tons/acre on medium to fine textured soil without negative effects and provides evidence that rate higher than the current regulated limit of 5 dry tons/acre may be applied on roadside with similar soil characteristics as this study. However, application rates must also consider the ECCE and moisture of the CGR to adjust rate even in medium to fine textured soils. We recommend NDOR develops a quick field method to estimate the ECCE during the grinding process so that application rates can be adjusted appropriately.

Chapter 1 Introduction and Background

Diamond grinding is a concrete pavement restoration technique that corrects irregularities such as faulting and roughness on old concrete pavements and extends the life of pavement. Water used to cool the diamond cutting blades during the grinding of concrete pavement highways combines with the cutting residue generates slurry. More specifically, this slurry consists of water, hardenend cement paste and aggregate residue. In rural areas of Nebraska, this concrete grinding residue (CGR) slurry has been deposited along the highway shoulder during grinding operations. Recently, disposal of CGR in Nebraska changed from unregulated roadside discharge to a National Pollutant Discharge Elimination System (NPDES) permit (**General NPDES Permit Number NEG500000**). The permit is designed to control pollutant levels being land applied as a result of the spreading of CGR slurry. According to NPDES permit, the CGR primary pollutant is its alkalinity and the amount of CGR that can be roadside applied is restricted to 5 tons/acre or the agronomic liming rate whichever is lower. The NPDES permit defines agronomic rate as: "*the CGR rate which beneficially adjusts the pH of the soil to enhance plant growth but does not overload the soil with constituents, including pH, that may eventually leach to ground water, limit crop growth, or adversely impact soil quality*" (NDEQ, 2010). In the next paragraphs previously published information about the chemical and physical properties of CGR and soil and vegetation responses to application of CGR are summarized.

1.1 Properties of Concrete Grinding Residue

Characterization of CGR chemical properties includes inorganic and organic constituents, pH, electrical conductivity (EC), and liming quality (fineness and calcium carbonate equivalent), while physical properties studied involved particle size distribution, dissolved and suspended solids, and particle density. The main focus of the few studies on CGR properties has been on chemical properties, with emphasis in the content of inorganic and organic components that may be toxic/harmful in nature. Some studies reported CGR pH and EC, but no studies were found regarding characterization of CGR liming potential.

1.1.1 Constituents

Toxic and hazardous components: The studies from The International Grooving and Grinding Association (IGGA, 1990; DeSutter et al. 2011a and b) and the California Department of Transportation (CALTRANS, 1997) have focused on quantifying constituents of concern such as toxic metals and volatile organic compounds present in CGR. IGGA (1990) reported 16 inorganic and 9 organic CGR constituents from highways in Delaware, Pennsylvania, and South Carolina and compared them to the maximum permissible limits established by the U.S. Environmental Protection Agency (USEPA, 2013) and the North Carolina Department of Environment, Health and Natural Resources (NC-DEHNR). Given the reported composition of toxic constituents (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and benzene) were below US-EPA and NC-DEHNR limits, this report concluded "grinding slurry was non-ignitable, non-corrosive and non-toxic and considered a non-hazardous waste".

CALTRANS (1997) analyzed organic and inorganic constituents in CGR from Route 8 in California. For this study one CGR sample was collected from each of six grinders working on the same project by disconnecting the hose carrying the slurry from the grinder to the tanker truck. Each slurry sample was allowed to settle to separate the solid and aqueous phases, and constituents were analyzed on each phase. Regarding toxic regulated compounds, volatile organic compounds (benzene, toluene, ethylbenzene, xylene) and solid and aqueous phases of chlorinated pesticide and herbicide concentrations were either below detection limits or below the California Drinking Water Standards and the California Department of Toxic Substances Control Title 22 standards. Analyses of inorganic components indicated that out of 17 regulated toxic metals, 4 were below detection limits in all samples (beryllium, mercury, silver, and thallium) and 13 were below the Title 22 standards in all samples (antimony, arsenic, barium, cadmium, cobalt, copper, chromium, lead, molybdenum, nickel, selenium, vanadium, and zinc). However, a few samples met or exceeded the California Drinking Water Standards for chromium, antimony, and nickel. CALTRANS (1997) concluded that the CGR displayed no hazardous characteristics for inorganic and organic constituents when compared to the Title 22 standards.

DeSutter et al. (2011a) evaluated CGR slurry samples from California, Minnesota, Washington, Minnesota and Nebraska for the composition of the aqueous (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver) and solid phases (arsenic, barium, cadmium, chromium, cyanide, lead, mercury, selenium, and silver). The reported results regarding toxic and harmful constituents for all five states were either below report limits (cyanide, selenium, silver, chromium [hexavalent]) or below the regulatory level established by Title 40 part 261 of the Code of Federal Regulations (USEPA, 2013).

Other not regulated components: CALTRANS (1997) analyzed the aqueous phase for five not regulated metals (aluminum, magnesium, silica, iron, and calcium) and five not regulated anions (chloride, cyanide, nitrate/nitrite, sulfate, and sulfide) by the Title 22 standards. While reported sulfide concentrations were below detection limits in all samples, the concentrations of sulfate, chloride, nitrate/nitrite and calcium in the samples were larger than in the water used for the process. These ions likely contributed to the 2-3 fold increase in total amount of dissolved solids in the aqueous phase. DeSutter et al. (2011a) also analyzed the solid phase of the slurry for content of aluminum, antimony, beryllium, boron, calcium, cobalt, copper, phosphorous, iron, magnesium, manganese, molybdenum, nickel, platinum, potassium, sodium, strontium, sulfate, tin, thorium, tungstate, vanadium, and zinc. Across the five states, the most abundant cations were K (1.2 to 3.5 g kg^{-1}), Na (1.5 to 16 g kg^{-1}), Al (5.9 to 24.2 g kg^{-1}), Fe (3.5 to 27.8 g kg^{-1}), Mg (2.1 to 51 g kg^{-1}), and Ca (46 to 126 g kg^{-1}), while sulfate was the most abundant anion (0.7 to 4.1 g kg^{-1}) (DeSutter et al. 2011a). None of these ions are regulated and so there is no concern regarding their addition to soil.

1.1.2 pH and Electrical Conductivity

Reported pH values of CGR samples can be associated to the high calcium oxide content of the slurry. Goodwin and Roshek (1992) in Utah indicated CGR pH ranged 12.0 to 12.6. CALTRANS (1997) reported pH for the solid and aqueous phases of CGR ranged from 9.6 to 10.8. DeSutter et al. (2011a) reported a pH range between 11.6 and 12.5 for the aqueous phase of CGR samples from California, Minnesota, Washington, Minnesota and Nebraska. In Washington, Shanmugam (2004) reported CGR pH between 11.9 and 12.1. Evaporative drying of the slurry at 36 ºC resulted in the drop of one pH unit over a 24-hour period (CALTRANS 1997). Hanson et al. (2010) reported pH of 10.2 and 10.9 for two samples of CGR dried and reconstituted with water in Washington. In their study, the pH of each reconstituted CGR was similar for a range of concentration from 6 to 18% w/v. Druschel et al. (2012) reported a pH of 9.4 for reconstituted CGR (i.e. after re-wetting) from Minnesota but they did not report the pH before drying the slurry. Although pH of reconstituted CGR slurry is alkaline, it has not been reported how the pH of reconstituted slurry compares to the pH of the original, un-dried slurry. Hanson et al. (2010) reported the electrical conductivity of reconstituted CGR samples ranged between 0.2 and 2.1 mS.

1.1.3 Particle Size Analysis

Several particle sizes, i.e., from clay to fine gravel size, are generated during concrete diamond grinding (Druschel et al. 2012). Liming efficiency of materials is the product of the calcium carbonate equivalent times the effective calcium carbonate content which is based on the fineness of the liming material. Particles with diameter greater than 2.38 mm have 10% liming efficiency. Particles with diameter smaller than 2.38 mm but larger than 0.250 mm have 40% liming efficiency, while particles with diameter less than 0.250 mm have 100% liming efficiency (Mamo et al. 2015). DeSutter et al. (2011a) used the hydrometer and pipette method to characterize the particle size distribution of CGR. With the exception of the CGR slurry sample from California, particle size analysis of the slurry indicated the presence of silt-sized particles (0.002 - 0.02 mm) as a major constituent of the slurry (45 to 60 %), followed by fine sand-sized particles (20 to 30%) (0.2 - 0.02 mm) and coarse sand-sized particles (15 to 35%) (2 - 0.2 mm) (DeSutter et al. 2011a). Goodwin and Roshek (1992) used the hydrometer method on CGR from Utah and determined silt-size and finer particles were also the majority of the slurry (51%). Druschel et al. (2012) reported 85% of CGR samples that were previously sieved through 0.420 mm opening sieve (#40 mesh) had silt-size or finer diameter (<0.02 mm) using the hydrometer method. The large proportion of fine particles in the CGR can contribute to the high liming efficiency of the CGR and also may affect water infiltration rate into soil as the result of potentially clogging soil pores.

1.1.4 Suspended Solids, Dissolved Solids and Total Solids

The CGR can have variable amounts of total solids and solids in suspension/solution in the aqueous phase. Goodwin and Roshek (1992) indicated total suspended solids in the aqueous phase were greater than 50 mg L^{-1}. CALTRANS (1997) reported dissolved solids concentration of aqueous phase varied between 1300 to 2500 mg L^{-1}. DeSutter et al. (2011a) reported total solid content of CGR varied from 15.5 to 48.1% w/w with an average dissolved solids concentration of 3500 mg L^{-1}. Druschel et al. (2012) estimated an average of 800 minutes for sedimentation of 80% of suspended solids of CGR samples. By 24 hours, about 15% of total solids still remained in suspension.

1.2 Soil and Plant Responses to CGR Additions

Common disposal of CGR slurry have been along the highway shoulder during grinding operations in rural areas. Three studies were identified that evaluated plant and soil responses to CGR application. Shanmugam (2004) evaluated the impact of CGR slurry applications on soil pH and metal composition in Washington. In that study, soil samples from sites that received CGR slurry in the last 6 or 11 years were compared to soil samples from adjacent sites that had not received CGR slurry. DeSutter et al. (2011a) evaluated the impact of mixing different amounts of CGR with two contrasting textured soils on infiltration using soil columns. In an additional greenhouse experiment, DeSutter et al. (2011b) evaluated the effect of mixing different rates of CGR with soil on smooth bromegrass (*Bromus inermis* Leyss.) germination, growth, and composition and on soil chemical properties.

1.2.1 Soil Responses to CGR Application

Chemical composition: Shanmugam (2004) evaluated the levels of lead, cadmium, copper, zinc, magnesium, and calcium and found a high variability of metal concentrations in soils from the roadside evaluation study. The soil concentrations of lead, cadmium, copper, and zinc were not associated with the past application of CGR, while soil calcium and magnesium concentrations were greater on the sites with past applications of CGR. DeSutter et al. (2011b) evaluated a larger list of metals in a greenhouse experiment using soils of two different textures and two sources of CGR. The CGR was applied at 37 and 116 tons/acre rates to the soil and mixed with the soil. Soil concentrations of calcium, magnesium, sodium, sulfur, and aluminum increased with the application of CGR, while concentrations of silver, arsenic, beryllium, cadmium, chromium, mercury, nickel, antimony, selenium, tin, thorium, and vanadium were not consistently related to CGR application rate across the four soil-CGR source combinations (DeSutter et al. 2011b). The soil concentrations of calcium and magnesium in the control treatment at the end of the greenhouse study increased up to 6 and 10 times respectively compared to the original soil concentrations, which could be associated to the source of water to irrigate the treatments.

pH: On the roadside evaluation study, Shanmugam (2004) indicated an increased surface soil pH in one site six years after receiving CGR (pH 7.6 to 9.3) compared to adjacent soils which had not received CGR (pH 7.5). Similarly on a second site, surface soil pH 10 years after CGR addition ranged from 7.3 to 8.2, one pH unit higher than in adjacent soils not impacted by

CGR (pH 7.1 to 7.2). Subsurface soil samples at both roadside locations had pH values from 1 to 2 units higher in the areas that received CGR compared to non-treated areas. In the greenhouse study, DeSutter et al. (2011b) found a significant increase of soil pH in the CGR-treated samples after 80 days. The increase in pH was similar across rates and greater in the fine sandy loam soil (0.6 to 0.9 pH units) than in the silty clay soil (0.3 to 0.6 pH units).

EC: DeSutter et al. (2011b) found significant increases in EC values with application of CGR at 25% by weight compared to the control and the 8% by weight rate. They also reported a significant differences in EC between the CGR sources used, which could be attributed to the different concentrations of dissolved solids in the solution phase of the CGR sources.

Infiltration/ Hydraulic Conductivity: DeSutter et al. (2011a) evaluated water infiltration time with application of CGR using 2.5 cm (1 inch) diameter packed soil columns. On the coarser texture soil no influence of CGR was determined in the infiltration time; however, on the finer textured soil, infiltration time was reduced with the addition of CGR at 25% by weight and mixed with the soil or addition of CGR as a 2.5 mm layer on top of the soil. Druschel et al. (2012) evaluated the effect of CGR loading rate (particle sizes <0.841 mm) on the saturated hydraulic conductivity (K_{sat}) of sand filters using the center 30 cm (12 inches) diameter ring of a double ring infiltrometer. Adding CGR at a rate of 1 pound per square foot reduced the sand K_{sat} by 94% compared to no addition of CGR, while addition of CGR at a rate of 2 pounds per square foot reduced sand K_{sat} by 97%. The authors said that the reduction in sand K_{sat} was because of the clogging of the sand filter surface by the CGR sediments. Contrasting results between DeSutter et al. (2011a) and Druschel et al. (2012) could be attributed to the scale and methodology used in these laboratory studies.

1.2.2 Plant Responses to CGR Application

We found no specific studies about plant survival after application of CGR to established vegetation stands in the literature. No observations were reported in a study in which soil had received CGR in the past was compared to non-treated areas (Shanmugam, 2004). DeSutter et al. (2011b) conducted a greenhouse study to evaluate the growth and chemical composition of smooth bromegrass in CGR-treated soils. They used different textured soils with and without the addition of two CGR sources and then seeded the smooth bromegrass in pots. The authors reported that regardless of CGR source, shoot biomass of smooth bromegrass growing in a 25% CGR:soil mixture (w/w) was similar (coarse-textured soil) or reduced (fine-textured soil) compared to the control, while the biomass of plants growing in a 8% CGR:soil mixture was similar (fine-textured soil) or greater (coarse-textured soil) than the control. Plant tissue calcium and sulfur concentrations increased and magnesium concentration decreased with CGR addition. While the CGR sources were rich in calcium, magnesium and sulfate, the magnesium:calcium ratio in the soil at the end of the greenhouse study was significantly reduced with the addition of CGR which may explain the reductions in magnesium concentration in the plant tissue. Extrapolations of the results from DeSutter et al. (2011b) to field conditions, i.e. enhancement of vegetation growth, are not justified without further testing since CGR is applied to the vegetation in the field instead of mixed with the soil.

No reports in the literature have been identified that evaluated short- and medium-term effects of CGR application to in-situ soil properties or existing roadside vegetation. Furthermore, no studies in this topic have been conducted in Nebraska. Thus research to determine the effect of one-time application of different CGR rates to roadside soil properties and existing vegetation is needed. By monitoring how different roadside soils and vegetation communities respond to several rates of CGR, we expect to develop guidelines on the amount of CGR that can be safely applied for specific soil/vegetation combinations where Nebraska Department of Roads (NDOR) plans to conduct diamond grinding operations.

1.3. Objective

Determine the maximum rates of CGR that can be applied to roadside sites without negatively affecting soil properties (chemical and physical) and existing vegetation.

Chapter 2 Materials and Methods

2.1 Preliminary Testing

Collection of CGR samples during a diamond grinding operation in Grand Island was conducted on 16 October 2012 from the truck (i.e. when dumping the slurry in the disposal pit) and from the grinding machine (on site) in one liter glass jars.

The slurry samples in the glass jars were weighed and air dried to estimate percent solids. The samples were pulverized for elemental analysis (nitrogen, phosphorous, potassium, calcium, magnesium, sulfur, sodium, zinc, iron, manganese and copper) and lime quality analysis. The laboratory determinations were conducted at Ward Lab.

A laboratory experiment was initiated to evaluate the pH of the slurry after drying and rewetting. Rewetting of the slurry was done adding 80 ml water (distilled and tap) to 40 g dry slurry. The slurry pH was measured right after rewetting, and at 1, 2 and 24 hours after rewetting. Also, pH was measured after the rewetted slurry was added to soil similar to that of the anticipated experimental application site (NE State HWY 31) and allowed to dry. Soil and dried slurry was mixed and 40 gr sample and 40 mL distilled water used for pH measurement.

2.2 Sites That Received Slurry in the Past

2.2.1 Sites and Slurry Application

Soil samples were collected in August 2013 from two sites that had received CGR in the past: U.S. HWY 75 near Auburn (40º 46’ 28” N and 95º 83’93” W) and NE State HWY 92 east of U.S. HWY 81 northbound (41º 19’ 194” N and 97º 36’ 712” W). Slurry had been applied in August 2011 on NE State HWY 92 and in May 2012 on U.S. HWY 75. The GPS coordinates of sampling sites from U.S. HWY 75 were compared with the information received from NDOR of slurry application near Auburn to determine if sampling points corresponded to with or without slurry application. For NE State HWY 92, all the sampling points corresponded to past slurry application sites. As such, a new sampling was conducted in August 2014 further east of Surprise spur on NE State HWY 92 to which no slurry had been applied. Samples were processed and analyzed identically.

2.2.2 Soil Sampling and Analyses

Six soil cores (0-12" depth) were collected at each of 14 sampling points for a total of 84 samples **(Figure 2.1)**. The sampling points were georeferenced. At each sampling point 3 cores (cores 1 to 3) were taken near the road (2 feet off the paved shoulder) and 3 cores (cores 4 to 6) were taken close to the ditch (6 feet off the paved shoulder).

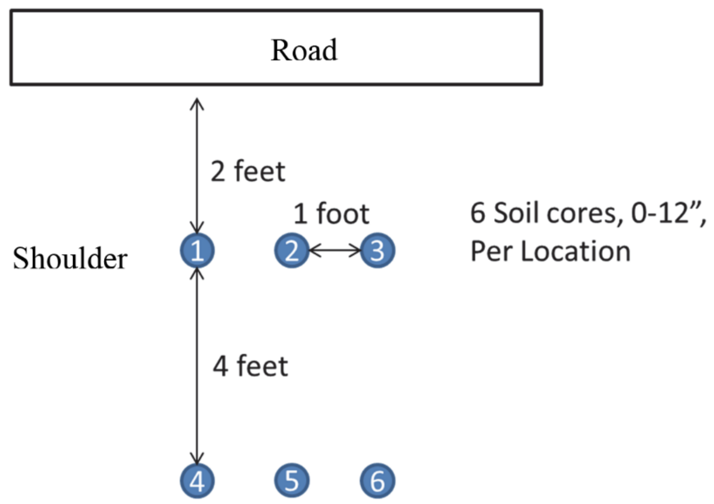

Figure 2.1 Layout of soil sampling strategy at each sampling point on U.S. HWY 75 and NE State HWY 92

The samples were split in 0-3 and 3-6 inches depth, air dried, ground to pass through 2 mm mesh sieve and combined for each location X slope position X soil depth for a total of 56 samples at each NE State HWY 92 and U.S. HWY 75 sites. Samples were sent to Ward Lab to determine pH (1:1) and EC (1:1).

2.3 Controlled Rate Application Experiments

2.3.1 Sites

Slopes of the shoulder of NE State HWY 31 were measured on 16 points between MM28 to MM36 on NE State HWY 31, (north of Elkhorn, to determine the range of slopes in sites that were both uniform in vegetation and adjacent to a relatively flat road area. Slopes varied between 9.3 to 23.8%. The selected sites for the experiment had an average slope of 21.3% for MM36, and 12.5% for MM34. The shoulders of both sites had established vegetation dominated by cool season grasses. Soil textural classes were from loam to silt loam at two sites with pH > 7.0 **(Table 2.1)**.

Table 2.1 Baseline soil properties of sites for 2013 and 2014 field experiments on NE State HWY 31 MM36 and MM34

Soil Properties	NE State HYW 31, MM36 2013	NE State HYW 31, MM34 2014
pH	8.2	8.5
EC, dS m^{-1}	0.86	1.2
Clay, %	22.4	11.6
Silt, %	39.1	53.1
Sand, %	38.5	35.3
Texture	Loam	Silt Loam
Ca, mg kg^{-1}	5 093	3 537
K, mg kg^{-1}	272	290
Na, mg kg^{-1}	778	897
Mg, mg kg^{-1}	160	154

2.3.2 Slurry Source and Characteristics

Slurry used in site MM36 experiment was collected directly from a diamond grinding operation in Grand Island into 55-gallon barrels in October 2012. The barrels were placed inside a building at the Agricultural Research and Development Center (ARDC) near Mead, Nebraska in November 2012 to prevent freezing. Slurry used at the MM34 site experiment was collected in a mixing cement truck from a diamond grinding operation in Elkhorn, Nebraska in May 2013 and transferred into 55-gallon barrels at the ARDC. Given the volume and lack of homogeneity of the grinding slurry both barrel to barrel and within barrel because of settling, the slurry for each experiment was air-dried, mixed to homogenize, and then re-wetted to approximate water content at an actual diamond grinding operation on the experimental sites at the time of treatment application.

Slurry density was estimated from the slurry in five barrels. Slurry in the barrels was agitated for five minutes using a power mixing paddle and 3 samples were collected in plastic bottles while still agitating the slurry. Slurry density was calculated by weighing and measuring volume of the slurry in the bottles (approach 1) and also by drying one sample and calculating the density with assumed solid density of 2.5 Mg m^{-3} (approach 2). The slurry density was 1.23

Mg m^{-3} (10.3 lb gal^{-1}) and 1.29 Mg m^{-3} (10.8 lb gal^{-1}), for the first and second approach, respectively.

Four subsamples of dried slurry from each experiment were used to determine moisture of the dried slurry to adjust application rate; the Effective Calcium Carbonate Equivalent (ECCE); potassium, calcium, magnesium and sodium concentrations (percent by weight) (Ward Lab.); and the heavy metal content (arsenic, cadmium, cobalt, copper, molybdenum, nickel, lead, mercury, selenium and zinc) following EPA method 200.7 (Midwest Laboratories).

2.3.3 Treatment Application

At each site, the field experiment consisted of 5 blocks with 5 treatments (0, 10, 15, 20, 40 dry tons slurry/ acre) per block. Application of treatments at the MM36 site occurred on 18 July 2013 (blocks 3, 4 and 5) and 22 July 2013 (blocks 1 and 2) 2013. Application of treatments at the MM34 site occurred on 6 June 2014. Blocks were laid out from south to north with treatments (0, 5, 10, 20 and 40 dry tons/acre, for treatment numbers 0, 1, 2, 3 and 4, respectively) randomly assigned to the plots within the block **(Figure 2.2)**.

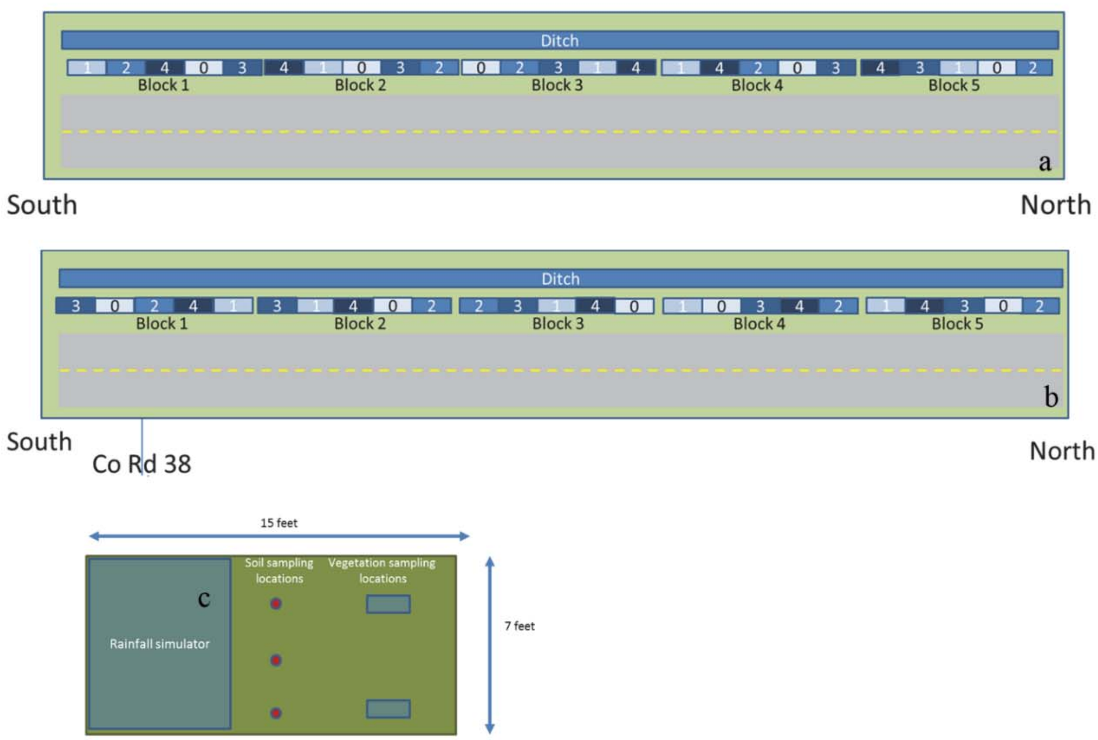

Figure 2.2 Experimental sites layout on NE State HWY 31 for 2013 at MM36 (a), 2014 at MM34 (b) and plot size and sampling locations within a block (c)

At both sites, the dried slurry was weighed into 5 gallon plastic buckets. Tap water was added on site to each bucket. The slurry was mixed to ensure complete wetness and more water was added to each bucket as needed to achieve a density of 10.5 lb gal^{-1}. To ensure uniform application coverage of the plot area, the slurry was applied by hand at the appropriate rate using small plastic pitchers **(Figures 2.3 to 2.6)**. **Figures 2.3 and 2.4** are from the application of treatments on 18 July 2013 at MM36 site, and **Figures 2.5 and 2.6** are from the application of treatments on 6 June 2014 at MM34 site.

Table 2.2 summarizes the dry and lime equivalent tons applied at 2013 field experiment on NE State HWY 31 MM36 site. The dried slurry had an average moisture of 22% which resulted in the effective rates of dry slurry (0% moisture) of 0, 4.1, 8.2, 16.4 and 32.9 tons/acre for each treatment. Slurry rates applied were converted to lime equivalent rates by multiplying by the average ECCE of the slurry (13%). These rates were: 0, 0.5, 1.1, 2.1, and 4.3 tons lime equivalent/acre respectively.

Table 2.2 Slurry rates for 2013 field experiment on NE State HWY 31 MM36

Target Slurry Rates tons / acre (Mg / ha)	Applied Slurry Rates tons / acre	Applied Lime Equivalent Rates* tons / acre
0	**0**	**0**
5	**4.1**	**0.5**
10	**8.2**	**1.1**
20	**16.4**	**2.1**
40	**32.9**	**4.3**

* Slurry rates were converted to lime equivalent rates by multiplying by the average ECCE of the slurry (13%).

Table 2.3 sumarizes the rates applied at 2014 field experiment on NE State HWY 31 MM34 site. Based on the experience of the previous year, more slurry was weighed into each bucket for MM34 site to compensate for moisture. The dried slurry used in MM34 site had an average moisture of 14% which resulted in the effective rates of dry slurry (0% moisture) of 0, 5.5, 10.9, 21.8 and 43.7 tons/acre for each treatment. Slurry rates applied were converted to lime equivalent rates by multiplying by the average ECCE of the slurry (28%). These rates were: 0, 1.5, 3.1, 6.2, and 12.3 tons lime equivalent/acre respectively.

Table 2.3 Slurry rates for 2014 field experiment on NE State HWY 31 MM34

Target Slurry Rates tons / acre	Applied Slurry Rates tons / acre	Applied Lime Equivalent Rates* tons / acre
0	**0**	**0**
5	**5.5**	**1.5**
10	**10.9**	**3.1**
20	**21.8**	**6.2**
40	**43.7**	**12.3**

* Slurry rates were converted to lime equivalent rates by multiplying by the average ECCE of the slurry (28%).

Figure 2.3 Rewetting and mixing the slurry

Figure 2.4 Application of slurry to plots

Figure 2.5 Rewetting and mixing the slurry

Figure 2.6 Side view of the plots after slurry

2.3.4 Soil Assessment before and after CGR Application

Base-line soil characterization was conducted at both sites prior to the application of treatments. At MM36 site, three soil samples (0-6 inches) were collected per block, combined, air dried and passed through 2 mm mesh sieve. Baseline soil sampling of MM34 site was done on the control (0 tons/acre CGR) plots of each block. At both locations, soil samples were collected at 8, 10 and 12 feet away from the road. At each distance, 3 subsamples (0-12 inches deep) were collected. Samples were split into 3 depths: 0-3 in, 3-6 in, and 6-12 in, air dried and sieved. Composite samples were made by depth within each distance. Baseline analyses included pH, electrical conductivity (EC), organic matter (OM), and particle size analysis (PSA).

Soil samples from each plot were collected also at one month and at one year after treatment application for both sites. Three soil cores (0-12 inches) were taken at three slope positions **(Top, Mid, Bottom, Figure 2.2)** on each plot for a total of 9 cores per plot. Cores were split into 0-3, 3-6, and 6-12 inches, combined by depth for each slope position within each plot, air dried, and sieved (2 mm) before analyses. Soil samples were analyzed for pH (1:1), EC (1:1), and exchangeable cations (calcium, magnesium, potassium, and sodium) and other soil nutrients (copper, iron, manganese, phosphorous, sulfate-sulfur, and zinc) by Ward Lab.

2.3.5 Vegetation and Ground Cover Assessment

Botanical composition and ground cover assessments were conducted at both sites on all plots using a quadrat method (Daubenmire 1953; **Figure 2.7**) before, one month after and one year after slurry application. At each time, botanical composition and groundcover were measured on two quadrats per plot except for the one year after at the MM34 site where only one reading was done due to plot disturbance from construction. Ground cover was classified into bare ground, litter, plant base, and slurry cover, while aerial botanical composition of canopy was classified by species.

Biomass production was measured at one month and one year after application of treatments on both sites except the one year after at the MM34 site. After the ground cover and botanical composition assessment were completed, the vegetation in the same two quadrats per plot was clipped to ground level and separated into seeded (tall Fescue) and non-seeded species (Kentucky Blue grass, Smooth Brome grass), and dried at 60 ^{o}C before weighing.

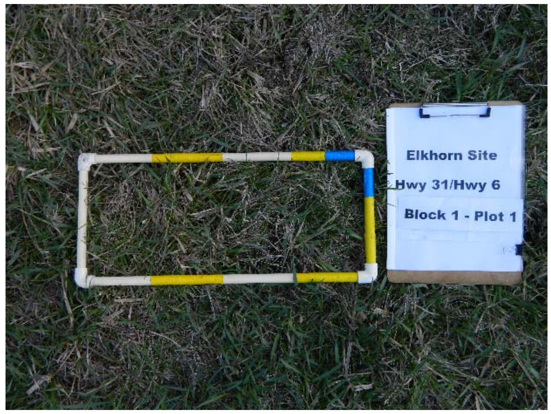

Figure 2.7 Daubenmire frame for vegetation assessment

2.3.6 Rainfall Simulation and Runoff

Rainfall simulator, TLALOC 3000 (Joern´s Inc. West Lafayette, IN), described in Humphry et al. 2002 was used for the runoff simulation. A 3.3 ft by 1.6 ft steel frame made by the UNL-Tractor Test Lab was used for collection of runoff under the simulator **(Figure 2.8)**.

Figure 2.8 Steel frame, 3.3 ft by 1.6 ft (a) and setup (b) used for rainfall runoff collection

We tested the rainfall simulator functioning and distribution uniformity by running it twice for 5 minutes each time both at 4 PSI and 5 PSI pressure. Each time, 25 cups were placed in the center of each cell of a 5 by 5 grid (16*16 inch). At the time of simulation tarps were used on two sides of the simulator due to wind **(Figure 2.8b)**. At the end of each simulation, the volume in each cup was recorded and a coefficient of variation was calculated.

We tested the head of water effect on the volume of water delivered by the pump. We filled a 50 gallon can with water and submerged the water pump attached to a 20 feet hose. We ran the pump and kept a constant water head while recording the time needed to fill a 5 gallon plastic pail. We tested 3 different heads of water (30 in, 24 in, and 18 in) in triplicates. We also tested the effect of coiling of the hose on the volume of water delivered by the pump. We run the pump with constant head of water and having the hose either coiled or extended.

Based on 10 year recurrence interval and 1 hour duration maximum precipitation event around Lincoln and Omaha areas, the rainfall simulations in the roadside experiments had a target intensity of 2.4 inches/hour (NOAA Atlas 14 Point Precipitation Frequency Estimates: NE http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ne). Procedures for rainfall simulation on the experimental sites were as follows: The steel frame was pounded into the ground in the center of the simulation area. Soil moisture at time of rainfall simulation was evaluated by taking 3 soil samples (0-15 cm deep) around the runoff frame prior to rainfall simulation. The soil samples were composited, weighed and dried at 105 ^{o}C for gravimetric moisture determination.

Rainfall simulation was run at 4 PSI pressure measured at the emitter. The rainfall simulation was run for 30 minutes once runoff began from the downslope end of the steel runoff frame. Time required for runoff to begin after initiation of simulated rainfall and total time of simulation were recorded. Total amount of rain applied was measured by placing 3 rain gauges around the runoff frame. After runoff commenced, volume was measured every five minutes for 30 minutes. A subsample of the runoff volume was transferred into 250 mL plastic bottles for analysis of pH, EC, turbidity and total solids.

Baseline rainfall simulation was conducted before application of treatments on the control treatment (0 tons/acre) plots of each block. The pre-application simulated rainfall intensity (average over all five blocks) was 2.1 inches/hr for the MM36 site and 2.9 inches/hour for the MM34 sites **(Table 2.4)**. One month after slurry application, rainfall simulations were conducted on the 0, 20, and 40 tons/acre treatment plots of all blocks at intensity of 2.9 inches/hr for MM36 and 2.3 inches/hr for the MM34 site **(Table 2.4)**.

Table 2.4 Summary of rainfall intensity, total rainfall, and average total runoff across block and treatment before and one-month after CGR slurry application at NE State HWY 31 MM36 and MM34

	Before CGR Application	**1-Mo. after CGR Application**
	MM36	
Rainfall intensity (in/h)	2.1	2.9
Total 30 min Rainfall (mm)	1.2	1.7
Total Runoff (mm)	0.02	0.12
Soil Moisture (g g^{-1})	0.15	0.20
	MM34	
Rainfall intensity (in/h)	2.9	2.3
Total 30 min Rainfall (in.)	1.6	1.5
Total Runoff (in)	0.81	0.16
Soil Moisture (g g^{-1})	0.23	0.17

2.3.7 Data Analyses

Data were analyzed using a factorial design with slurry treatment, slope position and soil depth as fixed effects. Proc Mixed (SAS) procedure was used for the analysis of variance. Means and standard errors were calculated for slurry, slurry by depth, and slurry by slope. For significant effects (alpha=0.05), least square means were computed and declared significant at 0.05 probability level.

Chapter 3 Results and Discussion

3.1 Sites That Received Slurry in the Past

The soil pH and EC data were averaged by site and CGR slurry application history. The analyses of variance for pH and EC data are presented in **Table 3.1** (U.S. HWY 75) and **Table 3.2** (NE State HWY 92).

Table 3.1 Analysis of variance for soil pH and EC in U.S. HWY 75 using a factorial design with slurry treatment, slope position and soil depth as fixed effects

Treatment (rate not known)	**pH**	**EC (dS m^{-1})**
No Slurry	8.3	1.36
Slurry	8.3	1.81
No Slurry, 0-3”	8.5	1.18
Slurry, 0-3”	8.6	1.60
No Slurry, 3-6”	8.1	1.55
Slurry, 3-6”	8.1	2.02
Effects	**Pr > F**	
Slurry	0.7338	0.0271
Slope	0.4287	0.0042
Slurry * Slope	0.5302	0.6604
Depth	0.0004	0.0529
Slurry * Depth	0.6284	0.8940
Slope * Depth	0.3503	0.9358
Slurry * Slope * Depth	0.2729	0.9057

Table 3.2 Analysis of variance for soil pH and EC in NE State HWY 92 using a factorial design with slurry treatment, slope position and soil depth as fixed effects

Treatment (rate not known)	**pH**	**EC (dS m^{-1})**
No Slurry*	7.8	0.61
Slurry	8.1	0.67
No Slurry, 0-3”	8.1	0.65
Slurry, 0-3”	8.1	0.49
No Slurry, 3-6”	7.6	0.57
Slurry, 3-6”	7.9	0.82
Effects	**Pr > F**	
Slurry	0.0719	0.7165
Slope	0.6871	0.8043
Slurry * Slope	0.0202	0.1515
Depth	0.0061	0.2494
Slurry * Depth	0.1296	0.0766
Slope * Depth	0.5287	0.3930
Slurry * Slope * Depth	0.8166	0.7068

*Two samples per depth of no slurry obtained in August 2014.

For U.S. HWY 75, soil pH was not affected by slurry application for the different soil depths, slope positions, and their combination **(Table 3.1)**. Soil pH was significantly higher at the 0-3" depth (pH=8.5) compared to the 3-6" depth (pH=8.1) **(Figure 3.1a)**. Soil EC values were well below the threshold of 4 dS/m for plant root growth. The increased in soil EC with depth was not significant **(Figure 3.1b)**. The higher EC value close to the road likely is associated with anti-icing/de-icing salts applied in winter to the road being washed to road shoulder and so are not related to CGR application. The higher pH closer to soil surface but lower EC may also be related to anti-icing/de-icing salts. Both sodium chloride and calcium chloride salts will completely dissolve in soil. Sodium and calcium ions have positive charges and can be held by the negatively charged clay minerals of soil, thus remaining in the first few inches of soil adsorbed to clays. In contrast, total dissolved salt is leachable. The addition of sodium chloride salts can lead to displacement of calcium ions from soil clays by the sodium ions, resulting in the increase of pH on soil surface. The leaching of the dissolved salts in turn can explain the increase in EC of soil with depth. Particle size analysis of the slurry indicated the presence of silt-sized particles (0.002 - 0.05 mm) as a major constituent of the slurry (45 to 60 %) (DeSutter et al. 2011a; Goodwin and Roshek, 1992). As fine particles will be more soluble than coarse particles, larger quantities of the former will more greatly increase the EC of grinding slurry (Hanson et al. 2010). DeSutter et al. (2011b) found significant increases in soil EC values with application of CGR at 25% and 8% by weight rate compared to no slurry being applied.

There are alternate explanations for the increase in EC without change in pH with slurry application along U.S. HWY 75. This site received approximately 5 tons (dry equivalent) of slurry per acre in 2012. We speculate that the amount of fines added with the slurry was so significant (i.e. 50 % of the total solids being applied) as to increase EC of soil at both depths as some of these fines leached into soil. We speculate that the lack of effect of slurry on soil pH on U.S. HWY 75 is due to a high soil buffer capacity, a low liming potential of slurry, or a combination of both factors.

For NE State HWY 92, slurry application did not have a significant effect on soil pH or EC **(Figure 3.2)**. However, depth as well as slurry by slope interactions did have significant effects on soil pH but not EC **(Table 3.2)**. Soil pH was higher at the 0-3" depth than 3-6" depth.

Near road (2 feet from road) pH was higher where slurry was applied, however, 6 feet from the road (near ditch), pH was higher in soil without slurry history.

The pH values for these shoulder soils were around 8.0 while EC values where well below 4 dS/m, suggesting no limitations for plant growth (Waskom et al. 2014). After 1.5 and 2 years of application of CGR to the shoulder soils there was no clear trend on soil pH and EC values. We speculate these soils may buffer the concentration of salts and solutes present in the CGR slurry.

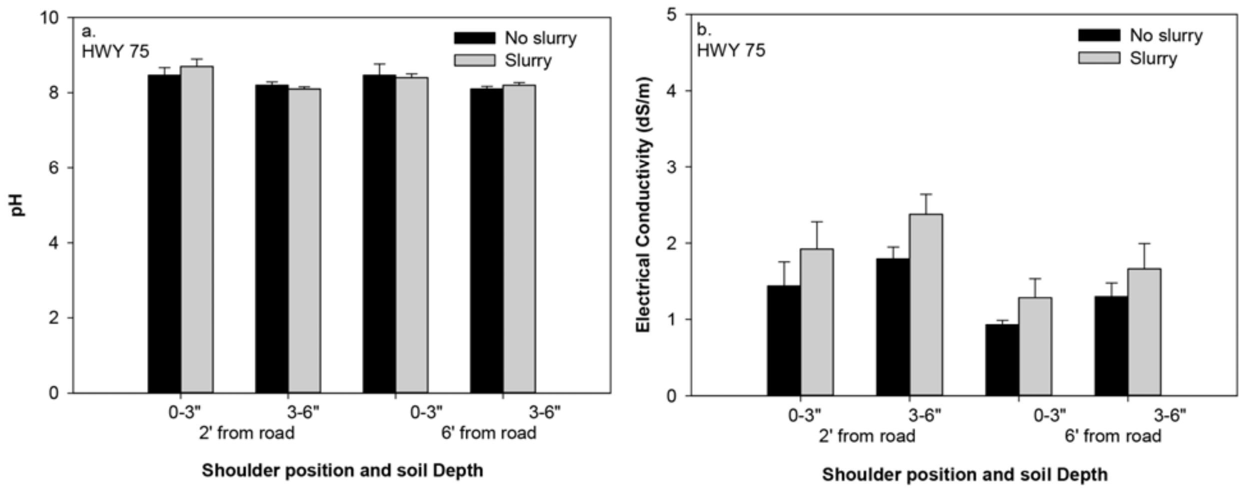

Figure 3.1 Soil pH (a) and EC (b) at U.S. HWY 75 North of Auburn, NE, for sites with and without application of slurry

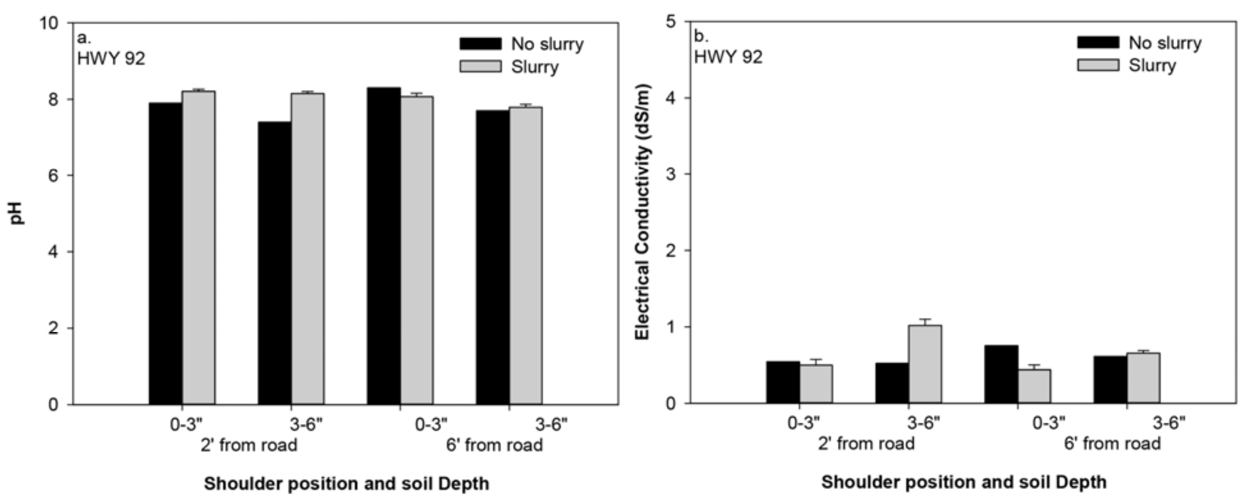

Figure 3.2 Soil pH (a) and EC (b) in NE State HWY 92 east of U.S. HWY 81, NE, for sites with and without application of slurry

3.2 Preliminary Testing of Slurry

3.2.1 Slurry pH after Rewetting of Dried Slurry

Changes in pH after mixing dried slurry with water or soil were measured over 24 hour period. The pH slurry-water mixture increased from initial rewetting of pH 9 to pH 10 two hours after rewetting. There was an increase in pH of 1 unit after mixing soil and slurry compared to the original soil pH **(Figure 3.3)**.

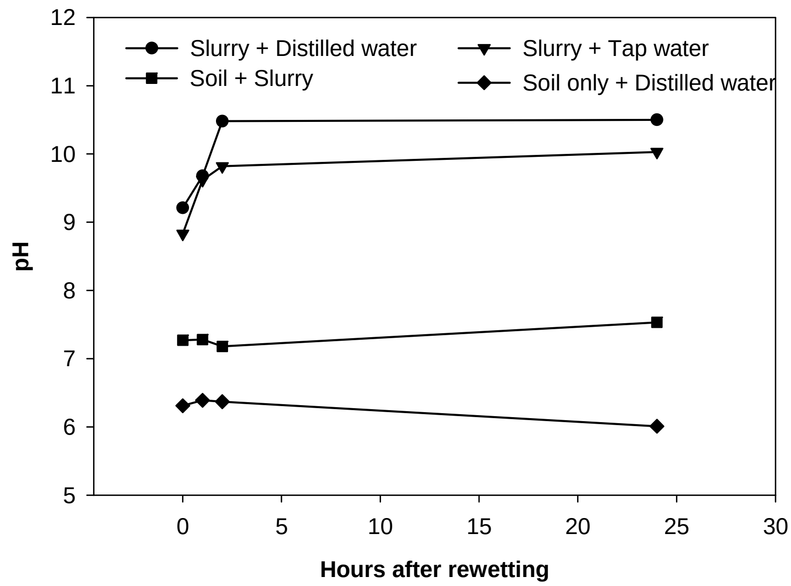

Figure 3.3 Changes in pH of rewetted slurry and soil after addition of slurry

3.3 Roadside Experiments

3.3.1 Slurry Properties

Cation Content and Lime Quality

Dried slurry used in the field experiments was analyzed to determine Effective Calcium Carbonate Equivalent (ECCE) and K, Ca, Mg and Na concentrations (percent by weight). **Table 3.3** summarizes cation content and lime quality data for both years. Slurry ECCE was twice as high in 2014 compared to 2013. For both years, the highest nutrient in slurry was Ca, followed by Na, Mg and K **(Table 3.3)**. Additional nutrient testing was performed for the slurry used in 2014 experiment. Average N, P, S, Zn, Fe, Mn and Cu contents were 200, 206, 4278, 39, 4815, 143, and 11 ppm, respectively.

Table 3.3 Nutrient composition and lime quality of slurry used for 2013 and 2014 field experiments

Year	K	Ca	Mg	Na	ECCE	fineness	$CaCO_3$	Moisture
	---------------- % by weight ---------------				%		%	%
2013	0.15	10.28	0.26	0.41	13.1	0.53	24.85	25
2014	0.12	12.40	0.30	0.39	28.2	0.74	38.10	14

Heavy Metals

Samples of the slurry used during application of treatments in NE State HWY 31 MM36 (2013) and MM34 (2014) were sent to Midwest Laboratories for determination of total heavy metals concentration **(Table 3.4)**. Mercury, arsenic, and selenium concentrations were below detection levels. All the heavy metals analyzed had concentrations well below the threshold levels for hazardous materials.

Table 3.4 Total heavy metal concentration of the dried concrete grinding slurry used in field experiments in 2013 and 2014. Reporting limit from Midwest Laboratories. BRL: Below reporting limit. Threshold limits taken from USEPA 2014, and CALTRANS 1990

	As	Cd	Co	Mo	Ni	Pb	Se	Zn	Hg	Cu	Cr
	mg kg^{-1}										
2013	BRL	0.6	12.9	7.7	12.4	5.9	BRL	48.2	BRL	15.3	11.4
2014	BRL	BRL	22.0	4.6	9.3	5.5	BRL	38.2	BRL	10.6	9.7
Reporting Limit	10	0.5	1	1	1	5	10	1	0.05	1	1
Threshold Limit	500	100	8000	3500	2000	1000	100	5000	20	2500	2500

3.3.2 Vegetation Responses

Site 1-MM36

Botanical composition and ground cover were estimated before slurry application at the MM36 site on 7 June 2013. Across the five blocks, the amount of bare ground (no cover) constituted less than 5% of the area **(Figure 3.4a)**. Canopy cover was dominated by 3 grasses: Tall Fescue (seeded), Kentucky bluegrass (non-seeded) and smooth bromegrass (non-seeded). Less than 15 % of the canopy cover across plots was composed of non-seeded annual and perennial forbs (common ragweed, knotweed, bindweed, and dandelion). Some elm seedlings were also present in the plots.

At one month after CGR application there was no significant vegetation response to slurry application at both slope positions **(Table 3.5, Figure 3.4b)**. However, slurry by slope interaction was significant. Near the road, slurry application did not affect litter cover, but decreased litter cover decreased with increasing slurry rate near the bottom or ditch position (6 feet from road). One year after CGR application, there was no slurry effect on ground cover **(Table 3.6, Figure 3.4c)**. There was higher litter cover near road than the bottom ditch position.

Table 3.5 Analysis of variance for vegetation cover <u>one month</u> after CGR slurry application at NE State HWY 31 MM36

	Pr > F						
	Bare	Litter	Plant Base	Seeded	Non Seeded	Weeds	Slurry*
Slurry	0.1737	0.4289	0.5259	0.1631	0.1724	0.7926	-
Slope	0.6139	0.2681	0.0884	0.6949	0.1985	0.1571	-
Slurry * Slope	0.3110	0.0024	0.3182	0.8278	0.5172	0.3640	-

*Slurry covered not measured

Table 3.6 Analysis of variance for vegetation cover <u>one year</u> after CGR slurry application at NE State HWY 31 MM36

	Pr > F						
	Bare	Litter	Plant Base	Seeded	Non Seeded	Weeds	Slurry
Slurry	0.4702	0.5181	0.4582	0.6140	0.4792	0.2612	0.2285
Slope	0.1033	0.0338	0.0126	0.5077	0.8850	0.2117	0.3877
Slurry * Slope	0.3243	0.3879	0.7942	0.0993	0.4570	0.2612	0.6983

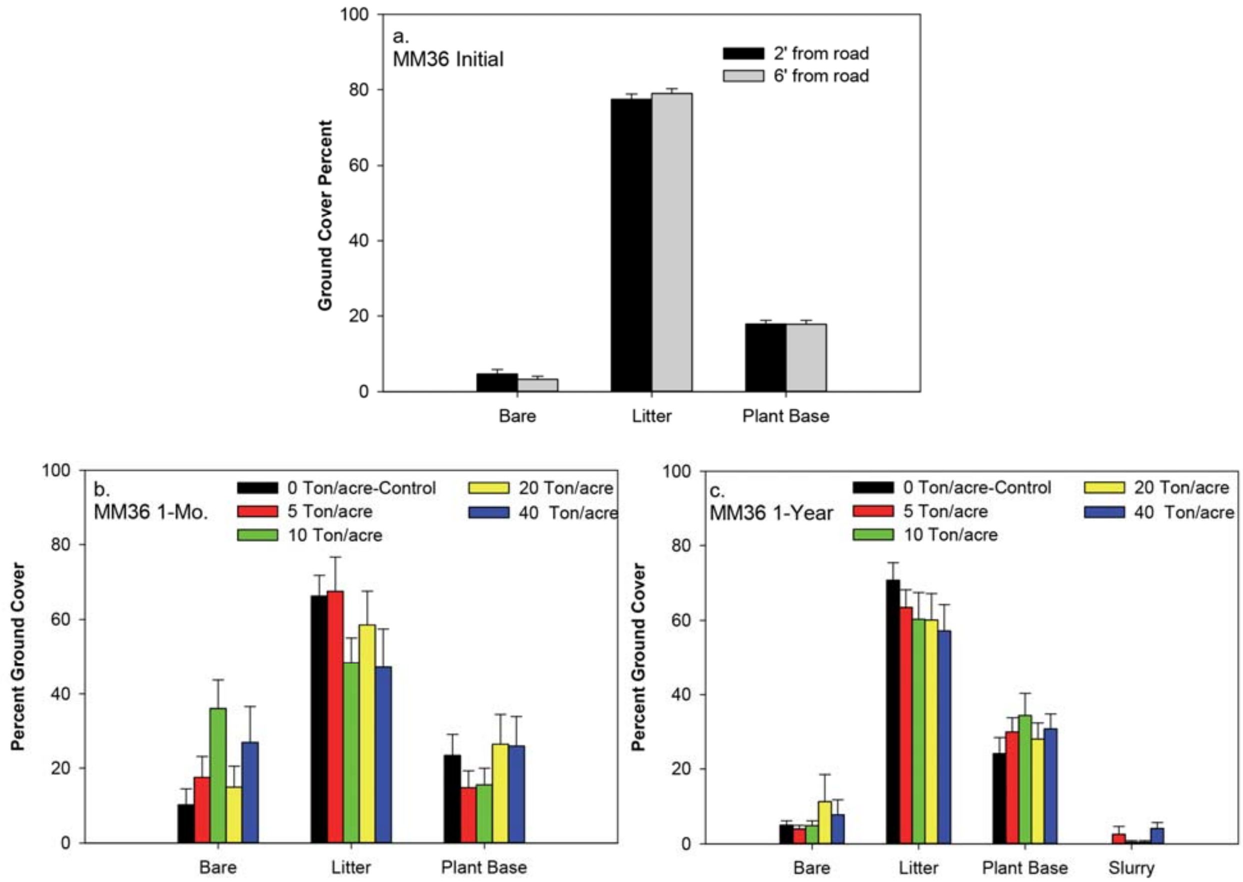

Figure 3.4 Ground cover of plots on NE State HWY 31 MM36 site before application of treatments (a), one month after application of treatments (b), and one year after application of treatments (c)

Biomass production of non-seeded species at both one month and one year after slurry application was higher than seeded species and ranged from 725 to 5505 lb/acre **(Tables 3.7 and 3.8)**. There was no significant slurry effect on both seeded and non-seeded biomass one month and one year after slurry application. However, there was slurry by slope interaction for seeded species biomass both one month and one year after slurry application.

Table 3.7 Biomass production of seeded and non-seeded species on NE State HWY 31 MM36 site one month after CGR slurry application

Treatment (Ton/acre)	Biomass (lbs/a)		Total Biomass lbs/a
	Seeded species	Non Seeded species	
0	1489	959	2448
5	910	1107	2016
10	1471	725	2196
20	571	1016	1587
40	772	977	1750
Effects	**P > F**	**P > F**	
Slurry	0.1271	0.9477	
Slope	0.4113	0.1302	
Slurry * Slope	0.0230	0.0920	

Table 3.8 Biomass production of seeded and non-seeded species on NE State HWY 31 MM36 site one year after CGR slurry application

Treatment (Ton/acre)	Biomass (lbs/a)		Total Biomass lbs/a
	Seeded species	Non Seeded species	
0	595	4777	5372
5	585	4856	5441
10	632	5504	6135
20	720	4753	5473
40	1142	3525	4667
Effects	**P > F**	**P > F**	
Slurry	0.6336	0.3107	
Slope	0.1385	0.3637	
Slurry * Slope	0.0487	0.5559	

Site 2-MM34

At the MM34 site, baseline botanical composition and ground cover was determined on 30 May 2014. Across the five blocks, the amount of bare ground (no cover) was in general less than 20% of the area **(Figure 3.5a)**. Canopy cover was dominated by smooth bromegrass (non-seeded). Less than 5% of the canopy cover across plots is composed of common ragweed and dandelion. Estimation of botanical composition and ground cover was determined on 7-8 August 2014, one month after slurry application assessment. Across the five blocks, the amount of bare ground (no soil cover) was in general 5% of the area for all treatments **(Figures 3.5b and 3.5c)**.

With the increase in slurry rate, there was an increase in the ground area covered by slurry and a decrease in litter cover with increasing slurry rate **(Table 3.9, Figure 3.5b)**. Canopy cover was dominated by smooth bromegrass (non-seeded), tall fescue (seeded) and Kentucky bluegrass (non-seeded) in all treatments. One month after application of slurry there were no differences in the botanical composition of the canopy cover among treatments. One year after slurry application, there was a decrease in seeded species with increasing slurry application rate **(Table 3.10)**.

Table 3.9 Analysis of variance for vegetation cover <u>one month</u> after CGR slurry application at NE State HWY 31 MM34

	Pr > F						
	Bare	**Litter**	**Plant Base**	**Seeded**	**Non Seeded**	**Weeds**	**Slurry**
Slurry	0.2640	0.0002	0.2517	0.3894	0.2280	0.1907	<0.0001
Slope	0.5047	0.1327	0.1928	0.7497	0.8160	0.6234	0.0687
Slurry * Slope	0.2241	0.5567	0.5422	0.4814	0.5778	0.8508	0.2363

Table 3.10 Analysis of variance for ground cover one year after CGR slurry application at NE State HWY 31 MM34. (Note upper slope position was covered by construction soil, thus vegetation cover was measured ONLY in bottom or ditch position.)

	Pr > F						
	Bare	**Litter**	**Plant Base**	**Seeded**	**Non Seeded**	**Weeds**	**Slurry**
Slurry	-	0.4951	0.4951	0.0322	0.1696	0.6557	-

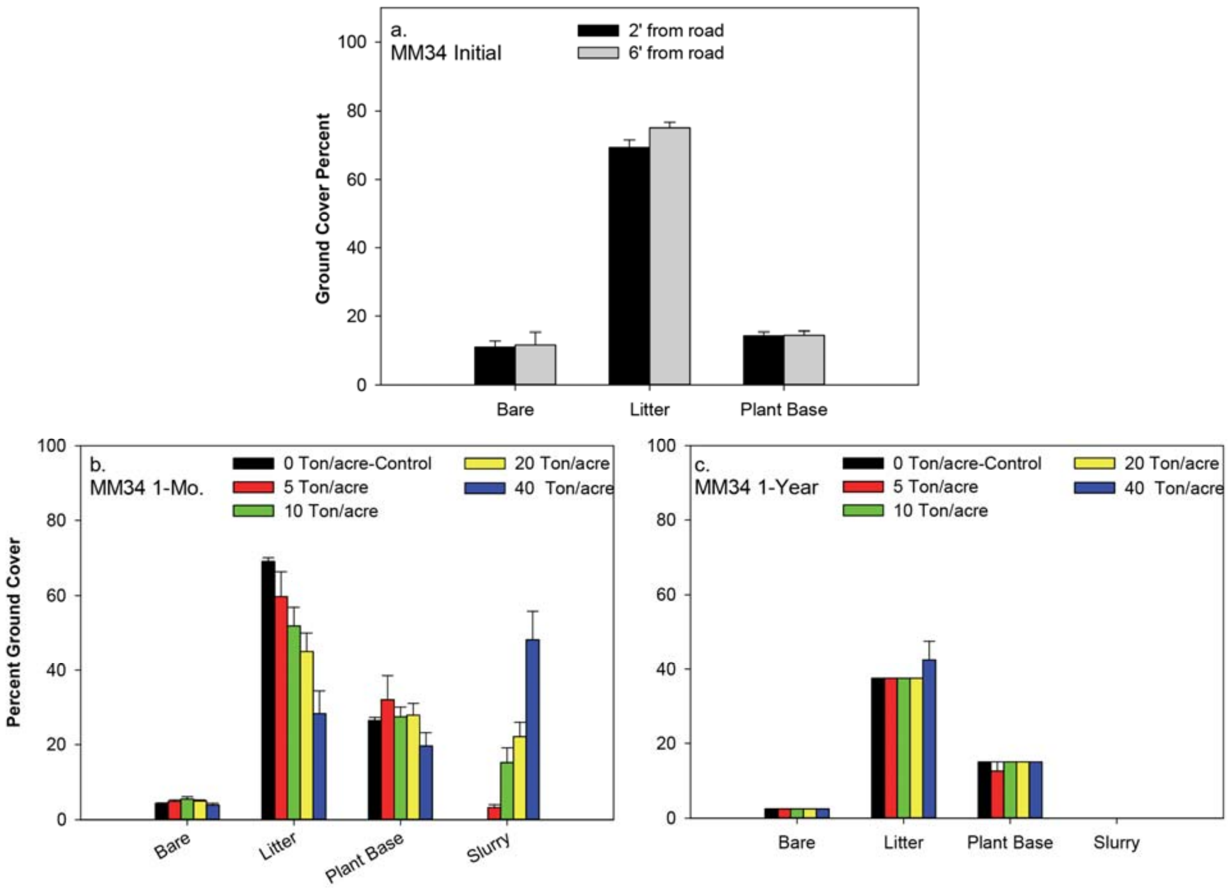

Figure 3.5 Ground cover of plots on NE State HWY 31 MM34 site before application of treatments (a), one month after application of treatments (b), and one year after application of treatments (c)

Biomass production was measured one month after slurry application, on 7-8 August 2014, for seeded and nonseeded plant species. Tall fescue was the only example seeded species; whereas, non-seeded species included smooth bromegrass, Kentucky bluegrass, and annual forbs and grasses. Biomass production ranged from 1764 to 2184 across the slurry rates **(Table 3.11)**. Seeded species production (306-645 lbs/acre) was lower than non-seeded species production (1205-1555 lbs/acre), similar to the Site 1 MM36 experiment. There was no biomass response to slurry one month after application. Slope was significant for non-seeded biomass, higher in lowest landscape position compared to top or mid-slopes.

Table 3.11 Biomass production of seeded and non-seeded species on NE State HWY 31 MM34 site <u>one month</u> after CGR slurry application

Treatment (Ton/acre)	**Biomass (lbs/a)**		**Total Biomass lbs/a**
	Seeded species	**Non Seeded species**	
0	629	1555	2184
5	561	1458	2018
10	629	1340	1969
20	306	1458	1764
40	645	1205	1850
Effects	**P > F**	**P > F**	
Slurry	0.6237	0.4979	
Slope	0.1901	<0.0001	
Slurry * Slope	0.9599	0.5019	

3.3.3 Runoff Amount and Sediments

Site 1-MM36

Runoff before application of treatments was conducted at Elkhorn site on 10 and 15 July 2013 on the control treatment (0 tons/acre) plots of each block then on 15 August 2013 for one month after CGR application. The simulated rainfall intensity (average over all five blocks) was 2.1 in/hr and 2.9 in/hr (equivalent to a 10-year storm for the area) for rainfall simulation before and after CGR application, respectively **(Table 3.12)**. Soil moisture, by mass, in the first 2 inches was low and below 15% at time of initial simulation and 20% at the time of the one month rainfall simulation. Runoff rate peaked in the second 5 min collection period and then stabilized **(Figure 3.6)**.

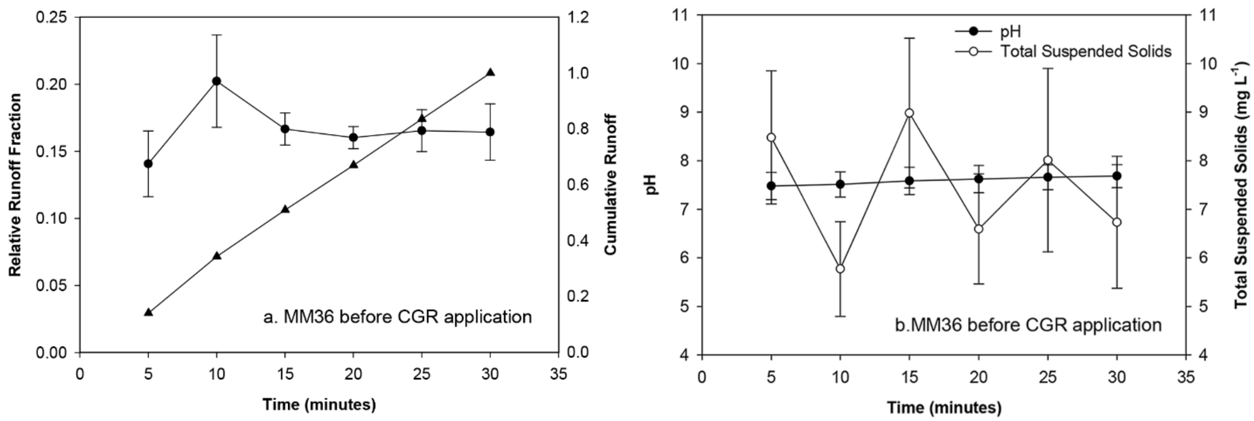

Figure 3.6 Simulated average rainfall runoff distribution (a) and runoff pH and total suspended solids (b) measured before CGR application (10-15 July 2013) at NE State HWY 31 MM36 site

For the pre-application simulation, the pH of the runoff water had a tendency to increase slightly from the southern-most block (Block 1- neutral pH) to the northern-most block (Block 5, slightly alkaline pH) (data not shown) with average pH for initial simulation of 7.5. Total suspended solids (TSS) were variable over time. Average total runoff volume, runoff fraction, runoff pH, EC, and TSS were not significantly different among CGR slurry rates **(Table 3.12)**.

Table 3.12 Average runoff volume depth, runoff fraction, pH, electrical conductivity (EC), and total suspended solids (TSS) one month (15 August 2013) after CGR application at NE State HWY 31 MM36

Treatment (Ton/acre)	Runoff Total Volume (mm)	Runoff Fraction*	pH	EC	TSS
0	2.8	0.083	7.31	0.78	0.97
20	3.0	0.090	7.44	0.76	2.44
40	3.7	0.101	7.49	0.85	0.98
P > F	0.9666	0.9858	0.5143	0.5989	0.3708

*Runoff volume fraction relative total amount of rainfall

Site 2- MM34

Runoff on the control treatment (0 tons/acre) plots of each block was conducted on 22 May 2014. The simulated rainfall intensity (average over all five blocks) was 2.9 in/hr, equivalent to a 5 year storm, and the average runoff collection was 20.6 mm in 30 minutes.

Runoff rate stabilized after the third 5 min collection period **(Figure 3.7a)**. Initial runoff pH was less than 7.0 and EC was less than 0.50 dS/m **(Figure 3.7b)**.

Rainfall simulations one month after application of treatments were performed on 0, 20, and 40 t/A rate plots on 7-11 July 2014. The simulated rainfall intensity (average over all five blocks) was 2.3 inches/hr, equivalent to a 10 year storm. The average runoff collection in 30 minutes was 4.5, 5.3 and 2.1 mm for the control, 20 and 40 Ton/acre treatments, respectively, which represented 11, 15 and 5% of the simulated rain. As on the MM36 site, CGR application had no effect on runoff volume, fraction pH, or EC **(Table 3.13)**.

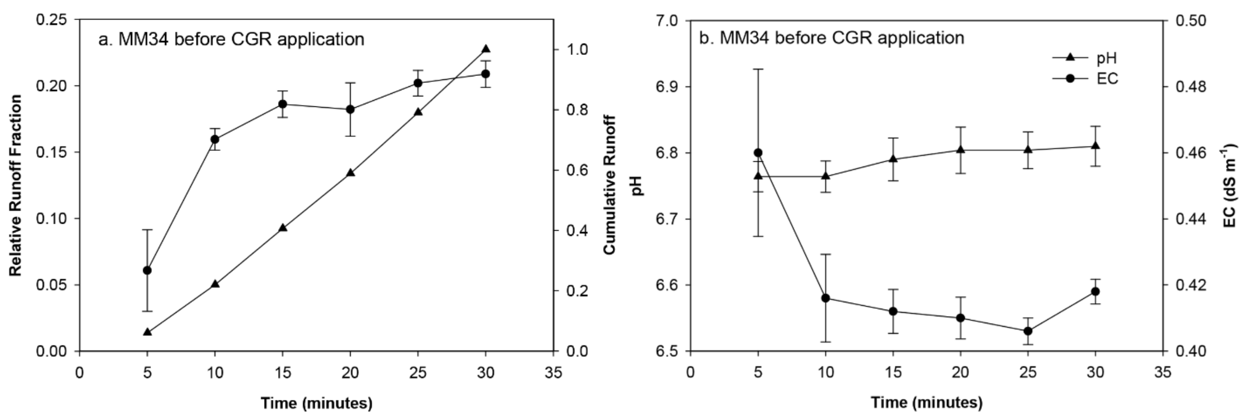

Figure 3.7 Simulated rainfall runoff distribution (a) and runoff pH and total suspended solids (b) measured before CGR application (22 May 2014) at NE State HWY 31 MM34 site

Table 3.13 Average runoff volume depth, runoff fraction, pH, and electrical conductivity (EC) <u>one month</u> (7-11 July 2014) after CGR application at NE State HWY 31 MM34*

Treatment (Ton/acre)	Runoff Total Volume (mm)	Runoff Fraction+	pH	EC
0	4.5	0.11	7.5	1.0
20	5.3	0.15	7.7	1.0
40	2.1	0.05	7.9	1.1
P > F	0.2614	0.1973	0.1138	0.7174

*sample insufficient volume for TSS measurement

3.3.4 Soil Responses

Site 1-MM36

pH, EC, and Exchangeable Cations

For the 2013 field experiment, pre-slurry application soil pH averaged 7.6, while soil EC averaged 0.7 dS m^{-1}. The adjacent agricultural site had soil pH of 5.74 and EC of 0.3 dS m^{-1}. Soil at the site was loam with 22.4% clay and 39% sand.

Without application of slurry, soil pH averaged 8.3 and EC averaged 0.8 dS m^{-1}. Both soil pH and EC increased with increasing CGR application rate. The highest CGR application rate (4.28 Tons Lime Eq. / acre) produced a significantly higher soil pH (8.4) than the control (8.3). The increase in soil EC over control was significant at both 20 and 40 tons/acre compared to the control **(Figure 3.8a and Table 3.14)**. At one month after slurry application, soil depth and slope position did not have a significant effect on soil pH or soil EC. One year after slurry application, soil pH at the highest slurry application remained higher than the control **(Table 3.15)**.

At one month after slurry application, exchangeable Mg, Na, Ca, and K were different based on soil depth. There was a significant decrease in exchangeable K with slurry application compared to control **(Table 3.14)**. Exchangeable Na level increased significantly with CGR application. For exchangeable Ca, there was an increase with increasing application rate in the 0-3” depth, while the changes at the 3-6” depth were not associated to slurry rate.

One year after slurry application, soil pH remained higher at the highest slurry rate of 40 tons/acre. However, EC and exchangeable cations were not significant **(Table 3.15)**.

Table 3.14 Soil pH, electrical conductivity, potassium, calcium, magnesium, and sodium at NE State HWY 31 MM36 site <u>one month</u> after CGR application

CGR (Ton/acre)	pH	EC dS m⁻¹	K	Ca	Mg	Na
			--------------------mg kg⁻¹---------------------			
0	8.3	0.79	231	4106	156	608
5	8.0	0.87	294	4756	152	698
10	8.0	0.83	291	4792	156	649
20	8.4	0.94	219	4072	140	757
40	8.4	1.03	184	4536	133	769
Effects			**P > F**			
Slurry	< 0.0001	0.0278	0.0112	0.0685	0.1143	0.2764
Slope	0.8073	0.0703	0.1127	0.5022	0.2487	0.2069
Depth	< 0.0001	< 0.0001	< 0.0001	0.0009	< 0.0001	< 0.0001
Slurry * Slope	0.9961	0.4408	< 0.0001	0.7852	< 0.0001	0.1305
Slurry * Depth	0.0070	0.0117	0.0162	< 0.0001	0.0219	0.0783

Table 3.15 Soil pH, electrical conductivity, potassium, calcium, magnesium, and sodium at NE State HWY 31 MM36 site <u>one year</u> after CGR application

CGR (Ton/acre)	pH	EC dS m⁻¹	K	Ca	Mg	Na
			--------------------mg kg⁻¹---------------------			
0	8.2	0.90	215	4176	147	584
5	8.1	0.91	240	4150	139	528
10	8.0	0.81	238	4210	145	449
20	8.2	0.99	210	4159	143	693
40	8.3	0.96	189	4530	128	616
Effects			**P > F**			
Slurry	0.0065	0.4621	0.2529	0.6051	0.5146	0.1824
Slope	0.3342	0.2498	< 0.0001	0.9277	0.0068	0.1662
Depth	< 0.0001	0.0100	< 0.0001	< 0.0001	0.0257	< 0.0001
Slurry * Slope	0.8678	0.2039	0.2507	0.9951	0.3867	0.3935
Slurry * Depth	0.4164	0.7586	0.1556	0.3879	0.0846	0.0037

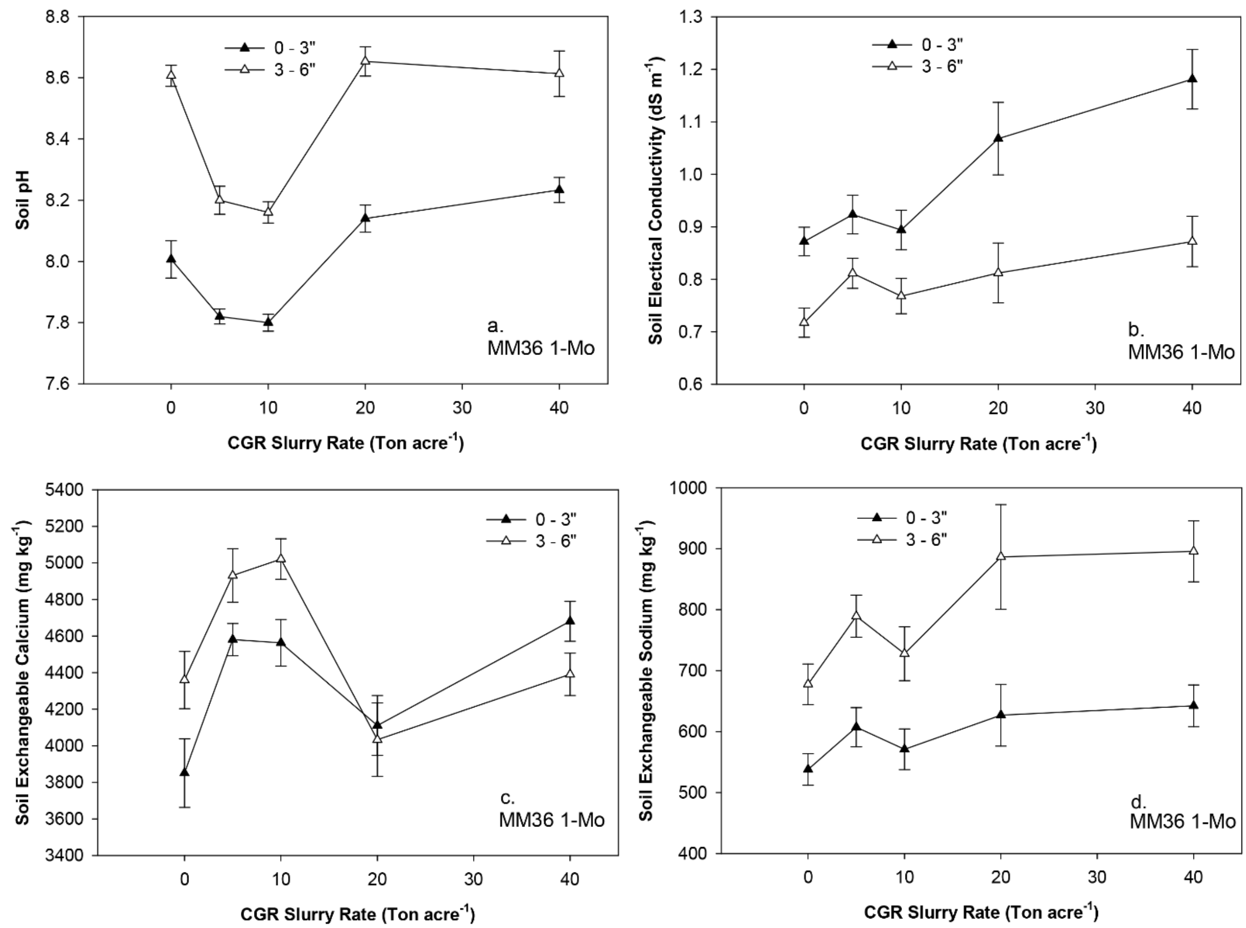

Figure 3.8 Soil pH (a), soil electrical conductivity (b), soil calcium (c) and soil sodium (d) measured <u>one month</u> after CGR application at NE State HWY 31 MM36 site

Site 2-MM34

pH and EC

For the 2014 field experiment, baseline soil pH averaged 8.5, while soil EC averaged 1.24 dS m^{-1}. Similar to the NE State HWY 31 MM36 site, pH was slightly alkaline with excess lime. There is minimal concern with soil salinity (i.e. EC is below 4 dS m^{-1}) and exchangeable calcium (3732 mg kg^{-1} or 74% soil saturation); however, there may be concern with high sodium (953 mg kg^{-1} or 17% soil saturation) as second dominating cation (soil high in sodium have alkaline pH, low EC, and sodium saturation greater than 15%).

At one month after slurry application, there was no significant slurry effect on pH, EC, K, Mg, and Na **(Table 3.16)**. Soil pH and EC were higher at the 3-6” depth at all slurry rates

(Figure 3.9). Slurry effect on Ca was significant, increasing with increasing slurry rate **(Figure 3.9)**. One year after slurry application, there was no significant slurry effect on any soil chemical properties measured **(Table 3.17)**.

Overall CGR rate did not show significant negative effect on soil one year after slurry application, suggesting roadside discharge of CGR at the rates used in this study will not have any detrimental effects on soil properties measured.

Table 3.16 Soil pH, electrical conductivity, potassium, calcium, magnesium, and sodium at NE State HWY 31 MM34 site <u>one month</u> after CGR application

CGR (Ton/acre)	pH	EC	K	Ca	Mg	Na
		dS m^{-1}	--------------------mg kg^{-1}--------------------			
0	8.7	1.27	279	3399	152	752
5	8.8	1.16	285	3551	146	640
10	8.8	1.17	323	3762	161	611
20	8.8	1.34	311	3786	147	795
40	8.9	1.34	314	4029	154	707
Effects			**P > F**			
Slurry	0.3515	0.4499	0.6220	0.0217	0.4904	0.6319
Slope	0.3166	0.0211	< 0.0001	0.1906	0.0003	0.1244
Depth	< 0.0001	0.0322	0.2522	0.0002	< 0.0001	< 0.0001
Slurry * Slope	0.3495	0.1496	0.6811	0.6863	0.0540	0.4203
Slurry * Depth	0.0550	0.5854	0.0535	0.1458	0.1596	0.0263

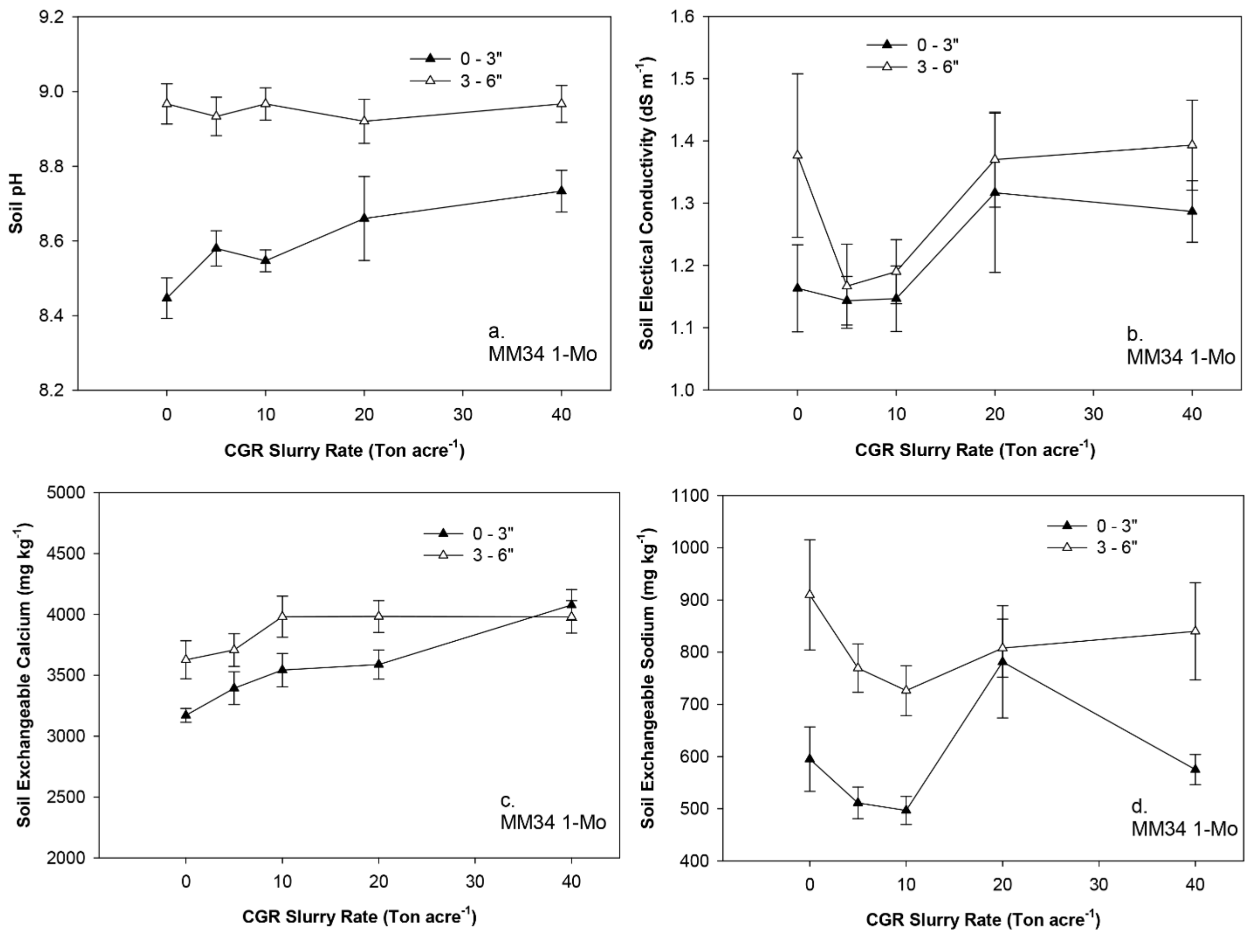

Figure 3.9 Soil pH (a), electrical conductivity (b), soil calcium (c), and soil sodium (d) one month after CGR slurry application at NE State HWY 31 MM34 site

Table 3.17 Soil pH, electrical conductivity, potassium, calcium, magnesium, and sodium at NE State HWY 31 MM34 site one year after CGR application

CGR (Ton/acre)	pH	EC	K	Ca	Mg	Na
		dS m^{-1}	--------------------mg kg^{-1}--------------------			
0	8.1	0.74	259	3835	162	1031
5	8.1	0.57	300	4434	206	647
10	8.2	0.58	305	4390	175	638
20	8.2	0.59	301	4498	179	736
40	8.2	0.60	314	4946	197	681
Effects			**P > F**			
Slurry	0.5927	0.1867	0.4896	0.0078	0.4255	0.1970
Slope	0.0008	0.3171	0.0002	0.0325	< 0.0001	0.2236
Depth	< 0.0001	0.4920	0.0003	0.0007	< 0.0001	< 0.0001
Slurry * Slope	0.8609	0.7677	0.6685	0.9023	0.8778	0.0184
Slurry * Depth	0.7901	0.0011	0.7768	0.0002	0.1726	0.8506

3.4 Slurry Application Guidelines

CGR slurry was applied at 0, 5, 10, 20, and 40 dry tons per acre at two NE State HWY 31 segments in 2013 and 2014. Because slurry has high calcium and sodium content, high application rate can load significant quantity of calcium and sodium **(Table 3.18)** and the effect on soil may then be immediate (one month).

Roadside soils have a pH between 7-8, thus not qualifying for agronomic liming rate calculation methods. In contrast to our hypothesis, the application of slurry used in this study did not significantly affect vegetation, soil properties, runoff volume, and soil chemical properties at the low rates (5 and 10 dry tons/acre) one month after application, but, there was an increase in pH, Ca, and Na levels one month after application at the highest rates (20 and 40 dry tons/acre). However, this effect did not persist one year after slurry application. This study showed that it is plausible to apply CGR slurry (13% to 28% ECCE) at rates up to 40 dry tons/acre on medium to fine textured soil without negative effects. It also provides evidence that rate higher than the current regulation of 5 dry tons/acre may be applied on roadside with similar soil characteristics as this study. However, the suggested rate may not be applicable on soils with sandy texture (sandy loam, loamy sand) due to their lower buffer capacity. Application rates must also consider the ECCE and moisture of the CGR to adjust rate even in medium to fine textured soils. We recommend NDOR develops a quick field method to estimate the ECCE during the grinding process so that application rates can be adjusted appropriately. **Table 3.19** provides overall summary of the effects for ONE time CGR slurry application of up to 40 dry tons/acre.

Table 3.18 Average load of potassium, calcium, magnesium, and sodium application load from concrete grinding slurry at the NE State HWY 31 MM36 and MM34 sites

	Applied Load- lbs/acre			
CGR rate (Ton/acre)	**K**	**Ca**	**Mg**	**Na**
0	0	0	0	0
5	14	1134	28	40
10	27	2268	56	80
20	55	4536	112	160
40	110	9072	224	320

Table 3.19 Consequences of one time CGR slurry application effects based on two site experiments, with loam and silt loam soil textures, at NE State HWY 31 sites in 2013 and 2014

Property	Observed Change		Comments
	Yes	No	
Runoff volume		x	
Runoff chemistry		x	
Ground cover		x	
Species composition		x	
Soil pH	x		pH increased at 20 and 40 tons after one month but effect did not persist after one year.
Soil EC	x		Immediate increase that did not persist after one year.
Soil Ca	x		Ca increased at 20 and 40 tons after one month and effect was persistent after one year.
Soil Na	x		Immediate increase that did not persist after one year.
Soil K	x		Possible decrease due to excess Ca load.
Soil Mg		x	Possible decrease due to excess Ca load.
Soil Heavy metals		x	Not measured but most are below threshold level in CGR slurry

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Links to Appendices

Appendix 1. Literature Review Tables and Graphs

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Appendix 2. Experimental Design NE State HWY 31 MM36 and MM34

https://unl.box.com/s/p856afhhme0q1o6y5txdjyer2m14qkfs

Appendix 3. Slurry Properties

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Appendix 4. Soil Data (U.S. HWY 75, NE State HWY 92; NE State HWY 31 MM36, MM34)

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Appendix 5. Vegetation- NE State HWY 31 MM36, MM34

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Appendix 6. Runoff- NE State HWY 31 MM36, MM34

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Appendix 7. Pictures

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