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Vegetation and Soil Responses to Concrete Grinding Residue Application on Highway Roadsides of Eastern Nebraska

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Abstract

As a precautionary principle, the National Pollutant Discharge Elimination System (NPDES) permit establishes that the primary pollutant in concrete grinding residue (CGR) is its alkalinity and restricts CGR roadside discharge to 11 Mg ha^{-1} or the agronomic liming rate, whichever is lower. We evaluated the effect of CGR application on roadside soil chemical properties, existing vegetation, and rainfall runoff. Five CGR rates (0, 11, 22, 45, and 90 dry Mg ha^{-1}) were tested on roadsides slopes at two different locations in eastern Nebraska. Vegetation, soil, and runoff characteristics were evaluated before CGR application and 30 d and 1 yr after CGR application. Soil pH of control plots averaged 8.3 and 8.5 for each site respectively, across depths and slope positions, thus not requiring any liming for agronomic purposes. Soil electrical conductivity (EC, 1:1) averages of control plots were 0.79 and 1.24 dS m^{-1} across depths and slope positions. In the short term (30 d) the highest CGR application affected the 0- to 7.5-cm soil depth by increasing soil extractable Ca (21 and 25% for each site, respectively), soil pH (0.2, south site), and soil EC (0.2 dS m^{-1}) compared with the control. However, these changes in soil did not persist 1 yr after CGR application. The pH buffering capacity of soil prevented post-CGR-application pH from exceeding 8.9, even at the highest application rate. Application of CGR did not produce any differences in biomass production, botanical composition, and runoff characteristics at either site. From our study, CGR up to ~90 dry Mg ha^{-1}—about the amount produced during diamond grinding operations—can be one-time applied to roadside soils of similar characteristics on already established vegetation.

Core Ideas

- We evaluated a one-time application of concrete grinding residue to highway roadsides.
- Uniform application of CGR up to 90 Mg ha^{-1} did not affect existing vegetation.
- Application of CGR did not affect soil chemical properties nor runoff characteristics.
- The highest CGR rate increased soil extractable Ca and Na and pH after 30 d.
- Soil extractable Ca and Na were not affected 1 yr after CGR application.

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Diamond grinding is a restoration technique that corrects irregularities in old concrete pavements, such as faulting and roughness, and extends the life of the pavement. Cooling water used during the diamond grinding of concrete pavement highways generates concrete grinding residue (CGR) consisting of water, concrete, and aggregate residue. During diamond grinding, a 5-mm layer of concrete pavement (2.4 Mg m^{-3} density) is removed, which results in ~45 Mg of dry CGR per kilometer of a lane that is 3.7 m wide (Andrew Dearmont and Nicholas Soper of the Nebraska Department of Transportation, personal communication, 2013). Disposal of CGR in rural areas has typically been by application to the roadside during grinding operations, resulting in additions of ~96 Mg dry CGR ha^{-1}.

Recently, disposal of CGR in Nebraska was changed from unregulated roadside discharge to a National Pollutant Discharge Elimination System (NPDES) permit (NDEQ, 2010). The change is intended to control pollutant levels being land applied as a result of the spreading of CGR. According to the NPDES permit, the primary pollutant in CGR is alkalinity, and the amount of CGR that can be roadside applied is restricted to 11 Mg dry ha^{-1} or the acceptable agronomic liming rate, whichever is lower. The intent of an agronomic lime application rate calculation is to determine the appropriate amount of lime to achieve a target pH increase (typically 6.5) at a minimum cost. The objective with CGR application to roadsides, however, is to maximize application rates without causing damage to soils or plants, thus minimizing costs. There are published studies that have characterized chemical and physical properties of CGR (IGGA, 1990; Goodwin and Roshek, 1992; Shanmugam, 2004; Hanson et al., 2010; DeSutter et al., 2011b; Kluge et al., 2018), but few published reports on how application of CGR affects soil and existing vegetation.

Contents of regulated toxic components in CGR are typically either below reporting limits or below the established regulatory level (IGGA, 1990; DeSutter et al., 2011b; Kluge et al., 2018). Six nonregulated cations were reported to be the most abundant constituents of the solid phase of CGR—K (1.2–3.5 g kg^{-1}), Na (1.5–16 g kg^{-1}), Al (5.9–24.2 g kg^{-1}), Fe (3.5–27.8 g kg^{-1}), Mg (2.1–51 g kg^{-1}), and Ca (46–126 g kg^{-1})—whereas carbonate from $CaCO_3$ determination (9.6–16.2 g kg^{-1})

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Abbreviations: CGR, concrete grinding residue; EC, electrical conductivity; ECCE, effective calcium carbonate equivalent; NPDES, National Pollutant Discharge Elimination System.

and sulfate (0.7–4.1 g kg^{-1}) were the most abundant anions, although the presence of carbonates and bicarbonates were not specifically reported (DeSutter et al., 2011b). Across CGR samples, pH ranged from 9.6 to 12.6 (Goodwin and Roshek, 1992; Shanmugam, 2004; DeSutter et al., 2011b). Particle sizes in the CGR ranged from clay to fine gravel size, with the most common being <0.05 mm and composing 45 to 85% of the CGR by mass (Goodwin and Roshek, 1992; DeSutter et al., 2011b; Druschel et al., 2012). The high basic cation (Ca, Mg, Na, and K) and carbonate contents of CGR make this byproduct a potential liming agent, which is also supported by the large proportion of fine particles that contribute to increase the liming efficiency (Mamo et al., 2015) of CGR. In contrast, the presence of Al and Fe can reduce the liming potential of the CGR.

Shanmugam (2004) evaluated the impact of in situ CGR applications on the pH and metal composition of highway roadside soil in Washington. Soil Ca and Mg concentrations were greater and surface soil pH increased by <1 pH unit on sites with applications of CGR 6 to 11 yr earlier, compared with adjacent soils that had not received CGR (Shanmugam, 2004). Similar results were reported by DeSutter et al. (2011b) from a laboratory experiment that evaluated the impact of mixing CGR with soils of contrasting textures (fine sandy loam and silty clay). After 80 d, the application of CGR at rates of 73 and 220 Mg ha^{-1} (8 and 25% CGR/soil [w/w]) increased soil concentrations of Ca, Mg, Na, S, and Al, soil pH, and soil electrical conductivity (EC) values compared with preapplication soil. The increase in pH was similar across rates and greater in the fine sandy loam soil (0.6–0.9 pH units) than in the silty clay soil (0.3–0.6 pH units). Both studies confirm the potential of CGR to raise soil pH and improve soil basic nutrient cation content. In a greenhouse experiment, DeSutter et al. (2011a) evaluated the growth and chemical composition of smooth bromegrass (*Bromus inermis* Leyss.) grown on two CGR-treated soils. Plant tissue Ca and S concentrations increased and Mg concentration decreased with CGR addition likely because of the reduced soil Mg/Ca ratio with the addition of CGR.

Studies on how CGR affects water infiltration are not conclusive. A laboratory study using sand filters suggested that CGR may reduce water infiltration rate into soil, potentially as the result of clogging soil pores (Druschel et al., 2012). A water infiltration study (DeSutter et al., 2011b) using columns of coarse-textured soil found no effect of CGR on the infiltration time. However, on finer textured soil, infiltration time was reduced (i.e., improved) with the addition of CGR either mixed with the soil or added as a 2.5-mm layer on top of the soil (DeSutter et al., 2011b). The difference between the Druschel et al. (2012) sand column and DeSutter et al. (2011b) fine-textured soil column studies could be related to an improvement of soil aggregation by the addition of CGR rich in cations.

Short- and medium-term effects of different rates of CGR application to in situ soil properties and existing vegetation are unknown. Extrapolations of the results from DeSutter et al. (2011a, 2011b) to field conditions (e.g., enhancement of soil basic cation content, vegetation growth, and water infiltration) are difficult, since CGR under those circumstances is applied to existing vegetation instead of being mixed with the soil. Consequently, we conducted a 2-yr study to characterize how different rates of CGR affect highway roadside soil chemical properties (pH, EC, and cation content), existing vegetation (botanical composition and biomass), and rainfall runoff. Our hypothesis was that application of CGR above the rate allowed by the NPDES permit would degrade soil quality, increase runoff volume, and reduce desirable vegetative cover.

Materials and Methods

Site Selection

The experiments were conducted adjacent to Nebraska State Highway 31 north of Elkhorn, NE, on a north site (41°26′38″ N, 96°13′39″ W) and south site (41°25′36″ N 96°13′57″ W). The roadsides at each site had mature established stands dominated by cool-season grasses including smooth bromegrass, tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.], and Kentucky bluegrass (*Poa pretensis* L.) that were seeded between 1964 and 1979. Roadside slopes were measured at 16 points on a 13-km stretch of Highway 31 to determine the range of slopes on sites that had uniform vegetation and a relatively flat road surface. Slopes varied from 9.3 to 23.8%. The average slope was 21.3% for the north site and 12.5% for the south site.

Concrete Grinding Residue Source and Characteristics

The CGR used on the north site was collected directly from a diamond grinding operation in Grand Island, NE, into 200-L barrels in October 2012. The barrels were stored indoors at the Eastern Nebraska Research and Extension Center, University of Nebraska–Lincoln, near Mead, NE, in November 2012 to prevent freezing. Concrete grinding residue used on the south site was collected from a diamond grinding operation in Elkhorn in May 2013, transferred into 200-L barrels, and also stored at the Eastern Nebraska Research and Extension Center. Given the volume and lack of homogeneity of the grinding because of settling (both barrel to barrel and within barrels), the CGR for each experiment was air dried, mixed to homogenize, and then rewetted at the experimental site at the time of treatment application.

Four subsamples of air-dried CGR from each experiment batch were used to determine moisture of the dried CGR to adjust the application rate, effective $CaCO_3$ equivalent (ECCE), K, Ca, Mg, and Na concentrations (% [w/w]) (Ward Laboratory, Kearney, NE), and the heavy metal and metalloid content (As, Cd, Co, Cu, Mo, Ni, Pb, Hg, Se, and Zn) following USEPA Method 200.7 (USEPA, 1994) (Midwest Laboratories, Omaha, NE).

Treatment Application

At each of the two sites, the field experiment was arranged as a randomized complete block design with five target treatment rates: 0, 11, 22, 45, and 90 Mg dry CGR ha^{-1} $block^{-1}$. Treatments were applied to the north site on 18 (Blocks 3, 4, and 5) and 22 July 2013 (Blocks 1 and 2) and to the south site on 6 June 2014 (all five blocks).

For each plot, the appropriate mass of dried CGR was weighed into 20-L plastic buckets, and tap water was added. The CGR was mixed to ensure complete wetness, and more water was added to each bucket as needed to achieve a CGR density approximately equal to that as delivered (1.25 Mg m^{-3}). To ensure uniform coverage of the plot area, the CGR was applied from the buckets by hand.

Soil Assessment Before and After Concrete Grinding Residue Application

Soils at both sites were characterized prior to the application of treatments. At the north site, three soil samples (0- to 15-cm depth) were collected per block, combined, air dried, and passed through a 2-mm mesh sieve for determination of soil pH, EC, organic matter, and particle size. Soil pH was measured at a 1:1 soil/water ratio, soil EC was obtained by saturated paste extract, soil organic matter was obtained by loss-on-ignition, and particle size was determined by a hydrometer method (Gee and Bauder, 1986; Nelson and Sommers, 1996; Thomas, 1996). Soil sampling at the south site was done on the control (0 Mg CGR ha^{-1}) plots of each block only. Soil samples were collected at 2.4 (top of slope), 3.0 (mid-slope), and 3.7 m (bottom of slope) away from the edge of the road. At each distance and in each plot, three core samples were collected to the 30-cm depth. The sample cores were split into three depths (0–7.5, 7.5–15, and 15–30 cm), air dried, and sieved to 2 mm.

Soil samples from each plot were also collected at 30 d and at 1 yr after treatment application for both sites. For these samplings, three soil cores (0–30 cm) were taken on three slope positions as before (top of slope, mid-slope, and bottom of slope) on each plot for a total of nine cores per plot. Cores were split into 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm increments, combined by depth for each slope position within each plot, air dried, and sieved to 2 mm before analyses. Soil samples were analyzed for pH (1:1), EC (1:1), extractable cations (Ca, Mg, K, and Na) by summation method, and other soil nutrients (Cu, Fe, Mn, P, S, and Zn) (Lindsay and Norvell, 1978; Sumner and Miller, 1996).

Vegetation and Ground Cover Assessment

Botanical composition and ground cover assessments were conducted at both sites on all plots using a 20-cm × 50-cm quadrat (Daubenmire, 1959) immediately before CGR application and 30 d and 1 yr after CGR application. At each time, canopy cover by seeded perennial grasses, nonseeded perennial grasses, weedy forbs, and white and red clover (*Trifolium repens* L. and *Trifolium pretense* L., respectively) was estimated within two quadrats per plot (top of slope and bottom of slope), except for 1 yr after CGR application at the south site, where only one quadrat per plot was done. Composition for each plant category was then calculated. Within each quadrat, ground cover of litter, bare soil, CGR, and plant base were also estimated.

Aboveground plant biomass was measured at 30 d and 1 yr after application of treatments at the north site. However, biomass was measured on the south site only at 30 d after CGR application. The site was disturbed by road construction several months after CGR application precluding the 1-yr sampling on the site. After ground cover and botanical composition assessment were completed, the vegetation in the same two quadrats per plot was clipped to ground level, separated into seeded (tall fescue) and nonseeded species (mostly Kentucky bluegrass and smooth bromegrass), and dried at 60°C before weighing.

Rainfall Simulation and Runoff

Rainfall simulation was conducted using a TLALOC 3000 rainfall simulator (Joerns) described in Humphrey et al. (2002). Rainfall simulation was conducted 30 d after CGR application on the 0, 45, and 90 Mg ha^{-1} treatment plots of all blocks at both sites. Rainfall simulation was performed on 15 Aug. 2013 (north site) and 7 to 11 July 2014 (south site); the rainfall simulations had a target intensity of 60 mm h^{-1} based on a 10-yr recurrence interval and a maximum precipitation duration event of 1 h for the area (NOAA, 2013). Simulation rainfall intensities averaged across five blocks were 73 and 58 mm h^{-1} at the north and south sites, respectively. Gravimetric soil moisture at the 0- to 15-cm depth taken near the simulator immediately before simulation was 0.20 g g^{-1} at the north site and 0.17 g g^{-1} at the south site.

A 1.0-m × 0.5-m steel frame was used for collection of runoff under the simulator. The steel frame was placed in the ground in the middle of the plot, and the rainfall simulation was run for 30 min after runoff began. Average total rainfall applications in the plots measured using rain gauges were 43 mm at the north site and 36 mm at the south site. Runoff volume collected from the frame was measured every 5 min for 30 min. A portion of the runoff volume was transferred into 250-mL plastic bottles for analysis of pH, EC, turbidity, and total solids (Ginting and Mamo, 2006).

Statistical Analyses

Data were analyzed using a factorial design with CGR treatment, slope position, and soil depth as fixed effects. Proc Mixed procedure was used for the ANOVA (version 9.3; SAS Institute, 2015). Means and SEs were calculated for CGR, CGR × depth, and CGR × slope. Least square means were computed and declared significant at the 0.05 probability level.

Results

Concrete Grinding Residue Characteristics

Calcium was the nutrient present in highest concentration in CGR at both sites, followed by Na, Mg, and K (Table 1). Concrete grinding residue used at the two sites also had the following average total nutrient concentrations: 150 mg N kg^{-1}, 503 mg P kg^{-1}, 4489 mg S kg^{-1}, 125 mg Zn kg^{-1}, 5113 mg Fe kg^{-1}, 142 mg Mn kg^{-1}, and 14 mg Cu kg^{-1}. The ECCE of the CGR used at the north site (13%) was less than half of the ECCE of the CGR used at the south site (28%). Concrete grinding residue concentrations of Hg, As, and Se were below detection limits or reporting limits (Table 2). All the heavy metals and metalloids analyzed had concentrations below the threshold levels for hazardous materials (USEPA, 2014). The air-dried CGR had average moisture of 22% at the north site and 14% at the south site. This resulted in higher actual rates of dry CGR for each treatment at the south site than at the north site (Table 3). The ECCE for each year was used to calculate the lime equivalent rates of the treatments at each site (Table 3).

Vegetation

Tall fescue (seeded), Kentucky bluegrass (nonseeded), and smooth bromegrass (nonseeded) dominated the north site. At this location, <15% of the canopy cover across plots was broadleaf weeds including common ragweed (*Ambrosia artemisifolia* L.), knotweed (*Polygonum* spp.), bindweed (*Convolvulus spp*.), and dandelion (*Taraxacum officinale* F.H. Wigg.) and elm (*Ulmus americana* L.) seedlings. At the south site, canopy cover was dominated by smooth bromegrass (nonseeded), with <5% being common ragweed and dandelion. Across the five blocks, the

Table 1. Nutrient composition and lime quality (pH, electrical conductivity [EC[,effective $CaCO_3$ equivalent [ECCE] fineness, $CaCO_3$, and moisture) of air-dried concrete grinding residue (CGR) used for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31.

Site year	pH	EC	K	Ca	Mg	Na	ECCE	Fineness	$CaCO_3$	Moisture
		dS m^{-1}	g kg^{-1}				%			
2013	8.4	17.2	1.5	102.8	2.6	4.1	13.1	53	24.85	22
2014	8.4	14.7	1.2	124.0	3.0	3.9	28.2	74	38.10	14

Table 2. Total heavy metal and metalloid concentration of air-dried concrete grinding residue (CGR) used for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31.

Site year or limit	As	Cd	Co	Mo	Ni	Pb	Se	Zn	Hg	Cu	Cr
	mg kg^{-1}										
2013	BDL†	0.6	12.9	7.7	12.4	5.9	BRL‡	48.2	BRL	15.3	11.4
2014	BDL	BDL	22.0	4.6	9.3	5.5	BRL	38.2	BRL	10.6	9.7
Detection 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

† BDL, below detection limit.

‡ BRL, below reporting limit.

§ Detection limit (Midwest Laboratories, Omaha, NE).

¶ Threshold limits taken from USEPA (2014).

surface was mostly covered by plant litter (>70% of area), whereas, 5 (north site) and 10% (south site) of the surface was bare ground.

Botanical composition was not affected by CGR 30 d after application at either site. Similar to before treatment, canopy cover was dominated by the introduced cool-season grasses, smooth bromegrass (nonseeded), tall fescue (seeded), and Kentucky bluegrass (nonseeded) across all treatments at both sites. At the south site, the increase in CGR rate increased the soil area covered by CGR and decreased the litter cover (data not shown).

There was no significant CGR effect on seeded, nonseeded, or total biomass at 30 d (both sites) and at 1 yr after CGR application (north site, Table 4). Regarding slope position, total biomass was larger near the ditch than near the road at 30 d (both sites) and at 1 yr after CGR application (north site), possible related to greater water availability near the ditch. There was significant a CGR × slope interaction for seeded species biomass both 30 d and 1 yr after CGR application at the north site; however, there was no discernable pattern to the interaction (data not shown).

Soil pH, Electric Conductance, and Extractable Cations

North Site

Soil had a loam textural class with 22% clay and 39% sand. Concrete grinding residue rate, soil depth, and CGR × depth interactions had significant effects on soil pH and soil EC 30 d after CGR application (Table 5). Soil pH and EC of control plots averaged 8.3 and 0.79 dS m^{-1}, respectively, across depths (0–7.5 and 7.5–15 cm) and slope positions. Soil pH showed a significant reduction with lower CGR rates and a slight increase with higher CGR rates, whereas soil EC increased with increasing CGR application rate. Across all CGR rates, the pH at the 0- to 7.5-cm depth was significantly lower than at the 7.5- to 150-cm depth, but EC was higher at the 0- to 7.5-cm depth. At the 0- to 7.5-cm depth, the highest CGR application rate (90 Mg ha^{-1}) produced a significantly higher soil pH than the control, and the rates of 45 and 90 Mg CGR ha^{-1} both resulted in significantly higher EC than the control (Fig. 1). At 30 d after CGR application, depth and depth × CGR interactions were significant for Ca, Mg, and K, whereas only depth was significant for Na (Table 5). At the 0- to 7.5-cm depth, Ca in the control was lower than at all CGR rates except 45 Mg ha^{-1} (Fig. 1).

One year after CGR application, soil pH remained significantly lower for the 11 and 22 Mg ha^{-1} treatments (8.1 and 8.0, respectively) than the control and 45 and 90 Mg ha^{-1} treatments (8.2, 8.2, and 8.3, respectively). Soil EC, Ca, K, and Mg were no longer affected 1 yr after CGR application, although there was a CGR × depth interaction for Na (Table 5).

Table 3. Target concrete grinding residue (CGR), actual applied CGR, and lime equivalent (60% effective $CaCO_3$ equivalent [ECCE]) CGR rates used for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31.

Target CGR rates	Actual CGR rates†		Applied lime equivalent rates‡	
	2013	2014	2013	2014
	Mg ha^{-1}			
0	0	0	0	0
11	9	12	2	6
22	18	24	4	11
45	37	49	8	23
90	74	98	16	46

† Adjusted to 0% moisture.

‡ Converted to lime equivalent rates (60% ECCE).

South Site

Preapplication soil pH averaged 8.5, whereas preapplication soil EC averaged 1.24 dS m^{-1}. At 30 d after CGR application, there was significant CGR effect on soil extractable Ca (Table 5), which increased with application rate (Fig. 2). The interaction effects of CGR with depth were significant for Na (Table 5). Although there were no responses to CGR application at the 7.5- to 15-cm soil depth for Na, there were differences in Na levels at the 0- to 7.5-cm depth only between the 22 and 45 Mg ha^{-1} CGR treatments (Fig. 2). Soil pH, EC, Ca, Mg, and Na were higher at the 7.5- to 15-cm depth than at the 0- to 7.5-cm depth across all CGR rates (Fig. 1 and 2). One year after CGR application, there were significant CGR × depth interactions on extractable Ca and EC (Table 5), but no clear tendency.

Table 4. Biomass production and ANOVA of seeded and nonseeded grass species at 30 d and 1 yr after concrete grinding residue (CGR) application for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31.

CGR treatment	30 d			1 yr†		
	Seeded	Nonseeded	Total	Seeded	Nonseeded	Total
	Biomass production					
Mg ha^{-1}	kg ha^{-1}					
2013						
0	1668	1074	2742	666	5350	8758
11	1019	1240	2259	655	5439	8353
22	1648	812	2460	708	6164	9332
45	640	1138	1778	806	5323	7907
90	865	1094	1959	1279	3948	7186
	Pr > *F*‡					
CGR	0.127	0.948	0.072	0.634	0.311	0.452
Slope	0.411	0.130	0.022	0.139	0.364	0.042
CGR × slope	0.023	0.092	0.775	0.049	0.556	0.954
	Biomass production					
Mg ha^{-1}	kg ha^{-1}					
2014						
0	704	1742	2446	–	–	–
11	628	1633	2261	–	–	–
22	704	1501	2205	–	–	–
45	343	1633	1976	–	–	–
90	722	1350	2072	–	–	–
	Pr > *F*					
CGR	0.624	0.498	0.498	–	–	–
Slope	0.190	<0.001	<0.001	–	–	–
CGR × slope	0.960	0.502	0.502	–	–	–

† Biomass production was not measured 1 yr after application at the 2014 site due to road construction at the site.

‡ Significance was declared at a probability level of ≤0.05.

Table 5. Analysis of variance for soil pH; electrical conductivity (EC, 1:1); extractable K, Ca, Mg, and Na at the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31, 30 d and 1 yr after concrete grinding residue (CGR) application.

Effect	*P* > *F*†											
	30 d after CGR application						1 yr after CGR application					
	pH	EC	K	Ca	Mg	Na	pH	EC	K	Ca	Mg	Na
2013												
CGR	<0.001	0.028	0.011	0.069	0.114	0.276	0.007	0.462	0.253	0.605	0.515	0.182
Slope (S)	0.8073	0.070	0.113	0.502	0.249	0.207	0.334	0.250	<0.001	0.923	0.007	0.166
Depth (D)	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.010	<0.001	<0.001	0.026	<0.001
CGR × S	0.996	0.441	<0.001	0.785	<0.001	0.131	0.868	0.204	0.251	0.995	0.387	0.394
CGR × D	0.007	0.012	0.016	<0.001	0.022	0.078	0.416	0.759	0.156	0.388	0.085	0.004
2014												
CGR	0.352	0.450	0.622	0.022	0.490	0.632	0.593	0.187	0.490	0.008	0.423	0.197
S	0.317	0.021	<0.001	0.191	<0.001	0.124	0.001	0.317	<0.001	0.033	<0.001	0.224
D	<0.001	0.032	0.252	<0.001	<0.001	<0.001	<0.001	0.492	<0.001	0.001	<0.001	<0.001
CGR × S	0.350	0.150	0.681	0.686	0.054	0.420	0.861	0.768	0.669	0.902	0.878	0.018
CGR × D	0.055	0.585	0.054	0.146	0.160	0.026	0.790	0.001	0.777	<0.001	0.173	0.851

† Significance was declared at a probability level of ≤0.05.

Runoff

The simulated rainfall intensity (average over all five blocks) was 73 mm h^{-1} at the north site (2013) and 58 mm h^{-1} at the south site (2014), equivalent to a 10-yr storm. The average runoff in 30 min was 3.2 mm in 2013 and 4.0 mm in 2014. Concrete grinding residue application had no effect on any runoff quantity or quality variable measured at either site (Table 6).

Discussion

The rationale for the study described here was to determine if CGR applied to highway roadsides with established vegetation has detrimental effects on plant cover, soil chemical properties, or runoff quantity or composition. If there are no such detrimental effects, then state highway departments and contractors would be able to dispose of CGR near the location of its generation rather than incurring additional expense transporting it to

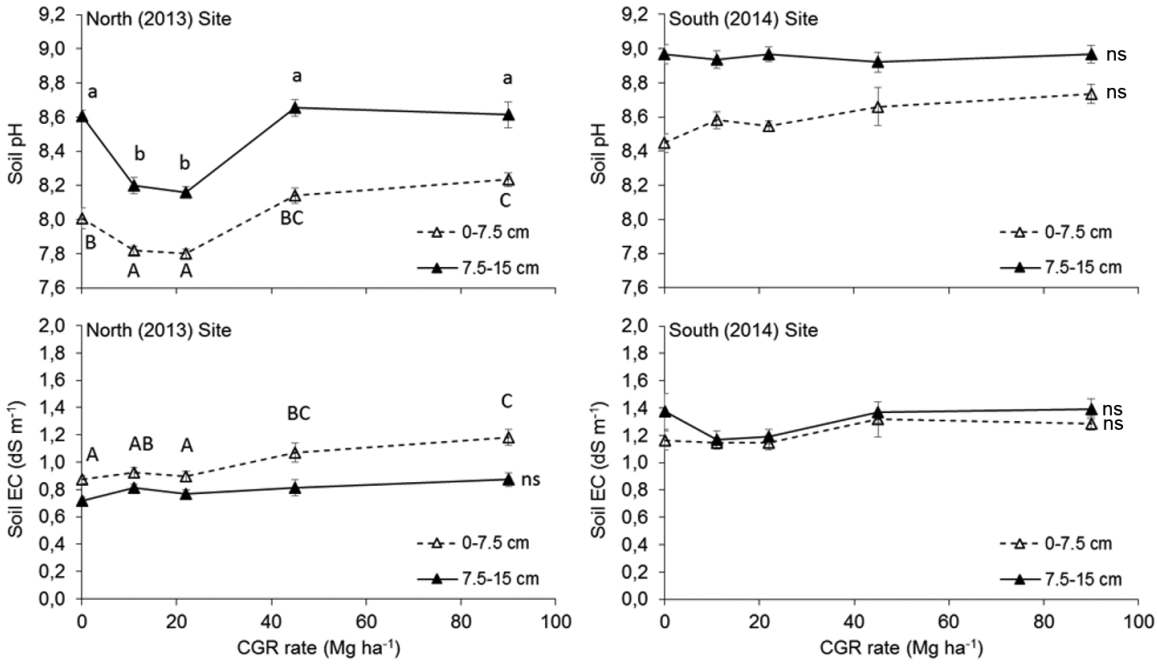

Fig. 1. Soil pH (1:1) and electrical conductivity (EC, 1:1) at 30 d after concrete grinding residue (CGR) application for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31. For significant depth × CGR interaction, means with the same letter(s) within each depth are not significantly different at $p < 0.05$ (uppercase letters for the 0- to 7.5-cm soil depth, lowercase letters for the 7.5- to 15-cm soil depth; ns, not significant).

another site for concentrated disposal. The latter approach itself could result in an environmental hazard. Critical characteristics of CGR, which might preclude its distribution on roadsides, include the presence of acutely or chronically toxic materials, soluble salts, excessively high pH, physical behavior that would cover and damage existing vegetation, and crusting and sealing the existing soil surface.

Although there are reports of heavy metals, metalloids, and synthetic organics in CGR (DeSutter et al., 2011b), the material used in this study was below critical or detection limits for all heavy metals and metalloids tested. No analysis was made for synthetic organics because there were no reports of fuel spills in the grinding area. In addition, the one-time nature of road surface diamond grinding and resulting CGR application means that accumulation of contaminants is not a concern unless the CGR is highly contaminated.

Soluble salts can damage vegetation directly and indirectly through reduction in soil water potential (Eppard et al., 1992; Blomqvist, 1998). Sodium salts can contribute to sodic soil formation and resulting structural deterioration (Agassi et al., 1981). The dried CGR used in this study had an EC of 17.2 (north site) and 14.7 dS m^{-1} (south site), so it could contribute to elevated soil salinity. However, the highest postapplication soil EC found (1.03 dS m^{-1}) was still well below that used to describe a soil as saline (2.16 dS m^{-1} for 1:1 dilutions; Zhang et al., 2005). In addition, the amount of salt applied in one-time CGR application is dwarfed by the amount of road salt typically applied in Nebraska and other northern state highways in winter (e.g., 2.2 Mg $lane^{-1}$ km^{-1} yr^{-1} in Nebraska; Transportation Research Board, 1991).

Although CGR can cover and potentially damage existing vegetation, particularly after it dries and forms a crust, this has not been addressed in industry standard best management practices (IGGA, 2013). There appears to be no research on surface application of CGR to existing, actively growing vegetation. According to the results of this study, such damage is minimal. For our study on mature stands of cool-season grasses, total plant biomass and species composition were largely unaffected by CGR application (Table 4). DeSutter et al. (2011a) found variable effects, both positive and negative, from CGR application on growth of smooth bromegrass. Surface application of CGR to sites with less vigorous plants or to newly planted vegetation may have a damaging effect on vegetation cover.

Crusting of dried CGR might inhibit soil water infiltration. This could result in excessive runoff and potentially promote transport of soluble and particulate material into roadside ditches. Runoff depth and runoff fraction (runoff volume as a fraction of total water applied) were not affected by CGR application at the north site or the south site (Table 6). Similarly, CGR application, even at 90 Mg ha^{-1}, had no significant effects on runoff composition (pH, EC, or total suspended solids) at either site (Table 6). DeSutter et al. (2011b) reported similar responses and even found increased infiltration rates with CGR application on a subset of their treatments. It is important to recognize, however, that an average, uniform CGR application as was used in our study does not necessarily reflect actual contractor practice. In diamond grinding during a roadside construction project, CGR is discontinuously dispensed from a hose, resulting in higher local concentrations of CGR with greater potential for surface sealing and runoff.

Conclusions

This study evaluated a one-time application of CGR to highway roadsides. Our hypothesis was that application of CGR above the rate allowed by the NPDES permit would degrade soil quality, increase runoff volume, and reduce desirable vegetative cover. Uniform application of CGR of up to

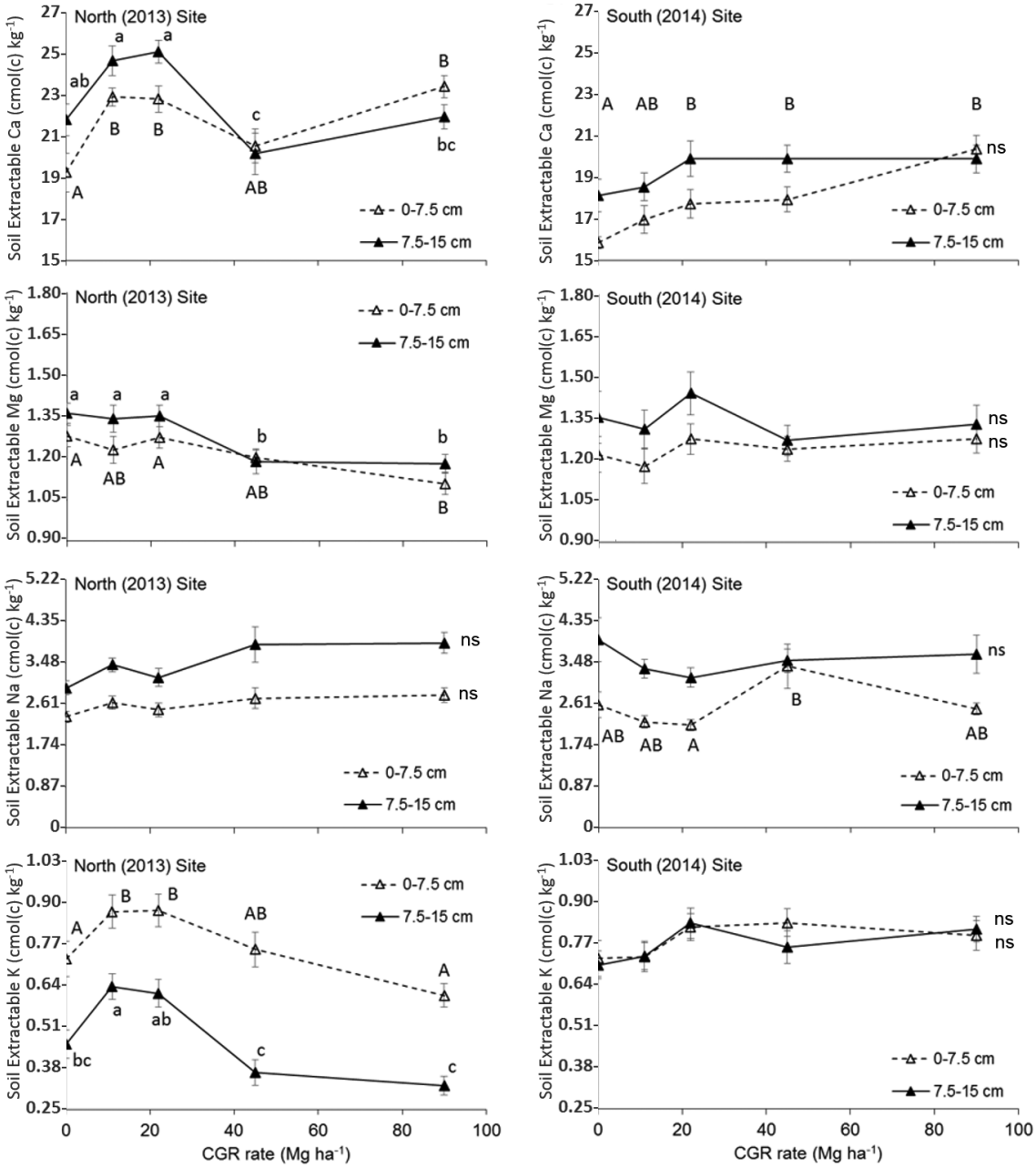

Fig. 2. Soil extractable Ca, Na, K, and Mg at 30 d after concrete grinding residue (CGR) application for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31. For significant depth × CGR interaction, means with the same letter(s) within each depth are not significantly different at $p < 0.05$ (uppercase letters for the 0- to 7.5-cm soil depth, lowercase letters for the 7.5- to 15-cm soil depth; ns, not significant).

Table 6. Runoff volume depth, fraction, start time, pH, electrical conductivity (EC), and total suspended solids (TSS) 30 d after concrete grinding residue (CGR) application for the north (2013) and south (2014) roadside field experiments at Elkhorn, NE, Highway 31.

CGR	Total depth	Total fraction†	Average pH	Average EC	TSS
Mg ha^{-1}	mm			dS m^{-1}	mg L^{-1}
2013					
0	2.8	0.083	7.31	0.78	0.97
45	3.0	0.090	7.44	0.76	2.44
90	3.7	0.101	7.49	0.85	0.98
P > *F*	0.967	0.986	0.514	0.599	0.371
2014					
0	4.5	0.11	7.5	1.0	–‡
45	5.3	0.15	7.7	1.0	–
90	2.1	0.05	7.9	1.1	–
P > *F*	0.261	0.197	0.114	0.717	–

† Runoff depth as fraction of the total amount of rainfall applied.

‡ There was an insufficient amount of sample from 2014 for TSS analysis.

90 Mg CGR ha^{-1} on loam and silt loam soils did not negatively affect existing vegetation, soil chemical properties, or runoff volume and composition. Although the highest CGR application rates increased the soil extractable Ca, extractable Na, and pH in the short term (30 d), the effect of CGR application faded after 1 yr. In addition, the pH buffering capacity of soil prevented post-CGR-application pH from exceeding 8.9, even at the highest application rate. From our study, CGR up to ~90 dry Mg ha^{-1}—about the amount produced during diamond grinding operations—can safely be one-time applied to roadside soils of similar characteristics on already established vegetation. Application rates should, however, be adjusted on coarse-textured soils with low pH buffering capacity. Last but not least, the impact of evaluation timing of CGR discharge (i.e., 30 d vs. 1 yr after CGR application) on soil and vegetation may lead to different recommendations, which is an aspect to consider in further research for different soils or roadside characteristics.

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References

Agassi, M., I. Shainberg, and J. Morin. 1981. Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. Soil Sci. Soc. Am. J. 45:848–851. doi:10.2136/sssaj1981.03615995004500050004x

Blomqvist, G.R. 1998. Impact of de-icing salt on roadside vegetation: A literature review. VTI rapport 427A. VTI (Swedish Natl. Road Transport Res. Inst.), Linköping.

Daubenmire, R.F. 1959. Canopy-cover method for vegetational analysis. Northwest Sci. 33:43–46.

DeSutter, T., P. Goosen-Alix, L. Prunty, P.M. White, Jr., and F. Casey. 2011a. Smooth brome (Bromus inermis Leyss) and soil chemical response to concrete grinding residue application. Water Air Soil Pollut. 222:195–204. doi:10.1007/s11270-011-0816-7

DeSutter, T., L. Prunty, and J. Bell. 2011b. Concrete grinding residue characterization and influence on infiltration. J. Environ. Qual. 40:242–247. doi:10.2134/jeq2010.0278

Druschel, S.J., L. Roue, and B. Wasserman. 2012. Concrete slurry, wash and loss water mitigation. Final Rep. Minnesota Dep. Transp. http://www.dot.state.mn.us/research/TS/2012/2012-21.pdf (accessed 1 June 2017).

Eppard, R.A., J.W. Norberg, R. Nelson, and J. Allison. 1992. Effects of deicing salts on overstory vegetation in the Lake Tahoe basin. Transp. Res. Rec. 1352:67–74.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. In: A. Klute, editor, Methods of soil analysis, Part 1: Physical and mineralogical methods. 2nd ed. SSSA Book Ser. 5.1. ASA, SSSA, Madison, WI. p. 383– 411. doi:10.2136/sssabookser5.1.2ed.c15

Ginting, D., and M. Mamo. 2006. Measuring runoff-suspended solids using an improved turbidometer method. J. Environ. Qual. 35:815–823. doi:10.2134/jeq2005.0219

Goodwin, S., and M.W. Roshek. 1992. Concrete grinding residue. Transp. Res. Rec. 1345:101–105.

Hanson, E.M., N.J. Connolly, and D.J. Janssen. 2010. Evaluating and optimizing recycled concrete fines in PCC mixtures containing supplementary cementitious materials. Final Rep. Transp. Northwest (TransNow) Reg. Univ. Transp. Ctr. http://ntl.bts.gov/lib/44000/44800/44889/TNW2010-03.pdf (accessed 1 June 2017).

Humphrey, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for pilot-scale runoff studies. Appl. Eng. Agric. 18:199–204.

IGGA. 1990. Grinding slurry analysis. Int. Grooving Grinding Assoc. http://7e846f23de4e383b6c49-2fba395bb8418a9dd2da8ca9d66e382f.r19.cf1.rackcdn.com/uploads/resource/194/Grinding_Slurry_Analysis_1990.pdf (accessed 1 June 2017).

IGGA. 2013 Diamond grinding slurry handling: Best management practices. Int. Grooving Grinding Assoc. http://7e846f23de4e383b6c49-2fba395bb8418a9dd2da8ca9d66e382f.r19.cf1.rackcdn.com/uploads/resource/193/Diamond_Grinding_Slurry_Handling_BMP2013.pdf (accessed 1 June 2017).

Kluge, M., N. Gupta, B. Watts, P.A. Chadik, C. Ferraro, and T.G. Townsend. 2018. Characterisation and management of concrete grinding residuals. Waste Manage. Res. 36:149–158. doi:10.1177/0734242X17744040

Lindsay, W.L., and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42:421–428. doi:10.2136/sssaj1978.03615995004200030009x

Mamo, M., C.S. Wortmann, and C.A. Shapiro. 2015. Lime use for soil acidity management. NebGuide G1504. Univ. Nebraska Ext., Lincoln, NE. http://extensionpublications.unl.edu/assets/pdf/g1504.pdf (accessed 1 June 2017).

NDEQ. 2010. General NPDES permit authorizing land application of concrete grooving/grinding slurry. NEG500000. Nebraska Dep. Environ. Qual. http://www.deq.state.ne.us/Publica.nsf/23e5e39594c064ee852564ae004fa010/b8c0b568325e2fc586257926005314d8?OpenDocument (accessed 1 June 2017).

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter analysis. In: D.L. Sparks, et a., editor, Methods of soil analysis, Part 3: Chemical methods. Book Ser. 5.3. SSSA, ASA, Madison, WI. p. 961–1010. doi:10.2136/sssabookser5.3.c34

NOAA. 2013. Atlas 14 point precipitation frequency estimates: NE . NOAA. http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ne (accessed 1 June 2017).

SAS Institute. 2015. The SAS system for Windows. Release 9.3. SAS Inst., Cary, NC.

Shanmugam, H. 2004. Assessment and mitigation of potential environmental impacts of Portland cement concrete highway grindings. MS thesis, Washington State Univ., Pullman. https://research.wsulibs.wsu.edu:8443/xmlui/bitstream/handle/2376/276/h_shanmugam_121304.pdf?sequence=1 (accessed 1 June 2017).

Sumner, M.E., and W.P. Miller. 1996. Cation exchange capacity and exchange coefficients. In: D.L. Sparks, et a., editor, Methods of soil analysis, Part 3: Chemical methods. Book Ser. 5.3. SSSA, ASA, Madison, WI. p. 1201–1229. doi:10.2136/sssabookser5.3.c40

Thomas, G.W. 1996. Soil pH and soil acidity. In: D.L. Sparks, et a., editor, Methods of soil analysis, Part 3: Chemical methods. Book Ser. 5.3. SSSA, ASA, Madison, WI. p. 475–490. doi:10.2136/sssabookser5.3.c16

Transportation Research Board. 1991. Highway deicing: Comparing salt and calcium magnesium acetate. Natl. Res. Counc., Washington, DC. http://onlinepubs.trb.org/Onlinepubs/sr/sr235.html (accessed 1 June 2017).

USEPA. 1994. Method 200.7, revision 4.4: Determination of metals and trace elements in water and wasted by inductively coupled plasma-atomic emission spectrometry. USEPA. https://www.epa.gov/sites/production/files/2015-08/documents/method_200-7_rev_4-4_1994.pdf (accessed 1 June 2017)

USEPA. 2014. Title 40 of the Code of Federal Regulations (CFR). USEPA, Washington, DC. http://www.ecfr.gov/cgi-bin/text-idx?SID=11ac450dd25de93cc4118baf5c42b274&tpl=/ecfrbrowse/Title40/40tab_02.tpl (accessed 1 June 2017).

Zhang, H., J.L. Schroder, J.J. Pittman, J.J. Wang, and M.E. Payton. 2005. Soil salinity using saturated paste and 1:1 soil to water extracts. Soil Sci. Soc. Am. J. 69:1146–1151. doi:10.2136/sssaj2004.0267