

# Research Reports

## Reestablishment of Perennial Ryegrass in Lawns Damaged by Diesel and Hydraulic Fluid Spills

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**ADDITIONAL INDEX WORDS.** hydrocarbons, petroleum, phytotoxicity, soil contamination, turfgrass

**SUMMARY.** Petroleum-based spills on turfgrass often occur during lawn care maintenance. Damage caused by diesel and hydraulic fluid is particularly difficult to correct. The objective of this study was to compare the effectiveness of combining mulching with remediation for reseeding spilled areas in lawns. Diesel and hydraulic fluid were applied to plots at a rate of 15 L·m<sup>-2</sup>. Immediately after the spill treatments, two liquid humic amendments and an activated flowable charcoal were applied at a volume rate of 8 L·m<sup>-2</sup>, respectively, with tap water/dishwashing detergent used as a control. Nitrate nitrogen was added to each remediation treatment to facilitate remediation. The spilled areas were reseeded with perennial ryegrass (*Lolium perenne*) and then mulched with biochar, peat pellets, and paper pellets, respectively. At 6 weeks after seeding, humic amendment 1 and activated charcoal showed better turf quality than humic amendment 2. Peat pellet mulching presented better turf quality than other mulching methods. Reseeding perennial ryegrass and mulching with peat pellets after remediation with either humic amendment 1 or activated charcoal resulted in acceptable turf quality 6 weeks after diesel and hydraulic fluid spills. Therefore, this reestablishment method is recommended as a practical way to deal with diesel or hydraulic fluid spills in cool-season turfgrasses.

Spills of petroleum-based products on turfgrass happen primarily because of equipment failure or improper refueling. Hydrocarbons are a major component of fuels and hydraulic fluids, and are hazardous to the environment (Aislabie et al., 2006). Soils contaminated by hydrocarbons become

hydrophobic, which reduces the availability of the water-soluble nutrients (Everett, 1978). Also, the elevated carbon content in hydrocarbon-contaminated soil causes an increased carbon (C) to nitrogen (N) ratio resulting

in decreased bioavailability of nitrogen and phosphorus (Aislabie et al., 2006). Damage caused by hydrocarbons to turfgrass can be long lasting and difficult to correct due to slow degradation of most hydrocarbons by microbes in soils (Aislabie et al., 2006; Elliott and Prevatte, 1995).

Johns and Beard (1979) compared activated charcoal and a detergent on the remediation of gasoline, motor oil, grease, and hydraulic fluid spills on 'Tifgreen' bermudagrass (*Cynodon dactylon*). Their results showed that a combination of charcoal and detergent can remediate motor oil damage in 3–4 weeks but not for gasoline. However, the results found by Powell (1981) on a motor oil spill on a 'Penncross' creeping bentgrass (*Agrostis stolonifera*) putting green indicated that flushing with dishwashing detergent was more effective than remediation with charcoal or calcined clay. Greenwalt (2003) recommended flushing and scalping before reseeding to reestablish turfgrass on soils contaminated with hydraulic fluid because many commercial products do not provide satisfactory remediation. The work by Bai and Li (2013) showed that using a liquid humic amendment to remediate soil and reseed perennial ryegrass immediately after a gasoline spill was able to reestablish acceptable turf quality in 5 weeks. However, diesel and hydraulic spills showed residue effect up to 2 months and reestablishment of turfgrass was not successful until 4 months after the spill (Bai and Li, 2013). An effective reestablishing method is yet to be identified for damages in cool-season lawns caused by diesel or hydraulic fluid spills.

Bioremediation is a process of using microbes to degrade hydrocarbons (Aislabie et al., 2006). Nitrate nitrogen added to soils contaminated by hydrocarbons was reported to benefit the bioremediation (Bai and Li, 2013; Norris and Dowd, 1993).

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### Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
40.7458	gal/ft <sup>2</sup>	L·m <sup>-2</sup>	0.0245
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha <sup>-1</sup>	0.8922
1	micron(s)	µm	1
70.0532	oz/acre	g·ha <sup>-1</sup>	0.0143
1	ppm	mg·kg <sup>-1</sup>	1

In general, results from previous research indicate that leaching contaminants with detergent water and applying absorbents such as a humic substance and activated charcoal are the most effective methods for reclaiming soils subjected to petroleum-based spills. Previous works focused on cleaning up the spills and recovery of damaged turf. There has been no information about the effects of mulching on the remediation and reestablishment of turfgrass from reseeding after petroleum-based spills. When recovery of fuel-damaged turfgrass takes too long, it is unpractical to rely on recuperation of the grass but reseed (Bai and Li, 2013). The objective of this study was to investigate if acceptable turf quality can be achieved by applying different mulching materials after soil remediation and reseeding perennial ryegrass on a cool-season lawn subjected to diesel and hydraulic fluid spills.

## Materials and methods

The study was conducted in field plots with established 'Kenblue' kentucky bluegrass (*Poa pratensis*) stand on a Fargo clay soil (Fargo series, fine, smectitic, frigid Typic Epiaquerts). The grass was fertilized in August annually at an N rate of 75 lb/acre using 29N-0.9P-2.5K (The Andersons, Maumee, OH). Micronutrients were applied using a backpack sprayer at a rate of 28 oz/acre from 0-0.4P-0.8K (The Andersons) containing 0.02% boron (B), 2.45% iron (Fe), 0.25% manganese (Mn), and 0.05% zinc (Zn). The grass was mowed at 2.5-inch height once weekly.

On 12 June 2012 and 15 May 2013, respectively, diesel and hydraulic fluid (AW100; Fleet Whole Supply, Appleton, WI) were applied to plots of 1.5-ft diameter at a rate of 15 L·m<sup>-2</sup>. The 2-year study was conducted on different sites with untreated plots representing control treatment in each year. The spill treatment rates were the same as reported by Bai and Li (2013).

The following remediation treatments were manually applied with a beaker immediately after the spill treatments at a volume rate of 8 L·m<sup>-2</sup>: humic amendment 1 (Rev<sup>TM</sup>; Dakota Peat, Grand Forks, ND), activated flowable charcoal (D. TOX; Cleary

Chemical Corp., Payton, NJ), humic amendment 2 (Turf Works<sup>®</sup>; Custom Agronomics, Palm City, FL), and tap water with dishwashing detergent (Ultra Concentrated Dawn<sup>®</sup>; Procter and Gamble, Cincinnati, OH) as a control, which is reported as an effective clean up method and used by many turfgrass managers (Greenwalt, 2003; Johns and Beard, 1979). The humic amendment 1 is derived from reed sedge peat, pH = 6.2, 92 mg·kg<sup>-1</sup> nitrate N, 5.3 mg·kg<sup>-1</sup> ammoniacal N, 4 mg·kg<sup>-1</sup> P, and 10 mg·kg<sup>-1</sup> K. The material contains particle sizes smaller than 100 μm, 21.2% humic acid, and 0.8% fulvic acid based on dry weight. The humic amendment 2 is derived from leonardite ore, pH = 9.5 and is 20.0% humic acid. The application rates for remediation were based on a previous study (Bai and Li, 2013). To all remediation treatments, nitrate nitrogen at a rate of 15 oz/acre was added using 4N-0P-0.8K (Cytosorb-S<sup>TM</sup>; The Andersons), which contains 4.00% N from nitrate nitrogen, 0.8% K from potassium nitrate, 0.53% magnesium (Mg), 1% sulfur (S) from combined sulfur, 2% Fe, 0.25% Mn, and 0.20% Zn.

'Pleasure Supreme' perennial ryegrass was overseeded into the plots at 305 lb/acre after the spill and remediation treatments were applied. Thereafter, three mulching treatments, biochar, peat pellets, and paper pellets, were applied at a thickness of 0.375 inch. The biochar (Energy and Environmental Research Center,

University of North Dakota, Grand Forks, ND) was ≈0.125 inch in diameter. The peat pellets (Dakota Peat) had an average diameter of 0.094 inch. The paper pellets (Phoenix Paper Products, Lostant, IL) were 0.125 inch in diameter and 0.25 inch long.

Irrigation was provided throughout the experiment to prevent drought stress determined by evaluating the untreated control plot. The experimental treatments were a 2 × 4 × 4 factorial combination of spill, remediation, and mulching. The experiment was arranged in a randomized complete block design with three replications.

The seeds were considered germinated when seedlings first appeared, and the germination time was the number of days required for the seed to germinate after overseeding. Turf quality was visually evaluated at 4 and 6 weeks after treatment (WAT) based on a 1-9 scale, where 1 is dead, 6 is minimum acceptable, and 9 is the best. A digital image was taken from each plot at 6 WAT, under natural light using a digital camera (Power Shot G3; Canon, Tokyo, Japan) with settings of F2.0 and 1/60 s. The digital images were then analyzed using the software package NIH Image (version 1.45i; National Institutes of Health, Bethesda, MD) for calculating the green density following the methods of Richardson et al. (2001).

The data were subjected to analysis of variance (ANOVA) using the GLM procedures in SAS (version 9.3;

**Table 1. Analysis of variance for green density, turf quality, and germination of perennial ryegrass seeded in June 2012 and May 2013 after simulated diesel and hydraulic fluid spills at 15 L·m<sup>-2</sup> (0.37 gal/ft<sup>2</sup>) and treated with different remediation (two humic amendments and activated flowable charcoal) and mulching (biochar, peat pellets, and paper pellets).**

Source of variation	df	GD (%) <sup>z</sup>	VQ (1-9 scale) <sup>y</sup>		Time to germination (d)
			4 wk	6 wk	
Spill (S)	1	*** <sup>x</sup>	***	***	*
Remediation (R)	3	***	***	***	***
Mulch (M)	3	***	***	***	***
S × R	3	**	*	***	**
S × M	3	NS	NS	***	*
R × M	9	***	NS	***	***
S × R × M	9	NS	NS	NS	*
CV (%) <sup>w</sup>		22.9	26.4	16.9	12.9

<sup>z</sup>Green density is the percentage of green pixels in the total pixels of a digital image following the method of Richardson et al. (2001).

<sup>y</sup>Visual quality: 1 = dead, 6 = minimum acceptable, 9 = best.

<sup>x</sup>NS, \*, \*\*, \*\*\*Nonsignificant or significant at P ≤ 0.05, 0.001, or 0.0001, respectively.

<sup>w</sup>Coefficient of variation.

SAS Institute, Cary, NC). Homogeneity of means and variability between the 2 years were tested with Hovtest

procedure in SAS. Treatment means were separated using Tukey's honest significance test at the 0.05 *P* level.

**Table 2. Comparison of different remediation methods on reestablishment of perennial ryegrass in terms of green density, turf quality, and germination after simulated diesel and hydraulic fluid spills at 15 L·m<sup>-2</sup> (0.37 gal/ft<sup>2</sup>) in June 2012 and May 2013 with data pooled across spills and different mulching (biochar, peat pellets, and paper pellets).**

Remediation type <sup>z</sup>	GD (%) <sup>y</sup>	VQ (1–9 scale) <sup>x</sup>		Time to germination (d)
		4 wk	6 wk	
No remediation	15.1 c <sup>w</sup>	2.8 b	4.0 c	12.3 a
Humic amendment 1	27.9 a	3.5 a	5.2 a	10.3 bc
Activated charcoal	25.7 a	3.9 a	5.3 a	9.7 c
Humic amendment 2	21.2 b	3.4 a	4.7 b	10.6 b

<sup>z</sup>All remediation also included addition of nitrate nitrogen at a rate of 1 lb/acre (1.1 kg·ha<sup>-1</sup>).

<sup>y</sup>Green density is the percentage of green pixels in the total pixels of a digital image following the method of Richardson et al. (2001).

<sup>x</sup>Visual quality: 1 = dead, 6 = minimum acceptable, 9 = best.

<sup>w</sup>Means within a column followed by the same letter are not significantly different at *P* = 0.05 based on Tukey's honest significance test.

**Table 3. Comparison of different mulching methods on reestablishment of perennial ryegrass in terms of green density, turf quality, and germination after simulated diesel and hydraulic fluid spills at 15 L·m<sup>-2</sup> (0.37 gal/ft<sup>2</sup>) in June 2012 and May 2013 with data pooled across spills and different remediation (two humic amendments and activated flowable charcoal).**

Mulching type	GD (%) <sup>z</sup>	VQ (1–9 scale) <sup>y</sup>		Time to germination (d)
		4 wk	6 wk	
No mulch	16.9 d <sup>x</sup>	2.3 c	3.8 c	14.2 a
Biochar	20.8 c	3.3 b	4.7 b	10.3 b
Peat pellet	28.3 a	4.4 a	5.9 a	9.2 c
Paper pellet	23.8 b	3.6 b	4.9 b	10.2 b

<sup>z</sup>Green density is the percentage of green pixels in the total pixels of a digital image following the method of Richardson et al. (2001).

<sup>y</sup>Visual quality: 1 = dead, 6 = minimum acceptable, 9 = best.

<sup>x</sup>Means within a column followed by the same letter are not significantly different at *P* = 0.05 based on Tukey's honest significance test.

**Table 4. Green density, turf visual quality, and time to germination of perennial ryegrass after simulated diesel and hydraulic fluid spills at 15 L·m<sup>-2</sup> (0.37 gal/ft<sup>2</sup>) in June 2012 and May 2013 with data pooled across different spills showing interaction between remediation (two humic amendments and activated flowable charcoal) and mulching (biochar, peat pellets, and paper pellets).**

Mulching type	No remediation	Humic amendment 1	Activated charcoal	Humic amendment 2
Green density (%) <sup>z</sup>				
No mulch	4.4 b <sup>y</sup>	21.8 ab	26.7 ab	14.7 b
Biochar	15.5 a	26.6 b	19.9 b	21.2 ab
Peat pellet	20.5 a	37.3 a	30.9 a	24.6 a
Paper pellet	19.8 a	25.8 ab	25.3 ab	24.4 a
Visual quality (1–9 scale) <sup>x</sup>				
No mulch	2.0 b	4.3 b	4.8 b	3.9 b
Biochar	4.3 a	4.9 b	5.2 ab	4.6 ab
Peat pellet	5.3 a	6.5 a	6.3 a	5.3 a
Paper pellet	4.6 a	4.9 b	5.2 ab	4.8 ab
Time to germination (d)				
No mulch	22.4 a	11.7 a	10.4 a	12.4 a
Biochar	10.7 b	10.3 ab	9.7 a	10.5 ab
Peat pellet	9.3 c	9.0 b	9.0 a	9.6 b
Paper pellet	10.7 b	10.3 ab	9.6 a	10.1 ab

<sup>z</sup>Green density is the percentage of green pixels in the total pixels of a digital image following the method of Richardson et al. (2001).

<sup>y</sup>Means within a column followed by the same letter are not significantly different at *P* = 0.05 based on Tukey's honest significance test.

<sup>x</sup>Visual quality: 1 = dead, 6 = minimum acceptable, 9 = best.

## Results and discussion

There were no differences in mean and variability between the two studies. Therefore, the data were combined for the ANOVA test (Table 1). Significant differences in time to germination, visual quality, and green density were found in the main treatments. Consistent interactions were detected for the time to germination, visual quality at 6 weeks, and green density between spill type and remediation, and between remediation and mulching (Table 1). Averaged across the different remediation and mulching, time to germination was 0.5 d longer, green density was 8% lower, and turf quality was 0.8 units lower for diesel spill than the hydraulic fluid spill. However, since the difference between the two spills for all measurements were small and not of great agronomical importance, the discussion for interaction will focus only on that between remediation and mulching.

Three different remediation methods resulted in ≈2 d earlier germination on average than the untreated control (Table 2). Three different mulching methods resulted in ≈4 d earlier germination on average than the untreated control (Table 3). Interactions between remediation and mulching for the time to germination showed that the major difference was found between the nonremediated and the remediated (Table 4), whereas the trend for different

mulching methods within each remediation appeared similar. Also, time to germination should not be overemphasized because it represented only the first appearance of seedlings and there was a lack of support from the data of actual percentage germination.

All remediation methods resulted in better green density of newly seeded perennial ryegrass than the untreated control. Humic amendment 1 and activated charcoal showed better results than humic amendment 2 (Table 2). All mulching methods showed better turfgrass green density than untreated control with peat pellets providing the best results (Table 3). The combination of peat pellets, mulching, and remediation with humic amendment 1 resulted in the best turfgrass green density in the reestablished perennial ryegrass (Table 4).

Ultimately the turf visual quality of the reestablished perennial ryegrass after the diesel and hydraulic fluid spills determines the acceptability of different methods in dealing with the damage caused by spills. Remediation resulted in better turf quality than the untreated control progressively. By 6 WAT, humic amendment 1 and activated charcoal showed better results than humic amendment 2 (Table 2). Mulching also progressively improved turf quality compared with the untreated control. At 6 WAT, mulching with peat pellets presented better turf quality than other mulching methods (Table 3). As a result, mulching with peat pellets after remediation with either humic amendment 1 or activated charcoal created acceptable perennial ryegrass turf quality at 6 WAT (Table 4).

A previous greenhouse study by Bai and Li (2013) showed that hydraulic fluid spill took a longer time to remediate than diesel and gasoline. In this field study, hydraulic fluid spill had slightly better results of reestablishment of perennial ryegrass than diesel spill as judged by the time to germination, green density, and visual quality. This may be contributed from the addition of nitrate

nitrogen to all remediation treatments in this study. Nitrate nitrogen was reported as an electron acceptor in the process of bioremediation under anaerobic conditions in hydrocarbon-contaminated soils (Agrawal and Gieg, 2013; Boopathy et al., 2012; Kaluarachchi et al., 2000).

Another finding from this study is that seeding immediately after application of remediation treatments was successful when mulching was provided, whereas a previous study (Bai and Li, 2013) showed that germination was inhibited up to 2 months after the diesel and hydraulic fluid spills. This indicates that seeds applied right after hydrocarbon spills do not necessarily lose viability but do not germinate due to hydrophobic conditions or die during the early stages of germination with the seedlings being in contact with the toxic materials. Combining mulching with remediation may have corrected these adverse conditions through adsorption of toxic materials and moisture protection as well as acceleration of the biodegradation of hydrocarbons.

In conclusion, with the remediation and mulching treatments, it was possible to reestablish perennial ryegrass in 6 weeks to reach acceptable turf quality instead of more than 4 months after spill incidents as reported previously by remediation only with organic amendments (Bai and Li, 2013). This study tested perennial ryegrass only. However, in a region where cool-season grasses predominate, overseeding with perennial ryegrass immediately after petroleum-based spills to create a grass cover is a practical option. Reseeding with a cool-season grass species conforming to the original lawn in a later stage can then be done if needed.

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