Bermudagrass Growth in Hydraulic-Fracturing-Drilling-Fluid-Contaminated Soil

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Introduction

Hydraulic fracturing or fracking is a recently developed process for extracting natural gas from shale deposits. The process involves the high-pressure injection of water, sand, bentonite, barite, NaOH, and other chemicals into geologic formations to increase the release of natural gas deposits (Arthur et al., 2008; Miller et al., 1980). Each natural gas well uses approximately 4×10^6 L of water in the fracking process (Airhart, 2011). When the fracking process is completed, the resulting fluid and shale cuttings are returned to the surface and transported to holding ponds where the solids settle (Fig. 1). The solids are referred to as drilling mud and the liquid phase is known as hydraulic-fracturing drilling fluid. In the past, it was possible to obtain a permit to surface apply the drilling fluid to land.

Fig 1. Drilling fluid was collected in settling ponds.

In Arkansas, the Department of Environmental Quality (ADEQ) regulated the land application process of water-based drilling fluids based upon the physical landscape (slope, storage capacity, and weather), physical and chemical soil properties (electrical conductivity, soil salinity, and pH), and the drilling waste characteristics (ADEQ, 2009). Excess application of drilling fluid results in increased soil salinity, which inhibits seed germination, survival, and plant growth. (Brady and Weil, 2002; Zvomuya et al., 2009). At some sites, over application of drilling fluid resulted in contaminated soil that could not be vegetated to meet ADEQ requirements (Fig 2).

Fig 2. Excess application of drilling fluid can increase soil salinity and restrict plant growth.

Hypothesis

Adding nutrients and deep plowing would increase plant growth in drilling-fluid-contaminated soil.

Objective

The objective of this greenhouse study was to evaluate the effects of inorganic fertilizer, broiler litter, and Milorganite® and soil depth interval (0-15 cm or 0-30 cm) on the growth of bermudagrass [*Cynodon dactylon* (L.) Pers] in soil from a site that had been contaminated with drilling fluid.

Materials and Methods

The experimental design for the greenhouse study was: two soil depths x four soil treatments x two vegetation treatments x four replications for a total of 64 sample units.

Soil

Soil was collected at soil depths of 0-15 cm (Ap horizon) and 0-30 cm (deep plow) from a drilling-fluid-contaminated field near a natural gas drilling site located in the Fayetteville Shale in west central Arkansas. Soil was analyzed for Mehlich-3-extractable nutrients and water-extractable Cl using inductively coupled argon plasma (ICP) spectrometry methods (Table 1). Electrical conductivity (EC) and pH were measured in 1:1 and 1:2 soil to water ratios, respectively (Donahue, 1992).

Table 1. Initial soil chemical and physical properties of two soil depths used in the 9-wk study.

	Soil Depth (cm)	
Soil Characteristic	0-15	0-30
Electrical Conductivity (dS/m)	7.29	5.94
pH	7.99	8.00
Extractable P (mg/kg)	6.0	4.3
Extractable Na (mg/kg)	2994	2550
Extractable Cl (mg/kg)	5603	5020
Sand (%)	11.5	8.8
Silt (%)	59.4	64.6
Clay (%)	29.1	26.7

Amendments

Inorganic fertilizer (179 mg NH_4NO_3/kg + 131mg triple super phosphate/kg), broiler litter (6.00 g/kg), and Milorganite® (2.95 g/kg) were added to the contaminated soil to provide 62.5 mg of plant available N/kg (Table 2).

Table 2. Chemical analysis of the two organic amendments used in the 9-wk greenhouse study.

Amendment	N	P	K	Na
	------------Total %------------			
Broiler litter	4.50	2.53	4.18	0.99
Milorganite®	7.11	2.29	0.64	0.17

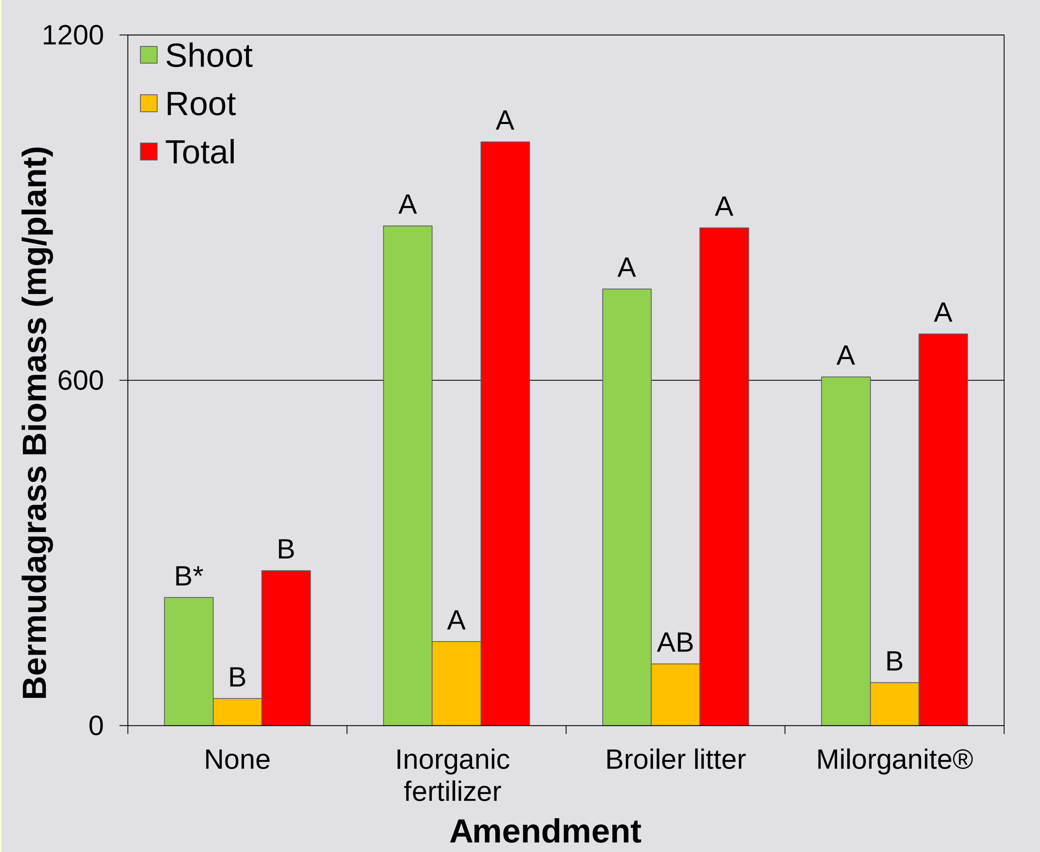
Vegetation

Two 7-cm Bermudagrass [*Cynodon dactylon* (L.) Pers] sprigs were planted per Conetainer® and were maintained at -33 kPa (20% gravimetric moisture) by daily application of distilled water during the 9-wk greenhouse study. Bermudagrass shoots were harvested, rinsed with distilled water, and dried to a constant weight at 55°C. Shoots were digested and elemental analysis was conducted using ICP methods (Donahue, 1992). Roots were rinsed and stained with an ethanol solution containing methylene blue. Root length, volume, and surface area were determined with WinRhizo 5.0® (Thompson et al., 2008). Root biomass was determined by drying the roots to a constant weight.

Statistical Analysis

The experiment was analyzed as a randomized complete block design with four blocks and a 4 × 2 × 2 factorial treatment structure. Least squares means for significant effects were compared using a protected least significant difference (LSD) procedure at $\alpha = 0.05$ using SAS® Version 9.2 (SAS Institute, Inc., Cary, NC).

Results and Discussion



* Bars with the same letter for a given parameter are not different (P ≤ 0.05).

Fig 3. Influence of four amendments on bermudagrass shoot, root, and total biomass production.

Vegetation

Inorganic fertilizer, broiler litter, and Milorganite® increased bermudagrass shoot and total biomass compared to the unamended soil during the 9-wk greenhouse study (Fig. 3). The three amendments did not differ in shoot and total biomass production.

Bermudagrass grown in soil from the 0-30 cm depth resulted in increased root biomass, length, volume, and surface area compared to the soil from the 0-15 cm depth (Table 3). The improved root growth was likely due to dilution of the surface-applied drilling fluid that resulted from the deeper sampling depth. Mixing the soil to a greater depth by deep plowing would be beneficial for plant growth.

Table 3. Bermudagrass root biomass, length, volume, and surface area after the 9-wk study.

Soil Depth	Biomass	Length	Volume	Surface Area
--cm--	mg/plant	cm/plant	cm^3/plant	cm^2/plant
0-15	64 B*	472 B	0.49 B	53 B
0-30	124 A	788 A	0.79 A	88 A

*Means in a column followed by the same letter are not significantly different (P ≤ 0.05).

Of the 64 plants, 11 died during the 9-wk study. For the unamended, inorganic fertilizer-, broiler litter-, and Milorganite®-amended soils, 1, 1, 7, and 2 plants, respectively, did not survive. Reduced plant survival in the broiler litter-amended-soil could be related to NH_3 toxicity due to the high level of NH_4-N and uric acid in the litter and the initial soil pH of 8.00. The reduced plant survival was consistent with data reported by Adams (2011) that observed damaging symptoms and mortality of ground vegetation by land application of drilling fluids. Nelson et al. (1984) reported that ryegrass yield reductions in drilling-fluid-amended soils were due to increased concentrations of soluble salts.

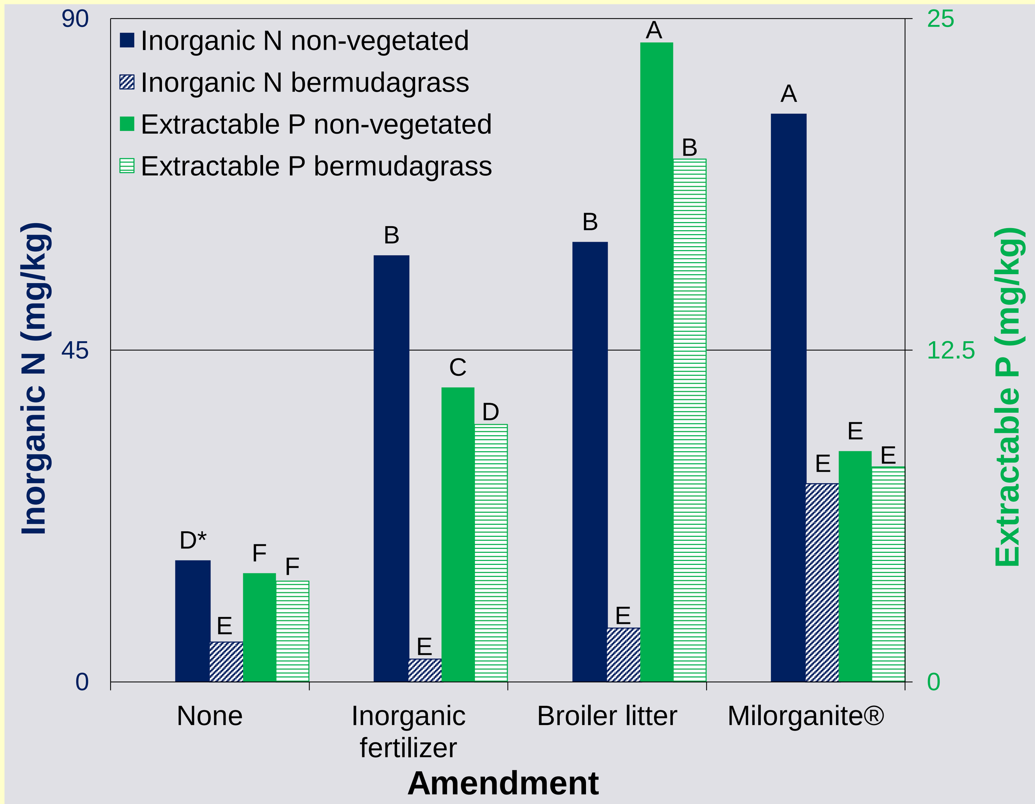
Plant shoot Na and Cl^- levels were unaffected by soil depth interval or addition of soil amendments (data not shown).

Soil

Using the relationship described by Zhang et al. (2005), the calculated saturated-paste EC values all exceeded 12 dS/m. The final pH values of the 0-15 cm and 0-30 cm soil depths were 8.00 and 7.94, respectively. Considering the high levels of EC and extractable Na, the contaminated soil would likely be considered saline-sodic (Brady and Weil, 2002).

Electrical conductivity, extractable Na, and Cl were greater in the 0-15-cm-depth soil compared to the 0-30 cm soil depth. Bermudagrass vegetation in the 0-30-cm-depth soil resulted in decreased EC and Cl^- (data not shown).

Inorganic N (N_i) decreased in all soils with bermudagrass vegetation compared to the non-vegetated soil (Fig. 4). The greatest plant uptake (54 mg/kg) occurred in the inorganic fertilizer- and broiler litter-amended soils. Mehlich-3-extractable P levels decreased in the inorganic fertilizer- and broiler litter-amended soils with bermudagrass. The greatest plant uptake (4.4 mg/kg) occurred in the broiler litter-amended soil. The addition of broiler litter resulted in the greatest extractable P levels in the non-vegetated and bermudagrass treatments.



* Bars with the same letter for a given parameter are not different (P ≤ 0.05).

Fig. 4. Interaction of vegetation and amendments on soil N_i and extractable P concentrations.

Conclusion

An effective management strategy to establish vegetation in soil contaminated with hydraulic -fracturing drilling fluid should include:

- Plowing the soil to a depth of 30 cm
- Applying inorganic fertilizer, broiler litter, or Milorganite®
- Sprigging bermudagrass
- Providing adequate soil moisture

Acknowledgement

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