Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences

Volume 12 Article 13

Fall 2011

Plant growth in soil amended with drilling mud

Satoshi Takaki
University of Arkansas, Fayetteville

Duane C. Wolf
University of Arkansas, Fayetteville

Recommended Citation

Takaki, S., & Wolf, D. C. (2011). Plant growth in soil amended with drilling mud. *Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences, 12*(1), 74-79. Retrieved from https://scholarworks.uark.edu/discoverymag/vol12/iss1/13

Plant growth in soil amended with drilling mud

*Satoshi Takaki** *and Duane C. Wolf*†

ABSTRACT

Extraction of natural gas generates drilling fluid and drilling mud that contain high concentrations of salts. Land application of the fluid and mud can have negative impacts on plant growth and soil properties. The objective of this study was to determine the effects of drilling mud on plant growth, plant chemical concentrations, and soil chemical properties. Sudangrass (*Sorghum sudanense* [Piper] Stapf [Piper]) and bermudagrass (*Cynodon dactylon* L.) were grown in a Roxana loam soil amended with 0%, 5%, or 10% (w/w) drilling mud in a 6-wk greenhouse study. Plant biomass production and concentrations of elements in biomass were determined. Electrical conductivity, pH, and concentrations of extractable and total elements in soil were analyzed. The addition of drilling mud significantly reduced shoot and total biomass production of both plant species and root biomass of bermudagrass. When drilling mud was added to the soil, plant Ca and Mg levels increased. Soil levels of Na, Cl, and the electrical conductivity significantly increased with increased levels of drilling mud application which indicated that salinity was most likely limiting plant growth. Excessive rates of drilling mud application can adversely impact soil properties and reduce plant growth.

---

* Satoshi Takaki is a 2010 graduate with a major in Environmental, Soil, and Water Science.

† Duane C. Wolf is a faculty mentor and a professor in the Department of Crop, Soil, and Environmental Sciences.

MEET THE STUDENT-AUTHOR

Satoshi Takaki

After I graduated from high school in Japan, I left for the United States and attended the University of Arkansas beginning in the fall 2006 semester. Since I hope to dedicate myself to addressing environmental issues in the future, I completed my B.S. degree in environmental, soil, and water science in December 2010. As an undergraduate I was involved in several research projects, including working with Dr. Thad Scott on a project to evaluate eutrophic urban streams and lakes in the Fayetteville area. The experience allowed me to learn the processes involved in scientific studies, which has been valuable in my subsequent studies. For my honors thesis project, I worked with Dr. Duane Wolf to evaluate the effect of drilling mud from natural gas extraction wells on plants and soil. I successfully conducted the study and completed the honors program. I returned home to Japan in December 2010 and plan to continue my education at the graduate level. Because there are still many Asian countries that have not installed adequate infrastructure for wastewater treatment, I would like to address wastewater treatment and water degradation problems in my future career path.

INTRODUCTION

Natural gas is the third largest energy resource and accounts for 15.6% of the annual global energy consumption (IEA, 2009). Annual production of natural gas increased from 2.1×10^{12} m^3 in 1995 to 2.8×10^{12} m^3 in 2005 (BP, 2006). It is anticipated to increase to 4.9×10^{12} m^3 by 2025 (Balat, 2009).

Extraction of natural gas uses water to lubricate and cool the drilling apparatus, transport formation cuttings to the surface, and seal porous geologic formations (ASME, 2005). The resulting water is known as drilling fluid that is transported to a holding pond where solids settle (Argonne National Laboratory, 2010). The drilling fluid is removed for disposal and the drilling mud remains. Drilling fluid and drilling mud often contain salts (Na and Cl), barite, water-based surfactants or diesel, and montmorillonite (Miller and Pesaran, 1980). The concentrations of soluble salts, trace elements, and the high pH of drilling mud have the potential to reduce plant growth (Nelson et al., 1984).

The objective of this study was to determine the effects of three rates of drilling mud on growth of two plant species, plant chemical concentrations, and chemical properties of a Roxana loam soil following a 6-wk greenhouse study.

MATERIALS AND METHODS

Experimental Set-up. Drilling mud was collected from a depth of 0 to 15 cm from a holding pond from which the drilling fluid had been removed. The soil used for the study was Roxana loam (coarse-silty, mixed, superactive, nonacid, thermic Typic Udifluvents), collected from a depth of 0 to 15 cm at the Vegetable Research Station at Alma, Ark. Drilling mud and Roxana soil were crushed to pass a 2-mm stainless-steel sieve. The drilling mud and soil were analyzed at the Arkansas Agricultural Diagnostics Laboratory (Fayetteville, Ark.) for pH and electrical conductivity (EC) in a slurry of 1:2 soil to water (w/w). The total nitrogen (TN); total carbon (TC); water-extractable Cl; concentrations of Mehlich-3-extractable Ca, Mg, Na, Cu, and B; and the total elemental analysis of Ca, Mg, Na, Cu, and B were also determined. The values of TN and TC were obtained by the Dumas combustion method using vario Max CN Element Analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). Water-extractable chloride, Mehlich-3-extractable, and total element analyses were conducted using an inductively coupled plasma atomic emission spectrometer (ICP-AES; SPECTRO ARCOS; SPECTRO Analytical Instruments Inc., Mahwah, N.J.; Mehlich, 1984; Donahue, 1992; Table 1). The total elemental analysis used United States Environmental Protection Agency method 3050 B (USEPA, 1996). The Roxana soil contained 12%, 49%, and 39% clay, silt, and sand, respectively, and had a -33 kPa moisture potential of 16% (w/w). Two samples of the drilling mud and soil were analyzed and the drilling mud had mean TN, TC, pH, EC, and Cl values of 0.13%, 3.66%, 8.0, 6.42 dS/m, and 6,425 mg/kg, respectively. The Roxana soil had mean TN, TC, pH, and EC values of 0.05%, 0.57%, 6.3, and 0.05 dS/m, respectively.

Greenhouse Experiment. The study involved three drilling mud rates (0%, 5%, or 10%; w/w), three vegetation treatments (sudangrass (*Sorghum sudanense* (Piper) Stapf), bermudagrass (*Cynodon dactylon* L.), or no plant), and four replications, for a total of 36 individual sample units. Each Conetainer® contained 500 g (dry weight) of Roxana loam soil. The rate of drilling mud amendment was 0.0 g (0%), 25.0 g (5%), or 50.0 g (10%) on a dry-weight basis. Roxana soil and drilling mud were thoroughly mixed and added into the 6.4-cm diameter by 25-cm long Conetainers® (Kirkpatrick et al., 2006). In each sudangrass treatment, five seeds of sudangrass were planted into each pot. The soil was adjusted to a moisture potential of -33 kPa by addition of distilled water.

The Conetainers® were blocked and arranged randomly in a greenhouse and watered daily. After 1 week, sudangrass germinated and was thinned to one plant per Conetainer®, and a 5-cm-sprig of bermudagrass was transplanted into the appropriate Conetainers®. After 3 weeks, each Conetainer® was fertilized with 25 mg NH_4NO_3/kg dry soil (Chapman, 1999).

Shoot and Root Analysis. After 6 weeks, plant shoots and roots were harvested. Shoots were cut at the soil surface, rinsed with distilled water, and dried to a constant weight at 65 °C. After weighing the shoot biomass, the samples were ground to pass a 2-mm stainless-steel sieve (Kirkpatrick et al., 2008). Harvested roots were washed, dried, and weighed.

The concentrations of Ca, Mg, Na, Cu, and B in shoots were analyzed by the ICP-AES method at the Arkansas Agricultural Diagnostics Laboratory (Donahue, 1992).

Soil Analysis. After shoots and roots were harvested, soils were crushed to pass a 2-mm stainless-steel sieve and air-dried. The EC, pH, Cl; the concentrations of Mehlich-3-extractable Ca, Mg, Na, Cu, and B; and the concentrations of total Ca, Mg, Cu, and B were analyzed at the Arkansas Agricultural Diagnostics Laboratory.

Statistical Analysis. The statistical analysis was based on a two-factor factorial design incorporated with four randomized complete blocks (RCB). The two factors were drilling mud and vegetation. The statistical analysis method employed was analysis of variance and multiple comparisons were conducted using least significant difference (LSD) with $\alpha = 0.05$. The analysis was carried out using SAS® version 9.2 (SAS Institute, Inc, Cary, N.C.).

RESULTS AND DISCUSSION

Plant Parameters. Shoot and total plant biomass were reduced at higher drilling mud rates (Table 2). Bermudagrass root biomass was not different among the drilling mud rates, but root biomass of sudangrass was less at higher drilling mud rates (Table 3). Bermudagrass root biomass was smaller than sudangrass at 0% and 5% drilling mud rates. Total bermudagrass biomass was smaller than sudangrass biomass with values of 1.35 g/pot and 3.27 g/pot, respectively.

The concentrations of plant Ca and Mg at 0% drilling mud rate were less than at 5% and 10% which reflected the levels of the nutrients contained in the added drilling mud (Tables 1 and 4). The concentrations of Na and Cu in bermudagrass were greater than sudangrass (data not presented). The concentrations of B in bermudagrass were not different among drilling mud rates, but the concentration in sudangrass at 10% drilling mud rate was greater than 0% and 5% (Table 5). The concentrations of B in bermudagrass were smaller than sudangrass at the same drilling mud rates. The B levels were not sufficient to be toxic to plants (Nable et al., 1997).

Soil Parameters. The EC and the concentrations of extractable Ca, Mg, Na, Cu, and B increased with increased drilling mud rates (Table 6). The soil pH following the 6-wk study was approximately 1 unit greater in soil amended with 5% and 10% drilling mud compared to the 0% drilling mud rate (data not presented). The Cl concentrations in soil from the no plant, bermudagrass, and sudangrass treatments increased with increased drilling mud rates (data not presented).

The increased soil extractable concentrations of Ca, Mg, and Na (Table 6) and Cl due to drilling mud addition resulted in increased soil salinity. Increased soil salinity was measured as greater EC levels at higher mud rates (Table 6). High soil salinity has negative effects on plant growth (Dashti et al., 2009). Others in previous studies of soils amended with drilling fluids and drilling mud have concluded that increased salinity was the major factor that inhibited plant growth (Bauder et al., 2005; Miller and Pesaran, 1980; Miller et al., 1980). The increased salinity was likely the major factor in reducing bermudagrass and sudangrass growth at the 5% and 10% rates of drilling mud addition used in the current study. Soils with soluble salt levels that inhibit plant growth are known as saline soils (Brady and Weil, 2002).

The concentrations of total Ca, Na, Cu, and B in soil were significantly increased with increased drilling mud rates (Table 7). The concentrations of total Mg were not different between 0% and 5% drilling mud rates, but the amount at 10% was greater than at 0% or 5%.

In addition to salt and Na levels, high concentrations of trace elements in soil can inhibit the growth of plants (Athar and Ahmad, 2002). Addition of high levels of trace elements contained in the drilling mud can be a concern. The concentrations of Mehlich-3-extractable and total Cu and B in soil were greater at higher mud rates (Tables 6 and 7). However, the Cu levels in the plants did not increase (data not shown) in response to drilling mud addition which could be related to the increased pH levels that reduce plant availability of Cu (Nelson et al., 1984; Miller and Pesaran, 1980; Miller et al., 1980). Results from the greenhouse study did not indicate that Cu or B added in the drilling mud amendment reduced bermudagrass or sudangrass growth.

Other Factors. In addition to the parameters reported in the current study, several other factors could reduce plant growth in drilling mud-amended soils. Barite ($BaSO_4$) is used to regulate density and viscosity of drilling fluid and control filtration (ASME, 2005). The drilling mud contains Ba, S, several trace elements, and lubricants and surfactants that would be added to the soil when the drilling mud was soil applied. Determining levels of the above parameters was beyond the scope of the present study. The Arkansas Department of Environmental Quality (ADEQ) Water Division is in charge of land application of drilling fluids and requires a land application permit (ADEQ webmaster, 2009). Land application of drilling mud in Arkansas is not currently allowed and disposal at an appropriate landfill is the common method of drilling mud disposal.

In summary, plant biomass production indicated that the addition of 5% or 10% drilling mud rates increased soil salinity and Na and Cl concentrations to levels that had negative impacts on the growth of bermudagrass and sudangrass. Future research should focus on determining suitable rates of drilling-mud application and applying agronomic management techniques to provide options for disposal of drilling mud and to protect the environment.

ACKNOWLEDGEMENTS

Financial support for this project was provided by an Honors College Undergraduate Research Grant and a Dale Bumpers College of Agricultural, Food and Life Sciences Undergraduate Research Grant. The author expresses appreciation to Ms. Faith Chu and Dr. Edward Gbur for statistical analysis of the data.

LITERATURE CITED

(ADEQ) webmaster 2009. Arkansas Department of Environmental Quality. Water Division. No Discharge Permits Section. Available at http://www.adeq.state.ar.us/water/branch_permits/nodischarge_permits/default.htm (Accessed 30 November 2010).

(ASME) American Society of Mechanical Engineers Shale Shaker Committee. 2005. Drilling Fluid Processing Handbook. Gulf Professional Publishing, Burlington, Mass., USA.

Argonne National Laboratory. 2010. The Drilling Waste Management Information. [Online]. Argonne National Laboratory, Ill., US. Available at http://web.ead.anl.gov/dwm/techdesc/land/index.cfm (Accessed 12 July 2010).

Athar, R. and M. Ahmad. 2002. Heavy metal toxicity: Effect on plant growth and metal uptake by wheat, and on free living *Azotobacter.* Water Air Soil Poll. 138:165-180.

Balat, M. 2009. Global trend of production and utilization of natural gas. Energy Sources, Part B: Econ. Plan. Policy 4:333-346.

Bauder, T.A., K.A. Barbarick, J.A. Ippolito, J.F. Shanahan, and P.D. Ayers. 2005. Soil properties affecting wheat yields following drilling-fluid application. J. Environ. Qual. 34:1687-1696.

Brady, N.C. and R.R. Weil. 2002. The Nature and Properties of Soils. 13th edition. Pearson Education, Inc., Upper Saddle River, N.J. 960 pp.

(BP) British Petroleum. 2006. Quantifying energy BP statistical review of world energy 2006 June. BP Press Office, London, UK. Available at http://www.bp.com/liveassets/bp_internet/russia/bp_russia_english/STAGING/local_assets/downloads_pdfs/s/Stat_Rev_2006_eng.pdf (Accessed 7 January 2011).

Chapman, S.L. (ed.) 1999. Soil Test Recommendations Guide. University of Arkansas Cooperative Extension Service and Agricultural Experiment Station, Fayetteville, Ark.

Dashti, A., A. Khan, and J. Collins. 2009. Effects of salinity on growth, ionic relations and solute content of *Sorghum bicolor* (L.). Monench. J. Plant. Nutr. 32:1219-1236.

Donahue, S.J. 1992. Reference soil and media diagnostic procedures for the southern region of the United States. Southern Cooperative Series Bulletin. 374:71.

(IEA) International Energy Agency. 2009. Key world energy statistics 2009. OECD/IEA, Paris, France. Available at http://www.iea.org/textbase/nppdf/free/2009/key_stats_2009.pdf (Accessed 7 January 2011).

Kirkpatrick, W.D., P.M. White Jr., D.C. Wolf, G.J. Thoma, and C.M. Reynolds. 2006. Selecting plants and nitrogen rates to vegetate crude-oil-contaminated soil. Int. J. Phytoremed. 8:285-297.

Kirkpatrick, W.D., P.M. White, Jr., D.C. Wolf, G.J. Thoma, and C.M. Reynolds. 2008. Petroleum-degrading microbial numbers in rhizosphere and non-rhizosphere crude oil-contaminated soil. Int. J. Phytoremed. 10:210-221.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Comm. Soil Sci. Plant Anal. 15:1409-1416.

Miller, R.W. and P. Pesaran. 1980. Effects of drilling fluids on soils and plants: Complete drilling fluids mixtures. J. Environ. Qual. 9:552-556.

Miller, R.W., S. Honarvar, and B. Hunsaker. 1980. Effects of drilling fluids on soils and plants: Individual fluid components. J. Environ. Qual. 9:547-552.

Nable, R.O., G.S. Banuelos, and J.G Paull. 1997. Boron toxicity. Plant and Soil. 193**:**181–198.

Nelson, D.W., S.L. Liu, and L.E. Sommers. 1984. Extractability and plant uptake of trace elements from drilling fluids. J. Environ. Qual. 13:563-566.

(USEPA) U.S. Environmental Protection Agency. 1996. Method 3050b Acid Digestion of Sediments, Sludges, and Soils. USEPA Rep. SW-846 Ch 3.2. Office, Washington, DC. Available at http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3050b.pdf (Accessed 16 January 2011).

Table 1. Mehlich-3-extractable chemical concentrations of the drilling mud and Roxana soil and total elemental analysis of the drilling mud.

	Drilling Mud		Roxana Loam
Element	Extractable	Total	Extractable
	------------------------------mg/kg------------------------------		
Ca	5,767	17,825	1,372
Mg	513	4,263	326
Na	4,980	5,335	13
Cu	11.0	59.1	2.3
B	4.7	13.4	0.2

Table 2. Influence of three drilling mud rates (w/w) on mean shoot and total biomass production of sudangrass and bermudagrass after the 6-week greenhouse study.

Drilling Mud Rate	Shoot Biomass	Total Biomass
-----%-----	-------------------- g/pot --------------------	
0	2.47 a*	3.62 a
5	1.49 b	2.11 b
10	0.84 c	1.20 c
LSD	0.47	0.70

*Means in a column followed by the same letter are not significantly different at $P = 0.05$.

Table 3. The interaction of three drilling mud rates (w/w) and two vegetation types on root biomass production after the 6-week greenhouse study.

	Drilling Mud Rate (w/w)		
Vegetation	0%	5%	10%
	-----------------------g/pot ----------------------		
Bermudagrass	0.57 c*	0.31 c	0.22 c
Sudangrass	1.72 a	0.92 b	0.51 c

*Means followed by the same letter are not significantly different at $P = 0.05$ (LSD = 0.35).

Table 4. Influence of three drilling mud rates (w/w) on plant element concentrations after the 6-week greenhouse study.

Drilling Mud Rate	Ca	Mg
-----%-----	-----------------% -----------------	
0	0.39 b*	0.17 b
5	0.60 a	0.23 a
10	0.69 a	0.25 a
LSD	0.15	0.06

*Means in a column followed by the same letter are not significantly different at $P = 0.05$.

Table 5. The interaction of three drilling mud rates (w/w) and two vegetation types on plant boron concentration after the 6-week greenhouse study.

	Drilling Mud Rate		
Vegetation	0%	5%	10%
	------------------- mg/kg	-------------------	
Bermudagrass	2.6 c*	2.6 c	3.7 c
Sudangrass	7.1 b	9.6 b	13.6 a

*Means followed by the same letter are not significantly different at $P = 0.05$ (LSD = 3.0).

Table 6. Influence of three drilling mud rates (w/w) on soil electrical conductivity (EC) and extractable element concentrations after the 6-week greenhouse study.

Drilling Mud Rate	EC	Ca	Mg	Na	Cu	B
----%----	--dS/m--	-----------------------------	mg/kg	-----------------------------		
0	0.094 c*	1,166 c	249 c	20 c	2.6 c	0.4 c
5	0.585 b	1,703 b	272 b	316 b	3.7 b	0.8 b
10	1.102 a	2,240 a	307 a	612 a	5.0 a	1.1 a
LSD	0.096	70	10	22	0.3	0.1

*Means in a column followed by the same letter are not significantly different at $P = 0.05$.

Table 7. Influence of three drilling mud rates (w/w) on total soil element concentration after the 6-week greenhouse study.

Drilling Mud Rate	Ca	Mg	Na	Cu	B
-----%-----	---	mg/kg	---		
0	1,631 c*	2,936 b	58 c	7.3 c	6.7 c
5	2,519 b	2,988 b	338 b	9.7 b	7.3 b
10	3,559 a	3,099 a	592 a	13.1 a	8.0 a
LSD	169	65	14	0.4	0.2

*Means in a column followed by the same letter are not significantly different at $P = 0.05$.