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Soil and plant response to unused potassium silicate drilling fluid application

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ABSTRACT

Drilling fluid, also referred to as drilling mud, is a major waste from oil and gas drilling. Land application is a novel approach to potassium silicate drilling fluid (PSDF) waste recycling, addressing its disposal requirements while potentially improving soil quality for land reclamation. Inorganic nitrogen (N) and phosphorus (P) fertilizer (0, 34 N: 45 P kg ha^{-1}) was added with PSDF (0, 30, 45, 60 m^3 ha^{-1}) as eight PSDF amendments. PSDF amendments were incorporated or sprayed on four reclamation soils (sand, loam, clay loam 1 and 2). Response to PSDF application was assessed in the greenhouse with two plant species (*Hordeum vulgare* L. (barley) and *Agropyron trachycaulum* (Link) Malte (slender wheat grass).

PSDF amendments had no detrimental effects on soil quality (macronutrients, pH, salinity, sodicity) and plant growth except in clay loam 2 soil. In loam soil, barley height and biomass were greater with PSDF at 45 m^3 ha^{-1} with fertilizer relative to soil without PSDF. In sand soil with PSDF at the highest rate without fertilizer, wheat grass height was 1.08 times and biomass was 1.76 times greater than the control. High electrical conductivity in clay loam 2 soil, and decreased density, height and biomass of wheat grass at highest PSDF application rates or with PSDF incorporation, suggest a threshold beyond which conditions are compromised for PSDF application. Increasing PSDF application rate increased soil potassium availability by 1.6–4.1 times relative to no PSDF. This initial research demonstrates that PSDF may be an appropriate soil amendment for agricultural crops and native plant species on land reclamation sites with consideration of substrates properties, plant species tolerances and inorganic fertilizer.

1. Introduction

Drilling fluid (drilling mud) is one of the primary wastes generated from drilling. It is used to lubricate and cool the drilling apparatus, transport drill cuttings to the surface and seal porous geologic formations. Drilling fluids typically consist of bentonite and various additives mixed with fresh water or hydrocarbons, and are classified as water based, oil based or synthetic based. Drilling fluids can be potentially toxic complex chemical mixtures and are therefore considered environmentally damaging (Fink, 2011). Toxicity to terrestrial and aquatic ecosystems could be related to high pH, salinity, metals and petroleum hydrocarbons of drilling fluids. In Canada drilling fluids are defined as either hazardous or nonhazardous due to their wide variety of constituent chemicals (Alberta Energy Resources Conservation Board, 1996).

Very large amounts of drilling fluids are generated around the world and must be disposed of. During 2012–2013, approximately 3800 wells were drilled for crude oil and natural gas production just in Alberta, Canada (Alberta Ministry of Energy, 2013). A typical shallow gas well (250–650 m deep) in this region generates approximately 68 m^3 of used drilling fluids (Zvomuya et al., 2009), thus an estimated 258,400 m^3 of drilling fluids in Alberta are disposed of annually. Disposal of drilling fluids varies with type and jurisdiction. For example, in western Canada, on site disposal of drilling fluid is permitted in accordance with regulatory requirements for maximum disposal rate and acceptable increases in electrical conductivity (EC), sodium absorption ratio (SAR) and sodium (Na) and nitrogen (N) loading for water based drilling waste (Alberta Energy Resources Conservation Board, 2012; British Columbia Oil and Gas Commission, 2006; Saskatchewan Ministry of Energy and Resources, 2011). An ecologically sound alternative

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to costly disposal methods for these abundant industry by-products is required. An alternative that can add human value by enhancing crop systems without negative effects on the environment is most highly desired.

Potassium silicate drilling fluids (PSDF) are relatively new water based systems developed to drill in water sensitive shales to reduce environmental impacts. Sodium chloride (NaCl) concentrations in traditional water based drilling fluids were considered to have the most detrimental environmental effect, thus replacing NaCl with potassium silicate (K_2SiO_4) in newer drilling fluids could reduce the impact. Hypothetically, high concentrations of K in PSDF could serve as a soil nutrient amendment for land reclamation, thus land disposal would be practical and provide reclamation benefits. However, PSDF properties and effects on soil, vegetation and water are not well known. With such unclear impacts, land application of advanced gel chemical muds, including PSDF, required site specific approval in Alberta at the beginning of this research (Alberta Energy Resources Conservation Board, 2012). Therefore, such environmental impacts must be determined before land disposal of PSDF and its use in reclamation can be regulated.

Only a few studies addressed impacts of disposal of used water based drilling fluids on soil–plant–water systems and results varied. Some researchers found high soluble salts, heavy metals and petroleum residue in used water based drilling fluids were detrimental to soil quality and plant growth (McFarland et al., 1994, 1992; Miller et al., 1980; Nelson et al., 1984; Wojtanowicz, 2008; Zvomuya et al., 2009, 2008). Others found positive or no impacts from water based drilling fluids applied at low rates to coarse textured soils in arid regions (Bauder et al., 2005, 1999; Lesky et al., 1989; Macyk et al., 1990; Miller et al., 1980; Moseley, 1983; Tucker, 1985). Drilling fluids initially had a strong impact on chemical properties of silt loam soil (Kisic et al., 2009), increasing soluble nutrients, such as nitrogen (N), magnesium (Mg) and sulfur (S) of sandy loam soil (Zvomuya et al., 2011), these effects significantly declined after the first year. Differences among studies primarily resulted from soil and drilling fluid properties, disposal rate, method and monitoring period.

Previous studies (Bauder et al., 2005, 1999; Macyk et al., 1990; Miller et al., 1980) focused on agricultural or horticultural crops, such as green beans (*Phaseolus vulgaris* L.), sweet corn (*Zea mays* L.), sorghum (*Sorghum bicolour* L. Moench) and winter wheat (*Triticum aestivum* L.), or forage species such as smooth brome grass (*Bromus inermis* Leyss.). Response to drilling fluid application varied with species and drilling fluids. Some wetland vegetation with big hog cane (*Spartina alterniflora* Loisel.), bull tongue arrowhead (*Sagittaria lancifolia*), wire grass (*Spartina cynosuroides* L. Roth) and black mangrove (*Avicennia germinans* L.) were tested by Kelley and Mendelssohn (1995) and Willis et al. (2005), they found that drilling cuttings, the solid part of drilling fluids, could be a potential sediment source for wetland restoration.

Fertilizer plays an important role in land reclamation, often dramatically improving ecosystem function and structure response (Marrs and Bradshaw, 1982). Drilling fluid normally has high pH and sodicity which can cause nutrient deficiencies by modifying availability of elements that play a major role in plant nutrition, such as phosphorus (P), K and Mg (Taiz and Zeiger, 1998). Thus investigating fertilizer use under drilling fluid application scenarios is important.

The objective of this greenhouse experiment was to evaluate whether application of unused PSDF (before drilling use) amendments to different textured soils with different application methods would affect selected soil properties and establishment and development of selected agricultural and native grass species. With unused drilling fluid, influence of the soils being drilled could be removed, and impact of the drilling fluid itself could be more clearly interpreted. This had not been done in previous research.

2. Materials and methods

2.1. Experimental design

A greenhouse experiment was conducted in a complete randomized design with 4 soils, 2 plant species, 2 methods of PSDF application and 8 PSDF amendments, each replicated 5 times. Greenhouse temperature was maintained at 21 °C by day and 15 °C by night, with a 16 h photoperiod, approximating the Alberta growing season. Pots were watered to eliminate water stress. The experiment ran for 16 weeks, sufficient time to assess effects of PSDF on plant establishment, survival and growth.

Treatments represented PSDF application under various end land uses. The 4 soils used covered a range with potential for PSDF disposal. A Brunisol soil with sand texture was from the farming area north of Edmonton, Alberta (Sand). A Black Chernozem, loam to silt-loam texture, was from the prairies of east central Alberta (Loam). A Brown Chernozem with clay loam texture was from the dry mixed grass region in southern Alberta (Clay loam 1). An Eluviated Black Chernozem of clay loam texture was from north of Edmonton (Clay loam 2).

Two application methods were spraying over soil and spraying then incorporating, approximating potential application on a field basis to uncultivated soils and cultivated soils, respectively. Plant species were slender wheat grass (*Agropyron trachycaulum* (Link) Malte ex H.F. Lewis) and common barley (*Hordeum vulgare* L.), representing a native grass species and an agricultural crop widely used in land reclamation. These two species are relatively alkali and salinity tolerant (Mckenzie, 1988; Wentz, 2001 Wentz, 2001).

To determine the effect of PSDF application rate in the presence and absence of nitrogen and phosphorus fertilizer, eight PSDF amendments were developed. Each soil was amended with one of eight PSDF amendments: control (without fertilizer and PSDF), fertilizer alone, 30 $m^3\,ha^{-1}$ PSDF with and without fertilizer, 45 $m^3\,ha^{-1}$ PSDF with and without fertilizer, 60 $m^3\,ha^{-1}$ PSDF with and without fertilizer. Three PSDF application rates were developed around the current Alberta Energy Resources Conservation Board (2007) summer maximum loading rate of 40 $m^3\,ha^{-1}$; they were 30, 45 and 60 $m^3\,ha^{-1}$ (R_{30}, R_{45}, R_{60}). Inorganic fertilizer rate was based on optimum macronutrients for agronomic species. Potassium was not applied due to its high content in PSDF. Fertilizer was ammonium nitrate (NH_4NO_3) at 0.06 g pot^{-1} and triple super phosphate ($3Ca_3(PO_4)_2{\cdot}CaF_2 + 4H_3PO_4 + 9H_2O \rightarrow 9Ca(H_2PO_4)_2 + CaF_2$) at 0.07 g pot^{-1}, equivalent to 34 and 45 kg ha^{-1}, respectively.

2.2. PSDF, soil collection and analyses

PSDF was manufactured by Marquis Alliance Ltd., Calgary, Alberta, Canada and refrigerated until used. Soils were collected from three Alberta locations where drilling was active. Soil and PSDF properties were determined by a commercial laboratory (Exova Ltd., Edmonton, Alberta, Canada). Three samples were taken for each type of PSDF and soil before the experiment. At the end of harvesting, from the fertilized treatment, one combination soil sample was taken from each of 5 replications per treatment.

Soil pH and EC were determined from saturated paste extracts (Miller and Curtin, 2008). Soil routine ions were determined by ion chromatography with chemical suppression (Clesceri et al., 1992). Sodium adsorption ratio (SAR) was calculated from analyzed concentrations of Na, Ca and Mg. Cation exchange capacity (CEC) was determined by exchange with ammonium acetate (NH_4OA_C) at pH 7 (McKeague, 1978), available nitrate (NO_{3^-}) and ammonium (NH_{4^+}) by extraction with 2.0 M potassium chloride (KCl) (Kroetsch