Ecotoxicology and Environmental Safety 120 (2015) 326–333

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Soil and plant response to used potassium silicate drilling fluid application

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ARTICLE INFO

Article history:
Received 14 October 2014
Received in revised form
21 May 2015
Accepted 11 June 2015
Available online 20 June 2015

Keywords:
Drilling fluid
Potassium silicate
Soil amendment
Revegetation
Reclamation

ABSTRACT

Use of drilling waste generated from the oil and gas industry for land reclamation has potential to be a practical and economical means to improve soil fertility and to decrease landfills. A four month greenhouse experiment with common barley (*Hordeum vulgare* L.) on three different textured soils was conducted to determine soil and plant response to incorporated or sprayed potassium silicate drilling fluid (PSDF). Two PSDF types (used once, used twice) were applied at six rates (10, 20, 30, 40, 60, 120 m^3 ha^{-1}) as twelve PSDF amendments plus a control (non PSDF).

Effects of PSDF amendment on plant properties were significant, and varied through physiological growth stages. Barley emergence and below ground biomass were greater with used once than used twice PSDF at the same application rate in clay loam soil. Used twice PSDF at highest rates significantly increased barley above ground biomass relative to the control in loam and sand soil. All PSDF treatments significantly increased available potassium relative to the control in all three soils. Soil electrical conductivity and sodium adsorption ratio increased with PSDF addition, but not to levels detrimental to barley. Soil quality rated fair to poor with PSDF amendments in clay loam, and reduced plant performance at the highest rate, suggesting a threshold beyond which conditions are compromised with PSDF utilization. PSDF application method did not significantly affect plant and soil responses. This initial greenhouse research demonstrates that PSDF has potential as a soil amendment for reclamation, with consideration of soil properties and plant species tolerances to determine PSDF types and rates to be used.

1. Introduction

Exploration and production in the oil and gas industry generate large volumes of drilling fluids, often referred to as drilling muds. Drilling fluids are pumped into bore holes to aid in the drilling process and to transport drill cuttings to the surface. These fluids can be water, oil or synthetic based and consist of bentonite, barite, lignite, chrome lignosulphate, sodium hydroxide and various additives mixed with fresh water or hydrocarbons. Environmentally friendly drilling fluids can minimize waste and decrease disposal cost. Potassium silicate drilling fluid (PSDF), an advanced gel drilling fluid with high performance, has recently been used in the oil and gas industry. PSDF is considered an environmentally acceptable alternative to traditional drilling fluids as it replaces hydrocarbons with silicate polymeric ions and lignite and sodium salts with potassium salts.

Economic and environmental sustainability requires innovative ways of thinking about oil and gas industry waste streams. In western Canada, land spraying while drilling is a disposal approach with criteria for maximum disposal rate and maximum acceptable increases in electrical conductivity, sodium adsorption ratio, sodium loading and nitrogen loading for water based drilling waste (British Columbia Oil and Gas Commission, 2006; Saskatchewan Ministry of Energy and Resources, 2011; Alberta Energy Resources Conservation Board, 2012). Used drilling fluids are sprayed then incorporated on cultivated land or spread on vegetated land. Due to a shortage of information, the advanced water based gel chemical muds (e.g. potassium silicate, potassium sulfate) were not included in regulatory updates for land spraying while drilling in Alberta, Canada and other jurisdictions.

Few studies have addressed the impact of disposal of used drilling fluids on soil–plant–water systems. Some researchers found high soluble salts, heavy metals and petroleum residue content of used drilling fluids were detrimental to soil quality and plant growth (Miller et al., 1980; Nelson et al., 1984; McFarland et al., 1992; McFarland et al., 1994; Wojtanowicz, 2008; Zvomuya

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http://dx.doi.org/10.1016/j.ecoenv.2015.06.021

et al., 2008, 2011). Others found positive or no impacts from drilling fluids applied at low rates in coarse textured soils in arid regions due to pH increase, potential micronutrient addition and/or improved soil physical properties (Miller and Pesaran, 1980; Moseley Jr., 1983; Lesky et al., 1989; Macyk et al., 1990; Bauder et al., 1999, 2005).

PSDF has high concentrations of potassium, which industry and regulators see as a potential problem for salt accumulation and soil structure deterioration. Few studies have addressed this concern. Processes that control potassium in soils from PSDF land disposal are complex and poorly understood, such as rate of potassium release, leaching and long term plant bioavailability. Potassium is required in many biochemical functions and increases plant tolerance to drought, low temperatures or salinity (Tisdale et al., 1999; Whitehead, 2000). PSDF land application may result in potassium availability that can be in excess of plant requirements. Hypothetically, potassium in PSDF could serve as a nutrient amendment for reclamation, thus not only would land disposal be practical, but also provide benefits for reclamation.

In a recent greenhouse experiment (Yao and Naeth, 2014), unused PSDF had no detrimental effects on soil and plant properties at rates $\leq 45\ m^3\ ha^{-1}$. Whether used PSDF has the same impacts on soils and plants as unused PSDF is unknown. In this experiment, changes in properties of different textured soils and responses of a common agricultural crop species were studied to determine effects of two used PSDFs applied at different rates, and with PSDF surface sprayed and incorporated.

2. Materials and methods

2.1. Experimental design

A completely randomized design was used in the greenhouse with 3 soils, 2 PSDF application methods and 12 PSDF amendments plus controls consisting of unamended soils, each replicated 5 times. Treatments represented reclamation application scenarios in cultivated land. The plant species was common barley (*Hordeum vulgare* L.), representing an agricultural crop widely used in land reclamation. Three soil textures were sand, loam and clay loam, covering a range of soils with potential for reclamation using drilling fluids. Two application methods were spraying PSDF over soil and spraying PSDF over soil followed by incorporation, approximating likely field application methods.

PSDF amendments were developed based on two types of PSDF and six application rates. The two types of PSDF were used once (PSDF used in one drilling well) and used twice (PSDF used in two drilling wells). The six application rates (10, 20, 30, 40, 60, 120 $m^3\ ha^{-1}$) were developed around the current Energy Resources Conservation Board (2007) summer maximum loading rate of 40 $m^3\ ha^{-1}$.

2.2. Potassium silicate drilling fluid and soil collection and analyses

All PSDF used in this research was from the same source. Unused PSDF consisted of 1 m^3 fresh water with 6 pregelatinized starch, 2 polyanionic cellulose, 1 anionic water soluble polymer, 2 xanthan gum, 3 potassium hydroxide and 5.5 raw silicate (all units $kg\ m^{-3}$) (Ma, personal communication, 2008). Used once PSDF was collected from well sites after drilling; used twice PSDF was collected from well sites that recycled used once PSDF. Soils were collected from 20 locations per site from the upper 20 cm at three sites in Alberta where drilling was active. Soil and PSDF properties were determined by a commercial laboratory.

Soil samples were sieved to remove large particles, ground to <2 mm and the following analyses conducted. Available nitrate (NO_3^-) and ammonium (NH_4^+) was extracted with 2.0 M potassium chloride (KCl) (Maynard et al., 2008); available phosphorus (P) and potassium (K) by modified Kelowna extraction (Ashworth and Mrazek, 1995); and available sulfate (SO_4) by extraction with 0.1 M calcium chloride ($CaCl_2$) (McKeague, 1978) then concentrations determined with the autoanalyzer. Cation exchange capacity (CEC) was determined by exchange with ammonium acetate (NH_4OA_C) at pH 7 (McKeague, 1978). Total nitrogen (N) was determined by Kjeldahl digestion distillation (Bremner, 1996); total carbon (C) by dry combustion (Nelson and Sommers, 1996), total organic carbon by Walkley–Black wet dichromate oxidation method (Nelson and Sommers, 1996). Water soluble cations, sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), pH, electrical conductivity (EC) were determined from saturated paste extracts with flame-atomic absorption spectroscopy (Miller and Curtin, 2008); sulfate and chloride (Cl) by ion chromatography with chemical suppression (Clesceri et al., 1992). Sodium adsorption ratio (SAR) was calculated from Na, Ca and Mg concentrations. Hydrocarbon fractions (F1, F2, F3, F4) were from gas chromatographic results with purge-and-trap (USEPA, 1996). Trace metals restricted in concentration by Canadian Council of Ministers of the Environment (CCME, 2007), silver (Ag), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), thallium (Tl), uranium (U), vanadium (V), zinc (Zn) were determined by inductively coupled plasma (ICP) following strong acid digestion (USEPA, 2008) and hot water soluble boron (B) were measured using azomethine-H method (McKeague, 1978). Sand, silt and clay were determined by hydrometer after treatment with calgon (Kroetsch and Wang, 2008).

2.3. Greenhouse methods and plant measurements

Soil was placed in 15 cm diameter pots. PSDF was applied at rates described above. Untreated controls were included for each soil. PSDF was evenly applied by hand on the soil surface by pouring from beakers. PSDF was incorporated with shovels for incorporation treatments. Pots were allowed to settle for one week before seeding.

Fertilizer was added based on optimum macronutrients generally required by agronomic species so nutrient deficiencies would not be interpreted as plant response to PSDF application. Potassium fertilizer was not applied due to high concentrations in drilling fluid. Treatments were fertilized with 0.06 g pot^{-1} (34 kg ha^{-1}) ammonium nitrate and 0.07 g pot^{-1} (45 kg ha^{-1}) triple super phosphate.

Each pot was seeded with 20 barley seeds, then randomly placed on a greenhouse bench. Pots were watered regularly twice per day for the first 4 weeks and once per day thereafter, with sufficient water to keep the pots near field capacity by gravimetric methods throughout the four month experiment. Greenhouse temperature was maintained at 21 °C during the day and 15 °C at night, with a 16 h photoperiod.

Numbers of plants emerging and their death in each pot were recorded weekly. After 2 weeks, plants were thinned to the five most vigorous plants per pot. At the seed production stage, above ground biomass from each pot was clipped at soil surface. Roots in sandy soil were hand separated from soil; large gravel particles in loam and clay loam soils were removed by hand, then pots were soaked in water for 12 h in a tray. Roots were cleaned by washing with tap water. All biomass was oven dried at 80 °C for 48 h to constant weight.

2.4. Statistical analyses

Analyses were conducted with R software (R Development Core Team, 2012). Soils were considered separate reclamation scenarios