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Environmental Impact of Potassium Sulphate-based Drilling Mud Systems: Development of Criteria for Waste Disposal in Terrestrial Ecosystems.

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Abstract

The chemical and physical characteristics of potassium sulphate (K_2SO_4) drilling mud systems are effective and affordable. Advantages afforded by this system include reduced borehole size, superior shale inhibition and reduced drilling costs. The regulatory body (Alberta Energy and Utilities Board) for the energy sector has established chemical and toxicological criteria to limit loading rates of potassium sulphate-based systems. However, knowledge about the ecotoxicological effects of these systems has not been fully explored.

In this paper, significant impacts on commercial, remedial and native plant species will be related to the chemical behavior and physicochemical impact on receiving soils challenged by potassium sulphate systems. A variety of soil types representing different Alberta soil ecoregions will be exposed to K_2SO_4 using a range of loading concentrations. Three different potassium sulphate-based drilling mud systems – commonly used drilling product mixes – will also be examined to determine potential additive or synergistic effects by the product constituents. Dose response relationships of plant growth will be assessed against changes in soil-physicochemical measurements such as soil salinity, cation exchange capacity, base absorption and sodium adsorption ratio.

As a result of our studies, we will propose a parametric benchmark for potassium sulphate with respect to environmental impact. Through this study we hope to provide realistic regulatory limits on K_2SO_4 mud systems which will provide protection for the environment and economic benefits to the drilling industry.

Introduction

The Petroleum Industry has been utilizing a number of different drilling mud systems to facilitate and expedite the advancing of wells from surface to producing zones. Deep wells in particular (1000 to 5000 meters) benefit from hydrocarbon-based (invert) or salt-based mud systems. Potassium sulphate mud systems have realized increasing popularity as a substitute for invert drilling, particularly owing to the cost of treating or hauling away invert mud to waste treatment and disposal facilities. Potassium sulphate mud systems confer the advantage of reduced well bore (smaller hole size, thus fewer returns to dispose of), superior shale inhibition (prevent the swelling of down-hole clay materials), and subsequently, reduced drilling times[1].

Alberta has implemented a set of guidelines for disposing of drilling wastes that were generated using gel-chemical mud systems (mud systems using primarily water, bentonite and a polymer). This guideline called the “Drilling Waste Management Guidelines” or “G-50” (Guide-50), was published in 1996 by the Energy Resources Conservation Board (ERCB) [2].

Until recently, most potassium sulphate-based drilling mud systems were disposed of under the auspices of the G-50. In August of 2001, the AEUB issued its Interim Guidelines for the Disposal of Advanced Gel-Chemical wastes (IL 2001-3), of which potassium sulphate was classified. According to the IL 2001-3, off lease disposal of clear, non-toxic drilling fluids from a potassium sulphate system had to be restricted to a maximum application rate of 90 kg/ha for sulphate, and 1100 kg/ha for potassium. These fluids were once disposed of off lease at rates far in excess of these levels. Little or no reported monitoring was done to gauge the effects of this practice. The current practice is to pump off the clear, non-toxic fluids over very large surface areas, dispose of the fluids down a disposal well, or re-use the fluids as much as possible in subsequent drilling operations.

Without a lower safe limit for off-lease disposal, expensive treatments or disposal options for advanced gel chemical fluids waste could offset the economic gains from reduced drilling times. Also, if an accidental release of the potassium sulphate fluids occurs, there could be some potentially negative impact to the receiving system through exposure to fluids with a high electrical conductivity.

Salt-based mud systems suffer from a shortage of environmental impact data to validate or refute any claim that they are environmentally sound products. Information of Potassium sulphate drilling fluids and the impacts to environmental receptors is also scarce. There are several considerations when considering the effects of potassium sulphate drilling fluids to the environment. Does the product exert an effect, and if so, is it through ion toxicity, osmotic shock, or some other chemical, physical or biological mechanism?

Sulphur is considered a macronutrient. As such, it a required element for the construction of proteins, coenzymes, and the amino acids methionine, cysteine and its derivative, cystine[3]. Sulphur is also required for the activation of enzymes involved in nitrate reduction[4], mediates the uptake of sodium[5], and is important in chlorophyll synthesis and the production of oils in crops such as canola, soybeans and flax[6]. In plants, sulphur is taken up from the soil as free sulphate, and as such is used in the oxidized form such as sulphate esters in cell membranes[7]. While sulphate is regarded as non-toxic to plants, other sources imply toxicity from sulphate is possible through its low mobility and subsequent build up in plant cytoplasm to toxic levels[5].

Potassium is also a macronutrient. Potassium functions as an activator of various cellular enzymes, and facilitates plant metabolism, starch synthesis, nitrate reduction, photosynthesis and sugar[3]. Potassium uptake from soil solution is mediated by internal negative feedback mechanisms in certain plants[8]. Potassium lowers the cellular osmotic water potential, thereby reducing the loss of water through stomatal openings and increases the plants abilities to take up water. There is also evidence that potassium confers some disease and insect resistance to various plants, including facilitating the production of tannins and phenolics in Douglas firs[3,9]. Potassium is not deemed to be toxic at higher than normal[7], and in fact can be stored in plants at levels above basic requirements, an ability termed luxury consumption[3]. Other sources suggest that high levels of potassium are indeed toxic to plants, in spite of cytoplasmic tolerance for the element[10].

The application of saline fluids to soils may result in a number of effects, depending upon the nature and application rate of the saline fluids. Salts can have a direct effect on vascular plants by increasing the osmotic tension of soil solution, causing a water deficit, or salts can disrupt the metabolic and nutritional processes of plants. Salts can also affect plants indirectly by altering the structure of the affected soils[11,12,13]. A low application of saline fluids may stimulate the growth of various plants[14], but owing to the slow breakdown and utilization of salts, the potential exists for salt concentration to build up to toxic levels. With sulphate salts, calcium and magnesium may be displaced from binding sites on soil particles and the plasma membrane on rootlets[15,5,16,17].

Saline solutions set up an osmotic gradient that favors the transfer of fluids from less dilute media to the higher, more saline environment. Plant roots and rootlets have evolved to sequester soil moisture by setting up their own osmotic potential that favors the influx of fluids[18,19]. As the external environment increases in salinity, more energy is required to pull fluids into a plant's roots. A plant that has to expend considerable amounts of energy getting water will suffer in some other physiological vein. Shorter shoots, smaller leaf size, wilting, reduction in stomatal size and number, yield reduction in grains, flowers or other vegetative structures are some of the losses plants can experience when a plant has to invest more energy into fluid procurement than usual[20,13,18].

Non-vascular plants, such as the bryophytes, can not regulate water and ion uptake using an extensive root system. Water is obtained primarily from wet deposition. They do not possess active salt extrusion mechanisms, and therefore are potentially more at risk from exposure to salts than vascular plants would be. The application of fertilizers in the past has lead to a shift in vegetation composition from bryophyte-dominated to vascular plant-dominated communities[21,22]. The literature on bryophytes is not replete with examinations of moss communities exposed to potassium sulphate contaminated fluids. Several authors discuss a decline in bryophyte diversity with increasing salinity[23,24,25,26]. Two of these papers, however, deal with salinity from sodium chloride[23,25]. The importance of this non-vascular ground cover appears to be the mosses ability to maintain ground moisture, cooler ground temperature and ground cover. Exposed forest floor is prone to soil erosion[22]. Mosses make up a substantial portion of forest floor cover in boreal forests[27]. Forest floor mosses trap and retain considerable wet deposition (rain and melt water).

This paper will examine the effects of potassium sulphate drilling fluid on a variety of mosses, grass, commercial and tree species. Seedling emergence and root and shoot elongation tests will be conducted on a variety of grasses, commercials and tree species. A range of potassium sulphate applications will be tested to assess the effects on root and shoot growth, as well as on seedling emergence and survival. The moss species will be challenged to a range of potassium sulphate applications in a manner that approximates field conditions (as if the potassium sulphate fluids were being pumped off into the bush, as is common practice in the petroleum industry). Drilling fluid systems contaning potassium sulfate and other components common in the current industry will also be assessed fo it's affect on plant growth. The data from the drilling fluid tests will be compared to tests conducted with potassium sulfate alone, to assess any alteration of impacts.

Methods

Study Design

The project was conducted in two phases. The toxicity of potassium sulfate to terrestrial plants using K_2SO_4 in deionized water to provide a baseline of toxicity to which a comparative examination could be made relative to potassium sulfate based drilling muds. The second phase of the study examined the toxicity of three drilling muds to selected species in 28-day plant growth tests.

Seedling emergence and root elongation tests were conducted in potassium sulphate concentrations ranging from 22.5 kg/hectare up to 1440 kg/hectare, increasing by a factor of 2. Common mosses were exposed to potassium sulphate loading rates from 90 kg/hectare up to 720 kg/hectare. The lower range reflects a shortage of resources.

Plant growth studies using drilling muds were exposed to test concentrations of 625 to 10000 mg/kg as K_2SO_4. This equates to an approximate mix ratio of 3:1 with receiving soil, the maximum allowable mix ratio by G-50.

Receiving Soils

The primary area of interest, the Alberta Foothills region, served as the collection area for the test receiving soil. This is an area demonstrating increasing use of potassium sulfate gel chem systems due to the geology of the region. The collection area is located in West Central Alberta at the GPS coordinates N 53°29'13" ;W115°27'24. This site is part of the Foothills Natural Region, specifically the lower Foothills Subregion. The main soil Great Groups in this subregion are Luvisolics and Brunisolics with Gleyed Luvisols and Gleysols in the more poorly drained areas. Organic soils occur in depressional areas, with Regosolics found along stream valleys and steeper slopes. The soil zone and soil classification is Gray and Gleyed Gray Luvisol respectively.

The soil collected for this study from the Foothills region was a silty loam soil, comprised of 24% sand, 58% silt and 18% clay by hydrometer.

Seeds and seedling collection

Commercial and forage seeds, and grass seedlings (certified) were obtained from commercial suppliers in Alberta. Spruce, Pine and Birch seedlings were collected locally. The cones and nutlets were air dried and vigorously shaken to release the seeds. Pine seedlings were first exposed to a temperature of approximately 350 °C for 4 to 6 minutes. After cooling, the seeds were liberated by gently tapping the opened cones against a clean dish.

Moss collection

The mosses were collected from the foothils soil collection area. The most common moss species (by visual observation) in the collection area was *Hylocomium splendens*. *Ptilium crista-castrensis* was the next most populous followed by *Pleurozium schrebri* and the brown moss Tomenthypnum nitens. Mosses were collected by cutting six square blocks approximately 25 cm X 50 cm in length. The moss mats were gently teased off the underlying soil and transferred to clean plastic trays. These trays were fitted with clear plastic domes and placed in the growing chamber. Mosses were monitored for four weeks and lightly misted with distilled water as required. Mosses which were successfully cultured for the four week period following collection were used for testing, and included Knights Plume (*Ptilium crista-castrensis*), Golden Moss (*Tomenthypnum nitens*), Broom Moss (*icranum scoparium*) and Big Red Stem (Pleurozium *schrebri).*

Test Chemicals

Potassium sulfate stock solutions were prepared using certified reagent grade K_2SO_4 diluted to volume with deionized water.

The three drilling fluid mixes used in toxicity tests were supplied by Alberta mud suppliers (Canamara, Burlington). These muds were prepared using typical products and proportions used currently in the Alberta industry (benonite, xantham gum, partially hydrolyzed polyacrylamide simulated rill solids and caustic soda). Two of the muds, Burlington and Canamara #1, were 3% K_2SO_4 systems, while the third mud, Canamara #2 consisted of a 1.5% K_2SO_4, and 0.5% K2. The K2 product is a quaternary amine commonly used as an additive in potassium sulfate muds to reduce the conductivity in the final waste in order to dispose within regulatory criteria, while maintaining the shale inhibition characteristics required.

Root and Shoot Elongation tests:

The root and shoot elongation test subjected the following plants to potassium sulphate solutions; grasses represented by Fowl Bluegrass (*Poa palustris* L.), Canada Wild Rye (*Elymus canadensis* L.)., Annual Rye (*Lolium multifloum*), and Slender Wheat grass (*Agropyron trachycaulum*); commercials represented by Barley (*Hordeum vulgare* L.), Alfalfa (Medicago sativa), and Fall Rye (Secale cereale); trees as represented by Paper Birch (*Betula papyrifera*), White Spruce (*Picea glauca*) and Lodgepole Pine (*Pinus contorta*).

Potassium sulphate was be made up as a 5% stock solution and serially diluted down by 0.5 to 2.5%, 1.25%, 0.625%, 0.313%, 0.156% and 0.078%. A distilled water control was included. Filter papers were placed into sterile petri dishes and saturated with one milliliter of the solution to be tested. Ten seeds of the species being tested were placed into a petri dish. A second filter paper was laid over top and saturated with an additional milliliter of the solution to be tested. The species tested was be exposed to the above concentrations of potassium sulphate. There were five replicates per treatment. The plates were placed in a warm, dimly lit area and monitored daily until approximately eighty percent of the controls germinate, or for 7 days, which ever came last. Root and shoot lengths were measured to the millimeter. Treatment averages were computed and these analyzed statistically to determine a Lowest Observed Effects Concentration (LOEC) as well as a No Observed Effect Concentration (NOEC).

Seedling Emergence Tests

Collected soil was sieved with a 2mm screen to remove large stones and other woody debris. Approximately 86 grams of soil was placed into a plastic container. A total of thirty-two containers were placed into a full tray. Seeds from the selected species above were sown into the soil in each of the containers. Five seeds were placed into each plastic pot, with four pots being used per treatment, for a total of twenty seeds per treatment (five seeds, four replicates). Sulphate loading rates were calculated based on stock solution concentration and area of soil within each pot. An equal volume of fluid was added to each pot, utilizing the various concentrations of potassium sulphate solutions. Fluids were added by weight using a balance accurate to 0.1 gram.

After the seedlings were challenged to each treatment, the plant pots were covered and left in the growing chamber for a minimum of 28 days. After 28 days (or a time allotted to optimize germination in the control, based on species) the plants were cut off at soil level and weighed. Plants were dried for 2 hours at 205 °C and weighed again. The difference in weights was examined to determine if, in addition to any germination effects, there was an effect with the various application rates.

Moss Surface Application Test

Healthy moss cultures were selected for testing. Pre-washed pots were filled with a mixture of sieved gray wooded soil and clean sawdust. Approximately 350 grams of soil to 50 grams of sawdust were mixed. This served as a “mock” LH horizon and underlying mineral soil horizon (Aegj). The soil and sawdust mixture in each pot was moistened with 50 ml of water (sufficient to moisten the entire mixture) and allowed to sit in the growth chamber for at least two weeks. A growing and observation chamber was constructed using planting trays with holes cut into the bottom to accommodate the 4 inch pots. The pots were placed into the holes and the trays allowed to rest on wooden blocks, keeping the bottoms of the pots just above ground level. A clear plastic cover was placed on top of the chambers to retain humidity while allowing light to enter. A data logger (Omega Nomad Data Logger) placed into one of the trays monitored temperature and humidity over the course of the two-week experiment.

Mosses were placed onto the soil/sawdust mix in clusters. Anywhere from 5 to 20 of each species of moss (depending upon availability) were teased away from the main culture and grouped with other moss species, then placed into each pot. Approximately 25 stems of Ptilium spp., 10 stems of Tomenthypnum spp., 15 stems of Dicranum spp. and 10 to 15 stems of Pleurozium spp into each pot. Once each collection of moss was placed into pots, a few grams of Shrub Funnel Lichen (*Cladonia crispata*) was placed around the planted mosses to mitigate moisture loss from the soil between the mosses and the edge of the pots.

A modified funnel was used to assist with the application of potassium sulphate treated fluids to the mosses. The funnel was fitted over the mosses starting with the controls. A calibrated sprayer applied the selected treatment to the collection of moss species in each pot. The funnel prevented a lateral loss of fluids from the spray bottles. The required volumes of fluid were calculated based on pot surface area and desired application rate. Application rates were 0 kg-SO_4/Ha (control), 90 kg-SO_4/Ha, 180 kg-SO_4/Ha, 360 kg-SO_4/Ha, and 720 kg-SO_4/Ha. This test did not utilize the lower two treatments and highest treatment used in the grass and tree tests due to limitations of space and moss species. After two weeks, the mosses were observed for visible effects. These observations included Chlorosis, necrosis, and/or browning of tips. At the end of the recording period, the mosses were removed, any loose soil shaken off and the mosses weighed. After drying for 1 hour at 180 °C (or to crispness), the mosses were weighed again.

Numerical data generated from root and shoot elongation tests, seedling emergence tests and wet/dry weights were statistically analyzed using the computer program Toxstat.

Drilling Mud Toxicity Tests

Toxicity tests were performed by Norwest Labs, Edmonton AB. The tests consisted of exposing the seeds of eight plant species to the receiving soil treated with three drilling muds using several treatment concentrations and two test soils. Test duration was 28 days. The plant toxicity tests were based on the method of ASTM[28].

There were six exposure concentrations (treatments) including the experimental control for each drilling mud. Exposure concentrations were geometrically spaced from the lowest to the highest treatments, using a factor of 0.5. The exposure concentrations were 625 to 10,000 mg/kg as K_2SO_4.

A test unit consisted of a 4” x 4” x 4” depth plastic gardener’s pot with drainage holes. Each pot held 250 g wet weight (w.w.) of soil and ten seeds. Each treatment consisted of four replicate test units.

On Day 0, seeds were removed from cold storage and acclimated to test temperature. Ten seeds which were similar in size, shape and colour were placed into the test units randomly across treatments. Seeds were planted in the test soil at a depth approximately twice that of the average seed diameter.

Prior to test initiation, soils were treated with the test drilling muds. 1200 g w.w. of soil was distributed to several plastic dishes; one for each treatment concentration and the control. Stock solutions were prepared from chemical by weighing the required weight in a beaker, transferring chemical to a volumetric flask and diluting to volume with deionized water. This solution constituted the stock that would be used to spike the highest soil treatment. Subsequent treatments were prepared by serially diluting stocks by 50% with deionized water in graduated cylinders.

Appropriate volumes of each stock solution were added to the corresponding soil treatment, and mixed thoroughly by hand, until uniform in colour and moisture level. The treated soils were distributed to four replicate test units for each treatment. On Day 0, ten seeds were planted to each test vessel, then randomly distributed on the shelves in the testing area.

The conditions for the test were as follows: test duration of twenty eight days; 24 ± 2°C; first 48 hours in the dark, followed by exposure to intense (approximately 12 inches from light source) fluorescent lighting using cold white and warm lights (VitaLite) on a 16 h light:8 hour dark photocycle. Temperature of the testing area was recorded with a mercury thermometer (Fisher Scientific) to the nearest 0.5°C.

Soil pH, conductivity, moisture, CEC and salt content were determined at test initiation and termination. The initial measurements were made from each soil treatment prior to distribution to replicate test vessels. Termination measurements were done by collecting subsamples from composite soils made from each replicate per treatment, after removal of germinated plants. All chenmical analyses were conducted by Norwest Labs using accepted methodologies.

Emergence, root length, shoot length and dry phytomass (biomass) were determined at test termination. Seedling emergence was measure visually by counting the number of seedlings that had emerged from the soil in each test unit. The criterion for emergence was a plant height of 3 mm above the soil surface. Plant shoots and roots were gently extracted from the soil and rinsed with deionized water to remove soil particles. Shoot and root lengths were measured with a ruler and recorded in millimeters. The total phytomass for all emerged plants per replicate was determined by placing the individual plants from each replicate into a single tared aluminum pan. The plants were dried for a minimum of 48 h at 30°C, then weighed (0.1 mg).

Statistical Analysis

The results of the toxicity tests were manually entered into data spreadsheets, graphed, and analyzed. All calculations were based on nominal concentration of K_2SO_4 present in the soil treatment as dry weight (mg K_2SO_4 /kg d.w.). The dry weight correction was determined using the mean moisture content measured for each treatment at test initiation.

The median effect concentration (EC50) and 25% effect concentration (EC25), together with the 95% confidence limits were calculated for emergence, shoot length, root length and biomass. The EC25 and EC50 were calculated using linear interpolation methods of regression analysis with the statistical program ICPIN[29]. The EC25 concentration provides an estimate of the minimum significant effect concentration. The EC25 level is often used in toxicological analysis to represent the lowest effect which can be significantly detected above rates of random lethality and error. It is similar to the Threshold Effect Concentration (TEC, often used by U.S. EPA) to provide a single endpoint between the NOEC and LOEC (geometric mean of the two endpoints).

The data were also analyzed for the no-observed-effect concentration (NOEC) and lowest-observed-effect concentration (LOEC); the effect defined as emergence, root length, shoot length or biomass. These endpoints were determined using hypothesis testing with the computer program TOXSTAT[30]. Conformity and homogeneity of data was determined by Shapiro-Wilks and Bartlett’s tests. If conditions for normality of data were satisfied, an analysis of variance (ANOVA) was carried out, followed by Williams test, a multiple-comparison test that determines which concentrations are significantly different from the control. Williams test takes into account the order of concentrations by magnitude, a desirable feature to increase sensitivity, and an appropriate attribute for most toxicity tests[31].

Transformation of data was used to improve normality of data if required. If unequal replication existed due to loss or other causes, then Bonferroni's adjustment of the t-test was used. If conformity and homogeneity could not be satisfied by transformation, nonparametric analysis using Steel's many-one rank test was used (Wilcoxon rank sum tests for unequal replication).

Linear interpolation and multiple comparison analyses require greater than one replicate. Therefore, in cases where 0% emergence occurred in three to four replicates, this concentration was eliminated from further analysis for root length, shoot length and biomass. If no significant effect was detected at the lowest concentration for which statistical analysis could be performed (two or more replicates exhibiting emergence), then the LOEC and EC25/50 were reported as greater than this concentration.

Results

Moss Tests with K_2SO_4

The effect of K_2SO_4 on moss species *Ptilium, Tomenthypnum*, *Pleurozium* and *Dicranum*, as assessed by visual scoring of chlorosis, browning and necrosis is presented in Figures 1 through 4. *Ptilium* species appeared to be the most sensitive, exhibiting notable chlorosis for treatments greater than 180 kg/ka, with significant browning and necrosis evident at 360 and 720 kg/ha. *Tomenthypnum* also exhibited significant chlorosis at 360 and 720 kg/ha treatments. *Peurozium* and *Dicranum* demonstrated signficant visual effects only at the highest treatment.

Moisture loss was measured at test termination by subtracting the dry weight per plant, from the wet weight per plant (Figure 5). Interestingly, moisture loss with drying appeared to increase with K_2SO_4 exposure. In other words, plant wet weights were greater than control weights for all four species in the highest test treatment. The data appears to show plants may be compensating for passive uptake of high salt concentrations by increasing overall water absorption. However, high variability among replicates and a lack of a clear dose-response relationship resulted in difficulty in drawing conclusions regarding a toxic effect.

The data for moss species exposed to K_2SO_4 suggest that moss ground cover may be impacted by surface application of these drilling fluids at high (720 kg SO4/ha) application rates. Toxicity was characterized by chlorosis and browning of the mosses at higher test concentrations. Additionally, moss plants appeared to take in more moisture by test termination in treatments exposed to K_2SO_4 (as measured by moisture loss), perhaps as a protective mechanism. Further research is needed to characterize the impact, using larger replication and sample size to minimize effects of natural variability with these test species. Additionally, modifications to growth chambers are required to maintain moisture levels sufficient to maintain healthy growth for a longer test period.

Root Elongation and Seed Emergence Tests with K_2SO_4 (Filter Paper Tests)

Test results for seeds exposed to K_2SO_4 on filter paper are presented in Table 1. These test results were of the most sensitive indicator of toxicity, because of exposure being direct. No mitigating variables associated with soil-ion interactions were present. Test concentrations were calculated as ranging from 22.5 to 1440 kg SO4/ha, based on the surface area of the petri dishes. However, seeds and germinated seedlings were directly exposed to filter paper moistened with K_2SO_4 ranging from 780 to 50000 mg/L

All species demonstrated toxicity to K_2SO_4, demonstrated by reduced germination (Figure 6), shortened root length and reduced shoot length, relative to controls in exposure concentrations ranging to as low as 45 kg/ha SO4. The most sensitive species were Fowl Bluegrass, Birch and Alfalfa. Barley appeared to be the least sensitive, with no effect on germination rate, but still exhibited reduced root and shoot growth in concentrations greater than 360 kg/ha SO4.

Seed Germination Tests with K_2SO_4 in Foothills Soil

The results of the seed germination and growth tests for K_2SO_4 in Foothills Soil are presented in Table 2. Reduced germination was observed for all species except Annual Rye, Fall Rye and Barley, at concentrations of 720 and 1440 kg SO4/ha. Reduced biomass (dry weight per plant) was also observed for all species at 720 and 1440 mg/kg, including Annual Rye, Fall Rye and Barley. Reduced plant biomass was the most sensitive endpoint for all species.

Unfortunately, germination for several of the test species was low, possibly a result of the silty quality of the soil. In general, however, compared to the filter paper tests, The soil did appear to reduce the toxicity of pottasium sulfate as expected. For example, Fowl Bluegrass, which exhibited toxicity at levels as low as 45 kg/ha on filter paper, showed no effect up to the 720 kg/ha treatment.

Plant Tests with Drilling Fluids

At the time of writing, studies of plants exposed to drilling fluid mixtures were ongoing. Preliminary data suggest that seed germination in plants exposed to a 3:1 mix of a

3% K_2SO_4 drilling mud is similar to germination rates in control treatments. The data for this part of the study will be presented in greater detail at the conference for which this paper was intended for.

Conclusions

It is our opinion that the current regulatory limits placed on disposal of potassium sulphate based drilling systems in Alberta may be overly restrictive, uneccesarily limiting the ability to dispose of these wastes on a practical basis. Our data suggests that pottasium sulphate itself has limited effect on plant growth in soil up to an application rate of 720 kg/ha as SO4. This level is near to ten times the level cited by Alberta regulations. Of course, exceptionally sensitive species such as Fowl Bluegrass and moss species may not be protected adequately at higher application rates. However, most of the species tested for this study were tolerant to higher levels of salt. Additional studies with a greater variety of species, in multiple soil types would better characterize a safe disposal level for most foothills plant species.

We propose that the limit for disposal of drilling fluids containing potassium sulphate be based on the resulting electrical conductivity of the receieving soil and drilling waste mix. Our results showed toxic effects on test species at conductivity of greater than 4 dS/m2. This is similar to the levels proposed by several federal and provincial salt guidelines that indicate soil quality is reduced to “poor” in saline soil environments greater than 5 dS/cm.

By using electrical conductivity as a measure of limitation, all sources of salt found in the drilling fluid are included in the measurement, providing greater protection to exposed crops, than by measurement of specific anions or cations. Additionally, soils that are already sodic or saline because of natural or man-made sources, will be protected from additional salt input.

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Figures

Figure 1. Visual Effects of K_2SO_4 on *Ptilium*

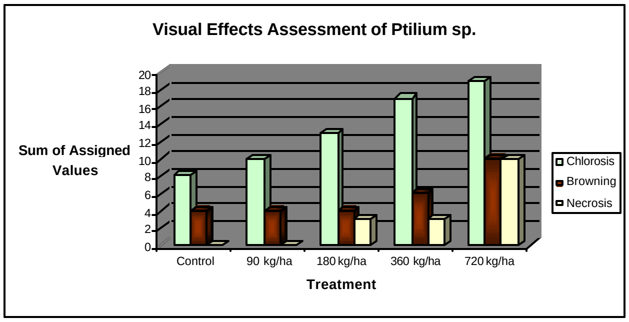


Figure 2. Visual Effects of K_2SO_4 on *Tomenthypnum*

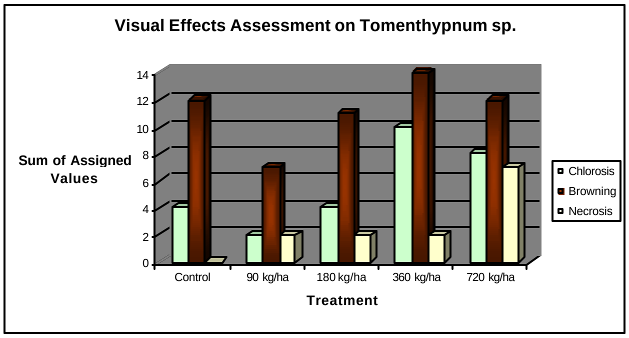


Figure 3. Visual Effects of K_2SO_4 on *Pleurozium*

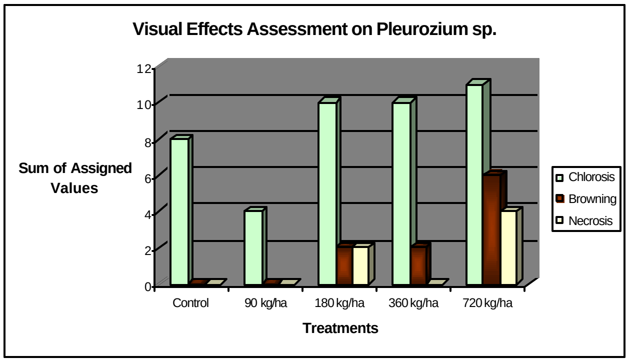


Figure 4. Visual Effects of K_2SO_4 on *Dicranum*

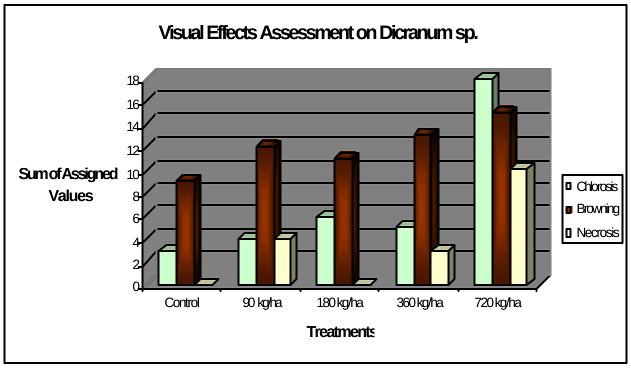


Figure 5. Moisture Loss of Moss Species exposed to K_2SO_4 for 14 Days.

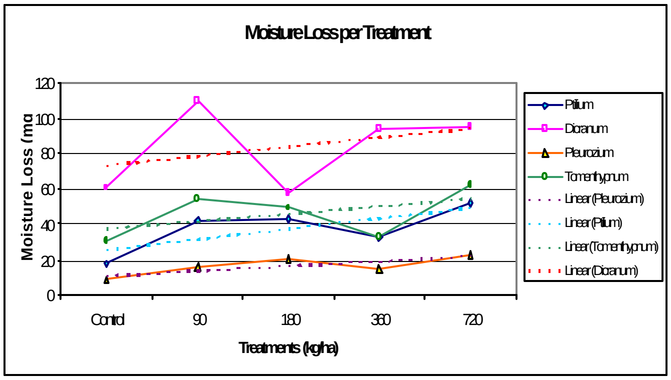
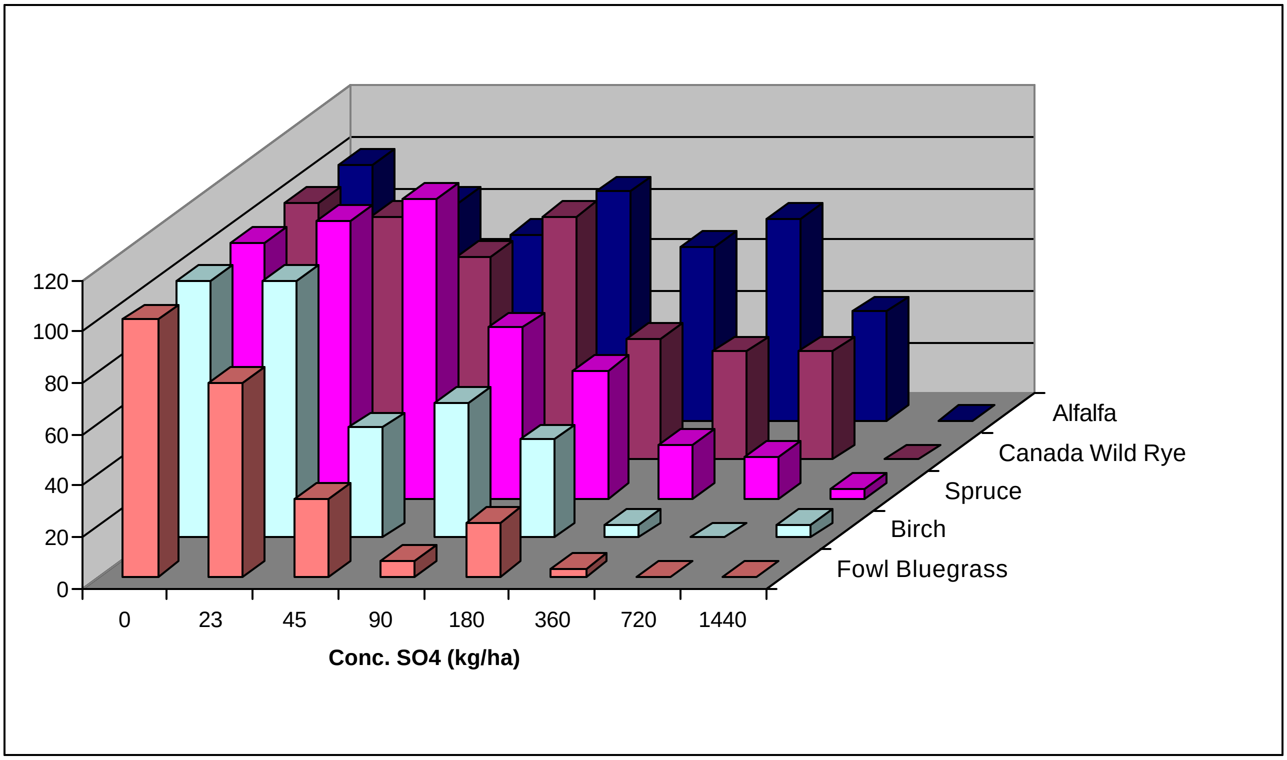


Figure 6. Seed Germination of Plant Species Exposed to K_2SO_4 (Filter Paper Tests)



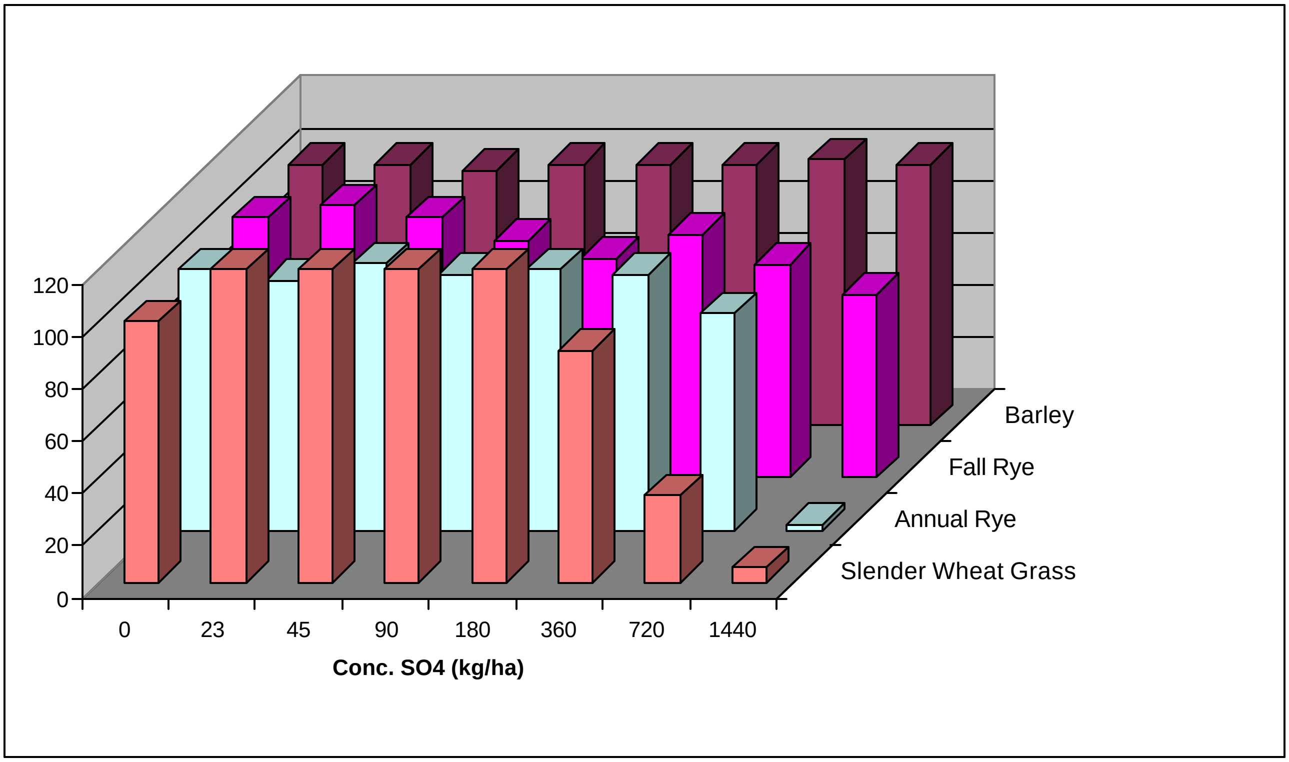


Table 1. Test Results for Root and Shoot Elongation (Filter Paper) Exposed to K_2SO_4

% K_2SO_4	**Control**	**0.078%**	**0.156%**	**0.313%**	**0.625%**	**1.25%**	**2.5%**	**5.0%**
Kg/ha as SO_4	**0**	**22**	**45**	**90**	**180**	**360**	**720**	**1440**
Root Length (% Control)								
Fowl Bluegrass	100	94	**34**	10	26	0	0	0
Fall Rye	100	144	119	100	**62**	55	38	4
Spruce	100	90	159	105	**120**	61	12	0
Annual Rye	100	89	85	73	**72**	27	11	0
Slender Wheat Grass	100	90	85	105	120	61	**12**	0
Birch	100	138	**51**	58	33	2	0	1
Canada Wild Rye	100	96	86	101	**18**	14	5	0
Barley	100	125	99	116	98	**55**	25	13
Alfalfa	100	99	**43**	87	25	15	3	0
Shoot Length (% Control)								
Fowl Bluegrass	100	79	**27**	6	23	1	0	0
Fall Rye	100	233	212	196	110	119	70	**15**
Spruce	100	161	147	84	48	**5**	19	3
Annual Rye	100	93	100	89	73	**32**	5	0
Slender Wheat Grass	100	109	**148**	123	114	66	11	0
Birch	100	88	**35**	47	28	3	0	3
Canada Wild Rye	100	107	73	85	**11**	6	1	0
Barley	100	97	112	102	119	92	**57**	16
Alfalfa	100	80	**37**	79	25	22	3	0
Germination (%Control)								
Fowl Bluegrass	100	76	**30**	6	21	3	0	0
Fall Rye	100	105	100	91	84	93	82	**70**
Spruce	100	108	117	**67**	50	21	17	4
Annual Rye	100	96	102	98	100	98	83	**2**
Slender Wheat Grass	100	144	156	161	178	89	**33**	6
Birch	100	100	**43**	52	38	5	0	5
Canada Wild Rye	100	95	79	95	**47**	42	42	0
Barley	100	100	98	100	100	100	102	100
Alfalfa	100	85	72	89	68	79	**43**	0

The LOEC for each species for root and shoot elongation is indicated by bold.

Table 2. Seed Emergence Results for K_2SO_4 in Foothills Soil

Species	Treatments							
	Control	22.5 kg-SO_4/Ha	45 kg-SO_4/Ha	90 kg-SO_4/Ha	180 kg-SO_4/Ha	360 kg-SO_4/Ha	720 kg-SO_4/Ha	1440 kg-SO_4/Ha
Slender Wheatgrass	14	14	16	15	15	14	11	**10**
Creeping Red Fescue	15	13	10	13	18	16	**4**	0
Canada Wild Rye	17	14	12	13	10	16	**4**	0
Annual Rye	8	21	19	18	15	20	17	17
Fowl Bluegrass	5	8	10	6	1	5	1	**0**
Birch	1	1	0	1	1	1	0	0
White Spruce	6	2	0	2	2	3	0	0
Barley	12	10	10	13	13	11	15	10
Fall Rye	14	15	8	7	5	8	16	9