Chloride Application Study, 2010

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December 2010

Description of Experiment

We studied the results of applications of high concentrations of chloride on a single species of woodland vegetation that is found throughout the state of West Virginia. V*accinium vacillans* is one of a group of plants known in this state as huckleberry.[1]

This experiment examined the possible effects on vegetation from land application of liquid high-chloride drill waste and fracture flowback as allowed under West Virginia Office of Oil and Gas' *General Water Pollution Control Permit*, GP-WV-1-88. The experiment was designed to test various concentrations and to determine if multiple gallons of a single concentration (load) should be a consideration.

As practiced now the maximum allowable chloride concentration for discharge is 12,500 mg/l with no load factor.

Process

The application fluid was rainwater with the specific amount of sodium chloride required to create each chloride concentration.

Two sets of application were initially planned.

The first was a single gallon application, each to a separate plant (or plants) occupying a square foot of surface, in the following chloride concentrations: 1,000, 2,000, 3,000, 5,000, 7,000, 9,000, and 12,000 mg/l.[2] This set of applications was made on 20 June 2010.

The second set was to study load with applications of 3 gallons made in the following concentrations of chloride: 1,000, 2,000, 3,000 and 5,000 mg/l. The application area was again a square foot. This set of applications was made on 30 June 2010 in a different location.

A third set of applications were made to check results from the first two sets. An application was made for 7,000 mg/l chloride to a smaller plant (on 6 July) and 3 gallon applications were made for 2,000 and 3,000 mg/l concentrations to smaller plants (on 11 July).

Surface leaf duff was scraped away from the base of a plant before application. In the first set of applications, the fluid was poured out of a jug and

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[1] Identification based on P. D. Strausbaugh and Earl Cole, [1978], *Flora of West Virginia.*

[2] Due to measurement accuracy limitations, actual concentrations applied are approximate.

some landed on the leaf surfaces of the plant. The second set of applications was made using a large funnel and pipe so that no fluid came in contact with the leaves. The third set of applications reproduced the process of the first and second sets: the 7,000 mg/l plant had solution poured onto it and the 2,000 and 3,000 mg/l plants did not.

Results of Fluid Contact to Leaves

Individual plants receiving the first set of applications at each concentration showed negative effects. All of the plants showed leaf scorch from contact with the poured liquid from the smallest chloride concentration examined (1,000 mg/l) to the highest (12,000 mg/l). Fallen leaves at the bases of plants for 5,000 mg/l and higher applications noted on 26 June included scorched leaves. Leaf scorching from fluid application sometimes resembled chlorosis, making it difficult to know, with certainty, whether leaf damage was caused by fluid contact or by uptake.

Results of First Set of Applications

Plants receiving 9,000 mg/l and 12,000 mg/l also showed severe chlorosis (edges of leaf browning and eventual loss of leaves) from uptake. The 12,000 mg/l plant appears to be dead. Plants receiving the 5,000 mg/l and 7,000 mg/l showed signs of chlorosis (leaf color changes and edge of leaves browning) but not the extreme leaf loss. Plants showing chlorosis also were found outside the 9,000 and 12,000 mg/l application areas.

Timeline for first set of applications	
June 20	1 gallon applications made.
June 21	First signs of leaf scorching from fluid contact.
June 23	Rain shower. Scorching and chlorosis increasing in severity.
June 26	Fallen leaves at bases of plants.
July 7	Plant in 12,000 mg/l plot is withered and dying.

Results of Second Set of Applications

Plants in the second set of applications of 3 gallons each showed none of the leaf scorch associated with fluid contact experienced in the first set. Effects from uptake were visible most profoundly for the plants receiving the 5,000 mg/l 3 gallon application with mortality of a smaller plant and severe chlorosis for the larger plant. No effects were seen in the plants receiving the 1,000 and 2,000 mg/l applications. Chlorosis was seen in the plants outside and downhill of the 3,000 mg/l application area.

In retrospect we realized that in planning the applications we had not taken in consideration either the larger size of plants that received the second applications nor the slope of that site. It is possible that, if the plant size and slope variables were not present, more extreme effects would have been observed after the second set of applications.

Timeline for second set of applications	
June 30	3 gallon applications made.
July 4	Chlorosis observed for 3,000 and 5,000 mg/l plants.
July 15	Smaller plant in 5,000 mg/l plot dying.

Results of Third Set of Applications

The third set of applications was to check the results we saw in the initial two applications sets. A smaller plant than the 7,000 mg/l plant in the first set of applications was chosen and received an application of 1 gallon. Smaller plants in a different area received 3 gallon 2,000 and 3,000 mg/l applications. A heavy rainfall of over an inch occurred hours after the 3 gallon application.

The smaller plant showed similar effects to those seen in the first set of applications but not as extreme as expected. The plants receiving the 3 gallon applications showed no effects, probably due to the rainfall.

Soil and Permeability

The test areas were located on Upshur/Gilpin soil, a silt loam/silty clay loam, with horizons ranging from a moderate to low permeability. Application was done slowly, but not slowly enough to take in consideration the site's ability to absorb the fluid according to data from the NRCS soil manual for the county (0.3 inches an hour).[3] A single gallon application was made in 5 to 10 minutes. For a low permeable soil that time should have been much, much longer. The state has no numeric guidelines for the rate of application and ours fit the verbal guidelines of in the *General Permit*.[4]

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[3] Soil Conservation Service, 1985, *Soil Survey for Putnam County, West Virginia*, Table 16.

[4] "The waste water shall be applied at a rate that, given the characteristics of the land, shall not cause ponding, erosion or run-off into the water of the state. (G.6.(d))" We have seen photographs of land applications performed in this state using a variety of methods, ranging

Discussion

Effects of salinity to various varieties of vegetation have been studied in a number of contexts including studies on road salt and tar sands reclamation. West Virginia species known to be sensitive include twinflower (*Linnaea borealis*), green alder (*Alnus crispa*), bunchberry (*Cornus canadensis*), chockcherry (*Prunus virginiana*), raspberry (*Rubus idaeus*), blueberry (*Vaccinium myrtilloides*), balsam fir (*Abies balsamea*), and American beech (*Fagus grandifola*).[5]

Toxicity thresholds for solutions of sodium chloride for vegetation have been found to be between 836-25,000 mg/l (EC25, CTV; note that chloride is approximately 60% of the sodium chloride concentration).[6]

Uptake damage to vegetation is enhanced by spray or fluid on the foliage.[7]

Injury is caused by a dual effect. Chloride disrupts osmosis by which roots absorb water from soil, effectively starving the plant. Chloride in uptake damages leaf structures (stomata and cell membranes), adversely affects transpiration, and creates an excess of sodium, potassium, calcium and magnesium ions in the plant. It should be emphasized that these effects are different between species.[8] Chloride is normally involved, for some species, in guard cell opening and closing of stomata in leaves, controlling transpiration.[9] Elevated chloride is found in open stomata guard cell vacuoles, much lower concentration in closed. Disruption of the normal chloride ion transfer between cells would also affect other ions. The sodium ion itself in excess can cause

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from a workman holding a large diameter hose pumping fluid onto plants and forest floor to stand alone large diameter flexible and perforated pipes spraying vegetation and forest floor. See Arkansas land application guidelines for the formula operators must use in that state to determine the rate of spraying: Arkansas Department of Environmental Quality, 2008, *Authorization to Land Apply Drilling Fluids*. The Arkansas formula would have required 5+ hours for application of one gallon in this study.

[5] See D. R. Howat, 2000, *Acceptable Salinity, Sodicity and pH Values for Boreal Forest Reclamation* for information on studies for the first six species listed. See Environment Canada, 2001, *Priority Substances List Assessment Report, Road Salts* for information on beech and other species (especially pages 99-105).

[6] Lori Siegel, 2007, *Hazard Identification for Human and Ecological Effects of Sodium Chloride Road Salt*, page 12.

[7] T. T. Kozlowski, 1997, *Responses of Woody Plants to Flooding and Salinity*, page 13.

[8] Kozlowski, page 13.

[9] See M. G. Penny et al, 1996, "Active Chloride Transport in the Leaf Epidermis of *Commelina communis* in Relation to Stomatal Activity," *Planta*, and Klaus Raschke and Heide Schnabl, 1978, "Availability of Chloride Affects the Balance between Potassium Chloride and Potassium Malate in Guard Cells of *Vicia faba* L.," *Plant Physiology*.

negative effects similar to chlorosis: mottling and leaf tip burn.[10] The calcium ion "antagonizes" the effects of chloride. [11]

It was noted during the first set of applications that effects seemed to be stimulated by rain showers 3 and 4 days after the application when transpiration uptake was multiplied. (National Climatic Data Center statistics for Charleston show 0.03 and 0.43 inch rainfall for those days.)

These applications were done in mid-summer, during the heightened period of transpiration by deciduous plants because of high temperatures. Effects of some of the third set of applications were nullified by a heavy rain storm (1.22 inches according to the NCDC) within hours of application.

The effects we have observed are directly related to the plants' response to chloride within fairly specific parameters: plant size, site slope, and intervals between and quantity of rain. The last parameter could, in the case of a light rain, augment the effects, or, in the case of a heavy rain, nullify the effects.

What we did not investigate was the retention of chloride in the soil after application, the extent of lateral spread or the influence of slope. Persistence of chloride in the soil was noted in the 2009 applications a week after application.[12]

We observed chlorosis in plants a foot down slope of the single gallon 9,000 mg/l application and a similar distance down slope of the 3 gallon 3,000 mg/l application. We did not observe adverse effects from chloride to any of the other species of vegetation within or outside the application areas. The variability of effects according to species, size of plant, rainfall, site slope and other variables makes it impossible to determine, in this study, general effects due to chloride application.

Load

We saw no damage to plants with single gallon per square foot applications of concentrations at or below 3,000 mg/l. We did note effects to plants outside

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[10] Sodium is an element that occurs in large concentrations in drill and fracture waste and boron has been found in elevated concentrations in some drill and fracture waste. Elevated levels of boron can cause similar effects in plants. See Ross O. Nable et al, 1997, "Boron Toxicity," *Plant and Soil* where effects in leaves similar to chlorosis appear where boron, in some species, accumulates at the end of the transpiration stream.

[11] Kozlowski, page 13. The concentration of calcium in drill and fracture waste tends to be twice that of sodium.

[12] In 2009 we applied chloride solutions of 6,000 and 14,000 mg/l at 4 gallons per square foot to varied vegetation. A week after application the soil was tested and chloride was found to be 331 ppm in each. See George Monk and Molly Schaffnit, 2010, *Gas Well Study, 2009*, page 25 and following.

the 3 gallon application area of 3,000 mg/l. It would seem from this that load is a factor and the maximum safe load for this species is 1,100 lbs per acre and that the maximum concentration should be 3,000 mg/l.

Conclusions

We were able to observe negative effects of chloride application to this species from foliar contact of as little as 1,000 mg/l chloride. Profound chlorosis and/or plant mortality resulted from a 12,000 mg/l single gallon application and 5,000 mg/l 3 gallon application. Chlorosis was observed with increasing severity from single gallon applications of 5,000, 7,000 and 9,000 mg/l solutions.

Factors that seem to inhibit or encourage effects from chloride include plant size, site slope, and rainfall after application.

Load is a factor that must be considered and for this species it appears to be no more than 1,100 lbs per acre chloride. The maximum concentration should be 3,000 mg/l.

Sources

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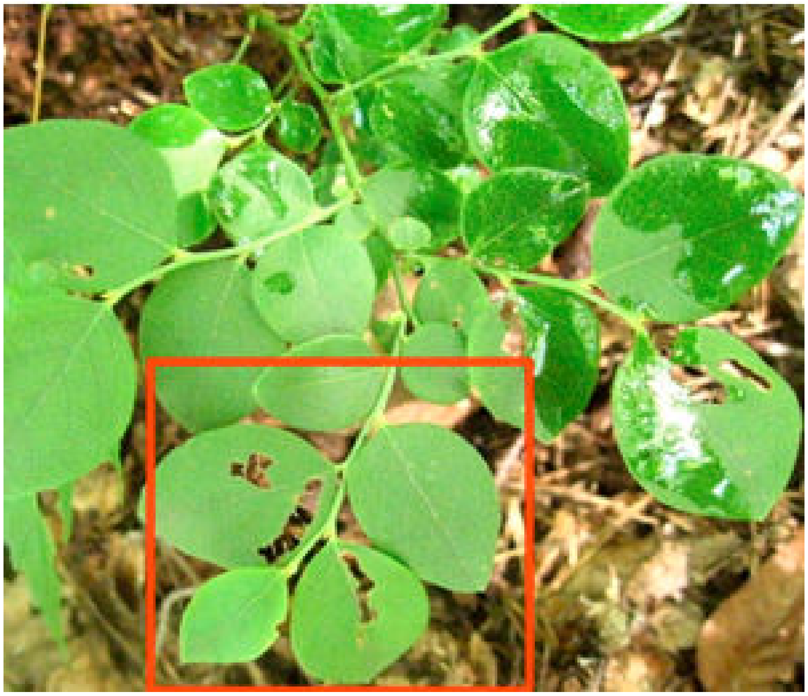

Photo 1. Taken after pouring of 5,000 mg/l chloride in the first set of applications on 20 June. Moisture is evident on some of the leaves. The red box in this and following photos marks leaves not affected by pouring.

Photo 2. The 5,000 mg/l first set plant on 21 June. Leaf scorch is evident on some leaves.

Photo 3. The 5,000 mg/l plant on 23 June with increasing withering of leaves affected by fluid contact.

Photo 4. The 5,000 mg/l plant on 23 June. Leaves not touched by solution beginning to show chlorosis.

Photo 5. Leaves on the ground below the 5,000 mg/l plant on 26 June. Many of the scorched leaves fell at this time.

Photo 6. The 5,000 mg/l plant on 4 July. Some leaves visible in Photo 4 outside of the red box have fallen. Leaves within the red box show chlorosis.

Photo 7. Leaves for the 1 gallon first set of applications 9,000 mg/l plant showing chlorosis on 23 June.

Photo 8. Severe chlorosis from uptake on plant outside area for 12,000 mg/l first set of applications. Photograph taken 7 July.

Photo 9. In the second set of applications, plant four days later (4 July) after receiving 3 gallons of 5,000 mg/l solution. Chlorosis is evident.

Photo 10. Chlorosis intensifying in plant seen in Photo 9. This was taken on 6 July.

Photo 11. The same plant as photos 9 and 10 as seen on 15 July. The smaller plant in the plot is withered and many of the leaves on the larger plant have fallen.