The Negative Effects of Deicing Salts on the Smith Campus Environment

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Abstract

Although sodium chloride is known to have detrimental effects on the environment, it has been used for decades as a deicer, and other chemicals have only recently entered the picture as alternatives. One of these which is currently popular is magnesium chloride, another chloride salt. In this project, I set out to discover what products are used on the Smith campus to combat dangerous snow and ice, as well as whether magnesium chloride might in fact be just as harmful to the environment as sodium chloride. To address these questions, I interviewed the grounds manager of Smith and I researched both the documented and hypothesized effects of magnesium chloride on the environment due to use as a deicer. In my interview, I was informed that Smith does use products containing magnesium chloride, most prominently the recently patented Ice Ban. The available literature on magnesium chloride's effects strongly supported the hypothesis that they were very similar to those of sodium chloride, including increased chlorination of ground- and surface waters, displacement of nutrients, mobilization of heavy metals in soils, and possible detriment to both land and aquatic plants. These results shed light on the little-known effects of magnesium chloride on the environment, and indicate that Smith should keep an eye open for more environmentally friendly products. The results also strongly advise other city and institution administrations to rethink their deicing methods and remain alert for any newer and more eco-friendly products.

Introduction

In cold temperate climates, where winters are marked by freezing temperatures and heavy snowfall, the accumulation of ice and snow can be incredibly dangerous for drivers and pedestrians alike. Deicing salts provide safer conditions by dissolving into water, either melting any ice or snow, or preventing the formation of ice on the roads. Deicers in the form of rock salt, sand, and liquid chemical sprays have been used in earnest for many decades to combat the hazards of ice and snow during the winter months. Introduced in the 1930's, rock salt, or sodium chloride, has since been the most popular choice of chemical deicer. Its effects on the environment were once thought to be only temporary, without causing lasting harm, but in the decades of research done since then, the common consensus is this belief is incorrect. In the past decade or two, magnesium chloride has been touted as the "environmentally friendly" alternative to sodium chloride, sand, and other chemical deicers such as calcium magnesium acetate. However, studies done even more recently have looked closely at its effects and seen that it is perhaps not as friendly as was once thought.

Although it is widely known and accepted that sodium chloride negatively affects the environment, there are no regulations as to the application and usage of salt for deicing. Instead, it is applied as needed by city, private, and academic institutions, often with the result being excess sodium chloride dissolved in runoff and distributed into roadside environments. Currently in the United States, 8-12 million tons of sodium chloride is applied to roads every year (Cunningham, Snyder, Yonkin, Ross, & Elsen, 2007). Any salt applied to roads eventually turns up at detectable levels in some part of the environment or other through meltwater runoff, leaching through soil, improper application, or airborne spray or splash deposits (Ramakrishna & Viraraghavan, 2005), and these levels can begin to have an impact on nearby vegetation and water supplies. Because both sodium chloride and magnesium chloride are inorganic chloride salts, they naturally have the same reaction when in contact with water: they “quickly dissociate into the chloride anion and associated cation, thereby releasing chloride ions into solution” (Benbow & Merritt, 2004). In other words, the negatively charged chloride separates from the positively charged sodium or magnesium, and they go their separate ways.

Because of its charge, chloride tends to leach through the negatively charged soil relatively easily into groundwater, which can then be transported to both surface water environments and into our drinking water (Thunqvist, 2003). Increased chlorination in aquatic environments can lead to changes in chemical stratification as well as in plant species composition due to chloride toxicity and damage to plants. In some areas downstream from salted roads, chlorine in drinking water exceeds the EPA-recommended upper limit of 250mg/L (Ramakrishna & Viraraghavan). However, on the way to ground- and surface waters, chloride can also be taken up by terrestrial plants, inducing chlorosis and contributing to diminished health. This is especially true in denser soils such as clays and tills, as particles are more tightly packed and it is more difficult for chloride to pass through (Lundmark & Olofsson, 2007).

Sodium, however, being positively charged, is attracted to the negative soil particles, and contributes to increased soil salinity, damaging plants and making them more susceptible to disease, possibly eventually changing the composition of species in an area by allowing more salt-tolerant invasives to outcompete less tolerant native species (Green, Machin, & Cresser, 2007). Sodium particles do eventually, however, make their way into the water system, and these particles contribute to an increase in salinity of both aquatic environments and drinking water; one study from the northeastern U.S. "measured Na [(sodium)] from road salt in well waters at concentrations that are 2-140 times the recommended limit for individuals on salt-restricted diets"(Amrhein, Strong, & Mosher, 1992). At these dangerously high concentrations, sodium can contribute even further to high blood pressure.

In this paper I will discuss the types of products Smith uses to diminish the effects of ice and snow, and whether they are aware of the effects of these products. I will also discuss both the hypothesized and conclusively known effects of magnesium chloride on the environment, demonstrating that it has some of the same negative effects as sodium chloride. As a third objective, I wish to discuss various alternatives in terms of effectiveness and environmental friendliness in order to display the available options on the market to consider.

Methodology

My first course of action was to interview Bob Dombkowski, the grounds manager at Physical Plant on the Smith campus. I asked him several very basic questions in order to determine what products were used on campus and under what conditions, as well as more specific questions regarding what each deicer contained and whether it might affect the surrounding ecosystems or not. Then I did some preliminary research, beginning with very general articles concerning very general information about deicers, then with the help of article search engines such as LexisNexis, Web of Science, and JSTOR, I narrowed my research down to the effects of deicing salts on the environment, and then even further down to magnesium chloride’s effects and to alternative products and methods of doing away with ice and snow. I also utilized the works cited in each article I found in order to find more relevant published works.

Results

From Interview:

In talking with Mr. Dombkowski, I discovered both which products are used on the Smith campus, and why. There are two separate problems ice poses that various deicers need to take care of: one is the matter of increased traction in previously formed ice, and the subsequent melting and breaking up of it; and the other is the problem of ice initially attaching to paved surfaces. Smith uses a combination of rock salt, sand, Ice Ban, and magnesium chloride pellets in order to solve both of these problems. Because the weather is often unpredictable or inconveniently timed, and depending on the types of storms that occur, and the nature of the surfaces being applied to, Smith’s use of these four products varies widely from year to year.

The products used at Smith each have their own high and low points. Sodium chloride (rock salt) is used for both the prevention of ice and traction and melting of previously attached ice, making it an extremely cost-efficient option (Dombkowski). It has the ability to lower the freezing point of water down to -9˚C, which aids in the prevention of ice formation, while it also effectively breaks up and helps melt ice once it’s attached to pavement. Sand, while not technically considered a deicer, helps dramatically with traction on otherwise hazardous roads and sidewalks, after ice has formed. A downside to sand is that it tends to clog storm drains and accumulate in water systems, and the silicas in sand break down and damage both terrestrial and aquatic plant life. Although both salt and sand have been used historically at Smith, since the introduction of Ice Ban their use has decreased incredibly: for example, Physical Plant used to use up to 250 tons of sand per year, and this year's usage was 15 tons. Similarly, salt was once applied to all paved surfaces on campus, whereas currently it's only applied to vehicular roads. Smith began using Ice Ban eight or nine years ago, beginning by testing certain areas to gauge its effectiveness. The product consists of agricultural byproducts such as alcohols, sugars, and salts from Anhauser-Busch Brewery combined with up to 50% liquid magnesium chloride. At different times in the past, the agricultural byproducts came from sugar cane and soybeans, respectively. Ice Ban is used to prevent ice from sticking on both sidewalks and roads, and therefore can only be used when prior warning of a storm is had. Magnesium chloride is capable of reducing the freezing point of water to -15˚C. In addition to use by itself on roads and sidewalks, it can be sprayed onto road salt to make the sodium chloride less corrosive to cars and pavement. Each year Smith uses anywhere from 1,000 to 10,000 gallons of Ice Ban, depending on both how long and harsh the winter is and whether Physical Plant has ample warning time before storms. Ice Ban is more expensive than sand and salt, but because, according to Dombkowski, it doesn't require labor and time to clean it up later (as sand does), it costs less in the long run. "Since the Ice Ban isn't bad for the environment like sand is, there's no clean-up involved," says Dombkowski. Smith was one of the first college campuses to adopt Ice Ban, although now Amherst College, UMass, and the city of Northampton all use it, as well as other colleges in the U.S. such as Vassar. The last product used by Smith are magnesium chloride pellets, imported from the Dead Sea, which are used to prevent ice and snow buildup on stairways and access ramps around campus. Put together, these four products join Physical Plant to make up Smith's ice-fighting team.

From Research of Primary Literature:

Although Physical Plant at Smith seems convinced that the magnesium chloride-based Ice Ban is harmless, studies show the opposite trend. From my research, I found that magnesium chloride's effects can be relatively similar to sodium chloride's, mostly due to its chloride anion. Magnesium chloride also dissociates in water, leaving the chloride ion to its own devices. In a study done in Poland, Czerniawska-Kusza, Kusza, & Duzynski (2004) report that chloride accumulation due to plant intake of chloride ions shows in "pathological changes in leaves": this includes alterations in color intensity, changes in the leaf blade edge, and chlorosis, which shows in damage to the center of the leaf. In addition to having the same chloride effects as rock salt, magnesium chloride also has some unique effects due to its magnesium ion. In studies which examine the accumulation of deicing salts in soils, research finds that magnesium actually sticks to soil particles much more effectively than sodium ions, presumably because they have a stronger positive charge. This attribute makes it easy for magnesium to displace sodium ions, causing them to leach out horizontally from the road, both deeper down and farther in distance than they might otherwise – high sodium concentrations were found up to 200 meters from the roadside in areas where both sodium chloride and magnesium chloride were used as deicers, whereas high magnesium levels dropped off at half that distance. (Cunningham et al.). According to Green et al., magnesium also appears to be more effective at displacing important nutrients such as potassium and calcium, which decreases the levels of these nutrients available for plant uptake, and causes an imbalance in elemental soil chemistry. In addition to harming the plants, this imbalance can lead to a change in pH, causing soil to become more acidic.

Magnesium also seems to be particularly good at mobilizing heavy metals within the soil by binding to cation exchange sites, thus displacing the ions generally located there, such as cadmium, copper, lead and zinc. Of these, copper seems to be especially susceptible to displacement by magnesium (Bäckström, Karlsson, Bäckman, Folkeson, & Lind, 2003). Although magnesium chloride is mainly used as a secondary deicer, with sodium chloride still the most prominent, magnesium is often the most abundant salt cation in soils near roadside areas where both products are used: magnesium levels within ten meters of roads were as high as ~115mg/100g soil, while the highest levels sodium reached were ~58mg/100g soil (Cunningham et al.). This is most likely due to the aforementioned characteristics of magnesium to stick to soils more effectively than sodium and to act as a leaching aid to sodium ions.

Another problem appears to be the corrosive effect of magnesium chloride to concrete and metals. According to Peter Snow of Burns Concrete, Inc., the recent shift to magnesium chloride-based deicers in a localized area have caused increases in the flaking and peeling of finished concrete surfaces in that area. When magnesium chloride dissolves in meltwater and remains on the finished surface, it permeates into the concrete. Here, there magnesium ions accumulate and react with the native compounds to form a mineral called brucite, which breaks down the bonds holding the concrete surface together, and it begins to deteriorate (Snow, 2003). This process is especially problematic if the concrete is under two years old. Thus, the process of magnesium accumulation indirectly causes a much shorter life span in concrete, which adds to the amount that needs to be replaced year after year.

Discussion

<u>Chloride Toxicity:</u>

Chloride toxicity effects are seen in both sodium chloride and magnesium chloride, which is a result of the two chemicals being strongly similar inorganic chloride salts. By definition these compounds are extremely soluble in water, and when used as deicers, precipitation is naturally and freely available – hence, their inclination to dissociate into the soil. The accumulation of chloride can weaken terrestrial plants by inducing chlorosis and can in some cases become toxic. Chloride in soils also contribute to a change in acidity, which can affect plant growth as well as the natural cycling of nutrients in soil. These changes will cause plants to look undernourished and damaged, and can make them more susceptible to disease and the competition of invasive species. On the Smith campus, chlorination of the soil and plants may be responsible for extra money and effort spent on fertilizers after the winter months.

In aquatic environments, chemical stratification can change the chloride concentrations of the water that native flora and fauna inhabit, which can lead to changes in species composition as well as upset the balance of delicate ecosystems. Given the Smith campus' proximity to the Mill River, a natural and diverse temperate aquatic habitat, a possible increase in chloride concentration should be taken into special consideration. In areas where the chlorine concentration exceeds the recommended limit for drinking, water treatment facilities have to add even more chemicals or activated carbon in order to remove it – and either of these options requires careful handling and diligence so as not to worsen the problem.

Effects of Magnesium:

In the case of the cations sodium and magnesium, both are positively charged metals that have a knack for sticking to soils. Magnesium happens to be better than sodium at this, and as a result displaces the sodium ions to areas further from the roads they are initially applied to. Because sodium chloride is still used at Smith to a fairly large degree, this means that magnesium is causing even greater areas to be affected by increases in soil salinity than might have occurred with just sodium chloride. This is a problem in any area where both sodium chloride and magnesium chloride are in use.

Sodium and magnesium ions also tend to displace nutrients that plants need, so that roots of plants take up extra sodium and magnesium instead of calcium and potassium. While magnesium is also one of the nutrients vital to plants, as it is a naturally-occurring metal in soil, the addition of extra magnesium due to deicing causes a severe imbalance in soil chemistry. Considering that magnesium chloride generally constitutes about half the total amount of Ice Ban product being sprayed onto pavement, and that anywhere from 1,000 to 10,000 gallons of Ice Ban are used at Smith every winter, this equates to between 500 and 5,000 gallons of liquid magnesium chloride being shoved into the soils and water systems here at Smith every year. Since magnesium is even more effective than sodium at displacing nutrients, this increase is bound to cause a profound imbalance in the elements present in soil, and thus in the intake of nutrients by plants.

In addition to displacing nutrients, magnesium accumulates quickly at soil cation exchange sites, which are areas of soil particles with an even stronger negative charge (usually clays), and in doing so displace the heavy metals which generally stay there. Once displaced, these metals are more easily mobilized, moving through the soil until they eventually find their way to the water supply. An increase in concentrations of heavy metals in either an aquatic ecosystem or a drinking water supply is not a good thing – it can be toxic to plants and animals, and have sometimes severe health ramifications for humans, if ingested. Copper seems especially susceptible to being displaced by magnesium, and studies show that an accumulation of ingested copper ions can cause cirrhosis of the liver and other unsavory health problems.

The fact that magnesium ions are much more abundant in soils near roads, despite being used less frequently and in smaller quantities as a deicer, is a tribute to its ability to stick to the soil much more effectively than sodium. The result of this attribute is that even though sodium chloride may be used more as a deicing agent, magnesium may have a stronger effect in the end, if only due to concentration levels. Lastly, due to its strong attachment to negatively charged soil particles, the likelihood of magnesium remaining there for a long time is high. With varying amounts of deicers being applied every year, the magnesium concentration in the soil will most likely be increasing as the ions continue to accumulate. A higher concentration each year will only lead to stronger effects on both plants and aquatic systems.

<u>Comparison of various deicing methods:</u>

Based on my research, magnesium chloride-based products seem only a tiny step above rock salt, in that the only benefits are that they reduce water's freezing point an extra 6 degrees, and do not seem to contribute to increased soil salinity as sodium chloride does. This renders magnesium chloride slightly more effective than rock salt, and slightly less damaging to plants. However, the fact that magnesium itself, in small quantities, is actually good for plants is not a valid reason to assume that the compound magnesium chloride is just as harmless – let alone beneficial. But if sodium- and magnesium-chloride are almost equally detrimental, then what does that leave us? Products which have been tried in the past are Calcium Magnesium Acetate, or CMA, and calcium chloride, another chloride salt. CMA is found to be extremely effective, preventing ice from forming in temperatures well below -15˚C, but the economic ramifications render this a doubtful choice: it costs $800 per ton, as opposed to sodium chloride's $40 (magnesium chloride is only slightly more expensive than sodium chloride). Research has also found that CMA can be detrimental if used near a water supply, due to the acetate forming a chemical reaction which harms aquatic flora and fauna. Calcium chloride, on the other hand, is extremely cheap, but also has been found to have negative effects. The most promising option currently available seems to be products made from agricultural byproducts, such as those Ice Ban is partly composed of – unfortunately, however, these products are not effective enough on their own to compete with sodium- and magnesium-chloride. However, those in production of such products are currently working on a completely natural and environmentally safe method of deicing that can one day take the place of inorganic salts.

Recommendations:

As Sink (2004) writes, "the problem we face is that there isn't a perfect product out there for de-icing the roads." While she is correct for the moment, human innovation and research promises that this will not always be the case. Smith has taken a step in the right direction by using a deicer made up of agricultural byproducts that would otherwise have gone to waste, but Physical Plant and the administration should keep their eyes open for even more environmentally friendly products which can improve the quality of both the Smith arboretum and the Mill River habitat. Until then, Smith can reduce magnesium chloride's negative effects by increasing the proportion of agricultural byproducts in its Ice Ban spray, and in order to reduce the amounts of deicing chemicals applied, perhaps increase the amount of manual snow removal before putting down salts. And, in case of one of those snow emergencies that ends up being a false alarm, it is better to try and clean up the chemicals applied before they get into the soils and plants than to wait and see if any effects show.

Conclusions:

Deicing salts have had an extremely positive influence on the safety of our communities while driving and walking in the snow. They help to prevent ice from forming, increase our traction, and allow ice to melt at an accelerated rate. There is no doubt that the number of traffic accidents has decreased since the 1960's when salts became widely used. However, we must not ignore the ecological ramifications that our increased safety may cause. There are other communities who can only live if we do our best to minimize the harm our actions cause to their natural habitats. Although it may take time and energy, it is important to discover to what extents these harms reach, and to do all in our power to turn back the clock on our misdeeds. Our own lack of foresight has caused sometimes irreparable damage to the ecosystems around us, and it is therefore our responsibility to attempt to undo as much of it as we can – and in a small way, doing away with chemical deicers, finding new solutions, and discovering their effects before using them universally, is one mode of changing our destructive pattern.

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