Chlorine Gas Exposure & Trees

by Dr. Kim D. Coder, University of Georgia School of Forest Resources June 2004*

Chlorine is a useful element and a dangerous element. Chlorine is an essential element in trees. It is found in thousands of natural and manmade compounds and materials. Chlorine is essential for both human thought and activating pesticides. Living things use chlorine and generate thousands of different organic compounds. Animal immune systems incorporate chlorine into natural materials to fight infections. Chlorine-containing organic materials are released every day from decaying plant materials. Organo-chlorines are also generated when plant materials are burned. Earth's volcanoes emit chlorine materials. Some rocks and minerals contain chlorine. We are surrounded by a chlorine recycling ecology essential to our lives.

Sometimes chlorine in the environment reaches a dosage or exposure level where it can impact trees and other landscape plants. This publication reviews chlorine gas impacts on trees and their supporting landscapes. This is not a toxicology or environmental dosage review, but is designed to help tree health care professionals understand the potential injuries sustained by trees and other landscape plants when exposed to chlorine gas.

History

Chlorine is a constituent of the Earth's crust. In nature, chlorine is always combined with something else. The major minerals containing chlorine found on Earth are: sodium chloride (table salt), carnallite (potassium magnesium chloride), and sylvite (potassium chloride). The element chlorine was discovered in 1774 and named in 1810. Because chlorine in a pure gas form is greenish-yellow in color, its name was taken from the Greek "khloros" which means a greenish-yellow color (chlorophyll shares the same root word origin.) Chlorine was found to disrupt and destroy cell membranes and cell wall components, especially in bacteria and viruses. The health benefit uses of chlorine are numerous. Chlorine has been used as a disinfectant since 1846.

It's A Gas

Chlorine is very reactive in pure form. It belongs to a element family (group) called the halogens which include fluorine, chlorine, bromine, and iodine. Halogens are almost always bound to another element which makes them easier to handle. Chlorine boils at -29^{o}F and so is a gas at room temperature. Chlorine gas is 2.3 times heavier than air, (see Table 1) which means at room temperature it sinks and flows along the ground and into low places. Humans make chlorine by taking salt water and running an electric current through it. The result is chlorine gas, sodium hydroxide (caustic soda), hydrogen, and oxygen.

Use & Value

Chlorine is used in medicines, disinfectants, plastics, pesticides, bleaches, polyesters, computer chips and paper making. Chlorine can be found in the mirror's reflectance, wood cabinet finishes, wall covering, carpet, deodorant, cosmetics, food packaging, and toothpaste. Our quality of life depends upon a almost universal manufacturing aid and ingredient – chlorine.

Changing States

We are surrounded with chlorine compounds in our environment. Low temperature burning and smoldering fire conditions form (and reform) many compounds. Some of the compounds formed when organic

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Table 1: Relative weight of atmosphere and select gases compared with chlorine gas (Cl_2).

	number of times heavier chlorine gas (Cl_2) is than:				
	Cl_2 chlorine	CO_2 carbon dioxide	O_2 oxygen	N_2 nitrogen	air
chlorine	1.0X	1.6X	2.2X	2.5X	2.3X

materials and other chlorine containing materials are openly burned are dioxins and furans, particulate matter (which can carry materials like chlorine), and PAHs (polycyclic aromatic hydrocarbons). These are all air pollutants. The United States EPA estimates unregulated trash burning is a major source of dioxins in the environment.

Blowing In The Wind

Chlorine gas (Cl_2) is heavier than air. When chlorine gas is released into the atmosphere it tends to stay close to the ground and follow the lowest topographic features like gullies and valleys, accumulating in low spots. Any breeze or an unstable atmosphere tend to quickly dilute chlorine with surrounding air and dissipate it downwind. Any chlorine which is hot from a fire or from smokestacks will tend to rise into the air and be mixed into the surrounding atmosphere.

Transformed

In the atmosphere chlorine gas quickly begins a transformation into other products. The first atmospheric reaction is splitting the chlorine gas into chlorine atoms: Cl_2 + sunlight = Cl + Cl. Bright sunlight is rich in wavelengths less than 475nm which have enough energy to separate the atoms in chlorine gas. Once the chlorine atoms are separated, each atom usually reacts with one of three other materials. These three reactions are the dominant ways chlorine interacts with the atmosphere surrounding landscapes. Chlorine atoms can combine with hydrogen (H_2), methane (CH_4), or water (H_2O) each forming hydrochloric acid (HCl) as one product – ($Cl + H_2 = HCl + H$; $Cl + CH_4 = HCl + CH_3$; $Cl + H_2O = HCl + O_2$). Chlorine gas in the atmosphere is quickly removed by its chemical transformations.

Removed

Chlorine gas is also removed from the air by three other means: rainfall; absorbed onto particulate matter surfaces; and, direct uptake at the soil surface. The soil surface, especially when moist, provides many reactions which destroy chlorine gas and generate chlorides. Chlorides can build up in the soil and need to be rinsed away. The chemical reactions which produce chlorides, as well as any water used to rinse chlorides out of the soil, will cause the loss of many valuable tree-essential elements like calcium, magnesium, and potassium from the soil. All these reactions initiated by chlorine gas assures its removal from the landscape-atmosphere system in less than 3 weeks under the worst conditions. Under perfect weather conditions chlorine gas can be removed from the landscape atmosphere in 2 days.

Whiff Of Death

Chlorine in the environment is quickly dissipated, chemically bound, and compartmentalized. Sunlight, organic matter in the soil, iron and manganese in the soil, nitrogen fertilizers, good soil aeration, clay soils, and plenty of soil water moving through the soil help minimize the impacts of chlorine. Figure 1. Living things like trees can be damaged by chlorine gas. The circumstances surrounding exposure concentrations and duration of exposure (dosage) will determine the extent of damage to trees and landscapes. Figure 2. Table 2 provides a list of impact factors which influence chlorine exposure damage in the landscape. Table 3 lists relative species tolerance to chlorine gas. Note, because of dosage and circumstance differences, some plants are listed as both sensitive and tolerant.

Landscape Treatments

Treatments in areas where landscapes have been exposed to chlorine gas could include: irrigate soil and wash plant surfaces to remove acidic materials, particulate matter, and accumulated chlorides; light fertilization with a slow release nitrogen to increase the ecological vigor of the site; application of a dolomitic limestone amendment to replenish base elements; and, assure adequate drainage of soil water – do not allow water accumulation. Plentiful rainfall can help rinse plant surfaces and soils. Remember chlorides are rinsed away by water but they take important essential elements with them.

The Tree Reacts

Tree reactions to chlorine gas and associated injuries are as varied as the circumstances and dosage of exposure. Generally, foliage has the most sensitive tissue with no inherent buffering or shielding, like soil-surrounded roots. Ephemeral absorbing roots are damaged by acids and chlorides. The photosynthetic system in a tree leaf is the most sensitive. The first few minutes of exposure causes enough damage to shut down the leaf. Foliage wilts upon exposure. It is important to not water during the gas exposure period as this will tend to keep stomates open and cause more damage. Spraying antitranspirants during the exposure period can reduce damage if the material is removed promptly after exposure. Antitranspirants will have the greatest positive impact on small, shaded trees.

Developing Symptoms

After the exposure event, damage will be visible as many minute necrotic or discolored points across the leaf surface. This stippling or flecking can appear similar to mite or sucking insect damage. As damage accumulates and other organisms take advantage of the injuries to enter the leaf, leaf damage will tend to be concentrated at the leaf margins and between the veins in mature and active leaf blades. Later onset symptoms include necrotic, bleached or brownish colored areas or spots. The veins are the last to show damage. Scorching or bleaching will be concentrated initially at the tips and along the edges of the leaves.

Older mature leaves will be more prone to damage than younger leaves. Young leaves not yet expanded and leaves enclosed in expanding buds usually show little damage from low exposure doses. Older leaf symptoms may include a spotty bleached appearance and sunken wet-looking spots. Needles can develop tip dieback. In pines, the newest active needles show significant damage while older needles show significant damage and drop. If damage is too great, the leaf may senese (systematic shut-down of living systems) and abscise (break-off and fall.)

Conclusions

A good tree health care program, including monitoring for secondary problems while reducing other stressors, will be critical for trees exposed to chlorine gas. The tree health care professional can conserve trees by preventing any more damage, removing damaging materials on plant surfaces and in the soil, and by enriching the soil with essential resources for the tree.

Figure 1: Soil reactions which minimize free chlorine content in soil water as chlorine exposure increases.

1. sunlight impact at soil surface.
2. iron & manganese oxidation.
3. binding onto organic materials.
4. binding into nitrogen containing compounds.
5. hydrochloric acid formation and nitrogen gas release
6. free chlorine remains available in soil water

Low Cl_2 Levels

High Cl_2 Levels

Table 2: Annotated list of factors which influence chlorine gas exposure damage in a tree-filled landscape.

impact factor	*comments on potential damage*
concentration in air	damage starting at 0.1 ppm & severe by 5.0 ppm depending on duration of exposure.
distance from source	the closer to the source, the higher the concentration in the air, and the more damage.
duration of exposure	longer duration means more damage.
meteorological conditions	warm, clear, bright, still, humid, high pressure, and inversions increase damage potential.
topography	with no wind, gas flows along the ground settling into low areas.
soil moisture	more soil moisture generates more damage through open stomates.
time of year	Spring during expansive growth is most potentially damaging season of exposure, followed by the rest of the growing season.
species	some species are more sensitive than other (see Table 3).
maturity of tissue	older, mature, & active tissues are prone to injury.
health of tissue	other stresses prevent effective reactions to any new damage.

Dr. Kim D. Coder, 2004

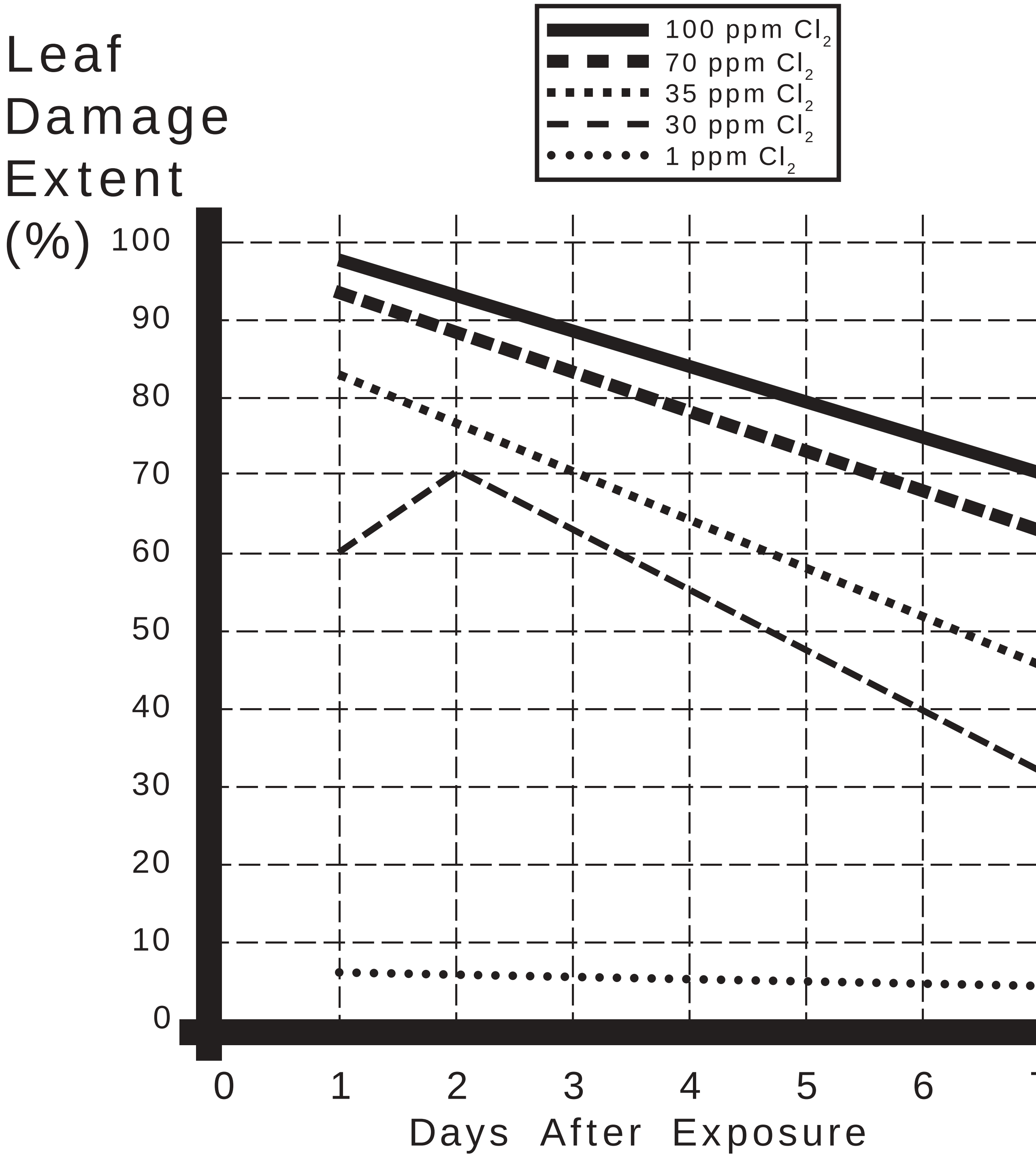

Figure 2: Laboratory chlorine exposure experiment examining plant leaf damage (100% is complete leaf damage and 0% is no leaf damage) over a one week period at five initial chlorine gas concentrations. Total chlorine gas exposure durations were 10 minutes. (after Griffiths & Smith, 1990).

Table 3: List of relative species sensitivity to chlorine gas taken from the research literature.

Not all plants are damaged by chlorine gas to the same degree. Some plants develop fewer and less intense symptoms for the same level of exposure. The closer to the ground plant foliage grows, the more likely it is to be damaged. Note, because of dosage and circumstance differences, some plants are listed as both sensitive and tolerant.

Landscape & Garden Plants Cited As Tolerant To Chlorine Gas:

arborvitae, autumn olive, azalea, beech, begonia, birch, boxelder, cactus, chrysanthemum, corn, cowpea, daylily, dogwood, eggplant, English ivy, fir, geranium, grass, hemlock, holly, iris, Japanese maple, red maple, English oak, red oak, oxalis, pear, pepper, pigweed, pine, Southern magnolia, spruce, soybean, tobacco, yew.

Landscape & Garden Plants Cited As Sensitive To Chlorine Gas:

alfalfa, amaranthus, apple, ash, aspen, azalea, barberry, bean, beech, birch, blackberry, black gum, boxelder, buckeye, catalpa, cherry, chickweed, coleus, corn, cosmos, crabapple, crapemyrtle, cucumber, dandelion, deodar cedar, dogwood, elder, elm, forsythia, grape, hibiscus, honeysuckle, hydrangea, juniper, larch, morning glory, mulberry, mustard, onion, peach, petunia, phlox, pin oak, jack pine, loblolly pine, shortleaf pine, slash pine, Virginia pine, white pine, poison ivy, pokeweed, poplar, primrose, privet, radish, redbud, rhododendron, rose, sassafras, serviceberry, silver maple, striped maple, sugar maple, spruce, sunflower, sweetgum, tobacco, tomato, tree-of-heaven, tulip, viburnum, violet, Virginia creeper, willow, witchhazel, yellow poplar, yellowwood, zinnia.