Trees & Chlorine Gas:
Dosage, Damage & Treatments

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The damage extent in trees from chlorine gas and associated water solution products depends upon the exposure dose. Exposure dose depends upon how much of the damaging agent is present (concentration), how long of time the tree is exposed (duration), how accessible are the living cells of the tree (entrance), and the time of the year exposed (season). The greater the concentration, duration, entrance avenues, and exposure in the early part of the growing season, the greater the damage potential to trees because the exposure dose is increased.

Poison Dose

Across many species and different climatic and topographic circumstances, concentration and duration values can be roughly defined which initiate damage in trees. Concentrations of 0.5 to 5.0 ppm initiated chlorosis and tissue death in tree leaves. A standard dose appears to be 3 hours at 1 ppm to initiate tree damage, but dosage could vary from 0.5 ppm for 8 hours to 5.0 ppm for 10 minutes. See Figure 1. The amount of leaf tissue damage quickly builds with small increases in exposure concentrations. Figure 2. Visual symptoms rapidly increase between 1-30 ppm.

Assessing Potential Damage

One standard formula for estimating changes in leaf damage is: potential leaf damage level = (chlorine gas concentration $)^2$ X time. This formula demonstrates chlorine gas concentration increases greatly outpace duration effects in impacting leaf damage. Another formula used for unconstrained outdoor exposures is: potential leaf damage level = chlorine gas concentration / wind velocity. This formula demonstrates how the more wind present, the less residence time chlorine gas has around the tree. My formula, which I use in the field as a rule of thumb, is a modification of the proceeding two formula: potential leaf damage level = ((chlorine gas concentration $)^3$ X (time$)^2$) / ((distance from the source $)^2$ X wind velocity). Any time dose components increase, or wind and distance decrease, relative leaf damage will increase.

Human PPMs

Humans start to smell chlorine in the air at approximately 1 ppm, with a strong odor sensed around 3 ppm. Chlorine gas coloration in the air can be sensed at about 2 ppm. For humans, 50% mortality averages are reached at dosages of 150 ppm for 1.7 hours, 350 ppm for 10 minutes, 800 ppm for 1 minute, or 1-2 breaths at 1,000 ppm.

A Good Mixer

As chlorine is released into the atmosphere, the more unstable the atmosphere and the more wind present, the more dilution and mixing which occurs. A stable atmosphere (inverted) and no wind allows for extended exposures to chlorine gas to locally exist. In general, foliage damage classes can be defined by the

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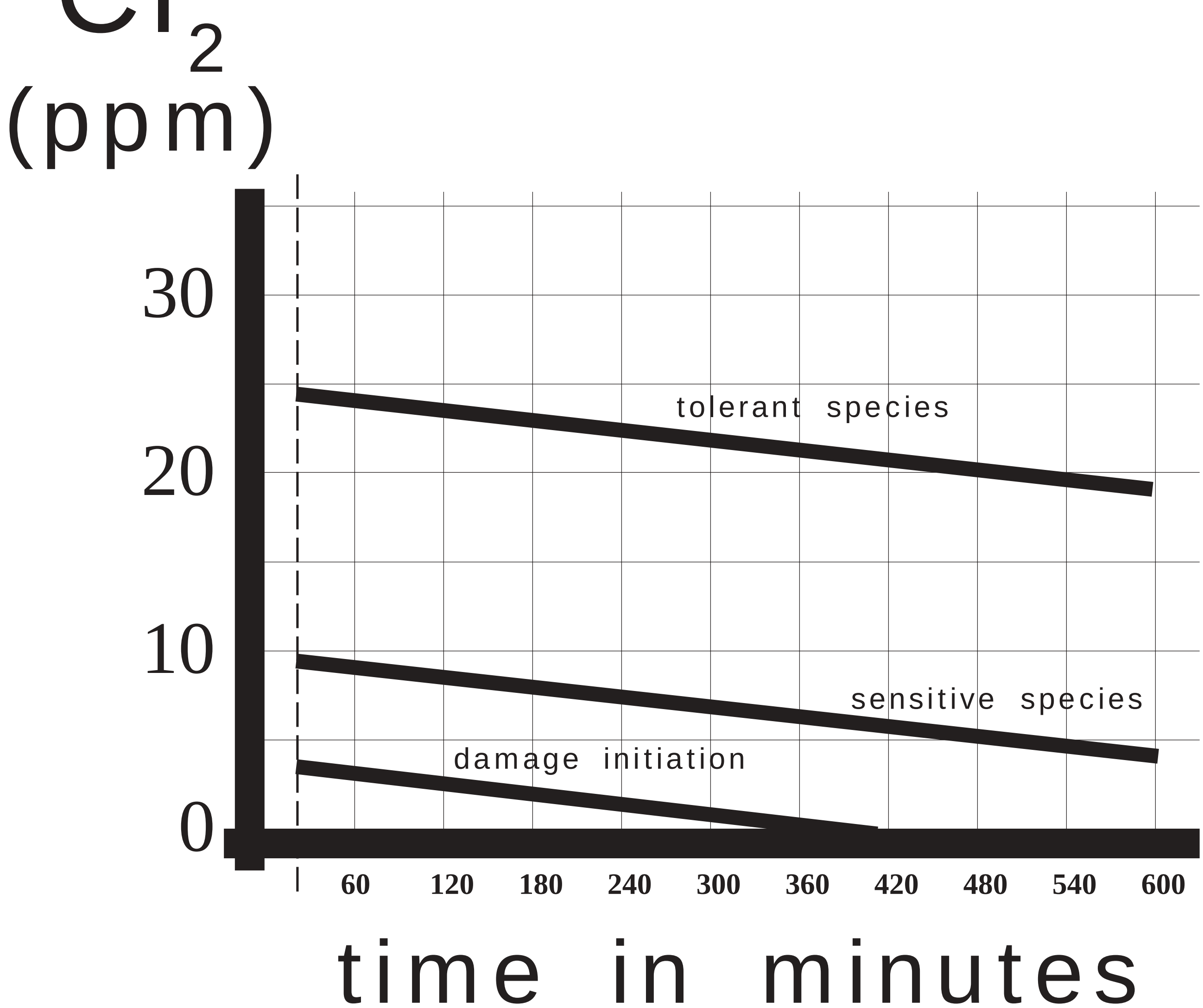

LINE EQUATIONS:

initiation of leaf damage -- Cl_2 ppm = -0.01 * (time) + 4.
Time = (ppm - 4) / -0.01.

damage to sensitive tree foliage -- Cl_2 ppm = -0.01 * (time) + 10.
Time = (ppm - 10) / -0.01.

damage to tolerant tree foliage -- Cl_2 ppm = -0.01 * (time) + 25.
Time = (ppm - 25) / -0.01.

Figure 1: Composite dosage and damage potential for chlorine gas on the leaves of chlorine-sensitive and chlorine-tolerant trees. Graph developed from summarizing diverse laboratory and field information without regard to humidity and precipitation.

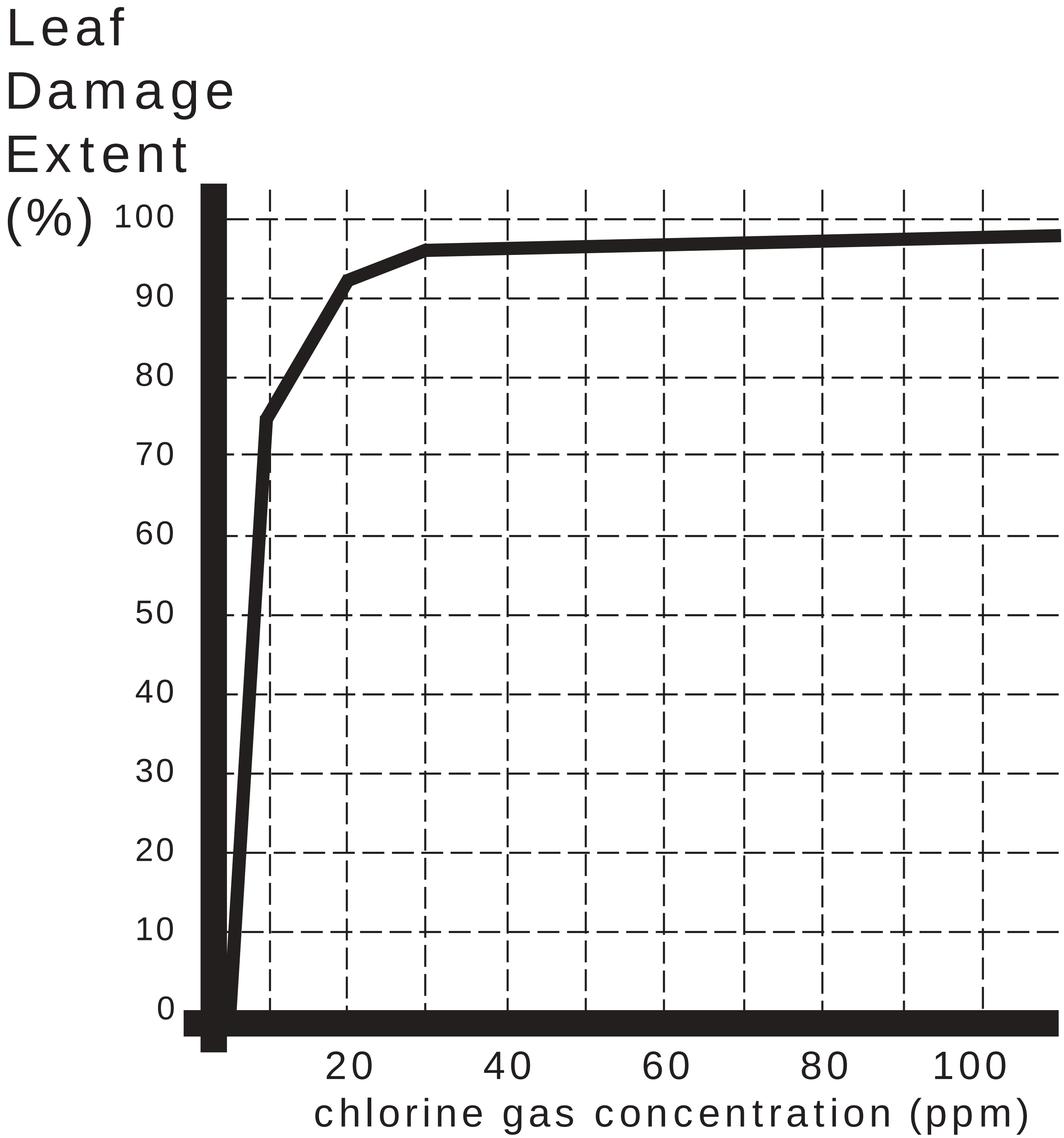

Figure 2: Laboratory chlorine exposure experiment examining plant leaf damage (100% is complete leaf damage and 0% is no leaf damage) across chlorine gas concentrations. Chlorine gas exposure duration was 10 minutes.

(after Griffiths & Smith, 1990).

distance from an exposure source. One example is: 1 mile from exposure source. -- all trees can be severely injured; 2 miles from exposure source -- chlorine-tolerant trees show little damage; 6 miles from exposure source -- sensitive trees show little damage; and, 11 miles from exposure source -- visible foliage damage can still occur but with little long term impact. All of these classes assume the gas stays close to the ground and is not quickly diluted or rapidly blown away. See Figure 3.

Treatments

Tree treatments for chlorine gas exposure revolve around preventing increased dosing and dissipating damaging agents. During exposure, irrigation, watering, or foliage spraying should not be done. Watering trees during exposure will cause a greater access to the living cells for the chlorine gas and associated damaging materials. Wetland trees can be especially hit hard by being low in the landscape topographically, and have open stomates for a relatively longer duration per exposure.

After the source has stopped emitting chlorine gas and the gas has been dissipated, watering, sprinkling and irrigation of the soil should commence. Use plenty of water to both dilute and rinse away chlorine products. A little water may actually be more detrimental than none at all. Use water to rinse plant surfaces and the soil. Water will help dilute acid and help to more quickly transform damaging materials. The additional benefit of water is to keep tree systems functioning biologically in order to effectively deal with damaging materials and repair internal damage quickly, especially essential processes like photosynthesis.

The rinsing of soil and plant surfaces will rinse away a number of essential elements. These elements need to be replenished through careful fertilization and liming of the soil. Dolomitic limestone should be added back to the soil because calcium and magnesium will be essential for tree recovery. A light fertilization with slow release nitrogen and plenty of potassium and phosphorus can help in the recovery process. Do not over-fertilize.

Future Expectations

Ecological and growth changes caused by chlorine gas exposure can last beyond 5 years close to the source. The farther away from the source, the less residual damage should be experienced in landscapes. The primary residual effect is a disruption and slowing of growth which accentuates other stresses. Long term damage is usually most noticeable on young, small, short trees. Generally, drought tolerant species and trees with strong water use efficiencies (WUE) are less prone to long term damage, while bottomland trees and wetland species are more prone to long term damage.

An accelerated tree health care program should be put in place for at least three full growing seasons because of the threat of insect pests. Extreme vigilance must be shown to valuable trees which have been damaged because of potential bark beetle and ambrosia beetle attacks. Drought stress and heat stress syndrome will be much more damaging in chlorine gas damaged trees. Less food production by the tree will lead to less growth and potentially poorer reactions in defense, reproduction, and resource gathering and control.

Conclusions

Trees and chlorine gas do not mix well. Short-term and long-term tree problems occur. Usually the dosage of any exposure determines damage. In trees, other environmental stresses, both before and after exposure, can further impact trees. An intensive tree health care program is essential for the future of great tree-filled landscapes.

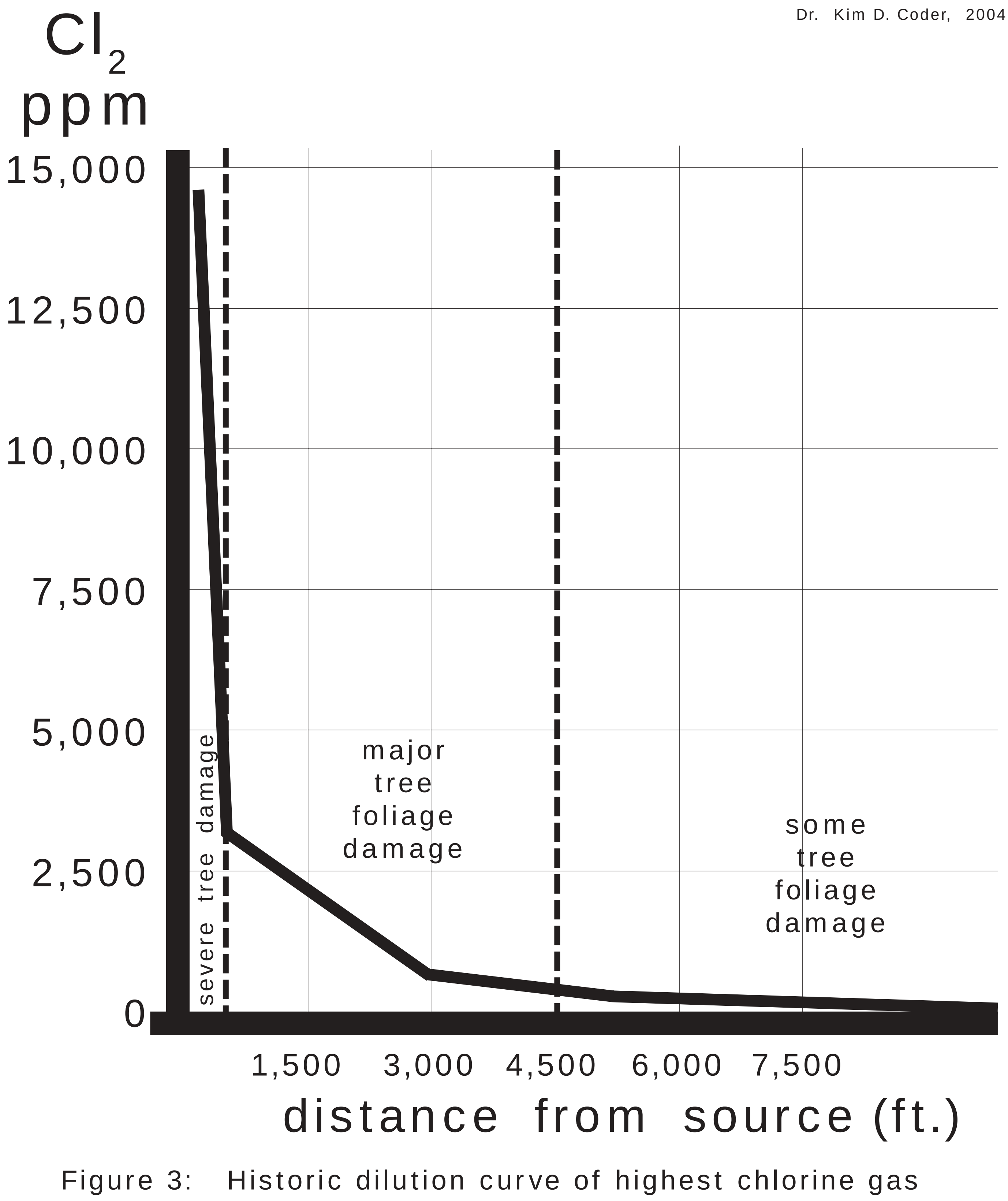

Figure 3: Historic dilution curve of highest chlorine gas concentrations measured in ppm over distances downwind from the source in a location with constraining topography. Dotted lines separate severe, major, and generalized damage zones.
(5 ppm at 30,000ft downwind)