Sodium Chlorate

Crops

Identification

Chemical Name(s):
Sodium chlorate

Other Names:
soda chlorate; chlorate of soda; chloric acid, sodium salt; sodium chlorate, aqueous solution

Trade names:
Chlorax; De-Fol-Ate, Drop-Leaf; Fall; Harvest-Aid; Tumbleaf

CAS Number:
7775-09-9

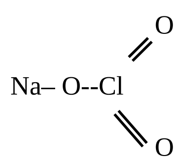
Other Codes:
DOT number: UN 1495/ UN 2428
NAERG Code: 140
PC Code: 073301

Summary Recommendation

Synthetic / Non-Synthetic:	Allowed or Prohibited:	Suggested Annotation:
Synthetic	*Prohibit*	

Characterization

Composition: $NaClO_3$.



Sodium chlorate belongs to the class of inorganic herbicides (containing no carbon), and was developed before the modern era of organic herbicides such as 2-4-D, which began in the mid 1940s. Others in this category include aresenicals, borates, cyannates, and ammoniuim sulfamate and are still in use today (Klingman, Meister).

Properties:
Sodium chlorate is a white, odorless, crystalline solid that looks like common table salt (sodium chloride) and is water soluble. It is a strong oxidant, not combustible but reacts violently with combustible and reducing materials. There is a risk of fire and explosion in dry mixtures with other substances, especially organic materials, i.e., other herbicides, sulphur, peat, powdered metals, strong acids, etc.

How Made:
Sodium chlorate is rapidly produced in solution form by the electrolysis of sodium chloride brine in a diaphragm-less chlor-alkali cell (Kent, Kirk-Othmer). The overall reaction is :

$$NaCl + 3\,H_2O + 6F \text{ (faradays)} \longrightarrow NaClO_3 + 3H_2$$

This process is currently efficient at the rate of over 90% and involves power consumption of 4500- 5800 kWh /metic ton of sodium chlorate produced. In 1990, total North American sodium chlorate capacity was 1.1 million tons/year, with most production in Canada because of lower energy costs. Ninety-four percent is used for manufacture of on-site chlorine dioxide for wood pulp blelaching; other uses are for herbicides, water treatment, mining, and as precursors for other chlorite and chlorate chemicals.

Specific Uses:
Sodium chlorate is a non-selective contact herbicide, considered phytotoxic to all green plant parts. It is used as spot treatment for serious perennial weeds, such as morning glory, Canada thistle, and Johnson grass and for vegetation control on roadsides. It is also used as a defoliant and desiccant for cotton, safflower, corn, flax, soybeans, and other crops. It is also known to have a soil sterilant effect (Extoxnet, Klingman et. al., Meister). It kills all plant growth except moss and persists for three to six months (Meister).

Defoliants are used in cotton as a harvest aid to remove green leaves, which can remain on the plants late in the season due to the indeterminate nature of the cotton plant. In some cotton growing regions, growers rely on frost to defoliate the plants, but in other regions, such as Arizona and parts of California's San Joaquin valley, frost is usually too late to be effective. California has a mandated plow-down date to for puposes of insect management, and this may occur before frost in late December. When leaves remain on the cotton plant, it interferes with mechanical harvest, causes staining of white cotton resulting in a lower quality grade, and accumulation of trash in the harvested product. Too much trash in the cotton modules (large compressed bales, often stored under tarps in the field until ginning) can lead to spontaneous combustion. Harvest management is usually a concern, also, as defoliation will allow earlier picking in an early season, and enable farmers to get the crop off the field before adverse weather sets in. Variety selection is a factor as well, as some of the white cotton varieties grown in the west are not considered "storm proof" and need to be harvested before any fall rains. Different types of harvest machines are suited to different varieties: "stripper cotton" is a type that must be totally dry as the machine strips the stem clean and separates the trash, whereas a picker with a rolling drum type of action pulls the fiber out of the boll and and can handle more green leaves on the plant. The stripper varieties are stiffer, with bolls held more tightly and can withstand windy conditions better.

Action:
Sodium chlorate is absorbed rapidly by the the plant through both roots and leaves. When applied as a foliar spray, the chlorate ions penetrate the cuticle and cause cell death. Soil applications result in root absorption and translocation through the xylem to living tissue in plant and foliage. Basic cause of toxicity is thought to be the effect of the high oxidizing capacity of the chlorate ion, toxic effects form decomposition products such ans chlorite, increased rate of respiration, and increased catalase activity (Klingman). The injury to plant leaves also causes the plant to produce ethylene, which is known to cause leaf abscission (Brown, Suttle, Wright). Chlorate-injured plants are more susceptible to frost. Sodium chlorate is 30-50 times more toxic to plants than sodium chloride (table salt).

Combinations:
The active ingredient sodium chlorate is found in a variety of commercial herbicides. Some trade names for products containing sodium chlorate include Atlacide, Defol, De-Fol-Ate, Drop-Leaf, Fall, Harvest-Aid, Kusatol, Leafex, and Tumbleaf. The compound may be used in combination with other herbicides such as atrazine, 2,4-D, bromacil, diuron, and sodium metaborate. Sodium chlorate comes in dust, spray, and granule formulations. It is usually marketed in formulations that contain a fire depressant, such as urea or sodium borate. Urea is a synthetic nitrogen source not exempted under OFPA, and thus prohibited. The NOSB recommended to prohibit use of any micronutrient (such as sodium borate) as a herbicide or dessicant in April, 1995.

Status

OFPA
The OFPA, 6517(c)(A) "Guidleines for Prohibitions or exemptions" states that synthetic substances may only be granted an exemption for use only if the Secretary determines, that the use of such subtance (i) would not be harmful to human health or environment and (ii) is necessary to the production or handling of the agricultural products because of unavailability of wholly natural substitute products. In addition the substance must falls into a permitted category under 6517(c)(B)(i): Sodium chlorate as a defoliant could be considered a crop production aid, and considered for inclusion on the National List provided it meets the other criteria.

Regulatory
In the U.S., sodium chlorate is a registered pesticide, but is not a restricted use pesticide. The label must carry the signal word "Warning." (EPA Toxicity class II, some formulations are class I, require "Danger" warning. Categories are based on combined hazard indicators for oral, inhalation, dermal and eye effects with I being most toxic and IV being least toxic). Sodium chlorate is considered a hazardous substance in citations fm DOT (US Department of Transportation), NFPA (National Fire protection Association), and EPA.

The EPA's Office of Pesticide Programs (OPP) lists 73 labeled products with NaClO3 as active ingredients. NIEHS (National Institute of Environmental Health Studies): refers to the International Chemical Safety Card (ICSC 1117). Cautions are issued relating to risk of explosion, fire, and human exposure.

Status Among U.S. Certifiers
Not listed under standards of U.S. certifying organizations. Specifically prohibited by Texas Department of Agriculture.

Historic Use
Used in conventional agriculture.

International
CODEX- not listed. No provision is made for herbicides or defoliants.

EU 2092-91 – not included in Annex II B, Pesticides. There is no category listed for herbicides or defoliants.

IFOAM – 1999 Basic Standards 4.5.5. "The use of synthetic herbicides, fungicides, insecticides and other pesticides is prohibited. Permitted products for plant pest and disease control may be found in Appendix 2." Sodium chlorate is not listed, and IFOAM also prohibits the use of other materials as herbicides (e.g., corn gluten meal).

Section 2119 OFPA 7 U.S.C. 6518(m)(1-7) Criteria

1. *The potential of the substance for detrimental chemical interactions with other materials used in organic farming systems.*
   Sodium chlorate has three atoms of oxygen per molecule, making it a powerful oxidizer (releases oxygen). It is a stable compound and not combustible by itself, but it is highly flammable when it comes into contact with organic materials such as clothing, wood, or even plants. It can be a fire hazard when foliage dries, and could be ignited by a spark (Klingman). It may react explosively with agricultural materials such as peat, powdered sulfur, sawdust, and organic matter (Lewis).

2. *The toxicity and mode of action of the substance and of its breakdown products or any contaminants, and their persistence and areas of concentration in the environment.*
   Acute Toxicity: The acute oral LD50 for sodium chlorate in rats ranges between 1,200-7,000 mg. The dermal LD50 is 500 mg/kg over 24 hours. A single dose of 5-10 g/person of sodium chlorate can prove to be fatal in adults, as can a single dose of 2 g/child in small children. Irritation of the skin, eyes, and mucous membranes has been noted Symptoms of oral ingestion of sodium chlorate include abdominal pain, nausea, vomiting, diarrhea, pallor, blueness, shortness of breath, unconsciousness, and collapse. Sodium chlorate may affect blood cells and damage kidneys. Acute exposure to the compound may damage the liver.

   Sodium chlorate is not reported to be a carcinogen, and no information is available for teratogenic or mutagenic effects (Extoxnet). It is a suspected neurotoxicant, cardiovascular blood toxicant, and respiratory toxicant, according to National Institute for Occupational Safety and Health's Registry of Toxic Effects of Chemical Substances (RTECS, reported by EDF).

   Persistence in Soil and Groundwater: The duration of residual activity for sodium chlorate in soil was three to four months after using 1,000 liters of a 1% solution/ha. Sodium chlorate may persist in soil for six months to five years, depending on rate applied, soil type, fertility, organic matter, moisture, and weather conditions. Toxicity in soil is decreased considerably by a high nitrate content, alkaline conditions, and high soil temperatures (Extoxnet). Sodium chlorate is also reported to be subject to leaching from soils (Klingman) and also is decomposed by soil microorganisms to chlorides. Fate depends on rainfall, soil texture and structure, organic matter content, and temperatures. Klingman also reports that under low rainfall conditions, sodium chlorate may remain toxic for five years or longer, with toxicity lasting 6-12 months in the humid Southeast.

   Effects on Birds: The long-term toxicity of sodium chlorate to birds resulted in reduced egg production and fertility.

   Effects on Aquatic Organisms: Sodium chlorate is considered non-toxic to fish. The possible 48-hour LC50 for various species of fish was 10,000 mg/l.

   Effects on Other Animals (Nontarget species): Sodium chlorate is considered non-toxic to bees. Toxicity to animals may occur if they feed on freshly treated areas. This chemical has a salty taste and salt-hungry animals may eat enough to become poisoned (Extoxnet, Klingman). Also, its use may make poisonous plants palatable and cause animal injury.

3. *The probability of environmental contamination during manufacture, use, misuse, or disposal of the substance.*
   Manufacturing uses large amounts of electric energy, but does not appear to otherwise represent an environmental hazard.

4. *The effects of the substance on human health.*
   See information on acute toxicity, number 2.

5. *The effects of the substance on biological and chemical interactions in the agroecosystem, including the physiological effects of the substance on soil organisms (including the salt index and solubility of the soil), crops and livestock.*
   The salt index is a measure of the relative tendency of a fertilizer to increase the osmotic pressure of the soil solution as compared to a reference standard of an equal amount of sodium nitrate. This is measured in the laboratory for various soil types, to develop a reference that predicts the tendency of a fertilizer to "burn" crops in field conditions. A previous memo to the NOSB (Baker, 1996) describes the relative salt index for a number of mined minerals permitted under NOSB recommendations. Sodium chlorate has not been evaluated according to this system; however, considering the salt index for sodium chloride it can be presumed that the salt index for this substance is in the range of that for sodium chloride, which is 153.8 (as compared to 100 for sodium nitrate). Chlorine is an essential plant nutrient, however excesses have a detrimental effect on some crops, including potatoes and tobacco (Tisdale). Soil concentration of salts increase as the soil dries out, and the salts can move up with capillary action into the surface layer. Excessive concentrations of salts in contact with roots and germinating seeds is injurious due to restriction of moisture availability, water loss of plant cells (plasmolysis) and direct toxicity (Tisdale).

6. *The alternatives to using the substance in terms of practices or other available materials.*
   Organic farmers currently manage cotton defoliation in a number of ways, depending on the region, climate, and management practices. In the U.S., hand picking of cotton is not considered a reasonable option, though this is practiced in Turkey and Egypt. In irrigated situations, a withholding of water and nutrients can be used to dry up the plants before frost. Plant breeders are working on varieties that will naturally defoliate and also have better weather resistance (Fox). NOSB approved the use of natural mined sodium chloride for emergency use in case of a mandated government spray situation. In Texas, a number of other materials are listed for similar emergency use with permission of the certifier (TDA), such as magnesium sulfate, magnesium chloride, postassium chloride, potassium sulfate, zeolite, and fulvic acid. These are not being requested for use at present in Texas. Many production areas already have high salt level in groundwater and would not be suitable (McKinnon).

   Organic farmers in wetter climates are experimenting with citric acid and mixtures of essential oils, with various degrees of success. Citric acid appears to be somewhat effective, when applied twice at rates of 5-10 lbs/acre. It is more expensive and less effective than sodium chlorate (McKaskle, Pepper). Growers are interested in finding reliable, effective techniques but are not using this product currently.

7. *Its compatibility with a system of sustainable agriculture.*
   This material could have long term impact on salinization in some climates, and shows persistence in the soil with toxic effects on plants. It is a health hazard for humans and some wildlife. It has not been historically been allowed in organic production, and does not seem compatible with organic principles.

TAP Reviewer Discussion

TAP Reviewer Comments

OMRI's information is enclosed in square brackets in italics. Where a reviewer corrected a technical point (e.g., the word should be "intravenous" rather than "subcutaneous"), these corrections were made in this document and are not listed here in the Reviewer Comments. The rest of the TAP Reviewer's comments are listed here minus any identifying comments and with corrections of typos.

Reviewer #1
[Organic farmer and research plant pathologist.]
I recommend that sodium chlorate be prohibited from use in organic farming systems. Sodium Chlorate is a strong oxidizing agent and highly flammable when mixed with organic materials (Klingman, 1975). Manufacturing of sodium chlorate is dependent of the use of large amounts of electric energy. Sodium chlorate is a non-selective herbicide that persists in the soil for periods of six months to five years depending on the rate applied, soil type, fertility, organic matter, moisture and weather conditions (Klingman, 1975). The compound is 30-50 times more toxic to plants than sodium chloride. A single 5-10 gram dose of sodium chlorate can be fatal in adults and two grams can be fatal in children if ingested. Sodium chlorate may affect blood cells and damage kidneys. Acute exposure to the compound may damage the liver. The long-term toxicity of sodium chlorate to birds resulted in reduced egg production and fertility (Extoxnet, 1995).

The primary use for sodium chlorate is to defoliate cotton. Currently there are alternatives available to organic farmers that include irrigation management, frost, hand harvesting, and citric acid sprays. Citric acid does not appear to work well on stripper cotton because it dries up the leaves but the leaf material still remains on the plant (Texas Dept. of Ag). A product of plant oils including sunflower, clove, and rosemary oils is being tested in Texas on 4-acre test plots by Ecosmart Technologies, Franklin, Tennessee (Texas Dept. of Ag.). Results from this work have not been definitive and tests are ongoing. Although the options for farmers may not be compatible to their growing situation (i.e., frost, water management), sodium chlorate in my opinion is neither an appropriate nor a workable option in organic farming systems.

Reviewer #2

[Research entymologist.]

Sodium chlorate is a strong oxidizing agent being considered for use in organic agriculture for its herbicidal and defoliant properties. It was used as a weedkiller in the U.S. before 1940, but currently is used less because of the many alternatives (Klingman et al. 1975). A notable exception is the current Section 18 EPA emergency exemption for use as a weed desiccant in wheat (EPA 2000). Considerable amounts are also still used to defoliate cotton (USGS 1992).

It is a synthetic, produced by electrolysis of a brine solution (Klingman et al. 1975). To be used in organic agriculture it would have to be added to the National List. Urea or sodium borate is added to formulations to reduce the fire hazard from the strong oxidant. Urea is a synthetic which would have to be added to the National List, and the NOSB recommended in 1995 to prohibit the use of herbicidal or desiccant micronutrients such as sodium borate (see TAP analysis).

No good argument can be made for sodium chlorate as a broadcast herbicide in organic crop production. It is a hazardous material, and repeated application to soil at herbicidal rates of 150-300 kg/ha (Naito et al. 1976; Parochetti 1972) could lead to increased salinization and phytotoxicity. Its salt index (Rader et al. 1943) is probably near that of sodium chloride, and when added to soil, microbials convert it to sodium chloride. Typical toxic persistence in soil is about a year where rainfall is adequate (Klingman et al. 1975). In Maryland, it took soil 3 years to recover from the toxic effects of an application at 400 times the label rate. Similar recovery from diuron abuse still had not occurred 12 years later (Isensee et al. 1973). It possibly has a limited use as a spot treatment in areas away from crop production.

A better case can be made for sodium chlorate as a defoliant. For this use, application rates are 3-6 lb/acre (Drexel 2000), and possibility of salt buildup in soil is less. To be considered for this application, risks to the environment would have to be balanced against need and alternatives. A more complete evaluation is given below.

Evaluation based on OFPA criteria

1. Weeds treated with aqueous solutions of sodium chlorate are a fire hazard when the foliage dries. It is a strong oxidizing agent, and reacts explosively with organic materials such as sulfur, peat, sawdust, and other materials (Lewis 1992). Tank mixtures with pesticides such as pyrethrins could explode on hot days (Reimer 1976).

2. The LD50 for oral administration to rats is 1200 mg/kg. Dogs have been killed with acute oral doses of 1000 mg/kg. Daily oral doses of about 300 mg/kg have also killed dogs. The material damages kidneys and destroys red blood cells (Heywood et al. 1972).

The mode of action starts with absorption by the plant. It is rapidly absorbed by leaves and roots. Penetration of leaf cuticle causes cell death probably through a disturbance of metabolism. Its oxidizing action may destroy components of the respiratory chain. Inhibition of catalase leads to a buildup of toxic peroxides. It is 30-50 times more toxic to plants than sodium chloride, so its toxic effects are not due just to salt desiccation (Klingman et al. 1975). Injured tissues cause production of ethylene, which increases its defoliant action (Brown 1997).

It is used mostly on cotton in the Central Valley of California and in cotton growing regions of Arizona, Texas, and the South, especially Mississippi. A considerable amount is also used to defoliate beans (USGS 1992).

Persistence in soil is a complex function of soil type and environmental conditions. Under low rainfall conditions, it can persist for six years. It persists longer in clay soils than sandy soils. Typical toxic persistence in the South, where the weather is wet and humid, is 6-12 months (Klingman et al. 1975).

It is either washed away from areas where it is applied, or converted by soil microbes into sodium chloride, which then either persists or is washed away. The mobility of sodium chlorate with water is so great that applications at the top of a slope can kill part or all the vegetation below, creating an erosion hazard (McCully and Bowmer 1971).

Applications of 224 kg/ha by aerial spray along a watershed led to a maximum water concentration of 26 ppm one hour later, but levels of .1 ppm were present one month later (Tsunoda 1972). The EEC limit for safe drinking water is 0.1 ppm (Richardson and Gangolli 1994). It thus should not be applied near wells or drinking water sources.

Long term exposure to birds leads to reduced egg production and fertility. Though not very toxic in general to fish, certain species such as trout are more affected than others (Tomlin 1997). Because of its water solubility, high tissue levels quickly wash out when contaminated fish are exposed to clean water (Harris and Eschmeyer 1975). Sodium chlorate is not a threat for bioaccumulation.

It is not a threat to bees or earthworms, when applied at recommended rates (Tomlin 1997). Animals may be poisoned if they feed on foliage freshly sprayed or otherwise treated (Klingman et al. 1975).

3. Manufacture is by electrolysis of brine. The starting material has low toxicity and 90% of the sodium chlorate produced is used to generate chlorine dioxide to bleach paper. This process produces fewer dioxins and organic halides than bleach and thus is more environmentally friendly. Rather large amounts of electricity are used in the manufacturing process, and this factor might be an environmental concern (Kent 1992).

Possible environmental contamination could come from improper disposal into storm drains or surface waters. Cattle have been deliberately poisoned (Ganiere et al. 1981), but these kind of malicious acts would not be within the scope of normal use or even misuse. Those who purchased it as a defoliant or herbicide would not use it that way.

4. Oral doses of 2 grams have been lethal to children. Chronic ingestion could damage red blood cells, liver, and kidneys. Exposure of eyes, skin, lungs, and mucous membranes causes irritation. It is a fire hazard, and clothing soaked in sodium chlorate solutions can catch on fire when dry (Extoxnet 2000).

Chronic effects on health have not been well investigated. It is a suspected neurotoxicant, cardiovascular and blood toxicant, and respiratory toxicant (EDF 2000).

5. Application to soil at 150 kg/ha led to a decrease in soil microbial metabolism, but did not kill microbes (Karki et al. 1973). Formation of mycorrhizae is stopped at concentrations of 100 ppm (Iloba 1977). Sodium chlorate inhibits microbial conversion of nitrates to ammonia for incorporation into plant protein (Koreishi and Hino 1984; McCarty et al. 1992).

Plant material desiccated with sodium chlorate could be poisonous to livestock (Klingman et al. 1975).

Though I could not find a published salt index for sodium chlorate, it is converted to sodium chloride by soil microorganisms and one would expect soil salinization effects to be similar to sodium chloride. (The salt index compares osmotic pressure increases from addition of a test material to soil to those produced by sodium nitrate. Osmotic pressure increases are measured by freezing point lowering or other methods and are due to the numbers of particles dissolved and ionic activity along with other factors.) The larger the salt index, the greater the danger of phytotoxicity. The salt index is mostly independent of water solubility. For instance, sodium chloride is less soluble in water than sodium nitrate, yet has a larger salt index. Addition of salt to sandy soil produces about 5 times the osmotic pressure, as the same amount added to clay soil (Rader et al. 1943; Tisdale et al. 1994). However, the salt probably washes out of sandy soil faster, and sodium chlorate persists longer in clay soil (Halim et al. 1977).

6. According to TAP information provided, withholding water in irrigated situations can lead to desiccation of plants before frost. Plant varieties are in the works that will naturally defoliate. Although the NOSB has approved sodium chloride for defoliation in emergency situations, that seems an undesirable alternative. As much as 50 times more sodium chloride would have to be used to get the same effect as sodium chlorate, and the salt index is probably similar (Klingman et al. 1975).

According to the review, Texas has approved emergency use of magnesium sulfate, magnesium chloride, potassium chloride, potassium sulfate, zeolite, and fulvic acid for this purpose. Some of these are micronutrients and could not be used in organic production without a demonstrated deficiency. Potassium chloride also has a high salt index (Rader et al. 1943).

7. Philosophically, the material is not compatible with sustainable agriculture. It affects soil microorganisms and increases soil salinity. The practical compatibility depends on how much is used and how often it is used. The 3-6 lbs/acre/year used for defoliation would probably have no effects on subsequent crops in the rotation or the environment. Spot treatments to kill difficult weeds away from crop production could be compatible with the needs

of sustainable agriculture. Broadcast use at the rates needed to kill agricultural weeds in crops would not be compatible with the principles and practices of sustainable agriculture.

Reviewer #2 Recommendation
My recommendation is that sodium chlorate not be approved for organic agriculture at this time. Although current organic defoliant alternatives are less effective and more costly than sodium chlorate, approval of the material now would discourage further work.

Alternatives are currently available to kill problem weeds in areas away from crop production, so it is not essential for this purpose. Sodium chlorate also poses a credible hazard to human health if it is not used properly and this is another reason to restrict the material.

Reviewer # 3
[Advisor to organic certifiers.]
Natural or Synthetic:
Sodium chlorate is a synthetic material, produced by the electrolysis of sodium chloride in aqueous solution (Merck, Klingman). Aside from persistence in the ecosystem as a result of applications made by humans (see below), sodium chlorate is not normally found in nature.

SECTION 2119 OFPA 7 U.S.C. 6518 (m)(1-7) CRITERIA:
1. Sodium chlorate is a powerful oxidizing agent, and can react explosively with a number of materials associated with organic farming systems. It poses a significant fire hazard under dry conditions, when ignited by a spark (Lewis). Contact of sodium chlorate with agricultural materials such as peat, wood products, powdered sulfur, or with plant matter or clothing is therefore potentially dangerous, particularly under dry conditions.

Presence of a high concentration of sodium in soil can result in detrimental effects on agricultural production, since it interferes with plant uptake of other cations such as potassium, calcium, and magnesium, as well as inhibits water uptake by plants due to unfavorable osmotic pressure.

2.. Sodium chlorate is toxic to vegetative material non-selectively, effective at killing all green plant materials that it contacts; it is absorbed readily through leaves as well as roots (Extoxnet, Klingman). It is used as an herbicide, and defoliant and desiccant for a number of conventionally-grown crops, most notably cotton, but also dry beans, hot peppers, safflower, rice, sunflower, corn, and sorghum (USGS).

The exact mechanism whereby sodium chlorate acts is not completely understood, but several cellular metabolic pathways may be interrupted, depending on the mode of use and point of entry into the organism. These include increased respiration rate with concomitant depleted food reserves, and decreased catalase activity with consequent peroxide accumulation to toxic levels. Injury to the plant caused by the sodium chlorate also induces the plant to produce greater amounts of ethylene (among other compounds, such as auxins and abscissic acid), which causes leaf abscission (Devlin, et. al).

Sodium chlorate is toxic to humans, in doses as low as 5-10g for adults and 2g for small children (Richardson et al); see section 4 below. Acute LD50 in other mammals varies between 500mg/kg – 8000 mg/kg, depending on the species and means of intake (Richardson, et. al, Extoxnet). The salty taste of the material makes it a potential hazard to any salt-hungry animals in the vicinity where it has recently been applied.

Sodium chlorate is considered generally non-toxic to bees and fish, but has been shown to reduce egg production and fertility in birds (Extoxnet).

Decomposition may be faster, but persistence of sodium chlorate in soils has been shown to range from one-half to five years, depending on the climatic and soil conditions. The degree of toxicity is also dependent upon soil type, fertility, organic matter content, nitrate content, pH, and temperature (Extoxnet). Higher temperatures and moisture result in faster leaching and disappearance of sodium chlorate, but where it persists, the toxic effects remain (Klingman). Because it is non-selective in its herbicidal action, this poses serious concerns for the organic producer. For example, use of sodium chlorate to defoliate cotton, while producing a short-term benefit for the harvest of that crop, might result in a decreased viability of subsequent crops on that field, especially in dryer areas. This might especially be the case in certain cotton-producing regions of the Southwest and dryer areas of California.

3. Synthesis of sodium chlorate is energy intensive, electricity use being reported at 4500-5800- kWh/metric ton produced (Kent et al), but otherwise there does not appear to be a serious environmental impact associated with its

manufacture. Hazards associated with use are discussed elsewhere in this review. Misuse or mishandling of sodium chlorate potentially poses a variety of hazards, as described elsewhere in this review.

4. Chronic and/or sub-lethal exposure to sodium chlorate may have deleterious effects on human health, such as redness of the eyes and skin (including dermatitis), sore throat, abdominal pain, blue lips or skin, diarrhea, nausea, vomiting, shortness of breath, and unconsciousness (NIOSH). Sodium chlorate may damage the liver, kidneys, and blood cells of humans (Extoxnet).

5. In addition to the toxicological data pertaining to humans, sodium chlorate has been shown to be toxic to other mammals, both in acute and chronic exposure situations (see section 2 above). Sodium chlorate is also said to have a sterilizing effect on soil (Extoxnet). Although some soil microbes can break down chlorate into chloride (Klingman), there is, especially at the onset of introduction to the soil, a toxic effect on at least certain microbial species. There is not significant research data available to detail such interactions. Nor is there data showing the affects of sodium chloride on other soil species, be they earthworms, insects, or others. However, from the toxicological data that is available, it is safe to conclude that sodium chlorate could have a negative effect on the viability of a number of these species, thereby reducing soil biological activity and diversity – which runs generally counter to principles of organic production. No data presented indicate that presence of sodium chlorate offers any long-term benefit to soil health or sustainability from an organic production standpoint.

No data regarding the affect of sodium chlorate on the salt index of the soil is available. However, certain deductions may be made, based on knowledge about the sodium chlorate molecule and comparable materials. Sodium chlorate is highly soluble in water, ionizing into the sodium cation and the chlorate anion. The chlorate ion is highly reactive (and toxic), and can break down via microbial action to chloride. Chloride itself is an essential plant nutrient, but is detrimental in crops (the amount varying with the crop). It is probably safe to assume that the salt index of sodium chlorate is reasonably close to that of sodium chloride (Baker).

The presence of salt ions in the soil increases osmotic pressure of the soil solution, which can have a negative affect on the overall viability of agriculture, due to restriction of water availability to plants. Accumulation of sodium can occur as a result of evaporation of soil moisture, and concomitant migration and deposition of sodium near the soil surface. Salinization of soils is a widely shared concern among organic producers, and several certification organizations specifically require that farmers take measures to ensure that buildup of salt in the soil does not occur over time. Materials lists of many organic certifiers generally severely restrict or prohibit sodium salts of all kinds; those materials that are allowed tend to be for emergency or special needs only, not as routine addition (OMRI). While there has not been worldwide consensus on use of various sodium salts in organic production systems, the evolution of standards on a global scale has definitely progressed toward greater agreement that these guidelines of close restriction or prohibition are appropriate.

From the above discussion, it can be concluded that

i) use of sodium chlorate on crops (and thereby transferred to soil) could result in excess addition and accumulation of sodium in the soil, resulting in overall negative impact on the soil and agricultural system, and
ii) the toxicity of sodium chlorate on a variety of organisms is not a positive interaction on the agroecosystem as a whole, and that less toxic materials should be used if at all possible.

6. While defoliants are a significant advantage to producers of certain crops, there are both practices and materials that are available to organic producers that are either natural and/or less toxic than sodium chlorate. Of all the crops listed in section 2 above, perhaps cotton poses the most significant challenge; for all the other crops mentioned, adequate alternative means of product handling are available and widely practiced by organic producers.

In the case of cotton, the challenges arise from green leaves left on the plant at harvest causing staining of the fiber, and from excess trash in bales post-harvest (Larson et al) posing a variety of problems. The main reason for using defoliants such as sodium chlorate is one of convenience and expediency of harvest. Timing of harvest can be logistically challenging otherwise, due to the indeterminate growth cycle of the cotton plant and the vagaries of weather.

There are a number of potential strategies that can be employed as alternatives to using sodium chlorate. Depending on the region, first frost is a viable method of defoliating cotton. In other regions, frost comes too late, and adverse weather could then damage the crop before harvest. Other strategies include strategic drying of irrigated fields, to induce leaf drop. Hand harvesting of cotton is no longer widely practiced in the United Sates, but is in certain other countries, and this method does avoid the problems that are solved by chemical defoliants. Other methods that warrant more investigation and trials are the cultivation of varieties of cotton with better characteristics for the region in which they are being cultivated (both in growth habit and boll formation), more intensive harvest labor at harvest, and development of improved harvest and ginning machinery.

Finally, other materials have been considered as defoliants as emergency use materials for cotton in organic production systems, including sodium chloride, magnesium chloride, magnesium sulfate, potassium sulfate, and others, all of which have less deleterious effects than sodium chlorate.

In summary, it can be concluded that either in combination or by themselves, there are numerous other possible options to sodium chlorate which better accord with organic production principles than does sodium chlorate. These all need to be explored further before sodium chlorate could reasonably be determined to be a better option.

7. Sodium chlorate has historically always been a prohibited material in organic production by all certifiers worldwide, for a variety of reasons, discussed in the above sections. In summary:

i) There is reason for serious concern that use of sodium chlorate could have long-term deleterious affects on soil health due to salinization.
ii) Sodium chlorate is toxic to a wide range of organisms, and can persist in the soil for years after application. The full scope its of toxicity is not completely understood.
iii) Sodium chlorate offers convenience and economic advantages as a harvest aid, especially for cotton. However, financial considerations should not be a significant factor when determining the compatibility of a material in organic production systems – especially when other effects of the use of said material are known to be deleterious, and there are no agronomic or ecological benefits known to result from its use.

REVIEWER #3 CONCLUSION: Sodium chlorate is a SYNTHETIC material that should be PROHIBITED in organic production systems. This reviewer agrees with the TAP review document.

Conclusion

All three TAP reviewers agree that sodium chlorate is a synthetic material, and recommend that it not be added to the National List. Concerns about soil salinization, toxicity, and environmental persistence were raised. A limited number of alternatives are available, but research and more suitable management techniques are encouraged. This material is not currently permitted in U.S. certification programs.

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