Ozone
Crops

Executive Summary

Ozone was petitioned for use as a gas that is injected into soil under plastic mulch for weed control. An additional request was made for use as an antimicrobial agent to clean irrigation lines. Ozone may also be used to treat soil for soil borne pathogens, and this was also considered in this review. In all these types of use ozone gas (O_3) is generated on-site using an electrically powered corona discharge ozone generator.

Ozone is a bluish explosive gas or blue liquid. It is found naturally in the atmosphere at sea level contains an ozone concentration at very low levels, but is also an air pollutant and a component of smog, reaching tenfold or higher levels in cities at times. Although it is a pollutant and health hazard in the lower atmosphere, naturally occurring ozone is produced in the outer atmosphere by the photoreaction of solar ultraviolet (UV) radiation on oxygen protecting the earth from excessive radiation.

Ozone decomposes spontaneously in water and is a very reactive oxidizing agent with a short half-life. It is used to disinfect water and to oxidize color and taste contaminants in water. It is also increasingly used for disinfection purposes of food and food contact surfaces and is permitted by the National Organic Standards for use in organic processing (including post harvest handling) with no restrictions.

Two reviewers felt that ozone should be permitted for use in organic crop production, though limited to use for cleaning irrigation lines, weed control and for soilborne pathogen control. One of the reviewers in favor of use found that this type of usage is a relatively new technique with unreliable results for pathogen control, and noted some reservations regarding possible surface crusting and loss of soil structure when used for weed control. One reviewer objected strongly to use of a "a known and problematic air pollutant" in organic farming and described hazards to workers and those downwind of application, negative impact on soil humic acid fraction, plant damage, and lack of evidence of effect on soil microorganisms. This reviewer did not object to use to treat irrigation water when ozone can be recaptured to prevent off-gassing into the environment.

Summary of TAP Reviewer's Analyses[1]

Synthetic/ Nonsynthetic	Allow without restrictions?	Allow only with restrictions?
Synthetic (3-0)	No (3) Yes (0)	Yes (2) No (1)

Identification

Chemical Names: Ozone, triatomic oxygen, O_3

Other Name: Trioxygen

Trade Names: SoilZone, Triox

CAS Number: 100028-15-6

Other Codes:
NIOSH RTECS #RS8225000

Characterization

<u>Composition</u>:
Ozone (O_3) is triatomic oxygen.

[1] *This Technical Advisory Panel (TAP) review is based on the information available as of the date of this review. This review addresses the requirements of the Organic Foods Production Act to the best of the investigator's ability, and has been reviewed by experts on the TAP. The substance is evaluated against the criteria found in section 2119(m) of the OFPA [7 USC 6517(m)]. The information and advice presented to the NOSB is based on the technical evaluation against that criteria, and does not incorporate commercial availability, socio-economic impact, or other factors that the NOSB and the USDA may want to consider in making decisions.*

Properties:

Ozone is a bluish, explosive gas or blue liquid. It has a characteristic pungent odor that is detectable at concentrations as low as 0.02 to 0.05 ppm. At greater concentrations it is irritating to eyes and the respiratory tract and at high concentrations ozone may be fatal. It is a strong oxidizing agent, mp –193° C, bp –111.9° C. It is sparingly soluble in water. At 20° C, solubility of 100 percent ozone is 570mg/L (Richardson, 1994).

Atmosphere at sea level contains an ozone concentration of about 0.05 ppm (Budavari, 1996). In cities with smog conditions ozone concentration may reach 0.5 ppm or higher at times. (Francis, 1997) Ozone decomposes spontaneously in water (US EPA, 1999). The reaction generates hydroxyl free radicals, which are very reactive oxidizing agents but have a half-life of microseconds. In aqueous solution, ozone can react by direct oxidation of compounds or can oxidize compounds by hydroxyl free radicals that are produced during ozone decomposition.

How Made:

Ozone is usually formed by combining an oxygen molecule with an oxygen atom in an endothermic reaction. Naturally occurring ozone is produced in the outer atmosphere by the photoreaction of solar ultraviolet (UV) radiation on oxygen. At ground level, ozone may be produced by reactions caused by changes in entropy, e.g. water falling on rocks in a waterfall. Ozone is also produced by photoreactions with nitrogen oxides (NO_x) and volatile organic compounds (VOC) from industrial emissions, vehicles and other sources (US EPA, 1999).

Because ozone is unstable it is generated at the point of use. It can be generated by irradiating oxygen-containing gas with UV light and other technologies but the primary industrial method is by the corona discharge method. The oxygen containing gas is passed through two electrodes separated by a dielectric and a discharge gap. When voltage is applied to the electrodes, electrons flow across the gap and provide energy for the disassociation of oxygen molecules, which leads to the formation of ozone (US EPA, 1999).

There are generally four system components to an ozone generating process: a power source or ozone generator, a gas source, an ozone delivery system and an off-gas destruction system. The gas source may be air, high purity oxygen or a combination of the two (US EPA, 1999). Air feed systems are more complicated than liquid oxygen feed systems because the air must be clean, dry, free of contaminants and with a maximum dew point of -60° C to prevent damage to the generator.

Specific Uses:

Ozone has been used in Europe to treat drinking water for more than 100 years (US EPA, 1999). Ozone in the United States has been used to disinfect water and to oxidize color and taste contaminants in water. It is increasingly used for disinfection purposes.

The petitioned use is for the use of ozone for weed control (Pryor 2001) with an additional request for use as an antimicrobial agent to clean irrigation lines as an alternative to chlorine (Herman 2002). In addition, the use of ozone for control of soil borne pathogens will be considered in this review. In all these types of use ozone would be generated on site.

Ozone gas for weed control is used in combination with plastic mulch and is applied in a gaseous form. The target treatment area is the space between the plastic mulch and either the drip irrigation tubing if it is buried or the soil surface if drip tubing is not buried. Ozone is applied under the mulch before the crop is planted. It has also been applied once the crop is in place (Pryor, 1999; Pryor, 2001). It may be applied through drip tape, which can later be used for crop irrigation. Ozone oxidizes plant tissue and weakens or kills emerging weeds. Ozone treatment for weed control may be used in combination with soil solarization. As described in the petition, ozone for weed control may be applied at rates of 2 lbs/acre with a total number of applications ranging from 7-30 depending on weed species.

Ozone uses for control of soil borne pathogens has been tested at rates ranging from 50-400 lbs per acre (Pryor, 1999). It can be applied through drip tubing under plastic mulch or by various methods of direct injection (Pryor 1996, 1997).

Ozone can be used to treat or prevent clogged drip irrigation systems by at least two methods. Recycled irrigation water can be treated with ozone before reuse. (NIDO, 1997) A requested additional use is to inject ozone into the irrigation lines to act as an antimicrobial agent (Herman 2002). This seems to be a fairly new use with little information to describe the method. One industry writer reports that the gas is generated on site in a closed system and dissolved in water under pressure, and that undissolved gas is collected and disposed of by means of a special separator to avoid accumulation of gas bubbles in the system (Hassan, undated).

Action:
Ozone is a strong oxidizing agent and very corrosive. In plants, it can cause membrane lysis and necrotic lesions. It may affect photosynthesis and generally represses various genes (Sandermann, 1996). It is germicidal against a wide range of organisms including bacteria, viruses and protozoa. In bacteria, it attacks the bacterial membrane, disrupts enzymes and affects nucleic acids (EPA, 1999). In viruses, ozone modifies the viral capsid and may break the protein.

Combinations:
Not sold in combinations.

Status

Historic Use:
Historically ozone has been used to disinfest and oxidize pathogens and contaminants from drinking water. It was first used in the Netherlands in 1893. Ozone was used in Los Angeles, California in 1987 to treat drinking water and by 1998, 264 water treatment plants in the U.S. were using ozone (US EPA, 1999). Since the implementation of the Surface Water Treatment Rule the use of ozone for primary disinfection of water has increased (EPA, 1999). Use as a soil treatment to kill living organisms is a relatively recent invention (Pryor, 1996).

OFPA, USDA Final Rule:
Ozone is listed for use in post-harvest handling and processing (7 CFR 205.605(b)(20). It could be considered a production aid under 7 USC 6518(c)(1)(B)(i).

Regulatory: EPA/NIEHS/Other Sources
The EPA sets standards for ozone levels under the National Ambient Air Quality Standards as required by the Federal Clean Air Act. EPA considers ozone producing equipment to be 'pesticidal devices.' Ozone generation is subject to pesticide worker safety requirements (40 CFR 170).

Ozone is subject to the National Primary Drinking Water Regulations under the Safe Drinking Water Act because it is used as a disinfectant in water treatment to kill pathogens. (40CFR 141.65)

FDA considers ozone to be GRAS as a direct food additive and allows the use of ozone as an antimicrobial agent for bottled water and food processing (21 CFR 184.1563). Bottled water maximum residual permitted ozone level is 0.4 mg/l at bottling.

OSHA: 29 CFR 1910.1000 Subpart Z
 Transitional Limit: PEL-TWA 0.1 ppm
 Final Limit: PEL-TWA 0.1 ppm; STEL 0.3 ppm
ACGIH: TLV-Ceiling Limit 0.1 ppm
NIOSH Criteria Document: None
NFPA Hazard Rating: Health (H): None
 Flammability (F): None
 Reactivity (R): None

Status Among U.S. Certifiers
California Certified Organic Farmers (CCOF) –CCOF Certification Handbook (rev. January 2000). Not specifically listed.
Maine Organic Farmers and Gardeners Association (MOFGA) –MOFGA Organic Certification Standards 2001. Not specifically listed.
Midwest Organic Services Association (MOSA) –MOSA Standards January 2001. Not specifically listed.
Northeast Organic Farming Association of New Jersey (NOFA-NJ) – NOFA-NJ 2000 Organic Certification Standards. Not specifically listed.
Northeast Organic Farming Association of Vermont (NOFA-VT) – 2001 VOF Standards. Not specifically listed.
Oregon Tilth Certified Organic (OTCO) – OTCO Generic Materials List (April 30, 1999). Not specifically listed.
Organic Crop Improvement Association International (OCIA) –OCIA International Certification Standards, July 2001. Not specifically listed.
Quality Assurance International (QAI) – QAI Program, Section 5.2 Acceptable and Prohibited Materials. Not specifically listed.

Texas Department of Agriculture (TDA) Organic Certification Program – TDA Organic Certification Program Materials List. Not specifically listed.
Washington State Department of Agriculture Organic Food Program – Chapter 16-154 WAC Organic Crop Production Standards. Not specifically listed.

International
CODEX – Not specifically listed.
EU 2092/91 – Not specifically listed.
IFOAM – Not specifically listed.
Canada – Not specifically listed.
Japan – Not specifically listed.

Section 2119 OFPA 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.*
As a strong oxidizing agent, ozone has the potential to react with many different substances. Ozone oxidizes pesticides, organic matter, and reacts with iron and most other materials. Ozonation of water produces various by-products such as aldehydes, ketones, carboxylic acids, organic peroxides, epoxides, nitrosamines, N-oxy compounds, quininones, hydroxylated aromatic compounds, brominated organics and bromite ion. (Kirk-Othmer, 1996)

When ozone is used for weed control, it is applied directly to the space between the buried drip irrigation tubing or the soil and the plastic mulch. It is not clear how much ozone diffuses into the soil in this system but Qui, et al. (2001) found that the ozone mass transfer rate was influenced by soil moisture and texture. An early study found that ozone applied as gas at 0.5 ppm did not penetrate the soil to a statistically significant extent (Blum and Tingey, 1977). More recent work examined the effect of ozone on soil organic matter when ozone is used to decontaminate soil . In a system where a soil extract was ozonated, researchers found a decrease in the humic acid fraction, a reduction of the average molecular size, and an increase in the low molecular acid fraction. The low molecular acid fraction is readily degradable by microorganisms (Ohlenbusch et al., 1998).

In lab studies ozone caused reduction in respiration rates of ectomycorrhizal fungal mats. However when these fungi were associated with their host plant roots the ectomycorrhizal roots were more resistant to ozone than non-ectomycorrhizal roots (Garret et al., 1982). In laboratory studies soil nematode populations of Meloidogyne javanica and free living nematodes were significantly reduced by ozone treatment and were dosage and flow rate dependent (Qui et al., 2001). In other research, ozone treatment of Easter lily bulbs did not reduce nematode numbers (Giraud et al., 2001) although it did give a positive yield response. In field experiments with tomatoes, Pryor (2001b) found that ozone treatments did not significantly reduce nematode populations, but may have led to increased yields in some cases.

Ozone is used for water treatment because it oxidizes or disinfects many components that impact water quality. It will oxidize iron and manganese which precipitate as ferric and manganese hydroxides. This could result in crop iron deficiencies (von Broembsen, 2002.). It partially oxidizes organic matter to forms that are more easily biodegradable. Ozone is also germicidal against many types of pathogenic organisms including viruses, bacteria and protozoa (US EPA, 1999). Ozone itself does not remain as a residual in irrigation water because of its rapid decomposition. It does form a variety of byproducts in reaction with organic matter. It can also react with the bromide ion if present to form brominated disinfection byproducts (US EPA, 1999). The ozone will most likely oxidize any materials that a grower injects into the irrigation lines at the same time as the ozone. For example, if growers inject fertilizer such as fish emulsion or other material into the irrigation system, ozone will oxidize the material. The extent would depend on the concentration of the added material, the concentration of the ozone and the contact time.

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.*
Ozone is a strong oxidant and is inherently bioreactive. Given its reactivity and relative concentration, it is the oxidant of primary concern in photochemical smog (Klaasen, 2001).

Ozone is rated as a high irritant via inhalation and to skin, eyes and mucous membranes. It also affects the central nervous system and there are mutation data and reproductive concerns. (NTP 2002, NJ 1996) Higher exposure can cause headache, upset stomach, vomiting, and pain or tightness in the chest. Ozone can irritate the lungs causing coughing and/or shortness of breath. Higher exposures can cause a build-up of fluid in the lungs (pulmonary edema), with severe shortness of breath. Liquefied ozone on contact with skin or eyes can produce severe burns. There is limited evidence that ozone causes cancer in animals. It may cause cancer of the lung, mutations (genetic changes) and may damage the developing fetus. (NJ 1996, Richardson 1994)

NTP Toxicity				
Type of dose	**mode**	**specie**	**amount**	**units**
LC50	ihl	cat	34,500	ppb/3H
LC50	ihl	gpg	24,800	ppb/3H
LC50	ihl	ham	10,500	ppb/4H
LCLo	ihl	hmn	50,000	ppb/0.5 H
TCLo	ihl	hmn	100,000	ppb/0.016 H
TCLo	ihl	hmn	1,000	ppb
Source: NTP, 2001				

Abbreviations
LC50 = lethal concentration 50 percent kill
LCL = lowest published lethal concentration
TCL = lowest published toxic concentration
H = hour
ihl = inhalation hmn = human gpg = guinea pig ham = hamster

Eco Toxicity (Richardson 1994):
Fish – LC 50 (96 hr) rainbow trout 9.3microg/l,
LC 50 (24 hr) bluegill sunfish 0.06 mg/l

Invertebrate – Bacteria species showed change in phospholipid levels after 30 sec. aeration with 1mg/l. *Euglena gracilis* had damaged plasma membranes. Enzyme deactivation in yeasts was found.

In plants, it can cause membrane lysis and necrotic lesions. It may affect photosynthesis and generally represses various genes (Sandermann, 1996). It is germicidal against a wide range of organisms including bacteria, viruses and protozoa. In bacteria, it attacks the bacterial membrane, disrupts enzymes and affects nucleic acids (US EPA, 1999). In viruses, ozone modifies the viral capsid and may break the protein.

When ozone is applied beneath plastic mulch for weed control its mode of action is in part by direct oxidation. It is taken up by the plant stomata where it is decomposed in the apoplast. Ozone effects chloroplast function and nuclear gene expression by mechanisms that are not understood at this time. Membrane lysis is thought to be a later effect of ozone (Sandermann, 1996). The ozone would also be in contact with soil. The amount of soil affected depends in part on the depth of the placement of the drip irrigation lines. Ozone oxidizes the soil humic acid fraction of organic matter (Ohlenbusch et al., 1998).

When ozone is applied under plastic the area of concentration is the zone between the drip irrigation tubing or soil surface and plastic mulch. When ozone is in contact with organic materials such as plants, its half-life is a few minutes. Potential concern would be for worker safety during the application of the ozone and any leaks in the system. The half-life of ozone in ambient air is 12 hours (Pryor 2001). Ozone's only decomposition product is oxygen.

In water there are two modes of action by ozone, direct oxidation and oxidation by hydroxyl free radicals. It oxidizes organic matter, attacks bacterial membranes, disrupts enzymatic activity, disassociates viral capsids and attacks RNA.

In water ozone decomposes rapidly and the only residual is dissolved oxygen. However decomposition by products may be present. If the bromide ion is present in water brominated decomposition products may remain. Formation of aldehydes has also been found as a result of ozone disinfection (Liberti and Notarnicola, 1999) Some of the disinfectant by products are potentially toxic or carcinogenic, however bioassay screening studies have shown that ozonated water induces substantially less mutagenicity than chlorinated water. (Kirk Othmer, 1996) Ozone does not form halogenated by products (trihalomethanes) when reacting with natural organic matter in water, unless bromide ion is present in the raw water. (US EPA 1999)

Disinfection and chemical oxidation rates by ozone are relatively independent of temperature (EPA, 1999). If recirculated irrigation water is treated with ozone, the excess ozone must be scrubbed to prevent release to the atmosphere and to protect workers from ozone exposure.

3. The probability of environmental contamination during manufacture, use, misuse, or disposal of the substance.

Ozone at ground level is considered a priority air pollutant by US EPA. Ozone would be generated on site both for use in soil treatment and as an antimicrobial agent in irrigation systems. Ozone is not stored on site. Because ozone is toxic care must be taken to avoid leaking of ozone from the system during generation. Levels of 1ppm for 30 minutes or more produce headaches. OSHA's maximum permissible exposure level (PEL) to ozone is not to exceed 0.1 mg/L by volume averaged over an 8 hour period.

During water treatment ozone gas is transferred to water. In treating recycled irrigation water, ozone that is not transferred to the water is released as off gas. The concentration of ozone in the off gas of these systems is above the concentration fatal to humans and may contain as much as 3,000 ppm ozone (US EPA, 1999). Off gas containing ozone should be captured and converted to oxygen before release into the atmosphere. Ozone systems that inject directly into the irrigation lines use much lower concentrations of ozone and do not treat off gas.

4. The effects of the substance on human health.

Ground level ozone may reach levels that are harmful to human health. Most of the studies regarding ozone as a threat to human health are related to ozone as an air pollutant generated by automobile exhaust and other fossil fuel generated sources (US EPA, 1999).

Acute Toxicity. High concentrations above 0.1 mg/L by volume average over an 8 hour period may cause nausea, chest pain, reduced visual acuity and pulmonary edema. Inhalation of > 20 ppm for at least an hour may be fatal.

Chronic effects. May have deleterious effects on the lungs and cause respiratory disease. See response to criterion number 1.

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 effects are mainly the immediate result of ozone's strong oxidizing capacity. Ozone is a broad-spectrum biocide that can oxidize soil organic matter and other substances in soil (Ohlenbusch et al., 1998). Ozone does not persist in soil with either the weed control or water treatment system application. It is converted to oxygen within a short period of time. The issue is what, if any, are the remaining impacts of ozone use.

When ozone is used for weed control, the ozone is in contact with the soil, soil organic matter and microorganisms. It has been shown in the laboratory that ozone can oxidize the soil humic acid fraction into lower molecular weight fractions which are more biologically available to soil microorganisms (Olenbusch, 1998). This research found that bacterial regrowth increased with ozonation time. The effects on the populations of other soil microorganisms were not examined in this research.

Other research has shown that ozone does reduce populations of at least some other soil microorganisms such as some nematodes while other nematodes appear unchanged (Qui et al., 2001 and Giraud et al., 2001). Soil injection at 250 lb/acre rate resulted in increases of yield of tomatoes comparable to chemical fumigants in one year, although it did not statistically reduce root galling by nematodes. (Pryor 1999). Yield increases were theorized to have resulted from other biological effects, possibly increase in nutrient availability. Conventional farmers use soil fumigation with methyl bromide to achieve large increases in yield in crops such as carrots, tomatoes and strawberries although the increases are not linked to specific elimination of known pathogens. A study of the populations of the different strains of the fungi *Fusarium* in organic (treatments used cultural methods) and non-organic farming systems (treatments used the fumigant *Telone*) found that the greatest number of pathogenic strains were recovered from the organic farm, however no plants at the organic site showed any symptoms while plants on the conventional site did show symptoms. In addition, the organic site was found to exhibit more than twice the number of non-pathogenic strains of Fusarium which have been shown to reduce the incidence of Fusarium wilt (Bao, 2000).

The availability and form of soil organic matter affects a broad spectrum of soil chemical and microbiological reactions. Soil organic matter influences cation exchange capacity, soil buffering, soil microorganism population dynamics, and plant disease among other aspects of the soil environment (Brady, 1974, Engelhard, 1989).

If the crop is present when ozone is applied there can be physiological impacts such as burning on the crop (Pryor, 1999). It appears that when plants are exposed to ozone it elicits plant responses that are similar to plant responses to pathogens. These responses to ozone are just beginning to be understood (Sandermann, 1996). Ozone is a known air pollutant that causes crop damage (Mersie 1990, Hatzios 1983), and in event of a leak in application method can cause crop loss (Pryor 1999).

Ozone that is used to treat water before it is injected into the irrigation lines does not come in contact with the soil or crop plants. The ozone off gas is recycled or converted to oxygen so that it is not released to the atmosphere. The reaction of ozone with the bromide ion or organic matter that may be in the water can create decomposition by products. No information was found on the potential impact of these on the soil environment when irrigation water is used. The decomposition byproducts of ozone treatment appear to be of less concern than the decomposition byproducts of chlorine treatment although brominated decomposition byproducts may be of health concern (von Broembsen. 2002, EPA, 1999, Braghetta 1997).

When ozone is injected with water into irrigation lines to clean them, there is the potential that some ozone will move from the irrigation lines to the soil or air. No information has been found that examined this question. In actual practice the grower must monitor the system to determine that enough ozone has been injected to reach throughout the irrigation line before it has been completely consumed by oxidation reactions.

6. The alternatives to using the substance in terms of practices or other available materials.

There are various weed control methods available to organic growers and in general growers need to use a variety of techniques to achieve effective weed control. Some of the methods include: flame throwers, mulch, cultivation, water management, bioherbicides, steam treatment and soil solarization (Smith et al., 2000 and Boyette et al., 1999).

Soil solarization is a technique that could be used alone or in conjunction with ozone or other material like cabbage residue (Chellemi et al., 1997). It can be used both for weed and pathogen control. New heat-retentive films are more effective at raising soil temperatures during solarization (Chase et al., 1999). *Cyperus* spp. (nutsedge) are particularly difficult weeds to control. Recent research showed that soil temperature of 45^{o} C was not lethal to *Cyperus spp*. tubers (Chase, Sinclair and Locascio, 1999). Temperatures of 50 - 55^{o} C were 100% lethal to tubers. The new heat retentive films were more effective at killing *Cyperus rotundus.*

Alternatives for control of soil borne pathogens include crop rotation, solarization, use of disease suppressive compost, other organic nitrogen amendments, biocontrol, and IPM methods. A recent compendium of a 2000 EPA meeting report lists 117 papers on alternatives to methyl bromide, including many tests of biocontrols and cultural methods (US EPA 1997, 2000; Bull 2000). One-year rotations out of strawberries increased subsequent strawberry yields by 18-44% relative to continuous strawberries (Duniway 2000). Varieties more suited for organic production are also identifiable, for instance the 'Camarosa' variety is significantly more susceptible to *Verticillium* than 'Chandler' or 'Selva' (Duniway, 2000.) Existing organic production techniques are considered to adequately control soil borne pathogens, and result in slightly lower yields that are offset by higher prices (US EPA 1996). Use of strawberry plant plugs rather than bare root resulted in earlier production, less transplant wounding, increased vigor and offset problems from soil born pathogens (Sances, 2000.)

Current potential alternatives to the use of ozone as an antimicrobial in irrigation systems include chlorine, acetic acid, and citric acid (OMRI, 2001). Ozone is a stronger oxidizing agent than all of these. Ozone by itself and in water does not form trihalomethanes, which are carcinogenic (US EPA 1999) Chlorine treatment forms trihalomethanes.

If a grower wishes to removed pathogens and particulate from their water source, slow sand filtration would be an alternative (Wohanka, 1995). Slow sand filtration is a water treatment system that has been used for more than 100 years. Untreated water filters slowly through a fine sand bed. A skin of organic and inorganic material and microorganisms begins to form on the surface of the sand bed. The biological activity of this area extends through the upper region of the bed. This method has been effective against several pathogens including *Cylindrocladium spp*., pythiaceaeous fungi, *Verticillium dahliae* and others (Wohanka, 1995).

There are certain situations where slow sand filtration would not be an alternative to ozone use. If a grower's irrigation lines are already clogged, sand filtration is not going to correct the situation. If a grower were applying a fertilizer such as compost tea or fish emulsion through the irrigation lines, the sand filtration process would not clean the irrigation lines or keep them from clogging due to biofouling. This is because the fertilizer would need to be injected after the sand filtration step. Otherwise the sand filtration would remove the desired nutrient content. The effectiveness of ozone injected into a drip irrigation system to prevent clogged emitters is not documented, and is questionable due to the rapid decomposition of ozone in the aqueous environment into oxygen. No supporting technical literature was found to substantiate this claim, it appears to be an experimental treatment.

7. Its compatibility with a system of sustainable agriculture.

To answer this question each use should be considered separately since the target organisms and methods and rates of application are different. In addition the mode of transport for each use is different. For weed control, ozone is injected into an air-water interface in the soil or on the soil surface. For use in cleaning of irrigation lines and water treatment, ozone is injected into the water either before or as it enters the irrigation line. In general the impacts of the use of a material should be targeted rather than widespread. Potential non-target, unintended impacts need to be considered.

Ozone for weed or soil borne pathogen is not selective with regard to the plant species that it kills. It is toxic to all plants, however different species respond differently to the same dose of ozone (Hatzios and Yang, 1983, and Sandermann, 1996). It is applied in a defined space, the area between the buried drip irrigation tubing or the soil surface and the plastic mulch (Pryor, 1999). It is a very strong oxidant and will oxidize the soil surface that it contacts. It can oxidize soil organic matter and make it more biologically available (Ohlenbusch et al., 1998). It is unclear from the references found by the reviewer how deep ozone will diffuse into the soil under the conditions of the proposed use. It was also unclear what concentration of ozone the weeds and soil would be exposed to. The petitioner claims the impact will only reach 0.25 inches when applied at rates suitable for weed control. It is very reactive, has a short half-life and does not leave a residual effect. It is destructive to a wide range of microorganisms but not all (EPA, 1999; Giraud et al. 2001; and Qui et al., 2001).

The production of ozone from oxygen is due to an endothermic reaction, and requires a considerable input of energy. The patent documents mention the presence of a generator on the apparatus (Pryor 1996, 1997) but does not describe the power requirements needed, presumably supplied by diesel or gas engine. The EPA describes the voltage requirements for an air-fed corona discharge system as 5-7 kilowatts/hour/pound of O_3 produced. As much as 85% of the energy used in ozone production is lost as heat. (US EPA 1999)

When ozone is used to treat water it is reactive with a wide variety of chemicals and compounds in the water including iron, manganese and organic matter. It is also germicidal against many microorganisms such as protozoan cysts, viruses, and bacteria including *E. coli 0157:H7* (EPA, 1999 and Unal et al., 2001). It is applied to water before use in irrigation or directly injected into irrigation lines with irrigation water. When ozone is used treat water prior to irrigation, ozone concentrations are higher than when it is injected into irrigation lines to prevent biofouling. In the first instance, the system is enclosed and excess ozone is captured and recycled or converted to oxygen before it is released to the atmosphere. Typical concentrations of ozone found during water treatment are from <0.1 to 1 mg/L (EPA, 1999). When ozone is injected directly into the irrigation system, concentrations are lower. A potential problem with the second system from a purification point of view is that the ozone may be completely consumed by oxidation reactions with chemicals, microorganisms and organic materials in the line before it reaches the end of the irrigation line. Excess ozone is not captured in this system.

Additional Questions for the reviewers:

Note: The initial petitioner only requested review for purposes of weed control, and did not respond to questions requesting more information on other uses. NOSB advised that it also be reviewed for soil pathogen control.

1. Have you seen or can you find any specific mention of use of ozone injected in drip irrigation systems as a cleaning agent?
2. Does anyone have access to this reference, and can you report on it:
   Raub, L., Amrhein, C., and M. Matsumoto. 2001. The effects of ozonated irrigation water on soil physical and chemical properties. Ozone Science and Engineering. 23(1):65-76
3. Do you have any additional evidence on impact of ozone on the soil ecosystem, short or long term?
4. Have you seen any information on the effect of ozone application on soil organic matter and nutrient availability.
5. Please express your technical review, advice and conclusions distinctly on each of these uses of ozone. Is it possible to permit use for some purposes but not others? (e.g for weed control but not soil pathogens)

TAP Reviewer Discussion

Reviewer 1 *[Ph.D. chemistry. Research entomologist advising growers and homeowners about pesticides and alternative pest control methods. Western US]*

OFPA Criteria Evaluation

(1) *The potential of such substances for detrimental chemical interactions with other materials used in organic farming systems*;

I agree with the criteria evaluation, with additional comment:
Since ozone is such a powerful oxidizing agent, it might attack the plastic irrigation tubing and destroy it over time. Seems like plasticizers such as dioctylphthalate in tubing would be destroyed. However, this is speculation, and no one seems to have observed this with limited ozone applications in the field.

(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*;

I agree with the criteria evaluation.

(3) The probability of environmental contamination during manufacture, use, misuse or disposal of such substance;

I agree with the criteria evaluation, with additional comment:
The possibility of a problem increases with the size of the ozone generator. For soilborne pathogen control, amounts generated and release volumes would be higher than with the other two applications, and thus might be riskier.

If the generator is set up properly, leaks in the ozone supply line, torn or compromised plastic sheeting, and the possibility of fire are the only risks that I can think of.

(4) *The effect of the substance on human health*;

Ozone has actually been used in medicine. Amounts in plasma higher than 80 μg/ml of gas per ml of blood are detrimental (Bocci et al. 2001).

(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*;

Ozone seems to have very little effect on soil nematodes. It seems to have more of an effect on soil bacteria than soil fungi. Treatment of strawberry fields with high rates of ozone improved colonization of *Trichoderma* when this microbial was used subsequently as an inoculant, so there must have been either an initial knockback of competing microbials or releases of nutrients favorable for *Trichoderma* sp. growth (Pryor 2001b).

(6) *The alternatives to using the substance in terms of practices or other available materials*; and

For nursery operations, steam is a practical alternative for management of pathogens. Suppressive composts are especially valuable in containerized production. Crop rotation is probably the most practical alternative for field crops (see Quarles and Daar 1996).

(7) *Its compatibility with a system of sustainable agriculture.*

One possible problem is destruction of soil organic matter. Raub et al. (2001) believed that oxidation of organic matter on the soil surface could lead to surface crusting and loss of soil structure. They suggested longterm studies to explore this possibility. Surface effects would be most likely with weed control. For weed and pathogen control there are several applications throughout a 30-day period. Amounts applied for pathogen control are 10-fold or more greater, but the ozone is applied about 3 inches deep, rather than directly on the surface. Cleaning of irrigation lines should not lead to any problem with soil structure because most of the ozone would be contained in the irrigation tubing.

Another consequence of ozonation could be release of copper ion, which is bound to organic matter. Lin et al. (2001) found that ozonation of humic acids in water degraded them to smaller molecules that were unable to chelate copper ion. In soils where Cu has been overapplied, ozonation could lead to phytotoxicity due to excess free copper.

RESPONSE TO ADDITIONAL QUESTIONS

(1) *Have you seen or can you find any specific mention of use of ozone injected in drip irrigation systems as a cleaning agent?*

I talked to [owner of a well known west coast organic farm supply company.] She has not heard of anyone cleaning irrigation lines by direct injection of ozone. She has heard of farmers treating irrigation water with ozone before it is applied to the irrigation system.

(2) *Can you find and report on this reference?:* Raub, L., Amrhein, C. and M. Matsumoto. 2001.

To check the effect of ozone on soil structure, Raub et al. (2001) applied ozonated water at 10mg/liter to 20 cm glass columns containing various California soils. They found that the ozone reacted with the humic acids and other organic material, degrading it to smaller molecules. Degradation of the organic matter released cations such as Ca+2. The organic acids and cations lowered pH of the applied water and caused clay in the soil to coagulate. Coagulation of the clay particles increased the water infiltration rate and allowed the soil columns to drain quicker. In soils with high sodium content (>15%) the improved drainage was not observed.

Positive results other than improved drainage was improved oxygenation, and probably increased microbial activity, since the humic acid was degraded to smaller molecules that could be metabolized by microbes. Anecdotal information was presented that soil ozonation might "improve crop vigor, reduce insect and disease, enhance water penetration, and reduce fertilizer needs."

Raub et al. (2001) felt, however, that longterm studies were needed to see if oxidation of organic matter on the soil surface would lead to surface crusting and loss of soil structure.

(3) Do you have any additional evidence on impact of ozone on the soil ecosystem, short or long term?
See Larson (1999), Lin and Klarup (2001), Hayes (2000) and Pryor (2001b).

(4) Have you seen any information on the effect of ozone application on soil organic matter and nutrient availability?
Ohlenbusch et al. (1998), Raub et al. (2001) and Lin and Klarup (2001) show humic acid breakdown into smaller molecules. Pryor (2001b) showed improved soil colonization of *Trichoderma* after soil ozonation. This fact could indicate that ozone treatment made more nutrients available. Earlier reports (Larson 1999) also speculated that the ozone soil treatment increased nutrients available for crops.

(5) Please express your technical review, advice and conclusions distinctly on each of these uses of ozone. Is it possible to permit use for some purposes but not others? (e.g for weed control but not soil pathogens)

1. Use of ozone to clean irrigation lines.

Cleaning irrigation lines with ozone seems a reasonable use of the material. Ozone is already being used to treat irrigation water. It does not seem to be much of a jump to use it to clean the irrigation system.

However, if it is injected directly into the tubing and flushed with water, care must be taken to do it safely and effectively.

2. Use of ozone to control soil pathogens.

Using ozone in this manner is probably safe enough, and data presented by Pryor (2001a) shows that there will probably be few impacts on soil microflora.
However, I could not find any information on effects on earthworms.

My major concern is that the technology has not yet been optimized and may be somewhat unreliable. The problem for pathogen control is soil penetration. Best results have come in sandy soils that were irrigated with water before fumigation. Perhaps because of patchy field coverage, published field trials on ozone pathogen control give inconsistent results. When yield increases do occur, they are not directly related to the dose of ozone used. Larger application rates often give lower yields. It may be that any yield increases are due to improved nutrient availability and better biocontrol. Both of these factors could vary considerably.

In the 1997 field trials reported at a methyl bromide alternatives conference, ozone was applied through drip tubing buried about 3 inches deep to sandy pre-irrigated soil. This placed the ozone very near the root zones. With these best-case conditions there were significant yield increases with tomatoes, carrots and strawberries (Pryor 1999).

California 1998 field trials were published in Larsen (1999). Ozone soil treatment reported here gave increased yields of tomatoes, carrots, strawberries and other crops. Applications were made through drip irrigation tubing to sandy soils. Large emitters (4 gallons/hr) were used to get a large flow rate. Strawberry fields that were treated were under heavy attack of *Verticillium*. Strawberry yields increased 51% as a result of ozone treatment. Ozone application rates were 400 lb/acre.

Hayes (2000) treated strawberry fields with ozone plus the biocontrol organism *Trichoderma*. The combination treatment generally gave increased yields over controls. However, increases were smaller compared to earlier trials because standard 0.5 gallon/hr irrigation drip emitters were used. According to the author, higher ozone flow rates with the larger 4.0 gallons/hour emitters give better results, especially if you are not dealing with sandy soil.

In field trials conducted in 2000, Pryor (2001b) tried treating tomatoes with ozone for nematode control and strawberries with ozone for pathogen control. Tomatoes were treated with ozone alone, ozone +biocontrol organisms, and standard nematicides (Telone). The highest application rate of ozone gave yields lower than the controls. Modest application rates of ozone plus biocontrol microbials gave yields similar to the standard chemical Telone. Best yields were shown with biocontrol microbials alone. Only Telone gave any nematode control, but yields with Telone were lower than with microbials alone.

Strawberries were treated with ozone alone, ozone plus microbials, and microbials alone. None of the treatments significantly increased yields over controls. This report, though, was for a year when the pathogen challenge was low.

Combination of ozone plus *Trichoderma* did, however, lead to increased colonization rates of the microbial (Pryor 2001b).

Despite my concerns about reliability, the technology should be allowed. Perhaps continued use will lead to more reliable treatments.

3. Use of ozone for weed control.

Laboratory data supplied by Pryor (2001a) show that ozone should only have minor non-target impacts on the soil ecosystem. The field test by Pryor and Bayer (2001) seems to establish efficacy. If oxidation of soil organic matter causes negative longterm impacts on soil structure (Raub et al. 2001), NOSB can suspend its use.

Reviewer 1 Conclusion – *Summarize why it should be allowed or prohibited for use in organic systems.*

a. Ozone should be allowed in organic agriculture for cleaning irrigation lines. Use in this manner should not violate any of the Section 2119 Criteria. Excessive amounts should not be used so there is no appreciable off-gassing and air contamination.

b. Ozone should be allowed in organic agriculture for weed treatments. Publications cited show that it is generally effective for this purpose, and use in this manner should not violate any Section 2119 Criteria. If long term use leads to problems with soil structure, the NOSB can determine that this use should be suspended.

c. Application for pathogen control should not violate Section 2119 Criteria. I have some reservations, however, that the technique has not yet been optimized for reliable pathogen control in the field.

Reviewer 1 Recommendation Advised to the NOSB:

The substance is Synthetic

Though a case can be made for non-synthetic, since ozone is already classified synthetic in Section 205.605 of the Final Rule, it should be classified as synthetic for the cases below.

For Crops, the substance should be

Added to the National List.

Suggested Annotation, including justification:

Ozone should be added to the National List for the following applications:

1. For cleaning irrigation lines
2. For weed control
3. For soilborne pathogen control

Reviewer 2 *[Ph.D. exposure assessment-toxicology, M.S. chemistry. Certification review committee member, Eastern U.S.]*

Comments on Database

The following information needs to be corrected or added to the database:

The photochemical production of ozone in the troposphere, and the difficulties associated with minimizing its impact are not adequately represented in this document. Most ozone in the troposphere is anthropogenically-generated, and is often above 0.80 ppm in prolonged afternoon and evening episodes (Lioy and Dyba, 1989). At this concentration, decreased pulmonary function and athletic performance, increased airway reactivity and decreased (respiratory) particle clearance were found in non-smoking adults (Hobbes and Mauderly, 1991). Significant reductions on respiratory function are proportional to tropospheric ozone concentration, which is alarming, as a large segment of the US population resides in locations where the National Ambient Air Quality Standards (NAAQS) are violated for more than 100 days per year (McDonnell *et al.*, 1993).

OFPA Criteria Evaluation

(1) The potential of such substances for detrimental chemical interactions with other materials used in organic farming systems;

I agree with the criteria evaluation

(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;

The criteria evaluation needs to be corrected or amended as follows:

I don't follow the NTP table very easily, as I don't use LC data alone.

Long-term exposure studies indicate that the primary target tissues are the nasal epithelium and the centrianinar region of the lung ((Hobbes and Mauderly, 1991). In the lower regions of the lung, where lining fluid is thin, damage to cells may be due directly to O_3 (Pryor, 1992). In higher regions, aldehydes and peroxides, which result from reactions in the lipid bilayers of the mucous lining with O_3, may be inciting damage (*ibid.*, 1992). See the section on human health (number 4) for additional human toxicity.

(3) the probability of environmental contamination during manufacture, use, misuse or disposal of such substance;

I agree with the criteria evaluation.

(4) the effect of the substance on human health;

The criteria evaluation needs to be corrected or amended as follows:

A correlation has been drawn between tropospheric summer ozone concentration and emergency room hospital visits for asthma, in four different regions of the North American continent (Cody, 1992). Healthy individuals at risk included those who exercise outdoors and who occupationally remain outdoors for much of the day, and also children, particularly in summer, when temperatures are comfortable for outdoor activities and ozone levels are at their highest. (See Database section for related comments.)

(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;

Here is additional supporting information or comments.

A three year study of Scots pine seedlings led to the conclusion that in a relatively O_3 tolerant species, the chronic effects of O_3 exposure include growth reduction, increased needle abscission and changes in C allocation that are influenced by plant N availability (Utriainen and Holopainen, 2001).

Response to ozone in ponderosa pine was greatest when there was low nutrients supplied (Andersen and Scagel, 1997). Significant effects on below-grown respiratory activity were apparent before any reduction of total plant growth was found.

(6) the alternatives to using the substance in terms of practices or other available materials; and

I agree with the criteria evaluation

(7) its compatibility with a system of sustainable agriculture.

I agree with the criteria evaluation.

RESPONSE TO ADDITIONAL QUESTIONS

1. *Have you seen or can you find any specific mention of use of ozone injected in drip irrigation systems as a cleaning agent?*
   No
3. *Do you have any additional evidence on impact of ozone on the soil ecosystem, short or long term?*
   No.
4. *Have you seen any information on the effect of ozone application on soil organic matter and nutrient availability ?*

See Ohlenbusch et. al 1998… I was unable to get more than the citation of the following. Also, see criterion (5).
Anderson, C.P. Ozone stress and changes below-ground: linking root and soil processes. *Phyton.* **2000**,*40*: 7-12.

5. See Conclusion.

Reviewer 2 Conclusion – *Summarize why it should be allowed or prohibited for use in organic systems.*

The use of ozone may be seriously detrimental to the health of humans who work with it, and those exposed indirectly, downwind of exposure. The use of a known and problematic air pollutant would make its consideration as a tool in organic farming questionable. One argument that is commonly submitted, utilizes that characteristic odor of O_3 as an early detection signal for avoidance. However, rapid olfactory fatigue is being overlooked, as is the tendency for workers to ignore minor, acute irritations, in order to achieve the work goal. Long-term and cumulative effects can not be ignored.

Additionally, the references provided and which I have obtained make little reference to long term effects of ozone in the soil characteristics. The effects of altering the humic acid fraction and precipitating iron oxides are significant to ban its use in soil applications, as an organic treatment. Damage to plants also is of concern, as even ozone-tolerant species are affected by ozone exposure. Further, I encountered no references in peer-reviewed work to impacts to beneficial soil organisms.

The use of ozone for (1) control of soil borne pathogens, (2) weed control, (3) to treat livestock waste for either control of pathogens or (4) to ozonate for fertilizer, should not be allowed, as the ecological and human health impact may be too high to warrant its use. Cleaning irrigation lines without recapture, should not be allowed for latter reason. However, water purification of recycled nursery or hydroponic and aquaculture systems, using the stipulation of off-gas recapture, may be reasonable, since other options for this goal often add unwanted by-products into the water stream.

Reviewer 2 Recommendation Advised to the NOSB:

The substance is Synthetic

For Crops the substance should Not Be Added to the National List.

Reviewer #3 [*Organic farmer, organic inspector, works with organic certifier. Western U.S.*]

OFPA Criteria Evaluation

For OFPA Criteria 1-3, 5-6:

I agree with the criteria evaluation

(4) the effect of the substance on human health;

I agree with the harmful effects discussed in the criteria section

I believe amendments should be added which discuss the claimed positive effects on human health. These effects fall roughly in three categories; water purification, use as a residential and office air cleanser, and use in alternative and conventional medicine. …The health claims [made by manufacturers of ozone generating] residential air purification systems are discounted, and [consumers are] warned against their use by the American Lung Association. (ALA, 2002) [Alternative medical publications describe] the use of ozone therapy in some human diseases and in medical therapy. (Bocci, 1996, Figueras undated; Bocci et al 1994)

RESPONSE TO ADDITIONAL QUESTIONS

1. *Have you seen or can you find any specific mention of use of ozone injected in drip irrigation systems as a cleaning agent?*
   Internet search turned up very few references concerning use of ozone in drip lines (Hassan, undated; Von Broembson 2002; Del Ag.2002)

3. Do you have any additional evidence on impact of ozone on the soil ecosystem, short or long term?
4. Have you seen any information on the effect of ozone application on soil organic matter and nutrient availability?
3 and 4. Discussion in criteria evaluation is sufficient. Some minor additional discussion is included in attached references.

5. *Please express your technical review, advice and conclusions distinctly on each of these uses of ozone. Is it possible to permit use for some purposes but not others? (e.g. for weed control but not soil pathogens)*
I think it is possible but difficult to separate soil application of ozone for weed control but not for soil pathogens control. The primary difference is the pounds per acre used. Appropriate record keeping may be able to track this, but since ozone is generated on site, tracking could be more difficult. Assuming honesty and integrity on the part of the producer, I believe it is difficult to justify limiting the amount of ozone used for these primary reasons:

The primary detrimental effects are how much ozone escapes into the atmosphere and how deeply the soil is sterilized. The atmospheric problem is dealt with by system design and monitoring. It is also in the producer's best interest to not waste the costly ozone. A poorly designed or maintained system for weed control could leak more than a well designed and maintained system for destroying soil pathogens. If both systems are well designed, the pollution of the atmosphere would be minimal. In practice, it is an identical technique and practice being used. The problem of how deeply the soil is sterilized is reflected in two concerns. One concern is what residues or breakdown products are left and the other concern is the effects on the soil microorganisms. Some data indicates that the breakdown products of ozone in the soil are beneficial to the microorganisms and subsequently to the crops. The concern of how quickly microorganisms recolonize is dependent of the effects of the residues. Ozone itself does not have significant residues and its breakdown products may actually encourage both the growth and diversity of microorganisms.

Ozone treatment for soil pathogens is a possible replacement for far more toxic materials (which, ironically deplete atmospheric ozone) and its use should be encouraged from the environmental perspective. The environmental perspective is an important element of the organic industry both in producer's intention and in market expectations.

Ozone's use in the soil is a technique as well as a material that affects both weeds and microorganisms at all levels of use. If it is approved for weed control but not soil pathogen control, it will be hard to specify what level will be allowed. In some regions for some weeds, the application rate needed to be effective may also be effective for controlling some soil pathogens. On what basis should it be decided which weeds and pathogens are allowed to be controlled by this technique (and which aren't) since the technique is the same and the residues similar at all levels?

For these reasons, I think if Ozone is approved for weed control, it should also be allowed for soil treatment.

Reviewer 3 Conclusion – *Summarize why it should be allowed or prohibited for use in organic systems.*

Ozone is a highly reactive oxidizer, that leaves little residue and fewer decomposition products than other oxidizers such as chlorine. It requires a high energy input and specialized equipment to produce. It does not have a history of being used in organic agriculture. No major certification agencies make reference to it nor is it mentioned in organic production guides. Ozone's use in conventional agriculture is relatively recent and still in research and development stage, though some commercial scale farms have begun to use it. The decision to use ozone by conventional growers is based on weighing these factors; the increased costs, increased efficacy and environmental regulations. Ozone is an alternative to materials that have higher undesirable residuals such as chlorine or are being phased out such as methyl bromide.

Being highly reactive, ozone exhibits many conflicting properties depending on the concentration and on which trace materials are present. It is.a major pollutant with severe negative health effects. It is used both in alternative and conventional medicine in therapy and also in large scale water purification systems designed for human consumption.

As a TAP reviewer with a farmer's perspective, my approach is to look primarily at the material itself, what it would replace and how it would be used in organic production. Since the material is not currently used in organic agriculture; the questions that need to be answered are: why would it be needed? What organic production problems might it solve? Are the effects of using the material compatible with organic agriculture's goals? I will also address the environmental effects of producing the material.

The environmental effects of producing ozone are primarily related to the energy required to produce it (85% of which is lost as heat). The cost of equipment and the effort needed to maintain it limit ozone's use to medium and large scale operations. The high energy cost is a potential reason to not permit its use in organic agriculture due to energy related pollution. On the other hand, if a more efficient method of ozone production were developed, this objection would disappear. Therefore, the high use of energy is not sufficient reason to support its ban from organic agriculture.

The more important question is on what basis should a new, synthetic material be introduced to organic agriculture. The only reasons for inclusion I can support are:

1. If the material being introduced replaces materials that are less desirable to use because of environmental, safety, residue or health considerations. In short, if the new material fits the idealized organic criteria more closely than existing materials. This concept envisions an evolving organic production system that continually changes toward the idealized criteria as both new materials and new knowledge become available. This is true for some uses of ozone.

2. The material fits the criteria for use in organic agriculture except for being synthetic AND is an effective solution for an organic production problem or contributes to the expansion of organic production systems. This concept allows the methods and techniques of organic production to evolve and handle new situations and reach further into mainstream society.

In the current organic climate, concerns about contamination from use of manures and compost products are new threats to organic agriculture. An effective sanitizer or disinfectant without residues may be needed to meet changing USDA and HAACP regulations and still be acceptable to the organic market. Ozone has already been accepted in organic food processing for direct contact with food. Current ozone technology may not be sufficient to meet crop production problems, but if more efficient ozone production or techniques were developed, the material itself may be able to provide a partial solution.

Reviewer 3 Recommendation Advised to the NOSB:

Ozone should be considered as a Synthetic allowed only with annotations

1. Restricted to use as weed and disease control with appropriate environmental controls and monitoring AND only after other methods have been tried. This method must be considered as a last resort

   Comment- There are many approved organic alternatives for weed and disease control in soils. These should be tried first. The potential for ozone to develop into an alternative to extremely high polluting materials is important to explore. If shown to be effective and clean, it should be allowed as a tool for organic farmers.

2. Allowed for use in cleaning drip irrigation lines with appropriate environmental controls and monitoring
   Comments- The efficacy of using ozone in this manner has not been shown but there is potential that it may be an alternative to chlorine or hydrogen peroxide.

Conclusion - Ozone for organic crop production:

Two out of three reviewers felt that ozone should be permitted for use in organic crop production, with use limited to:

1) cleaning irrigation lines,
2) weed control and
3) for soilborne pathogen control.

One suggested further restrictions limiting weed and pathogen control use to that of "last resort. " If approved for use, this requirement is already established under 7CFR 205.206(d-e). A possible further restriction on use in irrigation as suggested by one reviewer, could be stated at 205.601(a)(5) "ozone, injected in irrigation lines in a method to prevent off-gassing."

These two reviewers did not find a compelling reason to reject usage, despite a lack of data in some areas such as effect on soil structure or earthworm populations. They did find some benefits to use and generally felt further experimentation might yield more data on effectiveness and impact.

The third reviewer found that health and safety reasons are a strong argument to prohibit use, along with the known effects on soil humic acid fraction, and the unknown long-term effects on soil and beneficial soil organisms.

This use is not permitted under current regulatory language of CODEX, the EU, or Japan and may require further consultation over equivalency issues if approved in the US.

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**= included in packet*

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