

Soluble Boron Products

Crops

Identification of Petitioned Substance

Chemical Names:

boric acid
(BH_3O_3 , boracic acid, hydrogen borate)
disodium tetraborate
($\text{Na}_2\text{B}_4\text{O}_7$)
disodium tetraborate pentahydrate
($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$)
disodium tetraborate decahydrate
($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$)
disodium octaborate tetrahydrate
($\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$)

31 Anhybor
32 Optibor
33 Etibor
34 Etidot

CAS Numbers:

10043-35-3 (boric acid)
1330-43-4 (disodium tetraborate)
12179-04-3; 12045-88-4 (disodium tetraborate pentahydrate)
1303-96-4 (disodium tetraborate decahydrate)
12280-03-4 (disodium octaborate tetrahydrate)

Other Name:

borate salts, boric oxide, borax (tincal, hydrated sodium borate, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), kernite (hydrated sodium borate, $\text{Na}_2\text{B}_4\text{O}_6(\text{OH})_2 \cdot 3\text{H}_2\text{O}$), colemanite (calcium borate, hydrated calcium borate, $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$), ulexite (sodium calcium borate hydroxide, hydrated sodium calcium borate, $\text{NaCaB}_5\text{O}_6(\text{OH})_6 \cdot 5\text{H}_2\text{O}$), probertite (sodium calcium borate hydroxide, $\text{NaCaB}_5\text{O}_7(\text{OH})_4 \cdot 3\text{H}_2\text{O}$)

Other Codes:

R57ZHV85D4 (FDA UNII; boric acid)
91MBZ8H3QO (FDA UNII; disodium tetraborate decahydrate)
U2EEC8170G (FDA UNII; disodium octaborate tetrahydrate)
483W67CPF4 (FDA UNII; boron trioxide)
233-139-2 (EC number; boric acid)
215-540-4 (EC number; disodium tetraborate)
603-411-9 (EC number; disodium tetraborate decahydrate)

Trade Names:

Solubor
Granubor
Fertibor

Summary of Petitioned Use

Soluble boron products appear on the National List of Allowed and Prohibited Substances (hereafter referred to as the "National List") under the "Micronutrients" listing at 7 CFR 205.601(j)(7). Also included under "Micronutrients" are sulfates, carbonates, oxides and silicates of zinc, copper, iron, manganese, molybdenum, selenium, and cobalt. Synthetic micronutrients on the National List are restricted for use as described in the annotation for "Micronutrients", which currently states, that micronutrients may not be used as defoliants, herbicides, or desiccants, that nitrate and chloride forms are prohibited, and that deficiencies must be documented by soil or tissue testing or another verifiable method as determined by a certifying agent.

The majority of synthetic boron compounds used in agriculture, including USDA organic agriculture, are at least moderately soluble, including boric acid and the sodium borate salts. Insoluble or barely soluble boron compounds are typically used in other industrial or commercial applications (Smith, 2000) and are not widely useful as fertilizers due to their limited release of boron to plants.

51 Several naturally occurring boron minerals are commercially important, including ulexite, colemanite, kernite,
52 and borax (tincal, crude borax)¹ (USGS, 2021b). These minerals are the most prevalent starting materials for
53 borates used across all industries. As nonsynthetic minerals, these boron sources are permitted in organic crop
54 production as long as they do not contribute to contamination of crops, soil, or water by plant nutrients,
55 pathogenic organisms, heavy metals, or residues of prohibited substances (7 CFR 205.203). This technical report
56 will focus on the widely used processed boron sources with medium to high solubility. The most common
57 agriculturally applied boron sources are nonsynthetic crushed ores, and processed disodium tetraborate,
58 disodium tetraborate pentahydrate, disodium tetraborate decahydrate, disodium octaborate tetrahydrate, and
59 boric acid (Martens & Westermann, 1991; Shorrocks, 1997). In contrast to these forms exhibiting moderate to high
60 solubility, borosilicate glass frits² are sometimes used due to their extremely low solubility, allowing for a very
61 slow release of boron in soils that are prone to leaching (Martens & Westermann, 1991).

62
63 Naturally occurring, nonsynthetic borate mineral sources are available and marketed for use in organic
64 agriculture (OMRI, 2021). Due to lower solubility than refined borate salts and boric acid, ulexite and
65 colemanite minerals are marketed as slow release boron fertilizers (Broschat, 2008; ETiMADEN ETIMINE
66 USA Inc., 2018b). Since naturally occurring borate minerals are permitted in organic crop production (as
67 described above), this report concentrates on synthetically produced soluble boron compounds appearing
68 on the National List.

69
70 This technical report is intended to support the NOSB's sunset review of "Soluble boron products." As boron was
71 not discussed at length in the 2010 Micronutrients Technical Evaluation Report (USDA, 2010), the NOSB has
72 requested this report include information that was absent in the previous technical report. The focus questions
73 are:

- 74
75 1) Is there a toxic or other adverse action of the petitioned substance or its breakdown products? (7 U.S.C.
76 §6518(m)(2).)
77
78 2) Describe any environmental contamination that could result from the petitioned substance's
79 manufacture, use, misuse, or disposal (7 U.S.C. §6518 (m)(3)).
80
81 3) Describe and summarize any reported effects upon human health from use of the petitioned substance (7
82 U.S.C. §6517(c)(1)(A)(i), 7 U.S.C. §6517(c)(2)(A)(i) and 7 U.S.C. §6518(m)(4)).
83

84 As phrased, *Focus Question #1* nearly duplicates the first part of *Evaluation Question #5*, so the relevant
85 information will be addressed there in this report.
86

87 **Characterization of Petitioned Substance**

88 **Composition of the Substance:**

89 Due to its reactivity, elemental boron does not occur naturally in the environment (Kot, 2015). Boron readily loses
90 electrons to non-metals like oxygen (oxidation) and can form three or four bonds with other atoms. These bonds
91 are typically covalent or coordinate-covalent³ (dative) bonds, and result in a variety of boron compounds
92 (including the soluble borate salts), much like occurs with silicon and carbon (Bhat et al., 2005; Kochkodan et al.,
93 2015; Kot, 2015). Typically, salts of boron are at least partially water soluble (Kochkodan et al., 2015).
94
95

¹ Ulexite, colemanite, kernite, and tincal are mineralogically classified as sodium calcium borate hydroxide, calcium borate hydroxide, sodium borate hydrate, and sodium borate hydroxide minerals, respectively (USGS, 2021b; Woods, 1994).

² Frits are small particles of silica (SiO₂) glass, often containing other chemical substances incorporated into the structure. In many cases, the reason for incorporating another material is to reduce that material's mobility (Plodinec, 2000).

³ Covalent bonds occur when a pair of electrons are shared between two atoms. Coordinate-covalent (dative) bonds occur when one of the atoms donates *both* of the electrons that are shared, as opposed to each atom donating one electron each (Mingos, 2016).

96 Out of 200 naturally occurring boron minerals known, just 12 are commercially important in a wide range of
97 applications (Adair, 2007; Kochkodan et al., 2015). Four of these comprise 90% of all boron material production:
98 ulexite, colemanite, kernite, and borax (tincal) (Adair, 2007). Other commercial borate minerals include inyoite,
99 priceite, szaibelyite, inderite, pinnoite, hydroboracite, datolite, and ludwigite (Garrett, 1998).

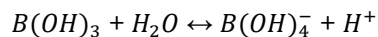
100

101 *Boric acid*

102 Boric acid (sometimes called boracic acid or hydrogen borate) is a weak acid with the formula $B(OH)_3$. Boric acid
103 typically occurs as a solid, and its water solubility increases with temperature (Kochkodan et al., 2015; Smith,
104 2000). When dissolved, boric acid does not carry a charge. It acts as a Lewis acid (an acceptor of electrons), so it
105 can accept a hydroxyl group (OH^-) and form the borate anion $B(OH)_4^-$. These substances occur in equilibrium: at
106 high pH (greater than approximately 8.5-9) the borate anion is dominant; at lower pH the boric acid molecule is
107 dominant (Kochkodan et al., 2015; Parks & Edwards, 2005). The equilibrium equation follows:

108

109



110

boric acid + water \leftrightarrow borate anion + hydrogen ion

111

112 *Sodium borate salts*

113 This group of substances are simply sodium salts of boric acid. They are a framework of boron and oxygen atoms
114 attached to sodium metal ions. They tend to be sparingly soluble to soluble in water (Kochkodan et al., 2015) (see
115 *Properties of the Substance*, below).

116

117 Sodium tetraborate salts incorporate varying amounts of water molecules into their molecular structures
118 (hydration states) (Smith, 2000). The number of water molecules incorporated determines the identity of the
119 substance. Disodium tetraborate *decahydrate* is commonly referred to as "borax." Disodium tetraborate
120 *pentahydrate* and disodium tetraborate *anhydrous* are sometimes identified as borax pentahydrate and anhydrous
121 borax, respectively. The hydration states of disodium tetraborate can be changed by adding heat or water. The
122 most common commercial forms are decahydrate and pentahydrate (Smith, 2000).

123

124 Disodium octaborate tetrahydrate has a higher boron content compared to the compounds listed above (Smith,
125 2000). It is composed of a boron and oxygen framework connected to sodium ions.

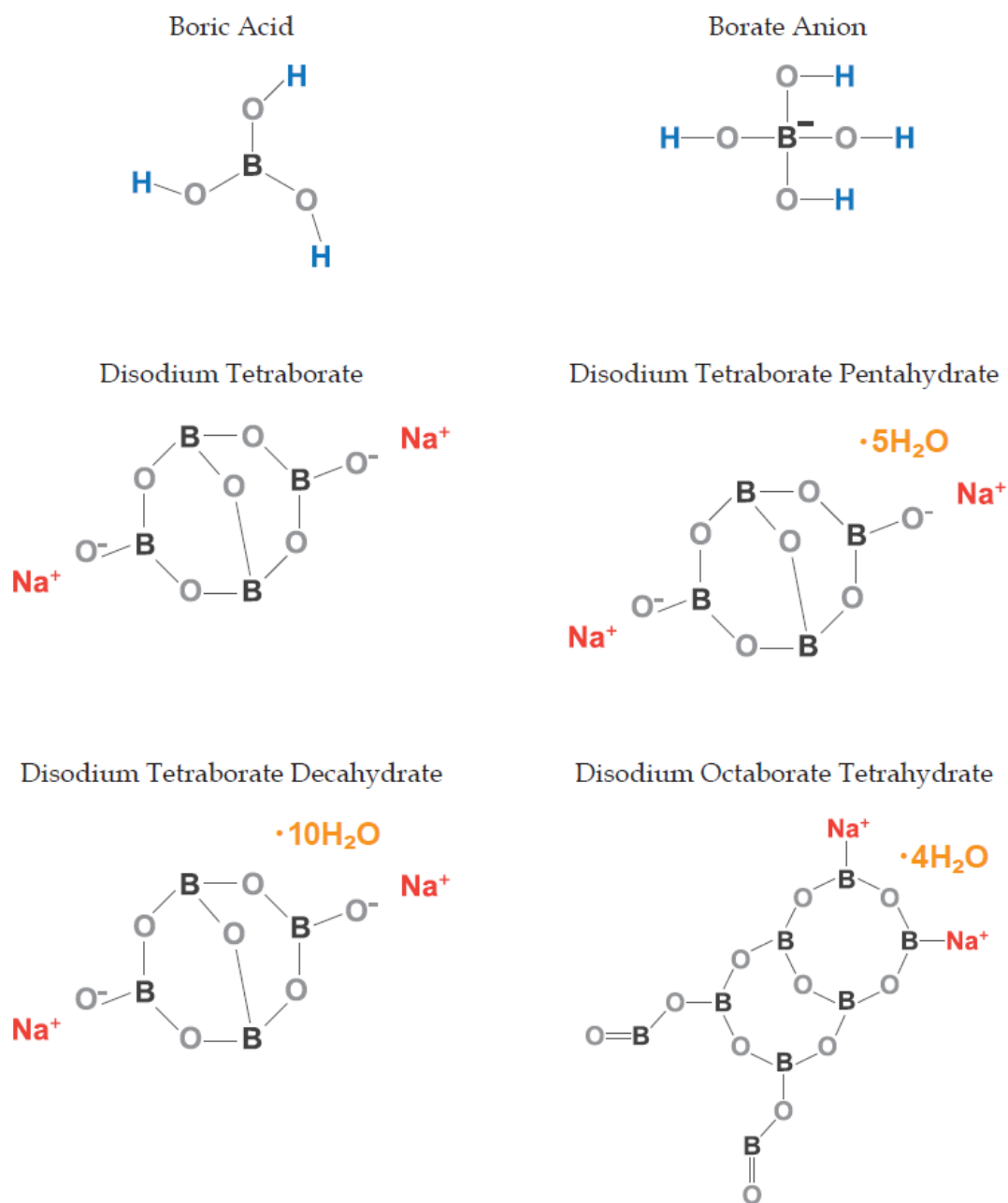


Figure 1: Structures of Soluble Boron Compounds

Source or Origin of the Substance:

Boron occurs in the Earth's crust at an average concentration of 10 parts per million (ppm) (Smith, 2000). This level can be significantly elevated in certain volcanic environments and sedimentary deposits (Kot, 2015; Smith, 2000; Wisniak, 2005). It is thought that clay-rich sediments become enriched in boron by adsorbing the dissolved solids from seawater (Chao et al., 2011). These sediments are transported to continental margins by plate tectonics, leading to boron enriched zones (Chao et al., 2011). As more common minerals crystallize from magma, rare elements become concentrated in the left-over fluids, eventually crystallizing into uncommon mineral deposits (Garrett, 1998).

Borax results from the solar evaporation of saline brines in arid playas, typically appearing as dried crusts on the shores of shallow lakes or associated with the drying of mineral spring waters (Garrett, 1998). Large bedded deposits occur in Boron, California, Argentina, and Turkey. Though not extensive, native borax deposits are also found near dry lake shores throughout California, Nevada, and the Tibetan plateau (Garrett, 1998).

143 Kernite (sodium borate) is often associated with the same environments as borax deposits; borax
144 dehydrates to kernite in hot conditions adjacent to volcanic activity at depth (Garrett, 1998).

145
146 Colemanite (calcium borate) is thought to result from hot geothermal springs containing abundant boron
147 mixing with calcium derived from sedimentary deposits (Garrett, 1998). Colemanite also occurs in
148 evaporated lake environments in California, Argentina, Turkey, Russia, and the Himalayan plateau
149 (Garrett, 1998).

150
151 Ulexite (sodium calcium borate) is often associated with colemanite deposits and the two minerals (along
152 with borax) form in different beds depending on the calcium and sodium content of the geothermal springs
153 (Garrett, 1998). Springs containing elevated sodium levels may form ulexite and borax in alternating
154 geological units (Garrett, 1998). Ulexite/colemanite suites may be found in California, Argentina, Bolivia,
155 Chile, Peru, and Turkey.

156
157 The United States and Turkey are the largest boron mineral producers by far (each producing millions of
158 metric tons per year), followed by Chile, China, Bolivia, Peru, Russia, and Argentina (producing between
159 70 - 400 thousand metric tons each per year) (Garrett, 1998; USGS, 2021a). The majority of boron products
160 used in the United States are produced domestically in one California pit mine, derived from solid ores of
161 kernite, borax, and ulexite, and to a lesser extent from brine solution mining, also in California (USGS,
162 2021b; Woods, 1994).

163
164 The processing of soluble boron products involves crushing ores, mixing with various clarifiers or other
165 mineral reactants to remove waste minerals, crystallization, and temperature control to achieve different
166 hydration states. The resulting sodium borates can be further processed into boric acid (Smith, 2000). See
167 *Evaluation Question #2* for more information on the manufacture of soluble boron products.

168
169 **Properties of the Substance:**

170 Despite the many naturally occurring borate minerals and various refined borate compounds, they all
171 inevitably become boric acid or borate anion when dissolved in water (Brown et al., 2002; Kochkodan et al.,
172 2015). Heating tends to decompose the boric acid/borate system into boron oxide (Smith, 2000). The
173 solubility of boric acid and borate salts also increases with increasing temperature and pressure
174 (Kochkodan et al., 2015). Boric acid is a very weak acid⁴ containing three protons capable of dissociating
175 (Brown et al., 2002).

176
177 Unlike the other micronutrients that are absorbed by plants as dissociated ions, plants uptake boric acid
178 directly in its undissociated form, indicating a unique uptake mechanism (Brown et al., 2002). The
179 observation that boric acid is absorbed directly as the entire molecule rather than as charged ions has not
180 been fully explained in the literature and disagreements remain about whether boron enters plant cells
181 passively (by diffusion that does not require metabolic energy) or actively (through a transport mechanism
182 requiring energy input) (Brown et al., 2002).

183
184 Sodium borate salts hydrate or dehydrate depending on humidity, temperature, and pressure, and these
185 conversions are usually reversible by altering atmospheric conditions (Smith, 2000). See Table 1 for further
186 details regarding the physical and chemical properties of common boron compounds.

187
188

189

190

⁴ The dissociation constant for the first proton in boric acid is 5.8×10^{-10} mol/L and 1.8×10^{-13} and 3×10^{-14} for the second and third, respectively, at 25°C (Kochkodan et al., 2015), and the acid strength increases with increasing temperature. These values indicate extremely limited potential to dissociate into acidic hydrogen ions.

191

Table 1: Chemical and Physical Properties of Soluble Boron Compounds

Property	Boric acid	Disodium tetraborate	Disodium tetraborate pentahydrate	Disodium tetraborate decahydrate	Disodium octaborate tetrahydrate
Physical State and Appearance	Solid, crystalline	Solid, crystalline	Solid, powder	Solid, crystalline	Solid, powder
Odor	Odorless	Odorless	Odorless	Odorless	Odorless
Color	White	White/gray	White	White	White
Molecular Weight (g/mol)	61.84	201.2	291.3	381.4	412.5
Density (g/cm ³)	1.5	2.37	1.82	1.73	1.87
pH	3.8-4.8	9.3 (20°C)	9.3 (20°C)	9.3 (20°C)	8.5 (23°C)
Solubility in Water (g/100 ml)	5.6	2.56	3.8	5.1	n/a ^a
Stability	Stable	Hydrates in damp air	Stable	Stable	Stable
Reactivity	Decomposes upon heating	Decomposes upon heating	Low reactivity, incompatible with oxidizers	Decomposes upon heating	Stable

192 ^a Precise solubility cannot be determined because the compound converts to boric acid when dissolved and tends to
 193 supersaturate.

194 **Source: American Elements, 2021; Chemical Book, n.d.; European Chemicals Agency, 2009; National Center for**
 195 **Biotechnology Information, n.d.-d, n.d.-a, n.d.-c, n.d.-b; United States Department of Labor, 2021; US EPA, 1993**

196
 197 **Specific Uses of the Substance:**
 198

199 *Crop micronutrient*
 200 Approximately four percent of boron extracted globally is used in the correction of trace element
 201 deficiencies in crops (Kot, 2015; Woods, 1994). Shorrocks (1997) states that boron deficiency was reported in
 202 over 80 countries in 132 crops over the second half of the twentieth century, and that approximately 15
 203 million hectares of land are treated with boron compounds yearly. More recent figures could not be located
 204 at the time of this report. Of these numerous crop varieties, the most susceptible to boron deficiency are
 205 celery, groundnuts, beets, brassicas, rutabaga, coffee, carrots, palms, eucalyptus, cotton, sunflower, apple,
 206 alfalfa, olives, pine, and grapes⁵ (Shorrocks, 1997; Woods, 1994).
 207

208 Several growing regions worldwide are particularly susceptible to boron deficiency. Notably, the eastern
 209 and northwestern United States, northern Europe, eastern China, and certain nations in west and central
 210 Africa have reported common boron deficiencies (Shorrocks, 1997). These deficiencies are linked to soil
 211 types including ultisols, alfisols, oxisols, and spodosols⁶ (Shorrocks, 1997). Soils become deficient in boron
 212 through leaching, which is common in sandy or silty soils (Blevins & Lukaszewski, 1998).

⁵ Martens & Westermann (1991) report the following optimum sodium borate fertilization rates for the following crops, when deficient, in kg/hectare: alfalfa (2.24), brassicas (0.45), grapes (0.76), pine (5.7), soybeans (1.12), beets (2.2-3.4).

⁶ Generically, ultisols are soils occurring in warm, humid areas that tend to be enriched in clay and have low base saturation (a term describing a soil’s ability to exchange ions). Alfisols tend to occur in colder climates than ultisols and are characterized by moderate base saturation and occurrence of clays. Oxisols, commonly occurring in the tropics, are highly degraded soils which are easily depleted when cultivated. Spodosols tend to occur in cool, humid areas and are characterized as sandy, coarse, rich in aluminum and organic matter, but largely infertile (USDA Soil Survey Staff, 1999).

213
214 Crop farmers apply boron directly to soils before seeding, or apply it as part of a foliar spray, typically
215 mixed with other nutrients (Martens & Westermann, 1991). After crops are established, boron is sometimes
216 applied again, particularly in coarse soils subject to boron leaching (Martens & Westermann, 1991).
217 Disodium tetraborate decahydrate (borax) is popular in soil applications due to its increased solubility but
218 is subject to leaching for the same reason. The other disodium tetraborate hydrates, with lower solubility,
219 are also used in soils, as well as the more soluble boric acid to a lesser extent. Disodium octaborate
220 tetrahydrate is used in soil and dissolved foliar applications and dissolves easily (Martens & Westermann,
221 1991).

222
223 Excessive boron in soils can be phytotoxic (Rámila et al., 2015). Symptoms include leaf burn, leaf chlorosis,
224 reduced elongation of roots and shoots, and reduced crop yields. Arid and semi-arid regions are naturally
225 prone to this problem, but human activity (industrial glass and detergent production) has also increased
226 boron concentrations in surface waters, contributing to the problem. Excess boron in soil and water can be
227 difficult to remove (Rámila et al., 2015).

228 *Pesticide*

229
230 Boric acid and borate salts (particularly disodium octaborate tetrahydrate) are commonly used in wood
231 treatments to protect against fungi and termites (Woods, 1994). As insecticides, borates and boric acid can
232 be effective stomach poisons against cockroaches, wood-boring beetles, fleas, and ants (Krieger, 2010;
233 Woods, 1994).

234 *Other uses*

235
236 The majority of boron compounds produced are used in the manufacture of fiberglass insulation, glass,
237 enamels, bleach, and other non-agriculturally related chemicals (Woods, 1994). Due to boron's exceptional
238 ability to absorb neutrons, boron compounds are used in several capacities in nuclear energy reactors and
239 in nuclear waste management. Boric acid, boron carbide, boron-containing polymers and metal-boride
240 compounds are used in sensors, radiation shielding, nuclear material storage, reactor control rods, and in
241 vitrifying nuclear waste (Subramanian et al., 2010; Woods, 1994).

242
243
244 Boric acid is also used in eyewashes, contact lens solutions, oral gargles, cosmetics, and topical medicines
245 (Locatelli et al., 1987).

246 **Approved Legal Uses of the Substance:**

247
248 The USDA National Organic Program (NOP) currently permits soluble boron products for use as a crop
249 micronutrient at 7 CFR 205.601(j), and boric acid for structural pest control at 7 CFR 205.601(e). Borax (disodium
250 tetraborate decahydrate), disodium tetraborate, boric acid, disodium tetraborate pentahydrate, disodium
251 octaborate, and disodium octaborate tetrahydrate all appear on 2004 EPA List 3, Inerts of Unknown Toxicity (US
252 EPA, OCSPP, 2015). These substances are permitted on the National List as inert ingredients in passive
253 pheromone dispensers at 7 CFR 205.601(m).

254
255 The United States Environmental Protection Agency (EPA) requires boric acid and its sodium salts to be
256 registered when used as insecticides, fungicides, and herbicides (US EPA, 1994). Residues of boric acid and
257 its salts, borax (sodium borate decahydrate), disodium octaborate tetrahydrate, boric oxide (boric
258 anhydride), sodium borate and sodium metaborate are exempted from the requirement of a tolerance in or
259 on raw agricultural commodities when used as active ingredients in insecticides, herbicides, or fungicides
260 preharvest or postharvest in accordance with good agricultural practices (40 CFR 180.1121).

261
262 The FDA permits borax and boric acid to be used in adhesives and coatings in the manufacture of paper
263 and paperboard products used in food packaging (21 CFR 181.30).

264 **Action of the Substance:**

265
266 When compared to the other recognized plant micronutrients, deficiency in boron is the most common
267 (Blevins & Lukaszewski, 1998; Kot, 2015). Boron deficiency is responsible for significant crop losses,

268 whether in volume or quality, every year (Goldbach & Wimmer, 2007; Shorrocks, 1997). Despite extensive
269 study, the role boron plays in plants is not completely understood (Bolaños et al., 2004; Kot, 2015; Woods,
270 1994). It appears that boron plays a role in cell walls, cell membranes, plant development, and plant
271 metabolism (Blevins & Lukaszewski, 1998; Bolaños et al., 2004; Brown et al., 2002; Goldbach & Wimmer,
272 2007; Kot, 2015; Teasdale & Richards, 1990).

273

274 *Cell walls*

275 Boron-deficient plants exhibit a characteristic tissue brittleness, while plants exposed to toxic levels of
276 boron are more flexible (Loomis & Durst, 1992). Boron acts as a chemical bridge, forming bonds between
277 molecules of the cell wall sugar rhamnogalacturonan II⁷ (RG-II) (Chormova & Fry, 2016; Goldbach &
278 Wimmer, 2007; Matoh et al., 1996; Power & Woods, 1997). A deficiency of boron leads to a reduction in
279 bonds cross-linking RG-II in cell walls, causing the leaf brittleness observed in boron-deficient plants
280 (Blevins & Lukaszewski, 1998; Chormova & Fry, 2016). Goldbach & Wimmer (2007) have postulated that
281 RG-II may have contributed to the evolution of terrestrial vascular plants by allowing upright growth of
282 aquatic plant ancestors through boron cross-linking.

283

284 *Cell membranes*

285 In cell membranes, boron is thought to have a structural stabilizing effect (Blevins & Lukaszewski, 1998;
286 Goldbach & Wimmer, 2007). Deficiencies in boron lead to “leakage” of nutrients (notably potassium),
287 amino acids, and sugars from plant cells (Blevins & Lukaszewski, 1998; Cakmak et al., 1995; Goldbach &
288 Wimmer, 2007).

289

290 *Plant development*

291 Deficiency in boron has a striking effect on plant reproduction, inhibiting budding, pollination, flowering,
292 and fruit-setting, as well as leading to prematurely dropped fruit (Brown et al., 2002; de Wet et al., 1989).
293 Boron is important for cell elongation in plants but does not appear to affect cell division (Song et al., 2021).
294 The application of boron to soil dramatically increases seed and pollen tube production but has relatively
295 little effect on vegetative growth (Blevins & Lukaszewski, 1998; Brown et al., 2002; Shireen et al., 2018).

296

297 *Plant metabolism*

298 Boron deficiency can effect plant metabolism, though the complexity of cellular systems have made it
299 extremely difficult for researchers to reach solid conclusions (Brown et al., 2002). Deficiencies in this
300 micronutrient have been linked to disruptions in the ascorbate-glutathione cycle⁸ (Lukaszewski & Blevins,
301 1996), phenol metabolism⁹ (Ruiz et al., 1998), nitrogen metabolism, and nitrogen fixation by rhizobial
302 bacteria (Bolaños et al., 1994; Camacho-Cristóbal & González-Fontes, 2007; Shireen et al., 2018).

303

304 Boron can enhance the uptake of other nutrients in the soil, and affects the nitrate content within plant
305 tissues (Ahmed et al., 2011; Camacho-Cristóbal & González-Fontes, 2007; Shireen et al., 2018).

- 306 • On cotton crops, Ahmed et al. (2011) showed that the application of boron resulted in a significant
307 increase in the uptake of nitrogen, phosphorus, potassium, copper, iron, and zinc, but
308 simultaneously reduced calcium, magnesium, and manganese levels. The study demonstrated an
309 increased crop yield.
- 310 • On greenhouse tomatoes, the application of boron caused increased uptake of calcium,
311 magnesium, sodium, and zinc, while reducing uptake of manganese (Smit & Combrink, 2004). The
312 reduced manganese did not appear to affect the quality of fruit.
- 313 • On boron-deficient hydroponic tobacco, Camacho-Cristóbal & González-Fontes (2007)
314 demonstrated that plants did not assimilate nitrate through their roots as they normally would.
315 Instead, the deficiency promoted ammonia uptake.

⁷ Rhamnogalacturonan II is a type of pectin (Chormova & Fry, 2016).

⁸ The ascorbate-glutathione cycle is critical in the control of oxygen free radicals in a cell. Reactive oxygen is produced as a byproduct of many metabolic processes, and the ascorbate-glutathione system helps to regulate the levels of reactive oxygen species (Drażkiewicz et al., 2003).

⁹ Phenolic compounds (a class of chemicals that all share an aromatic hydrocarbon ring bonded to hydroxyl groups) play many roles in plant biochemistry, including enzymatic processes, growth regulation, and cell-wall formation (Ruiz et al., 1998).

316
317 **Combinations of the Substance:**
318 Uniformity of application is important when using boron fertilizers since there is a narrow range between
319 deficiency and toxicity for many crops (Brdar-Jokanović, 2020; Garrett, 1998; Goldberg, 1997). Borates are
320 sometimes mixed with sand or soil before applying (Shireen et al., 2018; Shorrocks, 1997). Uniform
321 application is often achieved by mixing boron sources with blended fertilizer mixes, sometimes through
322 irrigation lines (Martens & Westermann, 1991; Shorrocks, 1997).

323
324 Many boron products on the market are formulated with macronutrient fertilizers, other plant
325 micronutrients, growth regulators, or chelating agents (OMRI, 2021). Some products without additional
326 formulants contain label instructions to mix with fertilizer products or wetting agents before application
327 (OMRI, 2021).

Status

330
331 **Historic Use:**

332 Researchers believe that natural borax (or tincal) was first exported from the Far East to Babylon during the
333 Bronze Age (around 3,300 to 1,200 BCE), possibly from the dry lakes on the Tibetan plateau (Garrett, 1998;
334 Wisniak, 2005; Woods, 1994). It was used in metallurgy and medicine (Wisniak, 2005). Evidence indicates
335 that natural borax was later traded in the Middle East (beginning in the eighth century A.D.) for use in
336 precious metal refining, building materials (as a component of wall plaster), and ceramics, and later used in
337 goldsmithing in medieval Europe (Garrett, 1998; Ozturk et al., 2010; Woods, 1994).

338
339 During the late 19th and early 20th centuries, large borate deposits were found in Turkey and the United
340 States, and it was discovered that these minerals could be converted into borax through a reaction with
341 sodium sesquicarbonate¹⁰ (Woods, 1994). At that time, a significant amount of borax was used in soap and
342 detergent (Travis & Cocks, 1984).

343
344 Boron was recognized as an essential plant nutrient in the early 20th century, specifically in legumes
345 (Loomis & Durst, 1992; Shorrocks, 1997). Later, boron essentiality was identified in a great diversity of
346 plants (Loomis & Durst, 1992). Boron fertilizer application became commonplace for many crops after this
347 discovery, and it became apparent that each species has a different boron requirement (Blevins &
348 Lukaszewski, 1998).

349
350 During World War I, the import of potash fertilizers from Germany ceased and new potash sources in the
351 United States were used for crop fertility (Shorrocks, 1997). Brine-derived potash from California contained
352 elevated levels of boron, sometimes leading to toxicity from over-application (Breckenridge, 1921;
353 Shorrocks, 1997). At the same time, small amounts of boron were found to be beneficial to plant growth,
354 indicating a small window between a plant's boron requirement and an injurious dose (Blevins &
355 Lukaszewski, 1998; Breckenridge, 1921).

356
357 **Organic Foods Production Act, USDA Final Rule:**

358 Boron products are not specifically identified by name in the Organic Foods Production Act of 1990
359 (OFPA). However, since soluble boron products appear on the National List, Section 2118 (c)(1)(A) [7
360 U.S.C. 6517] is applicable.

361
362 Soluble boron products have appeared on the National List for use as micronutrients since it was first
363 published in the year 2000 (*National Organic Program, 65 Fed. Reg. 80547, 2000*).

364
365 **International**

366
367 *Canadian General Standards Board Permitted Substances List*

¹⁰ Sodium sesquicarbonate is derived from naturally occurring trona ore. It is a combination of sodium carbonate and sodium bicarbonate (Kent, 2012).

368
369 Soluble boron products are permitted by the Canadian Organic Standards at CAN/CGSB 32.311-2020
370 Table 4.2, column 1, entry for *Boron*. Borate (boric acid), sodium tetraborate (borax and anhydrous), and
371 sodium octaborate are permitted only when one of the following has been established:
372 • soil and plant deficiencies are documented by visual symptoms
373 • testing of soil or plant tissue demonstrates the need
374 • the need for a preventative application can be documented (CGSB, 2020)
375
376 The *Boron* entry further references the *Micronutrients* annotation at CAN/CGSB 32.311 Table 4.2, column 1.
377 This entry permits using chelating agents also appearing on CAN/CGSB 32.311 Table 4.2 with
378 micronutrients. The *Micronutrients* annotation also specifically prohibits ammonium and nitrate forms and
379 those chelated¹¹ with:
380 • ethylenediaminetetraacetic acid (EDTA)
381 • diethylenetriaminepentaacetic acid (DTPA)
382 • ethylenediamine-*N,N'*-bis((2-hydroxyphenyl)acetic acid) (EDDHA) (CGSB, 2020).
383
384 *CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of*
385 *Organically Produced Foods (GL 32-1999)*
386
387 The Codex guidelines includes “Trace elements (e.g., boron, copper, iron, manganese, molybdenum, zinc)”
388 in *Table 1, substances for use in soil fertilizing and conditioning* (FAO, 2007). The need must be “recognized by
389 the certification body or authority” (FAO, 2007).
390
391 *European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008*
392
393 Several boron substances are allowed for soil management and fertilization by the European Union organic
394 regulations. EC Regulation No. 889/2008 Article 3 permits the use of substances appearing in Annex I
395 when the nutritional needs of plants cannot be met by certain preventative measures (European
396 Parliament, Council of the European Union, 2008). Annex I permits the use of boric acid, sodium borate,
397 calcium borate, and boron ethanolamine (European Parliament, Council of the European Union, 2003).
398
399 *Japan Agricultural Standard (JAS) for Organic Production*
400
401 Trace elements (manganese, boron, iron, copper, zinc, molybdenum, and chlorine) are permitted by the
402 Japanese Agricultural Standard for Organic Plants as fertilizers and soil improvement substances if a crop
403 is unable to grow normally because of a micronutrient shortage (MAFF, 2017).
404
405 *IFOAM – Organics International*
406
407 Boric acid, sodium borate, calcium borate, and “borethanolamin” (presumably referring to boron
408 ethanolamine) of mineral origin are permitted as fertilizers and soil conditioners in the IFOAM NORMS,
409 where soil or plant nutrient deficiency can be documented by soil or tissue testing or diagnosed by an
410 independent expert. Chloride and nitrate forms are prohibited, as are micronutrients used as defoliants,
411 herbicides, or desiccants (IFOAM Organics International, 2019).
412

Evaluation Questions for Substances to be used in Organic Crop or Livestock Production

413
414
415 **Evaluation Question #1: Indicate which category in OFPA that the substance falls under: (A) Does the**
416 **substance contain an active ingredient in any of the following categories: copper and sulfur compounds,**
417 **toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated seed,**

¹¹ Chelating agents are molecules that can bind to metals (using coordinate-covalent bonds) with at least two separate chemical groups (Lehman, 1963; Schubert, 1981). When a chelating agent and metal are in the bonded state, one or more rings is formed as a result. All else being equal, this formation is more stable than non-chelated chemical arrangements (Lehman, 1963; Schubert, 1981).

418 vitamins and minerals; livestock parasiticides and medicines and production aids including netting,
419 tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is the
420 substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological concern
421 (i.e., EPA List 4 inerts) (7 U.S.C. § 6517(c)(1)(B)(ii)? Is the synthetic substance an inert ingredient which
422 is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part 180?
423

424 Boron is not specifically addressed in the Organic Foods Productions Act, nor are micronutrients. Synthetic
425 soluble boron products are not active ingredients in the above listed categories, or synthetic inert
426 ingredients when used as micronutrients in organic crop production.
427

428 **Evaluation Question #2: Describe the most prevalent processes used to manufacture or formulate the**
429 **petitioned substance. Further, describe any chemical change that may occur during manufacture or**
430 **formulation of the petitioned substance when this substance is extracted from naturally occurring plant,**
431 **animal, or mineral sources (7 U.S.C. § 6502 (21)).**
432

433 All soluble boron products are derived from mined borate mineral deposits. Borate minerals can be
434 extracted by surface mining or solution mining (Garrett, 1998).

- 435 • Surface mining involves stripping the surface of vegetation, topsoil and waste rock or blasting
436 open pits with explosives (Garrett, 1998). Deeper ores are reached by cutting benches (ledges) in
437 the pits for access and transport to the surface (Office of Energy Efficiency and Renewable Energy,
438 2002).
 - 439 • Solution mining involves the injection of water into subterranean spaces in order to dissolve
440 borates, which can be pumped back as a brine to the surface for processing (Office of Energy
441 Efficiency and Renewable Energy, 2002).
- 442

443 *Borax/borate salts*

444 Refined sodium borate salts are typically produced by crushing solid borate ores and dissolving in water
445 alongside trona (a double salt of sodium carbonate and sodium bicarbonate), or supersaturating brine with
446 carbon dioxide in the case of solution mining (Office of Energy Efficiency and Renewable Energy, 2002;
447 Smith, 2000). Insoluble waste materials are filtered out of the liquor and disodium tetraborate pentahydrate
448 and decahydrate are selectively crystallized by temperature control and vacuum crystallization, followed
449 by centrifugation and drying (Smith, 2000). To prevent crystallization water loss and caking, disodium
450 tetraborate decahydrate crystals are sometimes washed with a boric acid solution that coats the crystals
451 with a thin layer of the pentahydrate variety (Smith, 2000).
452

453 High purity borax can also be produced in a reaction between boric acid and hot sodium hydroxide (Smith,
454 2000). Various dehydration and rehydration methods can be utilized to selectively produce the different
455 hydration states of disodium tetraborate (Smith, 2000). Boric acid reactions with sodium hydroxide can also
456 be used to produce disodium octaborate tetrahydrate (Kutcel, 2001).
457

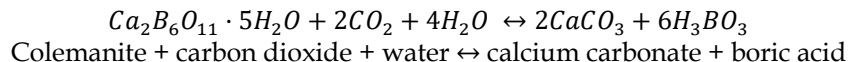
458 *Boric acid*

459 In the United States, boric acid is typically prepared by reacting naturally occurring solid sodium borate
460 minerals with strong mineral acids like sulfuric acid (Smith, 2000). This results in a concentrated solution of
461 boric acid and sodium sulfates, after which the boric acid is crystallized by evaporation. In Europe, the
462 source minerals are often calcium or magnesium borate, but the process is similar; sulfuric acid is added,
463 boric acid is crystallized, and calcium and magnesium sulfates are filtered out (Smith, 2000).
464

465 At Searles Lake, California, borax derived from solution mining is chemically bound to an organic¹²
466 chemical in order to facilitate extraction (Garrett, 1998; Smith, 2000). The organic phase (containing the
467 borax) is then reacted with sulfuric acid, forming boric acid, sodium sulfate, and impurities. Sodium sulfate
468 is removed through precipitation, and boric acid is crystallized by evaporation (Garrett, 1998; Smith, 2000).
469

¹² Containing the element carbon.

470 Some relatively new research has attempted to supplant the use of sulfuric acid with carbon dioxide in a
471 high pressure reactor in order to simultaneously sequester the greenhouse gas and produce purified boric
472 acid from the mineral colemanite (Bingöl & Çopur, 2019). Their proposed reaction follows:



476
477 The authors propose that the method could be used on an industrial scale and have advantages over the
478 sulfuric acid method; calcium sulfate (gypsum) waste would be eliminated, high-purity boric acid with
479 fewer impurities would be produced, and atmospheric greenhouse gases could be transformed into
480 insoluble mineral constituents for use in building materials and industrial applications (Bingöl & Çopur,
481 2019).

482
483 **Evaluation Question #3: Discuss whether the petitioned substance is formulated or manufactured by a**
484 **chemical process, or created by naturally occurring biological processes (7 U.S.C. 6502(21)).**

485
486 “Soluble boron products” appear on the National List of Allowed and Prohibited Substances at 7 CFR
487 205.601(j)(7)(i). Soluble boron products are derived from naturally occurring minerals, so are not created by
488 a naturally occurring biological process.

489
490 *Borax/borate salts*

491 Two production methods are summarized below.

492 *Production method 1:*

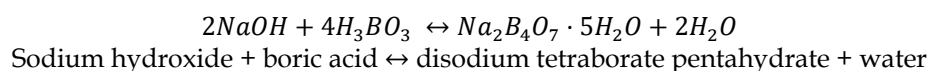
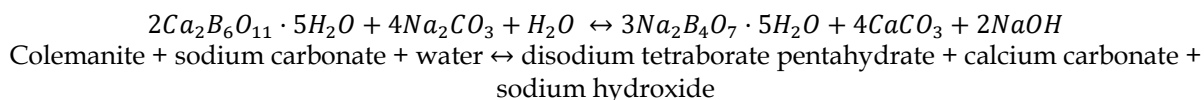
493 The largest volume of refined sodium tetraborate salts globally is produced at the Rio Tinto Boron Mine,
494 (formerly known as the U.S. Borax Boron Mine) in Boron, California, currently operated by the Rio Tinto
495 Group (Grube, 1970; Smith, 2000). See *Evaluation Question #2* for the process of refining sodium borate
496 minerals into purified borax and borax pentahydrate that is used at this refinery (Smith, 2000).

497 Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* states that if a
498 substance has undergone a chemical change (question 2), and the change is not the result of a naturally
499 occurring biological process or by heating or burning biological matter (question 3), then the substance is
500 synthetic (NOP, 2016). Dissolution of borax (tincal), followed by removal of insoluble wastes and selective
501 crystallization, are physical processes. Coating the crystals with disodium tetraborate pentahydrate
502 derived from boric acid that is produced using a chemical process, however, renders the final product
503 synthetic.

504 Dehydration and rehydration processes used to convert decahydrate to pentahydrate or anhydrous borax
505 are physical processes involving heat and drying.

506
507 *Production method 2:*

508
509 Sodium tetraborate pentahydrate can also be produced from the mineral colemanite in a complex chemical
510 reaction with sodium carbonate, sodium hydroxide, and boric acid (Mazzinghi, 1989), though a review of
511 the literature is inconclusive regarding the commercial importance of this production method:



519
520
521
522
523 *Boric acid*

524 Industrial production of boric acid relies on the chemical process described in *Evaluation Question #2*.
525 Mined borate salts of sodium, calcium, or magnesium¹³ are reacted with strong acids to produce boric acid
526 and mineral salts (Kuskay & Bulutcu, 2011; Smith, 2000). Based on Guidance NOP 5033-1, this chemical
527 process is synthetic (NOP, 2016). Depending on the source mineral and acid used, the waste salts may be
528 sulfates, chlorides, nitrates, and phosphates of sodium, calcium, and magnesium.
529

530 **Evaluation Question #4: Describe the persistence or concentration of the petitioned substance and/or its**
531 **by-products in the environment (7 U.S.C. 6518(m)(2)).**
532

533 According to the EPA (2008b), data is limited related to the volume of environmental releases of boron
534 resulting from fertilizer or pesticidal applications, as well as residence times in air, soil, and water.
535

536 As described in *Composition of the Substance* above, elemental boron does not naturally occur in the
537 environment due to its reactivity (Goldberg, 1997). Boron exists as borate salts, boric acid, or in nearly
538 insoluble silicate minerals (Goldberg, 1997). The by-products resulting from the weathering and
539 breakdown of boron-containing minerals are boric acid or borate anion, depending on the pH of the
540 medium (Woods, 1994).
541

542 The persistence of boron in the environment is dependent on soil type and texture, and climatic region
543 (Goldberg, 1997; Shorrocks, 1997). Boron adsorbs to soil minerals as pH increases, leading to soil boron
544 accumulation, but then decreases at pH levels above 10, (Goldberg, 1997). In coarser-grained soils, boron
545 becomes mobile, simultaneously allowing for easier plant uptake and leaching to the water system, while
546 finer-grained soils rich in clay minerals (montmorillonite, kaolinite, and chlorite) may hold onto boron
547 (Goldberg, 1997).
548

549 Environmental humidity, soil moisture, and precipitation rates greatly affect boron accumulation in soils
550 (Brdar-Jokanović, 2020; Goldberg, 1997). The mobility of boron in the soil tends to increase in wet or humid
551 zones due to the solubility of borates, and boron concentrations can increase with soil depth as borate
552 leaches downwards (Brdar-Jokanović, 2020). This behavior can lead to deficiency of boron in the soil as
553 well as a remobilization into the water system; heavy rain or heavy irrigation can contribute to boron
554 deficiency in plants (Shorrocks, 1997).
555

556 Just as boron concentrations decrease in wet climates, boron accumulates in soils in dry or semi-arid
557 environments (Goldberg, 1997; Shorrocks, 1997). These conditions are exacerbated by further addition of
558 boron from irrigation water derived from desalinated seawater or watersheds associated with boron
559 mining activity (Ozturk et al., 2010; Vera et al., 2019; Yuce & Yasin, 2012).
560

561 Arslan (2013) observed extremely elevated boron levels in streams near boron mining operations in
562 Turkey, reporting a maximum of 16.73 mg/L in stream water and 36.7 mg/L in riverbed sediments. The
563 author determined that the river, sediment, and irrigated land represents a significant sink of boron, with
564 the potential for injury to the ecosystem. Rivers draining heavily cultivated farmland in England have been
565 measured to contain up to 0.387 mg/L boron (Kochkodan et al., 2015), a level approximately 40 times lower
566 than the maximum water concentration found in the study in Turkey. Compared to the riverbed sediment
567 values, the compared value is even lower, but sediment values were not explored in the England study.
568 The following evaluation question provides additional information on potential harm to the ecosystem and
569 biological toxicity resulting from elevated boron in the environment.
570

571 **Evaluation Question #5: Describe the toxicity and mode of action of the substance and of its breakdown**
572 **products and any contaminants. Describe the persistence and areas of concentration in the environment**
573 **of the substance and its breakdown products (7 U.S.C. 6518(m)(2)).**
574

575
576 *Plants*

¹³ Most often, sodium borates are used in the United States (Smith, 2000). Calcium borates are used in European countries and the near East. Magnesium borates are used in Russia (Smith, 2000).

577 The generally agreed upon value where many crops exhibit toxicity is greater than 5 mg/L in soil (Ozturk
578 et al., 2010). The mechanism by which boron induces toxicity in plants is mostly unknown, but the number
579 of symptoms is extensive and wide-ranging (Landi et al., 2019; Reid et al., 2004). Landi (2019) reports that
580 excess boron can cause:

- 581 • metabolic imbalances
- 582 • tissue necrosis¹⁴
- 583 • fruit malformation
- 584 • root growth suppression
- 585 • deficiencies of other nutrients
- 586 • reduction of photosynthesis
- 587 • thinning of leaves
- 588 • inhibition of pollen germination
- 589 • genotoxic¹⁵ effects

590
591 Responses vary between plants species. Variations in boron tolerance can occur between different cultivars
592 of the same plant species (Ozturk et al., 2010).

593
594 Reid et al. (2004) proposed three likely causes for the onset of excess boron toxicity: disruption to cell wall
595 creation, binding and disrupting sugar molecules involved with plant metabolism, and binding to RNA or
596 sugars leading to suppression of cell division.

598 *Animals and Humans*

599 A lethal dose of boron is estimated to be 400-900 mg/kg body weight in animals of all types (Arslan, 2013;
600 Emiroğlu et al., 2010). The acute lethal dose in humans is difficult to determine because an individual's
601 response to a single dose varies widely depending on age group, weight, or other underlying conditions.
602 Researchers (Bakirdere et al., 2010; Locatelli et al., 1987) estimate that the acute lethal single dose (as boric
603 acid) is:

- 604 • 2,000-3,000 mg in infants
- 605 • 5,000-6,000 mg in children
- 606 • 15,000-20,000 mg in adults

607
608 Toxicity has been observed at doses as wide-ranging as 100-55,000 mg, however (Bakirdere et al., 2010).

609
610 The biochemical activity of boron in humans also seems to be related to bonding with sugars, particularly
611 ribose, a component of adenosine which plays a role in energy metabolism (Khaliq et al., 2018). It has been
612 hypothesized that boron interacts with the release of cellular calcium which is related to bone formation,
613 brain activity, liver function, and immune system function, but specific mechanisms remain unknown
614 (Khaliq et al., 2018).

615
616 Symptoms of acute boron toxicity in humans include dermatitis, kidney inflammation and failure, edema
617 (swelling caused by fluid retention), gastrointestinal discomfort, seizure, and delirium (Bakirdere et al.,
618 2010; Khaliq et al., 2018; Kingma, 1958). Chronic ongoing exposure has been linked to reproductive effects
619 such as testicular degeneration, low sperm count, atrophy of seminiferous tissues, and reduction in
620 ovulation in animal tests, but these effects have not been conclusively demonstrated in humans (Bakirdere
621 et al., 2010; Khaliq et al., 2018).

622
623 See *Evaluation Question #4* for information on the persistence of boron.

624
625 **Evaluation Question #6: Describe any environmental contamination that could result from the**
626 **petitioned substance's manufacture, use, misuse, or disposal (7 U.S.C. 6518(m)(3)).**

627

¹⁴ Necrosis is the process whereby plant tissue dies due to disease or injury (Gowariker et al., 2009).

¹⁵ Genotoxic means that a substance is damaging to genetic material, such as causing DNA mutation or large changes to chromosome structure (Gad, 2016).

628 The environmental effects of surface and subterranean boron mining are inherently significant at the local
629 level and contribute to water contamination and reduction of biodiversity.

630
631 Sulfuric acid is used as a reactant to make boric acid from colemanite, and calcium sulfate is sometimes
632 produced as a by-product (see *Evaluation Question #2*). This results in a significant waste stream and can
633 have environmental consequences related to the build-up of industrial waste (Bingöl & Çopur, 2019).
634 Wastewater discharge is also a source of boron pollution since boron appears in some soaps and washing
635 chemicals (Emiroğlu et al., 2010).

636
637 Boric acid and borate salts are both soluble and easily adsorbed into soil and sediment (Office of Toxic
638 Substances, 1975). As of 1975, a significant percentage of boron released into the environment resulted from
639 detergents used in washing chemicals, but due to the tendency of boron to adsorb to sediments, contact
640 with soil eliminates release to the water system (Emiroğlu et al., 2010; Office of Toxic Substances, 1975). A
641 1975 estimate by the Office of Toxic Substances department of the EPA (1975) indicated that laundry
642 products made up the bulk of anthropogenic boron releases to the environment at 14,000 metric tons,
643 followed by agricultural production (7,000 tons), coal burning (4,000 tons), mining (3,000 tons), and glass
644 and ceramics (1,500 tons), most of which ends up in the water system due to solubility. More recent
645 estimates could not be located.

646
647 Borate deposits, being related to volcanic activity, often contain elevated levels of arsenic and heavy metals
648 (Drever, 1997). However, data on environmental contamination associated with boron mining in the
649 United States was scarce at the time of this writing. The only information found was from a request to the
650 California Regional Water Quality Control Board from U.S. Borax to update mine discharge infrastructure
651 (California Regional Water Quality Control Board, Lahontan Region, 2018). U.S. Borax, Inc., Rio Tinto
652 Minerals reported leakage of processing fluids and arsenic-rich wastewater into the local aquifer and
653 sought to improve containment lining systems.

654
655 Borate mining in western Anatolia, Turkey, has led to significant boron, arsenic, and strontium
656 contamination in irrigation water, surface water, and groundwater (Gemici et al., 2008; Yuce & Yasin,
657 2012). Yuce & Yasin (2012) reported that the level of arsenic in the majority of groundwater samples
658 exceeded safe drinking water levels as allowed by the US EPA (10 µg/liter). This was attributed to
659 improper storage of mine tailings, which also contained elevated levels of strontium. Gemici (2008) found
660 arsenic levels as high as 911 µg/liter in groundwater samples taken near boron mines, and all 25 surface
661 and groundwater samples taken exceeded the recommended 10 µg/liter¹⁶. Ozturk et al. (2010) also
662 describes significantly elevated boron levels in watersheds near Turkish boron mines, resulting in boron
663 toxicity in agricultural lands and a reduction in plant biodiversity in undeveloped areas nearby.

664
665 Also in western Turkey, biodiversity of aquatic organisms was shown to be reduced in waters and
666 sediments associated with elevated boron concentration related to mine leachate, particularly among
667 bottom-dwelling (benthic) invertebrates (Arslan, 2013; Emiroğlu et al., 2010).

668
669 Fish can tolerate boron concentrations of 17 parts per million (ppm) or higher without apparent effect
670 (Garrett, 1998). The highest boron concentration recorded in the studies conducted by Emiroğlu et al. (2010)
671 was 3.88 ppm in watersheds associated with Turkish borate mine drainage. At 30 ppm, phytoplankton
672 experience reduced photosynthesis (Garrett, 1998).

673
674 **Evaluation Question #7: Describe any known chemical interactions between the petitioned substance**
675 **and other substances used in organic crop or livestock production or handling. Describe any**
676 **environmental or human health effects from these chemical interactions (7 U.S.C. 6518(m)(1)).**

677

¹⁶ Acute arsenic poisoning can result from a single dose as low as 5 mg, resulting in vomiting and diarrhea. A 100-300 mg dose results in death, with the lethal dose calculated to approximately 0.6 mg/kg body weight/day (Ratnaik, 2003). Chronic poisoning resulting from prolonged exposure to small amounts of arsenic over time is more difficult to quantify and can exhibit a wide range of serious symptoms and disease (Ratnaik, 2003).

678 Boron deficiency has been shown to be more prevalent on land that has been treated with lime or calcium
679 carbonate, particularly during times of drought or in soils that drain easily (Shorrocks, 1997). Boron tends
680 to become less available to plants at higher pH, leading to deficiency potential (Abou Seeda et al., 2021).

681
682 The addition of organic matter to soil increases the availability of boron to plants and microorganisms
683 (Vera et al., 2021). Vera hypothesized that this occurs through a possible mechanism involving interaction
684 with easily broken-down carbon and nitrogen compounds, which effectively release boron to plants and
685 microbes as they degrade.

686
687 Boron sometimes appears to have an antagonistic relationship with calcium uptake (Ahmed et al., 2011;
688 Shkolnik, 1984). In field studies, Ahmed et al. (2011) found calcium content decreased in cotton leaves,
689 burrs, stems, seeds and lint after increasing applications of borax fertilizer. In contrast, other researchers
690 have noted a synergistic relationship with calcium (in tomatoes), possibly arising from the complex
691 interactions of soil type, plant, and biochemical processes in different environments (Abou Seeda et al.,
692 2021). Similarly conflicting reports have been published for nitrogen, phosphorus, potassium, magnesium,
693 zinc, copper, iron, molybdenum, and manganese (Abou Seeda et al., 2021). Interactions may not be related
694 at all. Boron deficiency can exhibit the same effects as boron excess in relation to the uptake of other
695 nutrients, and the full picture of chemical interactions remains unresolved (Abou Seeda et al., 2021).

696
697 Boron addition appears to play a role in blocking the availability of nitrogen to plants (Vera et al., 2019).
698 This may be due to the formation of boron-nitrogen compounds that do not readily break down (Vera et
699 al., 2019).

700
701 **Evaluation Question #8: Describe any effects of the petitioned substance on biological or chemical**
702 **interactions in the agro-ecosystem, including physiological effects on soil organisms (including the salt**
703 **index and solubility of the soil), crops, and livestock (7 U.S.C. 6518(m)(5)).**

704
705 Only recently have researchers begun to address the effect of boron on the soil microbial community, and
706 its effect remains largely unknown.

707
708 In a study of microorganisms and ryegrass in Spain, Vera et al. (2019) treated high carbonate soils with
709 boric acid and borax. At the highest boron doses used (50 mg/L), the authors found a reduction in soil
710 microbial respiration. With boric acid, they observed a reduction of microbial biomass, but an overall
711 increase in total biomass when using borax. Both boric acid and borax treatments led to a reduction in
712 fungal biodiversity. The high levels of boron also negatively affected the ryegrass. Vera et al. (2019)
713 concluded that high boron input interfered with the soil enzyme urease¹⁷, reducing nitrogen uptake by
714 plants and microbes. At lower levels (1 mg/L), no harm was observed to soil or plants.

715
716 Lemon trees are particularly sensitive to boron and show symptoms of toxicity when irrigated with water
717 having a boron concentration of 1 mg/L. Another study by Vera et al. (2021) looked at the effect of boron
718 (ranging from 1 - 15 mg/L) on lemon trees and soil microbiota in a) conventional soils and b) soils
719 amended with composted sheep manure. The authors concluded that soils amended with organic material
720 showed greater mobility of boron, as well as increased boron uptake by plants. The amended soil also
721 resulted in increased tolerance to excess boron by lemon trees. Microbial biomass, particularly bacterial,
722 was also reduced with increasing boron accumulation, but the addition of organic matter helped the
723 microbial community resist boron toxicity. The lemon trees eventually died when the boron content of the
724 water reached 15 mg/L, but the authors propose this may have been a result of fungal infection due to
725 weakened plants, rather than directly resulting from boron poisoning (Vera et al., 2021).

726
727 With increasing demand for freshwater used in irrigation, desalinization of seawater has become more
728 realistic in certain coastal arid regions such as Spain, Israel, and California (Martínez-Alvarez et al., 2016).
729 Desalinated seawater is rich in boron (Vera et al., 2019). Desalinated seawater has a boron content between

¹⁷ It is established in scientific literature that boron can inhibit the soil enzyme, urease (Kumar & Kayastha, 2010). Urease breaks down urea into ammonia.

730 0.5 – 1 mg/L, but boron can accumulate to higher levels when regularly applied, particularly in arid and
731 semiarid regions where borate is not sufficiently absorbed by biology, adsorbed to soil minerals, or leached
732 away (Vera et al., 2021).

733
734 Some livestock appear to be less affected by boron compared with plants. For example, cows showed no ill
735 effects when exposed to 120 mg/L boron in drinking water (Garrett, 1998). Sheep are less tolerant, and
736 developed intestinal inflammation after grazing where soil boron ranged between 30-300 mg/L, when their
737 drinking water contained boron between 1-20 mg/L, or when eating food with 40 mg/L boron (Garrett,
738 1998). This still remains above the generally accepted level at which many crops are affected, of 5 mg/L
739 (Ozturk et al., 2010).

740
741 **Evaluation Question #9: Discuss and summarize findings on whether the use of the petitioned**
742 **substance may be harmful to the environment (7 U.S.C. 6517(c)(1)(A)(i) and 7 U.S.C. 6517(c)(2)(A)(i)).**

743
744 Natural environmental releases of boron, such as the weathering of rocks, volatilization of seawater, and
745 volcanic processes outweigh anthropogenic releases (US EPA, 2008a). Of the environmental releases caused
746 by humans, agriculture makes up just one source of many, including coal power generation, glass
747 manufacturing, release of wastewater containing borate cleaning agents, borate mining, leaching or
748 burning of treated lumber, and sewage sludge (US EPA, 2008a). The combined human releases of boron are
749 largely insignificant when compared to natural sources arising from the breakdown of rocks, ocean
750 evaporation, and volcanic activity (Landi et al., 2019; Stangoulis & Reid, 2002).

751
752 Ozturk (2010) estimates that boron deficiencies may occur in plants grown in soils with boron
753 concentrations less than 0.5 mg/L, but when boron exceeds 2 mg/L, decreased production may be
754 apparent. Soil boron concentrations greater than 5 mg/L may lead to boron toxicity and a reduction in crop
755 yield, indicating that the addition of large amounts of boron fertilizer should be avoided (Ozturk et al.,
756 2010). Very small amounts of boron fertilization (1-2 kg/hectare) will correct deficiencies, and rates as low
757 as 100-200 g/hectare may be sufficient in some crops (Shorrocks, 1997). When used as a micronutrient
758 fertilizer, boron carries a low risk of significant environmental contamination when used as directed to
759 remedy a deficiency. Plants absorb soluble boron rapidly (Shorrocks, 1997) and the remainder is either
760 easily leached away or adsorbed to clay minerals in the soil, which does not evoke toxicity in plants
761 (Goldberg, 1997).

762
763 Based upon the information provided in *Evaluation Questions #4 through #8*, the application of boron
764 fertilizers is not likely to contribute to extensive and direct environmental harm. Over-application of boron
765 is more likely to harm the crops themselves than the surrounding environment. However, the effects of boron
766 mining on local environments are significant, including water contamination and biodiversity loss.
767 Large-scale borate mining occurs in a limited number of regions around the world, so associated
768 environmental effects are localized. With that said, only a small fraction of mined borates are used for
769 agricultural purposes (Woods, 1994).

770
771 **Evaluation Question #10: Describe and summarize any reported effects upon human health from use of**
772 **the petitioned substance (7 U.S.C. 6517(c)(1)(A)(i), 7 U.S.C. 6517(c)(2)(A)(i) and 7 U.S.C. 6518(m)(4)).**

773
774 Boron is essentially non-toxic to humans at levels found in the environment, even in areas where boron is
775 extremely concentrated such as mines, refineries, and other industrial settings (ATSDR, 2010). The EPA
776 does not currently regulate boron in drinking water, and posits that the boron level in drinking water poses
777 little to no threat to public health (US EPA, 2008a). As a fertilizer, the European Commission (EC, 2008)
778 states that:

779
780 *“...it has been assumed that inadvertent ingestion of boron fertilisers (amongst those farmers using such*
781 *fertilisers) is unlikely to exceed 100 mg/day. Since boron fertilisers may contain around 10% boron, it would*
782 *appear that the intake of boron could approach the tolerable upper intake level (UL) value of 10 mgB/day [mg of*
783 *boron] (as recommended by EFSA). However, the UL value is based on consideration of routine daily exposures*
784 *whereas fertilisers would only be applied sporadically during the course of a year.*

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On this basis, it is considered unlikely that the exposure to boron through the use of boron fertilisers would routinely exceed the UL value of 10 mgB/day. This, in turn, suggests that, although borates are likely to be present as free constituents in boron fertilisers and are classified as toxic to reproduction category 2, the associated risks to farmers (and other consumers) using boron fertilisers are unlikely to be of serious concern."

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Reproductive toxicant category 2 under the EC Regulations (European Parliament, Council of the European Union, 2008) refers to substances in which there is some experimental evidence of toxicity to sexual function, fertility, or development, but results are not sufficiently convincing. Categories 1A, and 1B contain those substances known to be reproductive toxicants based on conclusive evidence in human and animal studies, respectively.

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Modern reports of lethal boron poisoning involve accidental or intentional ingestion of boric acid, though 88 percent of acute oral exposures were still asymptomatic (ATSDR, 2010). Deaths are largely attributed to infant formula accidentally prepared with boric acid solution in place of water, leading to organ degeneration (ATSDR, 2010; Wong et al., 1964). Thirteen children died in Malaysia following the consumption of noodles contaminated with aflatoxin and boric acid, but the toxicity of the boric acid contamination compared to aflatoxin was not determined (ATSDR, 2010). Symptoms resulting from acute exposure to boric acid by ingestion include vomiting, diarrhea, kidney failure and heart failure, but newborn infants appear to be at far higher risk than adults (ATSDR, 2010; Wong et al., 1964).

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The Agency for Toxic Substances and Disease Registry (2010) reports that no clear links between serious illness and chronic occupational exposure to boron have been identified in humans through inhalation or skin contact beyond transient irritation of the skin, eyes, nose and throat. Tests have shown that at very high doses (≥ 100 mg boron/kg body weight/day), animals that are fed boric acid for two weeks to two years become sterile, and significant degeneration of the testicles occurs in mice, rats, and dogs (ATSDR, 2010; Dieter, 1994; Fukuda et al., 2000; Scialli et al., 2010). Exposure by inhalation did not produce similar effects in rats (ATSDR, 2010).

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Average human consumption of boron in the United States is estimated to be approximately 1 mg/day, but this can vary by diet and region (Meacham & Hunt, 1998; US EPA, 2008a). In Chinese borate mine workers, higher levels of boron may be absorbed by inhalation and ingestion, averaging 11.84 mg boron/day (ATSDR, 2010), but no effects on the male reproductive organs were found, even at levels as high as 41.2 mg/day (Scialli et al., 2010). The levels of ingested boron determined to be detrimental in animal tests far exceeds the levels encountered by humans, even with daily occupational contact with boron (Bakirdere et al., 2010). In terms of skin contact, borate ointments and topical medicines are less irritating than soap, and some studies on borate mine workers in California concluded that their lung function was actually healthier than the U.S. average (Garrett, 1998).

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In large-scale borate complexes in Turkey, significant elevation of boron in water, sediments, and wildlife of the region was observed, but no increased incidence of disease was apparent in the residents, whose diets include local plants and fish (Emiroğlu et al., 2010). No reproductive, nervous system, or cardiovascular system abnormalities were reported by the authors, despite many residents working in and living nearby the boron mines.

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One study observed a correlation between elevated boron in the drinking water supply and the incidence of reduced birth weight and birth length among newborn babies in Argentinian Andes communities near boron and lithium mines (Igra et al., 2016). Though the correlation was significant, additional factors may have been causative, including elevated lithium in the drinking water, the low-oxygen high-altitude environment of the study area, and that nearly half of the participants chewed coca leaves during pregnancy (Bolt et al., 2017; Harari et al., 2015; Igra et al., 2016).

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Some newer research has begun to focus on boron supplementation in the human diet due to its low dietary availability and a myriad of potential health benefits. Beneficial impacts to bone health, cancer prevention, wound healing, magnesium absorption, cognitive function, chemotherapy recovery, and

840 hormone utilization have been demonstrated when boron is consumed in excess of the average dietary
841 intake, particularly in those whose diets do not include substantial fruits, vegetables, and nuts (Bakirdere et
842 al., 2010; Khaliq et al., 2018; Pizzorno, 2015).

843
844 **Evaluation Question #11: Describe all natural (non-synthetic) substances or products which may be**
845 **used in place of a petitioned substance (7 U.S.C. 6517(c)(1)(A)(ii)). Provide a list of allowed substances**
846 **that may be used in place of the petitioned substance (7 U.S.C. 6518(m)(6)).**

847
848 Since boron is an elemental substance and essential for plant health, there are no absolute substitutes for
849 boron itself. Another element on the periodic table, germanium, has been shown to replace boron in certain
850 metabolic processes (Loomis & Durst, 1992). Ishii et al. (2002) determined, however, that germanium was
851 not a viable alternative to boron in the case of cell wall reinforcement because it does not form a stable
852 cross-link of the RG-II polysaccharide (see *Action of the Substance* above). Additionally, the germanium
853 concentration on the Earth's crust is just 1.5 parts per million (ppm) on average, far lower than the average
854 occurrence of boron at 10 ppm, so it is not an economically feasible alternative (USGS Mineral Resources
855 Program, 2015).

856
857 Nonsynthetic borate mineral fertilizers may also be used in place of synthetic refined borates or boric acid.
858 Boron can be supplied to soil or plants through the application of nonsynthetic, mined colemanite (calcium
859 borate), ulexite (sodium calcium borate hydroxide), and probertite (sodium calcium borate hydroxide)
860 ores. Typically, these natural borate minerals provide for far slower release of boron due to reduced
861 solubilities, and provide less boron per volume of application in comparison with refined borates and boric
862 acid (Broschat, 2008). Unrefined borate minerals sometimes contain higher levels of arsenic, strontium,
863 aluminum, iron, and sulfates, (ETiMADEN ETIMINE USA Inc., 2018b, 2018a)¹⁸, which might be expected
864 for minerals derived from volcanic or hydrothermal processes (as described in *Source or Origin of the*
865 *Substance* above).

866
867 Borate products produced by evaporative rather than reactive mechanisms may be considered
868 nonsynthetic when following NOP 5033-1, *Guidance, Decision Tree for Classification of Materials as Synthetic or*
869 *Nonsynthetic* (NOP, 2016). However, it is difficult or impossible to compare production volumes of
870 nonsynthetic vs. synthetic products (Garrett, 1998). The limited number of competitive global producers
871 (sometimes referred to as an oligopoly) introduces uncertainties in borate production data. High-purity,
872 refined (synthetic) products have tended to prevail in the marketplace since the mid-1990s (Garrett, 1998).

873
874 OMRI currently lists products in the following categories (OMRI, 2021):

- 875 • Borates, nonsynthetic: 6 products
- 876 • Borax (Sodium Tetraborate), nonsynthetic: 2 products
- 877 • Boron Products, synthetic: 69 products¹⁹

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879 **Evaluation Question #12: Describe any alternative practices that would make the use of the petitioned**
880 **substance unnecessary (7 U.S.C. 6518(m)(6)).**

881 Given the prevalence of boron deficiency around the world, the only alternative to direct boron application
882 for plants grown in deficient areas is enhancing the uptake of boron by plants (Shireen et al., 2018). Boron is
883 ubiquitous in the Earth's crust, but typically only at very low concentrations (Woods, 1994), so enhancing
884 plant uptake in deficient areas could help meet boron needs without requiring the application of boron
885 fertilizer (Shireen et al., 2018).

886
887 Shireen et al. (2018) have proposed several methods to improve boron uptake, including selective breeding,
888 grafting of plants onto plant rootstocks known to express enhanced boron uptake or plants with deeper
889 root systems, application of growth regulators or mycorrhizal fungi, and through the use of

¹⁸ The ETiMINE USA Inc. website contains composition data for ulexite and colemanite consumer products. Of note, their ulexite product contains 30 ppm arsenic, 0.1% aluminum oxide, 0.6% strontium oxide, 0.02% iron oxide, and 0.2% sulfate. Their colemanite contains 25 ppm arsenic, 0.25% aluminum oxide, 1.15% strontium oxide, 0.04% iron oxide, and 0.3% sulfate.

¹⁹ Many of these are also listed in other categories, indicating that these are blended fertilizer products.

890 nanotechnology. As described above, boron may leach down through the soil in wet environments (Brdar-
891 Jokanović, 2020), so deeper root systems may reach the deeper leached boron. Selective breeding of plants
892 with deeper or more extensive root morphology may help alleviate boron deficiency near the surface
893 (Shireen et al., 2018). Citrus, stone fruits, grapes, pistachios, and tomatoes have exhibited increased tissue
894 boron concentration resulting from grafting onto other varieties known to uptake boron more efficiently
895 (Shireen et al., 2018).

896
897 The addition of humic substances, amino acids, composted sewage sludge, and seaweed extracts to the soil
898 was shown to increase the acquisition of some micronutrients (possibly through complexing mechanisms),
899 but boron uptake specifically was not explored (Shireen et al., 2018).

900
901 Mycorrhizal fungi are essential elements of the soil for many plant nutrient uptake mechanisms. Lavola et
902 al. (2011) described significant increases in the boron concentrations of ectomycorrhizal fungi in plots
903 fertilized with boron, indicating that these fungi may store soil boron despite little evidence that fungi
904 require boron for growth. The authors were not able to conclude whether or not that stored boron would
905 be mobile and available to plants (Lavola et al., 2011).

906
907 Some bacterial species have also been shown to absorb high levels of boron in soils, and these might be
908 utilized to improve available boron mobility to plants as well (Shireen et al., 2018). Novel nanomaterials,
909 such as nanoparticle chitosan and absorbent polymers, have been shown to improve micronutrient uptake,
910 reduce fertilizer needs, increase water retention, and reduce leaching, which could help to reduce boron
911 fertilization requirements (Shireen et al., 2018).

912

Report Authorship

913

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915 approval of this report:

916

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923
924 All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11 – Preventing
925 Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

926

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