United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/petitioned-substances

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Potassium Chloride

Crops

Identification of Petitioned Substance

Chemical Names:
hydrochloric acid, potassium salt (1:1); KCl; monopotassium chloride; sylvite

Other Names:
chlorure de potassium [French]; cloruro potásico [Spanish]; kaliumchlorid [German]; kelp salt; MOP; muriate of potash; potash; salt substitute

Trade Names *(not limited to)*:
Crystal Granular 0-0-60; Crystal Turf; Kali; Pegasus Fine; Pegasus Granular; Red Granular 0-0-60; Red Standard 0-0-60; White Standard 0-0-62

CAS Numbers:
7447-40-7: potassium chloride
14336-88-0: sylvite

Other Codes:
UNII: 660YQ98I10
EC number: 231-211-8
NIOSH RTECS number: TS8050000

Summary of Petitioned Use

In 1995, the National Organic Standards Board (NOSB) recommended that potassium chloride should *not* be placed on the list of nonsynthetic substances *prohibited* for use in organic crop production (NOSB, 1995). The NOSB also noted that only mined sources of potassium chloride are considered nonsynthetic, and that its "use shall be in a manner that prevents excessive chloride accumulation in soils. Soil testing may be required in both treated and untreated adjacent soils to verify absence of chloride build-up."

In June 2000, the NOSB recommended that the National Organic Program (NOP) delete reference to "mined minerals of high solubility" at §205.203(d)(2) of the *Soil fertility and crop nutrient management practice standard*, and instead "replace with NOSB recommendations regarding specific materials within this category" (NOSB, 2000). However, in the introduction to the draft of the Final Rule, the NOP stated that they modified the NOSB's request, retaining a category for these types of materials as different from other nonsynthetic substances (NOP, 2000):

> At its June 2000 meeting, the NOSB recommended that the NOP delete general references to mined substances of high solubility from the final rule, and incorporate the NOSB's specific annotations for materials of this nature. We have adopted this recommendation by retaining a place for mined substances of high solubility in the soil fertility and crop nutrient management practice standard but restricting their use to the conditions established for the material as specified on the National List of prohibited natural substances. **Under this approach, mined substances of high solubility are prohibited unless used in accordance with the annotation recommended by the NOSB and added by the Secretary to the National List.** We deleted the provision from the proposed rule that use of the substance be "justified by soil or crop tissue analysis." The final rule contains two materials—sodium nitrate and potassium chloride—that may be used in organic crop production with the annotations developed by the NOSB.

As a result, the final rule included a practice standard at 7 CFR 205.203 that limited the application of mined substances of high solubility to only those found on the National List (emphasis added):

> (d) A producer may manage crop nutrients and soil fertility to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances by applying:…

> (3) A mined substance of high solubility: Provided, That, the substance is used in compliance with the conditions established on the National List of nonsynthetic materials <u>prohibited</u> for crop production;

Potassium chloride was included on the National List of nonsynthetic substances prohibited for use in organic production, at § 205.602(e) (NOP, 2000), where it remains today:[1]

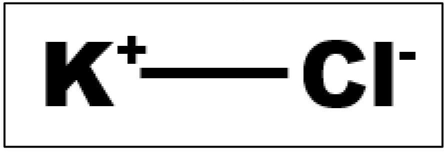
> The following nonsynthetic substances may not be used in organic crop production:
>
> (e) Potassium chloride - unless derived from a mined source and applied in a manner that minimizes chloride accumulation in the soil.

Characterization of Petitioned Substance

<u>Composition of the Substance:</u>

Potassium chloride is a metal halide salt composed of one potassium cation and one chloride anion with the formula KCl (National Center for Biotechnology Information, n.d.). Chemically, potassium chloride is defined as a binary ionic compound formed from the reaction of an alkali metal ion and a halogen ion (Zumdahl & DeCoste, 2017). Potassium chloride is similar to sodium chloride, or common table salt, in terms of crystal structure (Zumdahl & DeCoste, 2017).

Figure 1. Chemical Structure Depiction of Potassium Chloride



Potash is a generic term referring to several soluble potassium salts (naturally occurring or chemically produced) that provide plant-available potassium (K_2O). These soluble potassium salts include potassium chloride (muriate of potash, MOP), potassium sulfate (sulfate of potash, SOP), and potassium magnesium sulfate (sometimes known as sulfate of potash magnesia, SOPM, or langbeinite) (USGS, 2020). Muriate of potash typically refers to an agricultural grade of potassium chloride which might contain up to 5% sodium chloride (USGS, 2020). Potassium chloride made up approximately 20% of total potash production in the United States in 2019 (USGS, 2020).

Several grades of potassium chloride are produced, mostly designated by grain size (Kafkafi et al., 2001):

- Granular or coarse: 0.595-3.36 mm particle size. Granular grade potassium chloride is suitable for single-nutrient applications, or for mechanical blending with other fertilizer materials.
- Standard: 0.210-1.19 mm particle size. Standard grade is suitable for single-nutrient application, hand blending, or granulated mixed fertilizer blends.
- Fine: 0.105-0.420 mm particle size. Fine grade is typically useful in the production of granulated blended fertilizers or for production of potassium sulfate.
- Soluble/suspension: 0.105-0.420 particle size. Soluble/suspension grade has the same grain size range as fine grade, but is a purer product suitable for fully dissolved liquid fertilizer blends, in single-nutrient liquid applications, of for the production of potassium sulfate.
- Industrial/chemical; this grade does not carry a size designation, and is a nearly pure product only manufactured by a few producers. Only about 4-5% of all potash produced is industrial grade.

<u>Source or Origin of the Substance:</u>

The average concentration of potassium in the Earth's crust is approximately 25,000 ppm, almost wholly locked in aluminum silicate minerals like feldspar and mica (Kafkafi et al., 2001). Only about 2% of

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[1] Originally 7 CFR 205.602(g)

potassium in the crust is in exchangeable forms in soils. Crustal chloride (including potassium chloride, other chloride-containing minerals, and chloride dissolved in surface waters) concentrations are approximately 1,500 ppm, but the level is elevated in the oceans due to chloride's tendency to weather and solubilize from minerals easily (Kafkafi et al., 2001).

The naturally occurring mineral form of potassium chloride is known as sylvite, but it typically occurs in mixed salt deposits consisting of various other minerals including sylvinite (a sylvite and halite, NaCl, mixture); carnallite (a hydrated double salt of potassium chloride and magnesium chloride with the formula $KCl \cdot MgCl_2 \cdot 6H_2O$); kainite (a hydrated potassium and magnesium sulfate chloride with formula $KMg(SO_4)Cl \cdot 3H_2O$); and langbeinite (potassium magnesium sulfate, with formula $K_2Mg(SO_4)_3$) (Patnaik, 2003; Schultz et al., 2000).

As natural saltwater solutions evaporate, certain salt minerals precipitate in a specific order depending on their thermodynamic properties and concentrations. In general, first calcium carbonates form, then calcium sulfate (gypsum) crystallizes, depleting all of the calcium in the brine, followed by sodium chloride salt (Drever, 1997; Schultz et al., 2000). Finally, chlorides and sulfates of potassium and magnesium crystallize (Broughton, 2019; Drever, 1997; Schultz et al., 2000).[2]

The ultimate source of potassium ions in the oceans is the result of the weathering of potassium-bearing rocks like feldspars and micas (Schultz et al., 2000). Large amounts of chloride ions in seawater are thought to arise from chlorine released by undersea mid-ocean ridge volcanism, or by continental or "hotspot" volcanic processes and subsequent transport back to oceans by sedimentation and erosion (Schilling et al., 1978).

In the United States, approximately 50% of potash production occurs at operations in New Mexico (as of 2019), but significant deposits occur in Utah, Montana, North Dakota, Arizona, and Michigan (USGS, 2020). Globally, the largest potash-producing countries are Canada, Russia, Belarus, China, Germany, and Israel (USGS, 2020). Canada, the largest producer, is estimated to hold 50% of the world's potash reserves (Warren, 2010). Potassium ores, at current extraction rates of known deposits, are expected to last another 400 years (Ciceri et al., 2015).

Three geologic environments contain the majority of extractable potassium chloride: 1) evaporites, 2) brines, and 3) seawater.

Evaporites

Major potash deposits are invariably of marine origin (Schultz et al., 2000). As large bodies of seawater are isolated from the ocean by tectonic movements and sea level changes, the salt concentration increases through solar evaporation, sometimes becoming saturated and precipitating salt beds on the shore or lake bottom (Broughton, 2019; Warren, 2010). Climate adjustments over geologic time scales provide more or less atmospheric water, resulting in redissolution or later precipitation of salt beds as the saturation levels change, which leads to numerous salt deposits between clay layers (Schultz et al., 2000; Warren, 2010). In arid environments, eventually little to no water remains and mineral deposits are left behind (Schultz et al., 2000; Warren, 2010). These interbedded deposits are often significant and they are responsible for the massive potassium reserves found beneath the Canadian prairie, in Belarus, Russia, and New Mexico, USA (Broughton, 2019; Warren, 2010).

Due to the lack of notable deposits of potassium and magnesium chlorides forming in the present day, it is thought that some change to seawater chemistry occurred over hundreds of millions of years (Broughton, 2019; Lowenstein et al., 2001).[3] In the past, calcium carbonate and potash deposits were

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[2] This sequence of mineralization is simplified (Drever, 1997). A large number of factors can affect the sequence depending on environment and other minerals present (Drever, 1997). The general mineralization cycle is known as the Hardie-Eugster model and assumes a single stage, complete evaporation event (Drever, 1997; Hardie & Eugster, 1970). In nature, cyclic wetting and drying events also greatly complicate the system (Drever, 1997).

[3] Research with mineral fluid inclusions indicates that substantial changes to dissolved ion concentrations in the oceans occurred throughout the Phanerozoic Eon (about 541 million years ago to the present), particularly during the Cambrian (541 million years

commonly associated with evaporation of seawater, whereas today evaporites are more calcium sulfate (gypsum) rich (Broughton, 2019).

Brines

Brines may exist on the surface in inland lakes, such as the Great Salt Lake in Utah, or underground as groundwater beneath dry salt playas, such as the Great Salt Lake Desert west of the lake (Boden et al., 2016; Rupke, 2012). For surface lakes, various methods based on solar evaporation and beneficiation are used to isolate potassium salts (Schultz et al., 2000). In subsurface deposits, groundwater becomes enriched with potassium by the dissolution of solid beds of evaporite salts (Rupke, 2012). These brines can be exploited through well pumping (Rupke, 2012; USGS, 2020).

For very deep evaporite deposits, it may not be feasible to extract solid salts, necessitating solution mining techniques (Broughton, 2019). Fresh water is injected into the ore zones to dissolve the salts, followed by the injection of sodium chloride brine. The resulting super-saturation of sodium chloride causes precipitation of halite in the chamber and preferentially dissolves the potassium chloride in the ore, which can be retrieved (Broughton, 2019).

As solid subterranean salt deposits are extracted, groundwater may also flood the chambers, sometimes making them impossible to mine with conventional methods, as in some areas of the Canadian prairie evaporite zones (Broughton, 2019). These flooded mines are sometimes converted to solution mining operations where brine is the target (Broughton, 2019).

Seawater

Potassium and chloride ions make up a significant portion of the dissolved elements in seawater, sixth and first in abundance, respectively (Drever, 1997).[4] Compared to evaporite and brine deposits, however, the potassium content in seawater is not great enough to currently make economical extraction possible (Ciceri et al., 2015; Schultz et al., 2000). The prevalence of seawater evaporation-derived potash deposits in geologic history does not necessarily indicate that potassium was more concentrated in ancient seas. Instead, the crystallization sequence is affected by relative concentrations of magnesium, calcium, sodium, and carbonate in seawater through complex thermodynamic equilibria (Lowenstein et al., 2001).

See *Evaluation Question #2* for further information on potassium chloride production and refining.

<u>Properties of the Substance:</u>

Potassium chloride is freely soluble in water, soluble in ether, glycerol, and alkalies, and slightly soluble in alcohol (Patnaik, 2003). Pure potassium chloride forms cubic crystals resembling common table salt (National Center for Biotechnology Information, n.d.). Natural potassium chloride (sylvite) minerals may occur as massive rock crystals in a variety of colors resulting from impurities, most often reddish from iron oxide (National Center for Biotechnology Information, n.d.). See *Table 1* for Physical and Chemical Properties.

Potassium chloride tends to cake and the crystals often crack during transport and handling, producing a dust nuisance (Kafkafi et al., 2001).

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ago to 485.4 million years ago), Silurian (444 million years ago to 419.2 million years ago), and Cretaceous (145 million years ago to 66 million years ago) periods, likely associated with periods of high volcanic activity and high sea levels (Lowenstein et al., 2001).

[4] The concentration of chloride in seawater is approximately 19,350 ppm, and potassium is 399 ppm (Drever, 1997).

Table 1: Physical and Chemical Properties of Potassium Chloride

Property	Value[a]
Physical State and Appearance	cubic crystals, powder, or granular crystalline mass
Odor	odorless
Taste	saline, bitter
Color	colorless, white, bluish, or yellowish red
Molecular Weight	74.55 g/mol
Density	1.98 g/cm^3
pH	7
Solubility	almost completely water soluble
Boiling Point	1500 °C (sublimes)
Melting Point	770 °C
Stability	hygroscopic (prone to moisture absorption by air); incompatible with strong oxidizers and strong acids
Reactivity	not typically very reactive; reacts with sulfuric acid

[a]Source: (Dana, 1898; National Center for Biotechnology Information, n.d.; Royal Society of Chemistry, 2022)

Specific Uses of the Substance:

Greater than 90% of potassium chloride produced is used in fertilizer applications, as potassium chloride itself or in the production of potassium sulfate (Patnaik, 2003; Schultz et al., 2000). Due to its high solubility over a wide temperature range, and low reactivity with other dissolved ions when compared to potassium sulfate, potassium chloride is particularly useful in fertigation systems (Kafkafi et al., 2001).

Several studies indicate that split applications of potassium chloride throughout the growing season positively affect the quality and yield of rice, wheat, and peanuts (Annadurai et al., 2000; Mathukia et al., 2014; Sanadi et al., 2018; Surendran, 2006). The resulting increases in yield and quality have been interpreted to indicate that a single early dose of potassium fertilizer (basal application) leads to a deficiency later in the season due to rapid uptake of potassium by plants or soil leaching throughout the season (Annadurai et al., 2000; Sanadi et al., 2018; Surendran, 2006). Other studies have shown no significant effect on yield of potatoes between pre-planting (basal) potassium chloride application and split applications (Kumar et al., 2007; Mohr & Tomasiewicz, 2012). Kumar et al. (2007) concludes that a single basal application is preferable in potatoes.

Some research has shown promise that potassium chloride may be effective in the control of fungal and bacterial disease (Feng & Zheng, 2006; Kafkafi et al., 2001; Mann et al., 2004). Foliar applied potassium chloride was effective in reducing the severity of leaf blotch in winter wheat caused by genus *Septoria* (Mann et al., 2004), and induced systemic resistance to powdery mildew in cucumber (Kafkafi et al., 2001).[5] Feng and Zheng (2006) describe a synergistic fungicidal effect when adding potassium or sodium chloride to essential oils used for the control of *Alternaria alternata* in tomato. Kafkafi (2001) lists several studies indicating potassium fertilization can reduce infection severity in soybeans, potatoes, corn, oilseed, rice, and cotton. Similarly, potassium chloride in particular aids in pathogen resistance due to the chloride rather than the potassium content in many plant/pathogen systems (Kafkafi et al., 2001). See *Table 2* below.

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[5] Induced systemic resistance refers to the effect whereby plants gain resistance to pathogens or pests by previous infection, beneficial microbes, or the application of specific chemicals, generally across a broad spectrum of potential risks (Pieterse et al., 2014).

Table 2. Pathogen Resistance Associated with Chloride in Select Plant and Pathogen Systems. Adapted from Kafkafi et al., (2001)

Crop	Disease	Pathogen
Asparagus	crown and root rot	*Fusarium oxysporum*
Barley	common root rot	*Cochliobolus sativus*
Celery	*Fusarium* yellowing	*Fusarium oxysporum*
Coconut	gray leaf spot	*Pestalozzia palmarum*
Corn	stalk rot	*Diplodia maydis / Gibberella zeae*
Pearl millet	downy mildew	*Sclerospora graminicola*
Rice	stem rot	*Helminthosporium sigmoideum*
Rice	sheath blight	*Rhizoctonia solanis*
Sugar beet	root or crown rot	*Rhizoctonia solanis*
Wheat	common root rot	*Helminthosporium sativum*
Wheat	glum blotch	*Septoria nodorum*
Wheat	leaf rust	*Puccinia recondite*
Wheat	stripe rust	*Puccinia striiformis*
Wheat	powdery mildew	*Erysiphe graminis*
Wheat	“take-all rot”	*Gaeumannimyces graminis*
Wheat	tanspot	*Pyrenophora tritici-repentis*

Potassium chloride is often used as a salt substitute in foods (van Buren et al., 2016). The modern diet typically provides an excess of sodium, which is associated with higher risks of heart disease, and potassium chloride is becoming increasingly more popular as a replacement for sodium sources in the food industry (van Buren et al., 2016).

Approved Legal Uses of the Substance:

Food and Drug Administration (FDA)

Potassium chloride is on the FDA list of “Direct Food Substances Affirmed as Generally Recognized as Safe” at 21 CFR 184.1622 with no limitation other than current good manufacturing practice when used as a flavor enhancer, flavoring agent, nutrient supplement, pH control agent, stabilizer, or thickener. It may also be used in infant formula. It is also considered “Generally Recognized as Safe” in animal feed at 21 CFR 582.5622.

In 2020, FDA issued a guidance indicating that potassium chloride could be referenced as “potassium salt” on product ingredient statements to make it clear to consumers that the substance was included in the formulation as a sodium chloride salt substitute (Center for Food Safety and Applied Nutrition, 2020).

Environmental Protection Agency (EPA)

Potassium chloride is exempt from the requirement of a tolerance as either an active or inert ingredient in pesticide formulations at 40 CFR 180.950, and is classified as List 4A, a minimal risk inert ingredient, on 2004 EPA List 4 (US EPA, 2004).

United States Department of Agriculture (USDA)

The Food Safety Inspection Service (FSIS) permits mixtures of sodium chloride, potassium chloride, and sodium gluconate for use in muscle meats and poultry for sodium reduction, and mixtures of sodium chloride, sodium ferrocyanide, potassium chloride, magnesium carbonate, sodium nitrite, medium chain triglycerides, and sodium gluconate for use in whole muscle meats, meat products, and poultry products for sodium reduction and curing at up to 3% of a product formulation (Food Safety Inspection Service, 2021).

Action of the Substance:

Potassium

In general, as a primary plant macronutrient, potassium is essential in ensuring successful plant growth. Potassium chloride is extremely soluble, making the potassium ion easily available for uptake by plants (Gowariker & Krishnamurthy, 2009). The potassium ion is also extremely mobile in plant tissues (Oosterhuis et al., 2014; Xu et al., 2020). Nitrogen and phosphorus, the other two primary plant macronutrients, are components of biomolecules and have received more attention than potassium, which mostly occurs as a free cation (Sardans & Peñuelas, 2021). However, the relative lack of study does not indicate reduced importance to plant physiology, and the potassium ion is second only to nitrogen as a component of leaf biomass, making up as much as 10% of plant dry weight (Sardans & Peñuelas, 2021; Sustr et al., 2019).

Potassium serves a wide variety of functions in plant biology, including the activation of over 60 enzymes necessary for protein synthesis, sugar transport, photosynthesis, pH regulation, and nitrogen and carbon metabolism (Oosterhuis et al., 2014; Sardans & Peñuelas, 2021; Xu et al., 2020). Potassium is critical for regulation of osmotic pressure and electrochemical potential across the cell membrane, having a role in the control of stomata-opening, helping to regulate gas and water movement into and out of the cell (Ciceri et al., 2015; Sardans & Peñuelas, 2021; Xu et al., 2020). In chloroplasts, potassium improves the efficiency of photosynthesis by contributing to the structure of stroma lamellae (the connective tissues between cellular photosynthesis centers) (Sardans & Peñuelas, 2021). Cell expansion is also regulated by potassium as a result of internal cell pressure control (Sustr et al., 2019). The concentration of potassium in root tissue also affects the flow of sap from roots to shoots by cellular pressure regulation (Sardans & Peñuelas, 2021).

Plant tissue absorbs the potassium ion from the soil through the action of several proteins with potassium affinity (Kafkafi et al., 2001; Sardans & Peñuelas, 2021). The specific potassium transporting proteins differ between plant species, soil potassium concentration, salinity, and pH (Sardans & Peñuelas, 2021).

Potassium deficiency presents numerous detrimental issues to plants, particularly in stress response (Sardans & Peñuelas, 2021). Plants under environmental stress require greater amounts of potassium and simultaneously suffer stress from reactive oxygen species, thereby damaging cells (Sardans & Peñuelas, 2021). Sufficient potassium supply promotes the formation of antioxidants during drought or elevated salt conditions (Sardans & Peñuelas, 2021).

Sardans and Peñuelas (2021) describe a complex interplay between stressed plants and potassium concentration in plant tissues and the surrounding environment. When plants are stressed during droughts, floods, or by high salt content in the soil, potassium is transferred from roots back to soil, harming the plant's ability to endure stress (Sardans & Peñuelas, 2021). However, in response, genes encoding high-affinity potassium channels are activated, replenishing potassium levels and improving the plant's stress response (Sardans & Peñuelas, 2021). Deficiency also stimulates the formation of ethylene, which plays an important role in plant stress response through growth suppression as a survival mechanism (Oosterhuis et al., 2014; Vaseva et al., 2018).

Potassium deficiency is correlated with higher levels of sugars and amino acids in plant tissue, thereby attracting pests (Sardans & Peñuelas, 2021). Adequate potassium concentration in plant tissue helps defend against cold stress by depressing the freezing point of sap, so a deficiency can lead to extensive damage in freezing temperatures as well (Oosterhuis et al., 2014).

Potassium also plays a role in growth promotion through stimulation of ATPase (the enzyme that catalyzes the breakdown of adenosine triphosphate in cells, providing energy), ultimately promoting cell wall loosening and allowing cell growth (Oosterhuis et al., 2014; Xu et al., 2020). Cell walls are rigid structures, so loosening is essential for cell expansion rather than thickening of the rigid wall itself (Oosterhuis et al., 2014). Cell elongation is controlled in part by the plant growth promoters auxin, gibberellin, and cytokinin, and synergistic effects with potassium have been reported (Oosterhuis et al., 2014). The application of potassium fertilizers has also been shown to decrease evolution of ethylene and abscisic acid, both important plant growth hormones (Oosterhuis et al., 2014; Vaseva et al., 2018).

Important interactions occur between nitrogen and potassium in plants, but uncertainties about this complex system remain (Xu et al., 2020). Potassium deficiency leads to decreases in nitrogen incorporation into proteins (Oosterhuis et al., 2014). However, each plant type appears to demonstrate different interactions between nitrogen and potassium (Xu et al., 2020). In general, optimum potassium levels contribute to greater efficiency in nitrate uptake and use (Oosterhuis et al., 2014; Xu et al., 2020). Fertilization with nitrogen spurs rapid plant growth, which can also lead to weakened stalks, and the application of potassium fertilizers counteracts the tendency of plants to fall over by supporting lignification and increasing cell wall thickness (Kafkafi et al., 2001).[6]

Chloride

Chloride refers to the negatively charged ion of chlorine, an elemental substance. Like potassium, chloride is soluble and highly mobile in plant tissues (Gowariker & Krishnamurthy, 2009). Typically, the chloride content of soils is a function of soil management practices because of its high mobility in soil water (Kafkafi et al., 2001). Most growing environments contain adequate chloride for plant needs (Colmenero-Flores et al., 2019).

The majority of chloride available to plants ultimately comes from the oceans (Kafkafi et al., 2001). Near the coast, wind-borne spray, rain, and snow supply plentiful chloride, but atmospheric chloride deposition decreases exponentially with distance from the ocean (Kafkafi et al., 2001). The atmospheric supply of chloride is significantly depressed in mid-continental environments such the Great Plains of the USA, except for regions near industrialized areas, which receive ample chloride from the burning of coal (Kafkafi et al., 2001).

Chloride is essential in the water-splitting reaction that occurs during photosynthesis, and it is an essential nutrient for plant growth despite sometimes not being identified as a micronutrient (Gowariker & Krishnamurthy, 2009). Recent research indicates that chloride may be more appropriately identified as a beneficial (but not essential) macronutrient due to the levels that can accumulate in plant tissues comparable to other macronutrients, and benefits to plant growth performance (Colmenero-Flores et al., 2019).

During photosynthesis, water molecules are split, releasing oxygen (Yano & Yachandra, 2014). This reaction is catalyzed by a manganese and calcium complex, which requires two chloride ions to maintain its structure (Colmenero-Flores et al., 2019; Yano & Yachandra, 2014). Chloride also works to regulate some enzymes essential for nitrogen metabolism and cellular energy creation at micronutrient levels (Colmenero-Flores et al., 2019). Natural background chloride levels are typically more than sufficient to meet these plant requirements (Colmenero-Flores et al., 2019).

Fertilization with chloride solutions at greater concentrations than the required micronutrient level, but below toxic levels, has been shown to promote plant growth (Colmenero-Flores et al., 2019). Chloride concentration in plant tissues fertilized with chloride rival plant toxicity levels without demonstrating plant injury (Colmenero-Flores et al., 2019). Colmenero-Flores et al. (2019) state that *"Recent reports have shown that prolonged treatments with a nutrient solution containing* Cl^- *in the low milli-molar range (e.g., 4-5 mM* Cl^-*) determine leaf* Cl^- *accumulation values between 25 and 50* $mg \cdot g^{-1}$ *DW [dry weight] in different plant species…Despite these* Cl^- *contents clearly exceeding the critical toxicity values mentioned…these plants develop normally and grow without apparent symptoms of stress."*

Negatively charged chloride anions work to balance electrical charge in cell vacuole fluid, which can accumulate positively charged calcium and sodium ions (Colmenero-Flores et al., 2019). While it was once assumed that other anions could serve the same purpose, more recent evidence points to a preferential status of chloride (Colmenero-Flores et al., 2019).

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[6] The tendency of plants to fall over due to a loss in mechanical strength in stalks is known as "lodging" (Kafkafi et al., 2001).

Like potassium, chloride plays an important role in ion transport and regulation of osmotic pressure, and water flux into and out of plant cells (Colmenero-Flores et al., 2019). Colmenero-Flores et al. (2019) propose that higher levels of chloride in plant tissues increase water storage capacity, reducing damage by dehydration. As with potassium, chloride also interacts with nitrogen, reducing the rate of nitrification in acidic soils, which helps to increase nitrogen use efficiency by plants (Kafkafi et al., 2001). Chloride also has an antagonistic relationship with nitrate; increasing concentrations of each in plant tissues reduces the uptake of the other (Kafkafi et al., 2001).

Excessive chloride exposure is toxic to plants, causing leaf thickening and rolling when absorbed through the soil, and salt burn when applied in a foliar spray (Gowariker & Krishnamurthy, 2009).

Chlorine deficiency results in wilting, reduced root growth, dehydration, and chlorosis (Gowariker & Krishnamurthy, 2009).[7] Deficiencies in chloride tend to only occur in deep inland areas, and in crops with high chloride requirements, since sufficient chloride is typically supplied by atmospheric precipitation associated with the ocean (Kafkafi et al., 2001). Plant types that may exhibit deficiency include wheat, sugar beet, kiwi, palm, or plants grown in arid, leached soils in low precipitation areas (Kafkafi et al., 2001).

For additional information regarding chemical interactions, see *Evaluation Question #7.*

Combinations of the Substance:

The majority of potassium chloride used for fertilization is within formulations of mixed fertilizer blends (Kapusta, 1968). All of the agricultural grades of potassium chloride described under *Composition of the Substance* above are approximately 95% potassium chloride, with the remaining 5% consisting of mostly sodium chloride and impurities of magnesium chloride, bromide, and alkaline earth metal sulfates (Kafkafi et al., 2001; Organisation for Economic Co-operation and Development (OECD), 2001; USGS, 2020). Industrial grades of potassium chloride are 98-99% pure, with notable impurities of sodium, bromine, sulfate, calcium, and magnesium (Kafkafi et al., 2001). Agricultural grades of potassium chloride are often treated with amines or oils to reduce caking and dusting during transport and handling (Kafkafi et al., 2001).

In soil with very low potassium, coating potassium chloride with humic acid before application can result in increased yield of soybean and corn, which is thought to be a function of humic acid reducing potassium leaching and depletion (Rosolem et al., 2017). Potassium easily leaches in light-textured, clayey soils with low cation exchange capacity (Rosolem et al., 2017).

Irrigation with saline water, when used alongside potassium chloride fertilizers, greatly increases the risk of salt buildup in soils (Kafkafi et al., 2001). When water distribution is uniform, salt accumulation is somewhat controlled by leaching from the root zone since fewer areas in the field are dry; dissolved salt more easily leaches from the soil rather than recrystallizing in dry areas (Kafkafi et al., 2001). Combining drip irrigation techniques with the use of plastic mulch is useful to control salt accumulation as a function of reduced evaporation and uniform water distribution (Kafkafi et al., 2001).

Synthetic potassium hydroxide (KOH) can be prepared from potassium chloride, and appears on the National List as follows:

- 7 CFR 205.601(j)(1), As plant or soil amendments. Potassium hydroxide is permitted as an alkali extractant for aquatic plant products.
- § 205.601(j)(3), As plant or soil amendments. Potassium hydroxide is permitted as an alkali extractant for humic acids.

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[7] Though the term “chlorosis” may seem like it refers to chlorine, the etymology of the word is in reference to the Greek word for the color pale green, khlōrós. Gaseous chlorine is a yellowish-green color, and chlorosis is characterized as a yellowing of plant leaves (Gowariker & Krishnamurthy, 2009).

- § 205.605(b), Synthetic materials permitted as nonagricultural (nonorganic) substances allowed as ingredients in or on processed products labeled as "organic" or "made with organic (specified ingredients or food group(s)."

Potassium hydroxide is produced by electrolysis of potassium chloride brine, creating hydrogen and chlorine gas as by-products (Kapusta, 1968; Patnaik, 2003).

Status

Historic Use:

Potassium was recognized as one of the most valuable fertilization substances in 1840 by German scientist Justus von Liebig (Schultz et al., 2000). The development of many potash mines followed through the latter part of the 19th century, mostly in Europe (France and Germany) (Ciceri et al., 2015; Schultz et al., 2000). In the 20th century, potash deposits in Russia and the United States began to be exploited due to trade barriers with Germany during World Wars I and II (Ciceri et al., 2015; Schultz et al., 2000). The vast potash reserves in Canada were discovered in the mid-20th century (Schultz et al., 2000).

Since potassium is an essential nutrient for plants, the market for potassium fertilizers has been robust, particularly in the case of soluble mineral forms like potassium chloride, or other potash substances that are easily and quickly assimilated by plants (Ciceri et al., 2015). Using United States Geological Survey estimates for 2019, approximately 7.74 million tons of potassium chloride were used in crop fertilization that year, either as the chloride salt alone or as a precursor in the production of potassium sulfate (Patnaik, 2003; Schultz et al., 2000; USGS, 2020).[8]

Organic Foods Production Act, USDA Final Rule:

The Organic Foods Production Act of 1990 (OFPA) states the following:

> SEC. 2109 [7 U.S.C. 6508] PROHIBITED CROP PRODUCTION PRACTICES AND MATERIALS.
> …
> (b) SOIL AMENDMENTS.-For a farm to be certified under this title, producers on such farm shall not-
> …
> (2) use as a source of nitrogen: phosphorous, lime, potash, or any materials that are inconsistent with the applicable organic certification program.

Potash is not permitted when used inconsistently with the applicable regulations.

Potassium chloride appears on the National List of *Nonsynthetic substances prohibited for use in organic crop production* at 7 CFR 205.602(e) of the National Organic Program (NOP) regulations with the following annotation:

> Potassium chloride – unless derived from a mined source and applied in a manner that minimizes chloride accumulation in the soil.

As a mined mineral of high solubility, the *Soil fertility and crop nutrient management practice standard* at § 205.203 also applies. See *Summary of Petitioned Use* above for a discussion of the use of soluble minerals in organic crop production.

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[8] This is based on the estimate by Patnaik (2003) that 90% of potassium chloride produced is used for fertilization, and USGS' estimate of 43 million tons of potash production in 2019, along with the USGS estimate that 20% of potash production results in potassium chloride.

Potassium chloride also appears at § 205.605(a) as a nonagricultural, nonsynthetic substance allowed as an ingredient in processed "organic" or "made with organic (specified ingredients or food groups)" products.

Potassium chloride is permitted as a nonsynthetic livestock feed additive or supplement by § 205.237(a) and is not prohibited by § 205.604, *Nonsynthetic substances prohibited for use in organic livestock production*. Synthetic potassium chloride is permitted as a livestock feed additive used for enrichment or fortification by § 205.603(d)(2), *Synthetic substances allowed for use in organic livestock production,* when FDA approved.

Synthetic potassium chloride is permitted as an inert ingredient for use with allowed active pesticide ingredients in organic crop production at § 205.601(m)(1) due to its appearance on 2004 EPA List 4A, *Inerts of Minimal Concern* (US EPA, 2004).

International

Canada, Canadian General Standards Board – CAN/CGSB-32.311-2020 Organic Production Systems Permitted Substances List

The Canadian Organic Standards (COS) permit the use of potassium chloride as a soil amendment substance used in crop production (Canadian General Standards Board (CGSB), 2020). The *Organic production systems Permitted Substances Lists, Table 4.2* in CAN/CGSB-32.311-2020 state the following under the listing for "Potassium" (Canadian General Standards Board (CGSB), 2020):

> The following potassium sources are permitted:
> …
> c) potassium chloride-muriate of potash or rock potash. The use of potassium chloride shall not cause salt build-up in soil through repeated application;

Potassium sulphate also appears under the "Potassium" listing in PSL Table 4.2, with the annotation stating that it "shall be produced by evaporating brines from seabed deposits or combining mined minerals using ion exchange. Potassium sulphate made using sulphuric acid as a reactant is prohibited" (Canadian General Standards Board (CGSB), 2020). The Organic Federation of Canada's Standards Interpretation Committee (SIC) provides an opportunity for the public to submit questions about the Canadian Organic Standards and published the following (Organic Federation of Canada Standards Interpretation Committee, 2022):

> **Can potassium sulphate which has not been mined, but manufactured by combining mined potassium chloride, mined sodium sulphate and water, be used as a soil amendment in accordance with the PSL (166)?**
> Yes. Potassium sulphate produced from combining mined minerals using ion exchange is permitted (see Potassium d), PSL, Table 4.2);. Potassium sulphates made using sulphuric acid as a reactant are prohibited.

CODEX Alimentarius Commission – Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)

The Codex guidelines include "Rock potash, mined potassium salts (e.g., kainite, sylvinite)"in Table 1, substances for use in soil fertilizing and conditioning, with the compositional requirement that they must be less than 60% chlorine (FAO, 2007). Sylvinite is the mixed salt of sodium chloride and potassium chloride (halite and sylvite).

European Economic Community (EEC) Council Regulation – EC No. 834/2007, 889/2008, 2018/848 and 2021/1165

Crude potassium salt or kainit is permitted under "fertilisers and soil conditioners" at Annex 1 of the EC Council Regulations for organic production and handling in EC No. 889/2008 (European Parliament, Council of the European Union, 2008). The description refers to "products as specified in point 1 of Annex IA.3 of Regulation 2003/2003 (European Parliament, Council of the European Union, 2008). The referenced Annex contains muriate of potash as a permitted potassic fertilizer with the following descriptions (European Parliament, Council of the European Union, 2003):

- Data on method of production and essential ingredients: Product obtained from crude potassium salts and containing potassium chloride as its essential ingredient
- Minimum content of nutrients (percentage by weight), Data on the expression of nutrients, Other Requirements: 37% K_2O; Potassium expressed as water-soluble K_2O
- Other data on the type designation: Usual trade names may be added
- Nutrient content to be declared, Forms and solubilities of the nutrients, Other criteria: Water-soluble potassium oxide

The most current EU organic standards, 2018/848, which became enforceable in January 2022, permit crude potassium salt under 2021/1165 Annex II, "authorised fertilisers, soil conditioners and nutrients" with the specification that they contain minimum 9% K_2O and 2% MgO, expressed as water-soluble potassium oxide and magnesium oxide, respectively (European Parliament, Council of the European Union, 2021).

Japan Agricultural Standard (JAS) for Organic Production

Potassium chloride appears on *Appended Table 1, Fertilizers and soil improvement substances* (Ministry of Agriculture, Forestry and Fisheries (MAFF), 2017). The source criteria stipulate that "Those produced by grinding or washing and refining natural ores or those produced from seawater or lake water without using any chemical method" may be used (Ministry of Agriculture, Forestry and Fisheries (MAFF), 2017).

IFOAM – Organics International

Appendix 2 of the IFOAM Norms includes "Mineral potassium (e.g. sulfate of potash, muriate of potash, kainite, sylvanite (sic), patentkali)" as permitted fertilizers and soil conditioners, if they are obtained by physical procedures but not enriched by chemical processes (IFOAM Organics International, 2019).[9]

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

Evaluation Question #1: Indicate which category in OFPA that the substance falls under: (A) Does the substance contain an active ingredient in any of the following categories: copper and sulfur compounds, toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated seed, vitamins and minerals; livestock parasiticides and medicines and production aids including netting, tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is the substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological concern (i.e., EPA List 4 inerts) (7 U.S.C. § 6517(c)(1)(B)(ii))? Is the synthetic substance an inert ingredient which is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part 180?

Nonsynthetic potassium chloride fits under the OFPA category "vitamins and minerals." As a nonsynthetic material listed at 7 CFR 205.602 of the National List, potassium chloride is prohibited beyond the annotation therein, as described at 7 U.S.C. 6517(c)(2). Nonsynthetic or synthetic potassium chloride, however, is permitted as an inert ingredient in pesticide formulations by its inclusion on 2004 EPA List 4A.

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[9] It is presumed the intention here is sylvinite, the common mixture of NaCl and KCl. Sylvanite (with an "a") is a rare mineral composed of gold, silver, and tellurium.

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

Raw material collection

In solid potash deposits, mining methods differ based on the regional geology of the ore deposit (Schultz et al., 2000). In roughly horizontal deposits, the most common method for extraction is with heavy machinery (Schultz et al., 2000). Rooms are carved underground with pillars left in place to support the cavern (Broughton, 2019; Schultz et al., 2000). Cutting machines simply strip the ore which is transported by conveyor belt to trains, trucks, or processing facilities (Schultz et al., 2000). In steeply angled solid deposits, funnel-shaped channels are bored through the rock, then explosives are utilized to guide the rubble to certain areas by gravity, after which it is hauled out (Schultz et al., 2000).

Subsurface brines can also be directly pumped to the surface for processing, or produced by injection of fluids into subterranean deposits (Schultz et al., 2000). In the case of very deep deposits (such as some deposits in Canada that are greater than 1000 meters deep), it is unfeasible to use conventional mining methods (Broughton, 2019; Schultz et al., 2000). Additionally, unintentional flooding of subsurface caverns that have been mechanically mined may necessitate conversion to solution mining techniques (Broughton, 2019; Schultz et al., 2000). Since mechanical mining only allows an extraction rate of 25-60%, depleted deposits are often converted to solution mining to maximize yield (Schultz et al., 2000). Extracted brine is typically stored in surface ponds (Schultz et al., 2000).

Solid ore beneficiation and processing

Raw solid ore is first crushed to a particle size of 4-5 mm or less (Schultz et al., 2000). The three primary mechanical treatment methods are flotation, electrostatic treatment, and leaching-crystallization; all require a maximum of mineral separation into individual crystal grains since ore rocks typically consist of deeply intergrown mixed salts (Schultz et al., 2000).

The majority of potassium chloride production, 75% as of 2004, utilizes flotation processes (Schultz et al., 2000; Titkov, 2004). In flotation, large tanks are filled with a saturated solution of sodium and potassium chloride, along with the finely ground ore material and a "collector," commonly an aliphatic amine (Schultz et al., 2000; Titkov, 2004). Due to the high solubility of the salts, the solution must be previously saturated to keep the ore in a crystalline suspended state (Monte & Oliveira, 2004). The collector amines have an affinity for potassium chloride crystals and coat their surfaces (Schultz et al., 2000). Air bubbles are introduced which carry the amine-coated potassium chloride to the surface of the tank for skimming (Schultz et al., 2000). Additional chemicals, such as alcohols, are being investigated to improve flotation efficiency when combined with amine-based collectors (Monte & Oliveira, 2004).

The hot leaching process was the primary method to separate potassium chloride from ore material in the past, but is largely being replaced by flotation (Schultz et al., 2000). The ore material is mixed into a brine heated to just below boiling point, dissolving the sodium and potassium chloride (Schultz et al., 2000). The saturated hot solution is then fed to vacuum evaporators to cool, crystallizing sodium and potassium chloride crystals which are removed from the remaining liquor (Schultz et al., 2000). The two salts can be preferentially crystallized by the addition of more clean water to the evaporator liquor, or by temperature controls (Eatock, 1985; Schultz et al., 2000).

Electrostatic separation involves the use of conditioning agents added to the ground ore during drying to initiate an electric charge on the crystals (Schultz et al., 2000). The ore is then added to a free-fall separator containing electrodes, which attract the charged crystals before brushes remove them from the surface (Schultz et al., 2000). Electrostatic separation does not result in a satisfactorily pure product, so facilities typically combine this method with flotation or leaching (Schultz et al., 2000).

Brine beneficiation and processing

Surface brines, such as those occurring in the Great Salt Lake, Searles Lake (California), and the Dead Sea can be exploited by solar evaporation (Eatock, 1985). Evaporation ponds are constructed and the collected salts of sodium, potassium, and magnesium are separated by flotation methods (Eatock, 1985).

Deep deposits or mines that introduce other extraction challenges may employ solution mining (Eatock, 1985; Rahm, 2017). Bore holes are drilled to the salt deposits and hot water is pumped down, dissolving the ore body (Rahm, 2017). Following dissolution, hot brine is injected into the cavities to selectively dissolve the maximum amount of potassium chloride (Rahm, 2017). The potassium chloride-rich brine is cooled in surface ponds or in indoor crystallization apparatuses (Rahm, 2017). Though this method is energy intensive, it results in a product of high purity suitable for food and pharmaceutical applications; other methods sometimes result in a final product with a pink tint from iron oxide impurities (Rahm, 2017).

A novel method for production of high-purity potassium chloride from saturated brines, using a minimum of energy, has recently been investigated. Ji et al. (2022) tested the use of nanoporous metal oxide membranes combined with a relatively low heat to produce potassium chloride and recovered water. In their process, brine at 15% potassium chloride concentration is pumped through a hollow metal oxide membrane tube, and water is allowed to evaporate at 60°C until the solution reaches supersaturation (Ji et al., 2022). Narrow needles of potassium chloride form on the outside of the tube and clean water is recondensed (Ji et al., 2022). The authors propose that scaling up this method to industrial scales would reduce the environmental and monetary costs associated with current potassium chloride production technology (Ji et al., 2022).

<u>Evaluation Question #3</u>: Discuss whether the petitioned substance is formulated or manufactured by a chemical process, or created by naturally occurring biological processes (7 U.S.C. § 6502 (21)).

Potassium chloride is most often produced by physical separation of naturally occurring mineral deposits, or from solar or forced evaporation of naturally occurring saltwater. The chemicals utilized in froth flotation, such as amines, alcohols, or other surfactants, do not crystallize together with the potassium chloride after washing and drying. While possible to produce potassium chloride from potassium metal and hydrochloric acid, no reference was found to commercial products utilizing this chemical reaction, and we find it unlikely that this is at all prevalent due to the ready availability of mineral sources of potassium chloride.

<u>Evaluation Question #4</u>: Describe the persistence or concentration of the petitioned substance and/or its by-products in the environment (7 U.S.C. § 6518 (m) (2)).

Potassium chloride is freely soluble in water (See *Properties of the Substance*, above). When potassium chloride is applied to soil, it dissolves over time in irrigation, rain, or soil water, breaking down into equal parts potassium and chloride ions (Ren et al., 2015). The primary function of both of these "by-products" of potassium chloride is as nutrients, and they have different fates in the environment. Issues related to potassium in the environment are more likely to be related to a lack of it, as opposed to excess. Issues with chloride are more significant, and pertain to its accumulation in arid and semi-arid environments. These issues are discussed below.

Throughout the world, 90% of mineral potassium is applied as potassium chloride (Ren et al., 2015). According to older data collected from the EPA, tobacco fields have the highest application rates of potash fertilizers (primarily potassium chloride), at around 203 lb/acre (US EPA, 1999). However, corn (79 lb/acre) has a higher total application, because of its much larger acreage. Potatoes, tomatoes, celery, and bell peppers are other examples of crops that have high potash application rates (Torabian et al., 2021; US EPA, 1999).

Potassium ions

Factors that influence the movement of potassium in soils include (Munson & Nelson, 1963; Pandey & Mahiwal, 2020):

- increases in cation exchange capacity (CEC) of the soil, which increases potassium retention
- presence of other cations which could interfere with potassium exchange sites on soil particles
- organic matter, which increases CEC
- proportion of sand, silt, and clay, which affect CEC, water holding capacity, and rate of water movement (more clay, slower movement of K)
- types of clay (kaolin has the lowest CEC, hydrous mica has intermediate CEC, and montmorillonite has a high CEC)
- presence of liming agents, which reduce potassium leaching[10]
- method of potassium application (broadcast application leaches less than banded)
- rainfall intensity, duration, and frequency
- presence of cover crops
- soil microorganisms capable of solubilizing potassium

Potassium is abundant in soils and plant tissues (Khan et al., 2014). About 2.6% of the earth's crust is potassium, making it the seventh most abundant element (Pandey & Mahiwal, 2020). Potassium is the most abundant cation in plant tissues, existing as a free ion (Pandey & Mahiwal, 2020). Roughly 6% of dry matter in plants is potassium (Pandey & Mahiwal, 2020). Despite this, large areas of agricultural land are deficient in potassium, including roughly three-quarters of paddy soils in China, and two-thirds of the wheat belt of southern Australia (Römheld & Kirkby, 2010).

Plants take up potassium, typically through their roots at some depth, and release it near the surface when they decompose (Vetterlein et al., 2013). This is referred to as nutrient uplift, and can be seen in the composition of different minerals found at different depths within soil (Vetterlein et al., 2013).

Potassium in the environment can be broken into four recognized pools (Kaur, 2019; Pandey & Mahiwal, 2020; Römheld & Kirkby, 2010):

- soil solution potassium (SSK), 0.1-0.2% of total K
- exchangeable potassium (EK), 1–2% of total K
- fixed or slowly exchangeable potassium (SEK), 1-10% of total K
- structural or unavailable K (UK), 90-98% of total K

Once applied, potassium will enter into these pools and then either be taken up by plants, find equilibrium in the soil potassium pools, runoff, or leach into ground water (Torabian et al., 2021; Bar-Yosef et al., 2015). Once in the soil, potassium is relatively immobile, though it can leach, particularly in sandy or certain acidic soils with low cation exchange capacity (Römheld & Kirkby, 2010). In the United States, the fastest increases in potassium concentrations in river water occur in the Midwest, likely due to the use of potash fertilizers (Kaushal et al., 2018). In contrast, potassium concentration in rivers of the Pacific coast states and the Southwest has been declining over the last several decades (Kaushal et al., 2018).

Typically, SSK and EK are typically considered plant-available forms of potassium (Pandey & Mahiwal, 2020). The amount of potassium in the SEK and UK pools is very large, but these are commonly assumed to be less available (Pandey & Mahiwal, 2020). However, in a field study, researchers found that soil potassium is highly dynamic (Khan et al., 2014). In one part of the experiment, crops were grown on soil without potassium fertilization. Over the course of four years, crop removal had no consistent effect on soil concentrations of SSK/EK, SEK, and total potassium. Based on this and other data, the researchers' conclusion was that the mineral fraction of potassium (equivalent to UK) was important in maintaining the equilibrium found in the other potassium pools (Khan et al., 2014). Other researchers have come to similar conclusions (Kaur, 2019; Torabian et al., 2021; Römheld & Kirkby, 2010). Especially in soils with

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[10] According to Ernani et al., (2012), adding liming materials like calcium carbonate increases the number of negative charges in the soil, which cations like potassium can react with.

large amounts of 2:1 minerals, SEK can provide large amounts of potassium (Römheld & Kirkby, 2010).[11] For this reason, EK tests can be inadequate for making fertilizer recommendations in some soils (Khan et al., 2014; Römheld & Kirkby, 2010).

Soils that are saline, acidic, sandy, or waterlogged often have low potassium available to plants in the SSK and EK pools (Pandey & Mahiwal, 2020). However, some plants appear to be better at taking up potassium in the SEK pool than others. For example, ryegrass and sugar beet are more efficient at mobilizing potassium, while wheat and barley are less able to do so. This ability to mobilize potassium from the SEK pool may be related to the release of citric, oxalic, tartaric, maleic, or certain amino acids from plant roots. Microorganisms may use tactics similar to plants (such as releasing acids), to facilitate the release of potassium from soil (Pandey & Mahiwal, 2020).

Plants can directly affect weathering of soil minerals (Vetterlein et al., 2013). Plant roots can release ions like H^+ or OH^-, which can exchange with nutrient ions like magnesium, calcium, ammonium, potassium, and chloride. Within the area directly adjacent to roots (the rhizosphere) plants can induce the release of SEK and UK. For example, plants can cause the mineral illite to transform into the mineral vermiculite, through the removal of potassium. Radioactive isotope testing has shown that directly adjacent to the root, concentrations of potassium can be extremely low, inducing the release of potassium from between mineral layers. The presence of competing ions such as calcium and magnesium can also promote the displacement of potassium from minerals, making it more available (Vetterlein et al., 2013).

Depending on various factors such as soil type, types of crops grown, nutrient recycling practices, etc., organic farms with limited mineral fertilizer application could have a net loss of soil potassium over time (Römheld & Kirkby, 2010). Potassium sufficiency should be carefully managed on farms, because of the positive effects it has on the ability of plants to cope with biotic and abiotic stress (Römheld & Kirkby, 2010).[12]

Chloride ions

In the Earth's crust, chlorine (primarily as chloride) is present at around 0.064% (Lovett et al., 2005). While coastal soils can receive up to 175 kg Cl^-/ha/year from sea spray deposition, naturally occurring deposition inland (from rainfall) is typically only 1 kg Cl^-/ha/year (Geilfus, 2019). Significant anthropogenic sources of chlorine (some as chlorine gas, some as chloride) include combustion of coal, municipal and industrial waste incineration, and industrial processes (Lovett et al., 2005). In some places like the Midwest, road deicer (magnesium chloride), fertilizers, and household water softeners are significant contributors of chloride to the environment (Overbo, 2021). According to the USGS, potassium chloride fertilizers contribute to overall chloride levels in groundwater, which sometimes exceed U.S. EPA secondary maximum contaminant levels (Mullaney et al., 2009).[13] Fertilizing with animal manure can also contribute substantial quantities of chloride to soils (Geilfus, 2019).

Chloride ions are highly soluble, and are *generally* not readily absorbed by organic matter or clay (Mitra, 2015). Chloride is so mobile that it is sometimes used as a tracer to assess soil water movement (Geilfus, 2019). However, chloride can be immobilized in ecosystems by ion exchange, adsorption onto iron and aluminum oxide, and biological uptake (Svensson et al., 2012). Unlike potassium, chloride is very mobile in soils and leaches easily (Ren et al., 2015). As such, it is present in significant amounts in both natural bodies of water (especially the ocean) and in irrigation water (Lovett et al., 2005; Ren et al., 2015). Most of the chlorine deposited on land eventually returns to the ocean (Lovett et al., 2005). As an exception, chloride can accumulate as salt evaporates in arid and semi-arid regions, which are used as commercial sources of the material (Lovett et al., 2005). After hydrogen and oxygen, chlorine is the most abundant

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[11] 2:1 minerals refer to those composed of two tetrahedral sheets, and one octahedral sheet (Barton, 2002). Examples include mica, smectite, and vermiculite. These minerals have negative charges between layers that attract cations such as potassium (Barton, 2002).

[12] Over-application of potassium can have negative effects on yield and cause nutrient imbalance (see *Evaluation Question #7*).

[13] 2.5% of shallow monitoring wells and 1.7% of drinking-water wells showed chloride concentration above EPA secondary maximum contaminant levels, between 1991-2009 (Mullaney et al., 2009).

element in seawater (Lovett et al., 2005). Most of the chlorine cycling through terrestrial and freshwater ecosystems originates from the ocean (Lovett et al., 2005).

In wet environments, chloride leaches relatively quickly into water. The most relevant information about how chloride moves in wet environments comes from studies of forest ecosystems in the United States and Europe. With rainfall averaging between 750mm (30 inches) and 2650mm (104 inches), the median chloride input from natural sources was 6kg/ha/year (5.4 lbs/acre/year) (Svensson et al., 2012). Chloride concentration was essentially in equilibrium in 40% of the forests on a yearly basis. Often, forests not in equilibrium were those with lower than average chloride inputs, which correspondingly had net losses of chloride. Overall though, there was a strong 1:1 relationship between chloride inputs and chloride outputs in these environments (Svensson et al., 2012).

In contrast to wet environments, arid and semi-arid environments can cause chloride to concentrate. Irrigating agricultural land in arid and semi-arid areas with chlorine-containing water can cause chloride build-up in surface water and the soil (Lovett et al., 2005). Not enough water moves through soil to cause chloride to leach away, so salts build up as the water evaporates, causing salinization (Lovett et al., 2005).

Plants can use more potassium than chloride—there is a difference then in how much chloride is "left over" under some circumstances. This imbalance could lead to the accumulation of salts, or excess chloride leaching into the environment. Plants can only take up 20 to 80 kg of chloride per hectare (18-71 lbs/acre) per year (Mitra, 2015). Agronomic professionals recommend applying potassium in the range of 0–336 kg potassium per hectare (0–300 lbs/acre), measured as K_2O (McKenzie & Pauly, 2013; Ohio State University Extension, 2022; University of Minnesota Extension, 2018). To achieve this rate of application using potassium chloride, 0–531 kg/hectare (0-474 lbs/acre) would be necessary. Recommended rates vary by crop, soil type, irrigation and yield potential. The maximum recommended rate of potassium chloride application would contribute up to 252 kg chloride per hectare (225 lbs/acre), exceeding what can be taken up by plants. The remaining chloride would be available to either accumulate as salts (in arid and semi-arid environments) or leach from the soil.

Chloride is commonly found in fresh and salt water (Hunt et al., 2012). As mentioned above, it originates from natural sources, such as rocks in the earth's crust and seawater, but also from anthropogenic sources such as road salt, water softeners, sewage, and fertilizers. Irrigation water is a large source of chloride in soils, even compared with potash application (Kafkafi et al., 2001). Irrigation water with low-medium salinity contains 100-300g Cl^-/m^{-3}, while saline water contains 300-1200g Cl^-/m^{-3}.[14] Applying 500mm (~20 inches) of irrigation water that contains 200g Cl^-/m^{-3} would add about 1000kg of chloride to one hectare of soil. This is four times more chloride than would be supplied by applying 500 kg KCl/ha (446 lbs/acre) (Kafkafi et al., 2001). For comparison, roughly 9.6 million acres are irrigated in California with 34 million acre feet of water (California Department of Water Resources, 2022). On average then, each acre in California is irrigated with 42.5 inches of water.

<u>Evaluation Question #5</u>: Describe the toxicity and mode of action of the substance and of its breakdown products and any contaminants. Describe the persistence and areas of concentration in the environment of the substance and its breakdown products (7 U.S.C. § 6518 (m) (2)).

As a fertilizer, potassium chloride is not applied with the intent to act as a toxic substance. However, application of potassium chloride can contribute to soil salinity, which can result in toxic effects in a range of organisms, described below (Buvaneshwari et al., 2020). In cases where toxicity occurs, it can be difficult to determine the effect of a single ion, because they can only be added in salt form (occurring with a counter ion) (Wang et al., 2018). However, according to Arle and Wagner (2013), the negative effects of salinization are the result of the combined effects of cations (such as potassium, sodium, and

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[14] Salinity is a measure of the concentration of all soluble salts (or rather, their ions) in soil or water (Zaman et al., 2018). The major positively charged ions (cations) are sodium, calcium, magnesium, and potassium; while the major negatively charged ions (anions) are chloride, sulfate, bicarbonate, carbonate, and nitrate (Zaman et al., 2018).

magnesium), normally associated with chloride. Soil salinity reduces the productivity of many crops, including most vegetables (Machado & Serralheiro, 2017).

Potassium chloride is particularly toxic to molluscs (Wang et al., 2018). This aspect has led to its use as an aquatic molluscicide (Densmore et al., 2018). Researchers believe that the mechanism for the toxicity of potassium chloride in molluscs is that it interferes with gas exchange in their gill tissue (Densmore et al., 2018). Unlike molluscs, chinook salmon and brook trout are not significantly impaired by potassium chloride exposure up to at least 800 mg/L (Densmore et al., 2018).

Potassium chloride can inhibit bacteria, but at least in some cases, this may have more to do with chemical interactions with other nutrients (see *Evaluation Question #8*). It has also been shown to reduce powdery mildew; however, this appears to be a result of the fertilization effect on the plant, and not through toxicity to the fungal pathogen (Kafkafi et al., 2001).

Potassium

Potassium is required by all living organisms as an essential macronutrient (see *Action of the Substance*). However, large amounts of potassium can create nutrient imbalances, which can reduce crop yield (see *Evaluation Question #7)*. The dietary potassium needs for many organisms is large. For example, livestock need on the order of 1.5 to 20+ grams K per kg of feed, depending on species and stress levels. Toxicosis is usually caused by disturbances in potassium regulation, due to damaged body parts (kidneys, muscles, blood), rather than strictly from exposure to potassium (Committee on Mineral Toxicity in Animals Staff National Research Council (U.S.), 2005). Potassium chloride is used to euthanize animals by injection (AVMA, 2020). The American Veterinary Medical Association refers to potassium as a "nontoxic injectable agent," but also as "cardiotoxic" (AVMA, 2020). It is safe when given orally, but when injected into cardiac muscle, it eliminates the potassium gradient that is required to cause the muscle to contract (AVMA, 2020).

No information was found to suggest that potassium itself is toxic to plants or soil organisms when applied as a fertilizer. However, there is some evidence that potassium can harm aquatic organisms. Reporting unpublished data, Wang et al. (2018) state that there is evidence that in the case of the water flea *Ceriodaphinia dubia* (and likely other organisms), potassium from potassium chloride is responsible for toxic effects in this animal. The same researchers also determined that a dose of 30 mg/L of potassium chloride was enough to kill (or apparently kill, after a five minute observation) the fatmucket mussel (*Lampsilis siliquoidea*). In comparison with sodium chloride, potassium chloride was much more toxic. This supports the idea that for some organisms, potassium may be the toxic ion. The researchers noted that the four most sensitive genera to potassium chloride are all mussels (Wang et al., 2018).

Chloride

Chloride (Cl^-) is also an essential plant nutrient, which can be toxic when in excess (Mitra, 2015). The level that is toxic in plants varies, typically ranging from 4-50 mg Cl^-/g plant dry weight. Woody plants and beans tend to be more susceptible to chloride toxicity, as compared with non-woody crops (Kafkafi et al., 2001). While data showing the specific rates of potassium chloride fertilizer application that can result in plant toxicity was not found, toxic levels from irrigation water are shown in *Table 3* (below), for comparison. Levels over 30 ppm in the soil are considered "high" (A&L Canada Laboratories, 2013a), but are not toxic. Soil concentrations of 100 mg/kg soil and above can be toxic to plants (see *Table 4*). According to Gamalero (2020), a soil is defined as "saline" when the electrical conductivity is over 4 dS/m, or its salt concentration is ≥ to 0.25%, with a pH less than 8.5.

Table 3. Chloride Levels in Irrigation Water and Their Effect on Crops. Adapted from Zaman et al., 2018.

Cl^- ppm (or mg/kg)	Effect on crops
<70	Generally safe for all plants
70–140	Sensitive plants show slight to moderate injury
141–350	Moderately tolerant plants show slight to substantial injury
>350	Can cause severe problems

Table 4. Maximum Soil Cl Concentration Above Which Yield Decline to 95% of the Maximum Yield is Observed. Adapted from Kafkafi et al., 2001.

Crop	Chloride (mg/kg soil)
Strawberry	250
Lettuce	100
Apple	250
Sweet potato	300
Grape	400
Corn	800
Flax	500
Potato	500
Cabbage	500
Cucumber	600
Tomato	600
Wheat	600
Sorghum	700
Sugar beet	1600-3200
Cotton	1600

Chloride contributes to salt stress, but it is only one of many ions involved. Many of the effects of salt stress are attributed to the cations in salts (though not all), as opposed to the anions like chloride (Gamalero et al., 2020). In terms of salinization, chloride affects biota less than other ions (Arle & Wagner, 2013). Salt stress causes damage at the plasma membrane, for example influencing the electrical potential around the membrane and affecting membrane proteins. Salt stress ultimately creates osmotic imbalances, which decrease the availability of water to plants. This can also lead to the production of damaging reactive oxygen species. This has a variety of results, including (Gamalero et al., 2020):

- damaged membrane components
- seed dormancy
- reduced germination
- reduced root elongation
- reduced shoot biomass
- reduced leaf expansion
- reduced stomatal conductance
- reduced photosynthesis
- loss of productivity/yield

In non-saline soils, plants take up chloride through active transport (Geilfus, 2019). Under these conditions, the concentration of chloride in soil is lower than within the plant. Additionally, the membrane potential of cells is negative, which repels the negatively charged chloride ions. Moving chloride into the plant therefore requires energy.[15] Once transported into root hairs, the chloride moves down its concentration gradient, moving through the interior of plant cells (symplastic) until it reaches the plant xylem. Through the xylem, chloride travels up from the roots, to the stems and leaves of the plant (Geilfus, 2019).

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[15] Chloride transport is also coupled with the import of two hydrogen ions (H^+) per chloride ion (Geilfus, 2019).

In saline soils, the concentration of chloride exceeds what is found within the plant (Geilfus, 2019). Under these conditions, chloride moves into the plant passively, using anion channels. This can also result in chloride not only moving symplastically, but also apoplastically (moving through the spaces around the outside of cells). To limit toxicity under saline conditions, glycophytic plants:[16]

- down-regulate proteins that transfer chloride from root cells to xylem
- increase production of the hormone abscisic acid, which down-regulates proteins involved in transferring chloride to shoot tissues
- up-regulate proteins that help pump chloride out of root cells and into the soil
- move chloride into vacuoles to sequester it

When chlorine accumulates in shoots in excess of what plants can tolerate, it begins to limit cell division and photosynthesis (Geilfus, 2019). This leads to plant stunting, chlorosis, leaf-tip "burn," and necrotic lesions (Geilfus, 2019; Kafkafi et al., 2001). These symptoms are difficult to distinguish from the symptoms caused by other nutrient disorders (Kafkafi et al., 2001). The exact nature of this damage is unknown; however, chloride somehow induces dysfunction within plant cells (Geilfus, 2019). Excessive chloride accumulation can also cause imbalances with other important nutrients like nitrate and phosphate (Geilfus, 2019). High concentrations of chloride can also increase the mobility of cadmium; however, in some circumstances, chloride may also form a complex with calcium that at the same time reduces cadmium's bioavailability (Geilfus, 2019).

Little information could be found relating chloride to toxicity in animals or soil organisms. Most literature related to soil chloride levels and toxicity focused on the effects of sodium chloride on plant stress. According to the Committee on Mineral Toxicity in Animals (2005), chloride can in some circumstances be toxic to animals. They state that toxicity occurs by disturbing acid-base homeostasis, or by disrupting the correct balance of electrolytes (Committee on Mineral Toxicity in Animals Staff National Research Council (U.S.), 2005), presumably when large quantities are consumed directly.

Megda et al. (2014) summarized several field and laboratory studies, noting that chloride ions, even at low conditions, had the potential to inhibit soil nitrification. They concluded this was due to the oxidative potential of chloride and, at high chloride levels, the high osmotic potential in soil (Megda et al., 2014).

In contrast, a fact sheet from an independent laboratory states that soil biology is immensely complex, and that there is no reliable evidence to support a connection between chloride from fertilizers and adverse effects to the biological activity of soil (A&L Canada Laboratories, 2013a). They cite that the existence of healthy ecosystems in coastal regions of the world where chloride levels can be high is evidence that chloride addition is not a problem. However, in these regions, organisms can be locally adapted (e.g., a predominance of halophytes), and rainfall tends to be significant and thus able to leach away chloride excesses. A better comparison perhaps would be to look at arid and semi-arid areas, where chloride accumulates in soil. Gamalero et al. (2020) note that, currently, the relationship between soil characteristics (such as salinity) and their effects on the microbial community is unknown. They also note that the bacterial diversity in deserts is lower than elsewhere, and that this could be related to either high pH or salinity, but that there is a lack of studies regarding the impact of salinity on bacterial communities (Gamalero et al., 2020).

<u>Evaluation Question #6</u>: Describe any environmental contamination that could result from the petitioned substance's manufacture, use, misuse, or disposal (7 U.S.C. § 6518 (m) (3)).

Manufacturing and disposal

The processes used to mine solid potassium chloride ore employ large equipment that burns fossil fuels to extract and haul the material (Schultz et al., 2000). In some places, mining can cause the overlying ground to sink, as underground mining areas collapse. Potassium chloride can contain other mineral impurities that are often separated through flotation methods, using liquids such as tetrabromoethane

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[16] Glycophytes are plants that evolved under low soil sodium levels (Cheeseman, 2015). By contrast, halophytes evolved under perpetually saline conditions. Most crop plants are glycophytes (Cheeseman, 2015).

mixed with toluene, and aliphatic amines (containing an ammonium chloride chemical group).[17] Other processing aids such as foamers (substances that help create air bubbles) are made from oil and other synthetic compounds (Schultz et al., 2000).

According to Schultz et al., (2000), the primary environmental problem of the potash industry (including potassium chloride) is related to disposal of processing wastes. These wastes total approximately 200 million tons per year. Wastes are primarily salts such as halite (rock salt, NaCl), kieserite ($MgSO_4$), and aqueous magnesium chloride. This waste may be either dumped, backfilled into mining sites, pumped into the ground, or discharged into waterways. Brines that drain off dump sites are sometimes collected and returned to processing plants. Rainwater can create new brines from the potash wastes, which can leach into the environment, increasing the salinity of water and soils. Attempts to prevent leaching through covering wastes have been unsuccessful. In Canada, wastes are turned into a slurry and pumped to large lagoons that ultimately form flats. Wastes that are pumped into the ground can contaminate groundwater through leaks (Schultz et al., 2000).

The Werra River in Germany is an example of an area affected by waste from potash production (Arle & Wagner, 2013). Wastes from potash fertilizer production have been disposed of in the river for over 100 years, leading to a large increase in the concentration of dissolved ions (salinization). In 1976, researchers measured concentrations of up to 40,000 mg Cl^-/L in the river. Since then, the concentration of chloride ions has been reduced, but still greatly exceeds the threshold used for "good ecological status" of 200 mg Cl^-/L. As a consequence, the biodiversity in these areas has been severely impacted (Arle & Wagner, 2013). Similar issues exist for other potash mining areas, such as the Verkhne-Kamsk potash and magnesium salt mine in Russia (Lepikhin et al., 2012).

Heavy metals can be concentrated near potash production areas as well (Al-Khashman, 2012). For example, researchers found that zinc, cadmium, and lead were higher in the soil around a potash plant near the Dead Sea, as compared with soils found 1200 m away from the plant (Al-Khashman, 2012).

Potash (including potassium chloride) production is energy intensive (Parmenter et al., 2004). The energy requirements to produce, transport, package, and apply potash fertilizer are estimated to be 5,936 Btu/lb (13,800 kJ/kg). However, in comparison to synthetic nitrogen fertilizers which use 33,642 Btu/lb (17,500 kJ/kg), potash fertilizer energy use is relatively small (Parmenter et al., 2004).

Chen et al. (2018) found that the biggest environmental issue with potash production was its contribution to global warming. Using modelling software, Chen et al. performed a theoretical life cycle analysis for potassium chloride, and found that for every ton of K_2O (1.67 tons KCl), the equivalent of 190 kg of CO_2 are created (see *Table 5*, below). This was largely due to the energy needed to produce the substance.

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[17] Tetrabromoethane, or TBE, is a metabolic poison which also decomposes into other toxic materials such as carbonyl bromide or hydrobromic acid (Hauff & Airey, 1980).

Table 5. Impact of Producing 1 Ton K2O (1.67 Tons KCl) From Brine in China, Throughout the Material's Life Cycle. Adapted from Chen et al., 2018.

Categories	Unit	Amount	Range due to uncertainty
Global warming	kg CO_2 eq.	190	141 to 255
Land occupation	hectare/year	8.48×10^{-5}	5.00×10^{-5} to 1.44×10^{-4}
Terrestrial acidification	kg SO_2 eq.	0.295	0.215 to 0.406
Aquatic eutrophication	kg $PO4^{-}$ eq.	6.95×10^{-4}	3.78×10^{-4} to 1.28×10^{-3}
Respiratory inorganics	kg $PM_{2.5}$ eq.[18]	0.0545	0.0366 to 0.0812
Respiratory organics	kg NMVOC eq.[19]	0.281	0.183 to 0.433
Ozone layer depletion	kg CFC-11 eq.[20]	6.64×10^{-8}	3.39×10^{-8} to 1.30×10^{-7}
Water depletion	m^3	8.13	6.66 to 9.92
Metal depletion	kg Fe eq.	0.151	0.0751 to 0.305
Fossil depletion	kg oil eq.	25.7	18.6 to 35.6
Carcinogens	CTUh[21]	3.40×10^{-7}	1.53×10^{-7} to 7.54×10^{-7}
Non-carcinogenic toxins	CTUh	2.32×10^{-5}	1.03×10^{-5} to 5.23×10^{-5}
Freshwater ecotoxicity	CTUe[22]	82.2	39.1 to 17.3
Marine eutrophication	kg N eq.	6.07×10^{-3}	3.69×10^{-3} to 9.97×10^{-3}

Use and misuse

Use of potassium chloride can contribute to soil and groundwater salinity (Buvaneshwari et al., 2020; White, 2001). Increases in salinity can damage plants and other organisms (Megda et al., 2014; Pereira et al., 2019). This is especially problematic in arid and semi-arid environments (Megda et al., 2014).

Field data describing what constitutes high chloride levels, capable of causing plant or other damage was not found. According to A&L Canada Laboratories, (2013a) chloride levels in soil over 30 ppm (mg/kg) are considered high, and values under 7 ppm are low (with 16–22 ppm being "medium").

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

According to safety data sheets, potassium chloride is chemically stable during storage and handling, but absorbs water (hygroscopic) when humidity is above 72% (Mosaic, 2020; Nutrien North America, 2021). It is incompatible with strong acids or strong oxidizing agents, and can be corrosive to metal (Mosaic, 2020; Nutrien North America, 2021).

Potassium chloride is often a component of blended fertilizers (Kafkafi et al., 2001). It is compatible with most other fertilizers, such as rock phosphate (Kafkafi et al., 2001). It is present as an ingredient in a wide variety of blended fertilizers used in organic production, with diverse formulations (OMRI, 2022). Accordingly, it does not appear that potassium chloride reacts with other common inputs to create new substances.

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

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[18] $PM_{2.5}$ eq. is a standardized way to refer to very small (2.5 micrometer) particulate matter in the air.

[19] NMVOC eq. is a standardized way to refer to "non-methane" volatile organic compounds.

[20] CFC-11 eq. is a standardized way to represent chlorofluorocarbons, equivalent to the effect of the chemical trichlorofluoromethane.

[21] CTUh or "Comparative Toxic Unit for humans" is a way of expressing the "estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme)" (European Commission, n.d.)

[22] CTUe or "Comparative Toxic Unit equivalent" is similar to CTUh, except that it applies to other species. "An estimate of the potentially affected fraction of species (PAF) integrated over time and volume, per unit mass of a chemical emitted" (USEtox International Center, 2022).

Potassium chloride has the highest salt index of any common dry fertilizer, at 116.2 (A&L Canada Laboratories, 2013b).[23] Sulfate of potash (potassium sulfate) by comparison has a salt index of 43.4. Fertilizers with a high salt index must be used carefully, as they can make it more difficult for seeds or plants to extract water needed for growth from the soil (A&L Canada Laboratories, 2013b).

Potassium chloride fertilizer application can contribute to groundwater salinization (Buvaneshwari et al., 2020). Using chloride as a marker for salinization, Buvaneshwari et al. (2020) determined that roughly 60% of the chloride in groundwater sample sites in southern India originated from potassium chloride fertilizer.

Salinization affects roughly 20% of agricultural land, and is increasing (Machado & Serralheiro, 2017). Approximately ten million hectares (24.7 million acres) of land are destroyed each year due to salt accumulation. Efficient use of irrigation comes at the cost of reduced capacity to leach salts, and poor-quality water now used for irrigation often contains more salt-forming ions (Machado & Serralheiro, 2017).

Freshwater salinization is characterized by increases in base cations (such as potassium) and changes to water chemistry (Kaushal et al., 2018). The primary causes of freshwater salinization are agriculture, resource extraction (mining), and land clearing. Salinity can also contribute to a related phenomenon, alkalinization, which causes the pH of soil and water to increase. Sixty-six percent of United States Geological Survey (USGS) stream and river monitoring sites have shown an increase in pH over the last several decades (Kaushal et al., 2018)

Application of potassium chloride can reduce microbial activity, likely through reducing the availability of ammonium (Pereira et al., 2019). In one study of banana production, carbon dioxide, ammonium, and chloride content were monitored for 130 days after applying potassium chloride at different rates (Pereira et al., 2019). Applying potassium chloride at or above a rate of 400 mg/kg along with crop residue led to a reduction in microbial activity, compared with a control soil with no application of potassium chloride or crop residue (Pereira et al., 2019). In another study, potassium chloride reduced bacterial diversity in a laboratory aquatic environment (Muturi et al., 2016).

Potassium

Potassium can be antagonistic to, or synergistic with a variety of nutrients. While most researchers believe that it is important to add at least as much potassium each year as is removed by crops (Bar-Yosef et al., 2015; Pandey & Mahiwal, 2020), Khan et al., (2014) argue that potassium is abundant in many soils, and behaves in dynamic and complex ways. Citing numerous studies, they note that adding potassium does not increase yield or crop quality in all cases (Khan et al., 2014). Torabian et al. (2021) similarly note that, for example, the yield of tubers may decrease when potassium fertilizers are added to soils with already high levels (> 250 mg/kg) of exchangeable potassium in the soil. This causes an imbalance between potassium and other nutrients like magnesium and calcium, which can have antagonistic relationships (Torabian et al., 2021). Excess potassium application can induce magnesium deficiency symptoms in cereals, maize, citrus, potatoes, fruit trees, and sugar beet (Kafkafi et al., 2001). Likewise, calcium and magnesium can compete with (and inhibit) potassium for root uptake (El-Mogy et al., 2019). However, potassium reduces magnesium uptake more than the reverse (Kafkafi et al., 2001).

The relationship between potassium and nitrogen is complex. In the spring, nitrogen is the major driver of leaf canopy expansion (Römheld & Kirkby, 2010). Potassium is also needed during this time in order to provide leaf tissue with sufficient turgor to support itself (Römheld & Kirkby, 2010). In this way, potassium works synergistically with nitrogen to support plant growth and increase yield. In terms of uptake, potassium is sometimes (but not always) antagonistic to ammonium ions (NH_4^+) (Xu et al., 2020; Kafkafi et al., 2001). On the other hand, potassium is positively correlated with the uptake of nitrate ions (NO_3^-) (Xu et al., 2020; Kafkafi et al., 2001). In some plants like cotton, potassium deficiency reduces the

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[23] The salt index is a way to represent the increase in osmotic potential due to the addition of a fertilizer material (A&L Canada Laboratories, 2013b). It is based around sodium nitrate, with a value of 100 (A&L Canada Laboratories, 2013b).

activity of proteins that are involved in nitrogen absorption (Xu et al., 2020). In contrast, potassium deficiency up-regulates nitrogen metabolism proteins in thale cress (*Arabadopsis thaliana*) (Xu et al., 2020). In dwarf apple seedlings, low (0 mM) and high (12mM) potassium solutions inhibited nitrate uptake, while a moderate (6mM) potassium solution had higher nitrate uptake and carbon assimilation (Xu et al., 2020).

Potassium also has a synergistic effect with iron and manganese (Torabian et al., 2021; Awad-Allah & Elsokkary, 2020). It has been shown that when soil iron availability is low, potassium can stimulate the release of iron from root cell walls, allowing the iron to be recycled internally (Awad-Allah & Elsokkary, 2020).

Boron deficiency, aluminum toxicity in acid soils, soil compaction, high salinity, and drought can inhibit root growth, and therefore inhibit the ability of plants to acquire potassium, even when adequate amounts are present in the soil (Römheld & Kirkby, 2010).

Application of irrigation water with a high concentration of cations such as calcium can lead to an increase in potassium leaching (Kolahchi & Jalali, 2006). These cations can displace potassium, which then becomes mobile. This is more common in arid and semi-arid areas where low quality (i.e., saline) water may be used for irrigation (Kolahchi & Jalali, 2006).

High-potassium levels in livestock forage can induce magnesium deficiency in ruminants (Kafkafi et al., 2001). This disorder, hypomagnesemia (or grass tetany) is most common in lactating cows grazing pasture in the spring. This disorder is associated with high potassium fertilizer applications rates (Kafkafi et al., 2001).

Chloride

Application of potassium chloride fertilizers can solubilize cadmium in the soil, which leads to increased cadmium uptake by plants (McDowell, 2019). Cadmium can accumulate in livestock (and subsequently humans) when they consume plants that take up cadmium from the soil (Chunhabundit, 2016). The largest sources of cadmium for human exposure are food and tobacco (Andujar et al., 2010; Chunhabundit, 2016). Foods known to be high in cadmium include (Chunhabundit, 2016):

- shellfish
- kidney
- liver
- mushrooms
- root crops

We were not able to find studies that directly linked application of potassium chloride fertilizer to an increased risk of human health conditions associated with cadmium. However, cadmium is highly mobile, widely distributed, and can occur at increased levels due to both natural and anthropogenic causes (Kubier et al., 2019). With food being a major source of cadmium, the effect that potassium chloride has on mobilizing this substance presents a real concern. For matters of human health, farmers should be conscious of existing levels of cadmium in their soils, and how potassium chloride application might affect availability. Chronic dietary exposure to cadmium is associated with kidney disease, osteoporosis, diabetes, cardiovascular disease, and cancer (Chunhabundit, 2016). McDowell (2019) found that applying potassium chloride in the autumn (rainy season) allowed cadmium to leach to deeper soil layers, without being taken up by pasture crops.

Chloride ions are involved in suppressing diseases, including (Mitra, 2015):

- Barley: common root rot, *Fusarium* root rot, blotch rot
- Coconut: gray leaf spot
- Pearl millet: downy mildew
- Rice: stem rot, sheath blight
- Wheat: common root rot, stripe rust, leaf rust, *Septoria*

Elevated chlorine levels in waterways can decrease aquatic insect and plant biodiversity (Overbo, 2021). However, in areas such as Minnesota, where road salt and household water softeners are used, non-agricultural sources of chloride are larger than sources of chloride from agriculture (Overbo, 2021).

<u>Evaluation Question #9</u>: Discuss and summarize findings on whether the use of the petitioned 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)).

Production of potassium chloride is harmful to the environment (see *Evaluation Question #6*). Production contributes to the creation of greenhouse gases (largely in the creation of the energy that is used to mine and process the material), and creates wastes that can contaminate land directly adjacent to facilities. Furthermore, production wastes can contaminate streams and rivers over a larger area. This contamination is most toxic to aquatic invertebrates (see *Evaluation Question #5*).

When used carefully in locations deficient in potassium, and that do not have saline soils and are not prone to chloride accumulation (e.g., have sufficient rainfall), potassium chloride likely can be used safely (see *Evaluation Question #4*). However, nearby waterways should be carefully considered as invertebrates (especially molluscs) are sensitive to potassium (see *Evaluation Question #5*). Use of potassium chloride in arid or semi-arid areas has a high potential to contribute to soil salinity, due to its high salt index (see *Evaluation Question #8*). These environments may not be suitable to potassium chloride use.

<u>Evaluation Question #10</u>: Describe and summarize any reported effects upon human health from use of 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)).

Consumption of potassium, at levels as high as 6000 mg/day, is considered to pose little risk to human health (van Buren et al., 2016). By comparison, the World Health Organization (WHO) recommends less than 2000 mg/day of sodium for adults (van Buren et al., 2016). The WHO recommends that adults consume a minimum of 3510 mg of potassium per day, and typical diets fall short of this value (van Buren et al., 2016). The use of potassium chloride as a sodium chloride replacement in foods could serve to reduce the prevalence of heart disease while also helping people meet their dietary potassium recommendations (van Buren et al., 2016). A fatal single dose of potassium is estimated to be 500-5000 mg/kg of body weight, though likely on the upper end of that range (Organisation for Economic Co-operation and Development (OECD), 2001). This range converts to a single dose of tens to hundreds of thousands of milligrams when estimating based on average human weight.

No evidence has been found of genotoxicity, carcinogenicity, fetotoxic or teratogenic effects of potassium chloride, and stomach irritation appears to be the primary complaint from repeated doses (EFSA Panel on Food Additives and Flavourings (FAF) et al., 2019; Organisation for Economic Co-operation and Development (OECD), 2001).

While possible, potassium overdose from consumption of potassium chloride salt is rare in people with normal kidney function, and most cases involve accidents or suicide attempts (John et al., 2011; Saxena, 1989). In those with chronic or acute kidney disease, the condition hyperkalemia frequently arises from normally harmless amounts of dietary potassium, supplements, or medical treatments (John et al., 2011; Saxena, 1989). Potassium overdose results from a sudden overwhelming increase in blood serum concentration. Hyperkalemia symptoms may also simply result from the inability of the kidneys to filter potassium from the blood, leading to subsequent buildup in the body (Saxena, 1989). Symptoms of potassium toxicity include irregular heart activity, muscle weakness, nausea, vomiting, and loss of intestinal muscle function (John et al., 2011). Death can sometimes result, with or without treatment (Saxena, 1989).

The Organisation for Economic Co-operation and Development (OECD) of the United Nations (2001) reports that as a worst case scenario for the mining, refining, and fertilizer industries, assuming complete body retention from inhalation in a work environment during an eight hour shift, the daily intake would only amount to 140 mg of potassium chloride. Compared to dietary intake (approximated at 2000-4000 mg), this inhalation level is not a concern for miners, farmers, or industrial workers, and no occupational exposure limit could be located (Organisation for Economic Co-operation and Development (OECD), 2001).

A study of potash mine air quality was conducted in 2007 in German mines, but focused on nondescript respirable dust, diesel fuel particulate matter, and nitrogen oxides and carbon monoxide resulting from combustion of diesel and detonation of explosives. The researchers found that even in state of the art facilities with modern exposure control infrastructure, the levels of these volatiles and particulates were quite high, but mostly in compliance with German regulations (Dahmann et al., 2007). The study does, however, suggest that European threshold limits may warrant further investigation, despite only minor health effects being reported (Dahmann et al., 2007). Neumayer-Gromen et al. (2009) found a strong correlation between potash miner's exposure to diesel exhaust and development of lung cancer.

Unlike many other mine environments, potash mines are not typically associated with high-risk carcinogens like radon, asbestos, silica dust, and heavy metals (Neumeyer-Gromen et al., 2009).

Chloride enhances plant uptake of cadmium and its mobility in tissues, so fertilization with potassium chloride may pose toxicological concerns for humans (Khan et al., 2014). Dietary exposure to cadmium may be linked to breast cancers (Khan et al., 2014). Potassium and chloride also decrease the starch content of potatoes, increasing the oil retention in processed varieties, which can contribute to obesity and heart disease (Khan et al., 2014).

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

There is no substitute for potassium itself as an essential plant nutrient (USGS, 2020).

Kelp can supply potassium to crops when used as a fertilizer or soil amendment. Though the potassium content of dry kelp meal only ranges between 1 and 3% (as opposed to 50% potassium in potassium chloride), many commercial products are marketed to the home gardener as potassium fertilizers or biostimulant products (Chalker-Scott, 2019). Chalker-Scott (2019) states that there is little benefit to using kelp meal in a home garden setting, however. Mikkelsen (2007), conversely, describes seaweed products as valuable sources of available potassium, but their low potassium content combined with transportation costs from the coasts may make them undesirable for field-scale uses. Kelp products may also be synthetically hydrolyzed using alkaline materials like potassium hydroxide. Hydrolyzed kelp products are permitted on the National List. While some research demonstrates their efficacy as fertilizers, the primary potassium benefit likely arises from the potassium hydroxide used for extraction rather than the potassium content of the seaweed itself (Chalker-Scott, 2019; Mattner et al., 2013) and these products are not nonsynthetic alternatives to potassium chloride.

In the early 20th century, acetone was in high demand for its necessity in the production of explosives during World War I, and kelp fermentation processes were found to be an excellent source of acetone (Ciceri et al., 2015). Potash is a by-product (Ciceri et al., 2015). Compared to the large-scale mineral extraction taking place today, potash derived from kelp is expensive (Ciceri et al., 2015). Additionally, there may be environmental drawbacks to seaweed harvesting for agricultural uses (USDA, 2016). Overharvesting of wild seaweed can lead to habitat loss for other species, and reduced carbon sequestration by the oceans (USDA, 2016). Seaweed farms can lead to depletion of nutrients in coastal waters, reduced access to local fisheries, and pollution linked to application of inorganic fertilizers (USDA, 2016). In 2020, the NOSB recommended to the NOP that stricter restrictions be placed on harvesting practices for marine plants, but rulemaking action has not yet occurred (NOSB, 2020).

The production of nonsynthetic potassium sulfate is substantially similar to that of potassium chloride derived from brine through selective crystallization methods (Schultz et al., 2000). Some potassium sulfate is produced using synthetic methods, however, with the use of sulfuric acid reactions (Zehler et al., 1981)

Bakhsh et al. compared fertilization with potassium chloride and potassium sulfate in cereals (wheat, rice, and corn) over different crop rotation combinations (and fallow periods) and found no notable difference in yield improvements between the two. Zehler et al. (1981) also found negligible differences to quality and yield in cereals resulting from potassium chloride or potassium sulfate fertilization in the authors' survey of studies on the topic. Potassium chloride has a price advantage, however (Bakhsh et al., 1986; Khadr et al., 2004). Sugarcane has been shown to exhibit little yield or quality difference when using potassium sulfate or potassium chloride as well (Khadr et al., 2004). In the case of fodder crops such as grasses, legumes, and alfalfa, potassium sulfate and langbeinite (potassium magnesium sulfate) have been shown to have a clear advantage over potassium chloride due to the role of sulfur in protein synthesis and magnesium as a necessary nutrient for animals (Zehler et al., 1981). The same is true of oil crops like soybean, peanut, rapeseed, sunflower, olive, linseed, and castor; potassium sulfate leads to increased oil yields (Zehler et al., 1981).

Each plant has a wildly different tolerance range before exhibiting chloride toxicity; sugarcane and sugar beet are known to tolerate excessive chloride (Kafkafi et al., 2001; Khadr et al., 2004). Therefore, the choice to replace inexpensive potassium chloride with potassium sulfate may be one of cost and crop (Zehler et al., 1981). See *Appendix A* at the end of this report for more information on potassium and chloride tolerance in different crops.

Fertilization with potassium chloride leads to greater mobility of heavy metals in soil when compared to potassium sulfate (Kafkafi et al., 2001). This heavy metal mobility increase is likely the result of desorption (the process by which a substance may be released from a molecular surface) following the formation of complexes (Kafkafi et al., 2001). Metals may be released more easily from chloride complexes than sulfate complexes (Kafkafi et al., 2001). Greater heavy metal mobility means greater toxicity to living organisms (Asmoay et al., 2019).

Due to its higher mobility in some soils, chloride tends to depress the uptake of other nutrient anions (such as nitrate and phosphate) more than sulfate (Zehler et al., 1981). Conversely, chloride increases the uptake of cations such as potassium more than sulfate. . However, sulfate increases the content of complex carbohydrates and proteins in plants due to sulfur's role in their formation (Zehler et al., 1981).

Chloride depresses the nitrification process by negatively affecting microbiological organisms in the soil, while sulfate has a less pronounced effect on microorganisms (Zehler et al., 1981).

Zehler et al. (1981) describes several advantages of potassium sulfate over potassium chloride:

- It provides two nutrients, potassium and sulfur.
- The salt index is the lowest of all potash fertilizers.
- It is preferred over potassium chloride for crops sensitive to chloride, particularly high value specialty crops like tobacco, fruits, and flowers.
- It appears to improve aesthetic characteristics of crops, as well as disease tolerance and tolerance to weather, storage, and transport.
- The nitrogen and phosphorus content, as well as yield, tend to be depressed in plants grown in high chloride rather than high sulfate soils.

Irrigation water may contain elevated levels of chloride and other ions that contribute to soil salinization (Kafkafi et al., 2001). In systems using chloride-rich irrigation water, potassium sulfate is the preferred potassium fertilization source due to its lower salt index and lack of chloride. Fertilization with potassium sulfate also helps plants tolerate saline environments. An abundance of potassium in the tissue of plants susceptible to soil salinity (glycophytes) appears to improve shoot growth (Kafkafi et al., 2001).

Evaluation Question #8 contains further information regarding the salt indices of potassium fertilizers and their relation to soil salinization.

Sanadi et al. (2018) concluded that a split application of potassium chloride (day 1 and day 30), followed by a foliar application closer to harvest with potassium sulfate solution (day 60) increased yield and protein content of peanuts.

Langbeinite, a potassium magnesium sulfate mineral often associated with potassium chloride deposits, can be used as a valuable potassium source for crops with minimal processing (Mikkelsen, 2007). Langbeinite is sparingly soluble compared to potassium chloride and does not provide significant chloride (Mikkelsen, 2007; Schultz et al., 2000).

The mineral glauconite presents a partial alternative to potassium chloride, though the potassium content of 4-8% is significantly lower than that found in marine evaporite rocks (Rakesh et al., 2020). Sedimentary deposits containing a large fraction of glauconite are typically referred to as "greensand," and have been mined for soil amending purposes in the Eastern United States since the 19th century (Heckman & Tedrow, 2004; Mikkelsen, 2007). Franzosi et al. (2014) reported comparable yields in grasses when fertilizing with potassium chloride or magnetically concentrated Argentina greensand (glauconite is slightly magnetic). There was, however, a delay effect; the first harvests heavily favored potassium chloride, but the final, total values were roughly equal or slightly favored greensand. This was interpreted to mean that the rapid dissolution of potassium chloride provided a short term boost that was balanced later by the controlled release nature of greensand (Franzosi et al., 2014). Significant deposits of greensands found in India, Brazil, Australia, New Zealand, and Argentina have been proposed as a chloride-free mineral alternative to potassium chloride (Franzosi et al., 2014; Rakesh et al., 2020).

The term "potash" is derived literally from the words "pot ash," since the majority of soluble potassium was once derived from burning organic matter and soaking the ashes in water (Ciceri et al., 2015). Small-scale ash-derived potash operations still exist, but it is doubtful that ashes could ever supplant any significant proportion of potassium fertilizer currently provided by the mineral industries (Ciceri et al., 2015). Biochar produced by pyrolysis can also supply relatively minor amounts of slow-release potassium to crops (Basak et al., 2020). Additionally, burning plant matter or municipal wastes contributes to deforestation and/or the creation of pollution and, without significant technological advancement, this situation would be environmentally problematic as a replacement for mineral forms (Ciceri et al., 2015).

Raw and composted manure can contain significant potassium, typically around 1% (Herencia & Maqueda, 2016). Potassium is prone to leaching, however, and the composting process can lead to a reduction in potassium levels. Herencia & Maqueda (2016) compared soil and plant nutrient contents following four fertilization regimes in a comparison between conventional and organic production:

- Chemical fertilizers, including an unspecified potash as a potassium source
- Composted manure at low application rates, combined with crop residues over four years
- Composted manure at high application rates, combined with crop residues over four years
- Crop residues only over 10 years

The conventional plots were also treated with synthetic pesticides (Herencia & Maqueda, 2016). Crops were rotated twice per year between potato, tomato, lettuce, melon, spinach, broad bean, and cauliflower to mimic some organic systems used in Europe. The highest potassium levels in soil occurred with the high application of manure. The potassium content in leaves and edible portions of the crops did not exhibit statistically significant differences following any of the fertilization regimes. The authors found little variance of quality or yield between conventional production, organic production with manure application, and long-term organic production without application of amendments other than crop residues, particularly in the case of potassium content. They do, however, conclude that time is a necessary requirement for organic production to reach comparative short-term conventional yields (Herencia & Maqueda, 2016).

Wortman et al. (2012) showed similar results in a study using grains. Compared with a conventional fertilizer treatment, prolonged manure application resulted in higher soil potassium (1.6 times greater), and increased wheat yield. However, the manure treatment resulted in reduced corn and sorghum yields, in comparison with the conventional fertilizer treatment (Wortman et al., 2012).

Vinasse, a liquid by-product of the sugar production and alcohol distillation industries, contains significant potassium along with organic matter, nitrogen, calcium and magnesium (Prado et al., 2013). Vinasse is a troublesome industrial waste, but repurposing it as an agricultural fertilizer may also pollute ground and surface water. Vinasse has, however, been shown to improve the macronutrient and organic carbon content of soil (Prado et al., 2013).

Oil cakes derived from plant oil extraction, waste muds from sugarcane processing facilities, and fish waste can supply significant potassium, along with nitrogen and phosphorus (Basak et al., 2020).

Irrigation with recycled water is becoming increasingly important and, unlike with nitrogen and phosphorus, little potassium is removed in sewage treatment processes (Kafkafi et al., 2001). Dairy cows excrete a large proportion of the dry matter content of their food in feces and urine (approximately 38%), which leads to high potassium levels in the liquid fraction after solids separation and sewage treatment (Kafkafi et al., 2001). Sugar beet processing facilities also release significant amounts of potassium in wastewater, so treated effluents from these factories contain available potassium (Kafkafi et al., 2001). Treated water derived from dairies or sugar processors can supply a portion of a crop’s potassium needs through irrigation rather than through direct application of potassium chloride (Kafkafi et al., 2001).

Though potassium feldspar minerals constitute as much as 60% of the world’s potassium resources, they are not feasible fertilizer materials since they break down so slowly in the soil (Basak et al., 2020; Ciceri et al., 2017). It is estimated that by 2050, half of the world’s population will live in the tropics, an environment severely prone to nutrient leaching (Ciceri et al., 2017). Alternatives to highly leachable potassium chloride are currently being sought. Additionally, since the vast majority of potassium chloride deposits are found in the Northern hemisphere, food production challenges related to transport cost and efficacy of fertilizers are expected in the near future (Ciceri et al., 2017; Hellmann et al., 2021). Recent research describes an experimental process to double the availability of potassium derived from feldspars by grinding, mixing with calcium hydroxide and water, and heat-treating at pressure (200 °C, 14 atm), and proposes that the method could provide a more sustainable source of controlled-release potassium fertilizers for the future (Ciceri et al., 2017; Ciceri & Allanore, 2020). In tomatoes, researchers found that this novel hydrothermal material rivaled potassium chloride for harvested weight and leaf potassium content (Ciceri et al., 2019).

Certain *Bacillus* and *Aspergillus* microbial species can help to mobilize potassium when it is bound in silicate minerals as well, which may lead to increased biofertilizer or inoculant product development specifically marketed as potassium-releasing formulations (Basak et al., 2020). Basak et al. (2020) report that these products are already popular in China and South Korea.

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

In mixed crop and livestock operations, manure typically supplies sufficient potassium for crops, and deficiencies are only apparent when manure is stored, sold, or composted (Mikkelsen, 2007). In standalone crop operations, crop rotations and mixed crop systems can help to manage potassium levels without fertilization (Mikkelsen, 2007). Some deep-rooted crops can help to break down clays deep in the subsoil, and the released potassium can be made available to shallower rooted species (Mikkelsen, 2007). These deeper-rooted crop residues may also be applied as green manures to help cycle potassium (Römheld & Kirkby, 2010). Heming (2008) found that a single application of cattle manure could substitute for nearly 2 years worth of potassium fertilization of cereal crops, but greater accuracy in the measurement of manure application by farmers will be necessary to effectively reduce the use of mineral fertilizers. Applying organic amendments such as on-site compost also greatly improves potassium retention and the cation exchange capacity of the soil (Hue & Silva, 2000).

Mulching can also be particularly effective, and certain mulch materials from commercial crops have been shown to contain significant potassium, while also helping with leaching prevention (Andrews et al., 2021). Notably, almond, cacao, coffee, grape, pecan, hazelnut, oats, radish, ryegrass, and wheat wastes have been shown to rival some of the lower level potassium mineral amendments by percentage of potassium (in a range of 3-8%) (Andrews et al., 2021).

Reducing tillage, contour farming, and terrace farming can also help to reduce erosion leading to potassium loss (Basak et al., 2020).

The study and breeding of potassium-efficient genotypes of common crops can decrease the use of potassium fertilizers, and is becoming increasingly important (Römheld & Kirkby, 2010). Significant research into phosphorus-efficient cultivars has been conducted, but comparative studies with potassium are few (Römheld & Kirkby, 2010). Since both phosphorus and potassium uptake are heavily reliant on root architecture, existing phosphorus research may be invaluable in selecting potassium efficient genotypes (Römheld & Kirkby, 2010).

Khan et al. (2014) question whether potassium fertilization, specifically with potassium chloride, is effective or beneficial at all in terms of crop yield increases, after the authors analyzed 2100 field trials. Soil potassium testing may not be a useful determinant of deficiency or availability of exchangeable potassium, and it was observed that potassium levels may *increase* in the absence of fertilization, likely from mineral weathering in the soil or leaching from crop residues (Khan et al., 2014).

Römheld & Kirkby (2010) stress the importance of increased knowledge transfer between scientists and farmers regarding potassium management in soil, particularly in rural or underdeveloped areas, and see a disproportionate focus on nitrogen fertilization.

Report Authorship

The following individuals were involved in research, data collection, writing, editing, and/or final approval of this report:

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Appendix A

Deficient, Adequate, and High/Toxic Concentrations of Foliar Potassium and Various Tissue Chloride in Crops. Adapted from Kafkafi et al. (2001).

Foliar Potassium (g/kg^3)				Chloride (g/kg^3)			
Crop	**Deficient**	**Adequate**	**High**	**Plant part**	**Deficient**	**Adequate**	**Toxicity**
Alfalfa	-	-	-	S	0.65	0.9-2.7	6.1
Almond	10	14	14	-	-	-	-
Apple	10	15	20	F	0.1	-	>2.1
Apricot	20	25	30	-	-	-	-
Avocado	3.5	7.5	20	F	-	~1.5-4.0	~7.0
Banana	30	38	50	-	-	-	-
Barley	20-28	23-41	-	S	1.2-4.0	>4.0	-
Blueberry (Highbush)	3	5	9	-	-	-	-
Blueberry (Rabbiteye)	3.5	6	9	-	-	-	-
Cashew	7.2	8.9	14.4	-	-	-	-
Cherry (Sour)	12	16	21	-	-	-	-
Cherry (Sweet)	15	25	30	-	-	-	-
Citrus	7	7-11	12-17	F	-	~2.0	~4.0-7.0
Common Bean	-	15-35	-	-	-	-	-
Coconut palm	-	-	-	F	2.5-4.5	>6.0-7.0	-
Corn	-	20-25	-	F	-	1.1-10.0	>32.7
Corn	-	-	-	S	0.05-0.11	-	-
Cotton	-	-	-	F	-	10.0-25.0	>25.0-33.1
Cowpea	-	20-25	-	-	-	-	-
Cranberry	4	8	8	-	-	-	-
Currant	8	14	17	-	-	-	-
Fig	7	9	10	-	-	-	-
Garlic	30	39	-	-	-	-	-
Grape	10	13	14	-	-	-	-
Grapevine	-	-	-	P	-	0.7-8.0	10.0-11.0
Grapefruit (Nonfruiting)	6	8	22	-	-	-	-
Grapefruit (Fruiting)	6	8	22	-	-	-	-
Groundnut	-	-	-	S	-	<3.9	>4.6
Hazelnut	4	7	24	-	-	-	-
Kiwifruit	-	-	-	F	2.1	6.0-13.0	>15.0
Lemon	7	10	20	-	-	-	-
Lettuce	-	-	-	F	>0.14	2.8-19.8	>23.0
Macadamia	4	5	10	-	-	-	-
Mandarin	4.7	9	11	-	-	-	-
Oil palm	16	17	19	-	-	-	-
Orange	4	7	11	-	-	-	-
Papaya	28	33	55	-	-	-	-
Peach	10	20	-	F	-	0.9-3.9	10.0-16.0
Pear	8	10	-	F	-	<0.50	>10.0

Foliar Potassium (g/kg^3)				**Chloride (g/kg^3)**			
Pecan	8	12	-	-	-	-	-
Pineapple	20	22	-	-	-	-	-
Plum, Prune	10	16	-	-	-	-	-
Potato	-	35-65	-	S	<1.0	2.0-3.3	12.2
Potato	-	-	-	P	0.71-1.42	18.0	44.8
Raspberry	10	15	-	-	-	-	-
Red Clover	-	-	-	S	0.15-0.21	-	-
Rice	-	29-35	-	S	<3.0	-	>7.0-8.0
Rice	-	-	-	straw	-	5.1-10.0	>13.6
Sorghum	15	15-20	20-30	-	-	-	-
Soybean	12	17-25	26-28	F	-	0.3-1.5	16.7-24.3
Spinach	-	-	-	S	>0.13	-	-
Spring wheat	-	-	-	S	1.5	3.7-4.7	>7.0
Strawberry	-	-	-	S	-	1.0-5.0	>5.3
Subterranean clover	-	-	-	S	>1.0	-	-
Sugarbeet	10	-	-	F	0.71-1.78	-	-
Sugarbeet	-	-	-	P	<5.7	>7.1-7.2	>50.8
Sugarcane	-	12-20	-	-	-	-	-
Tobacco	-	-	-	F	-	1.2-10.0	>10.0
Tomato	10	29	-	S	0.25	-	~30.0
Walnut	9	12	-	-	-	-	-
Watermelon	30	35	-	-	-	-	-
Wheat	20-26	23-36	32-36	S	1.2-4.0	>4.0	-

Plant part key: F = foliar; S = shoot; P = petioles