A Review of Soluble Salts in Compost

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Abstract

The chemical, physical and biological conditions of soil and growing media can be greatly improved by the addition of compost. Compost contains a multitude of essential nutrients for plant growth, such as nitrogen (N), phosphorus (P) and potassium (K), and can also be a source of organic matter. However, recent concerns and criticisms have been directed toward composts with a high concentration of soluble salts. Soluble salts refer to the amount of soluble ions, such as calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+), present in compost. Soluble salts are measured indirectly and cumulatively through electrical conductivity (EC). High concentrations of Na^+ in soil solution are detrimental to plants due to its ability to accumulate and interfere with root uptake of water. Other soluble salts, such as K^+ and Ca^{2+}, are considered mineral nutrients and are required for plant growth. An agricultural index, or Ag Index, is an analytical ratio $((N + P_2O_5 + K_2O)/(Na + Cl))$ which can inform agriculturists of macronutrient composition and provide a better understanding of Na^+ concentrations in compost. Typically, composts with an EC result of 5.0 dSm^{-1} or more have been considered to be high and needed to be properly diluted or mixed with soils or growing media to ensure that the soluble salts do not induce salt stress in the plants. The purpose of this paper is to explore the known knowledge regarding the speciation of the specific salt measured by the EC test and determine if further research is needed to identify the specific salts and their impacts on plant growth.

When done properly, these compost-soil mixtures can enhance plant growth and yields. Additionally, composters or compost users can leach their composts or provide adequate irrigation to ensure salt stress does not occur. Applying composts with high EC has been shown to aid in the remediation of saline-sodic soils by increasing the cation exchange capacity, which enables leaching of Na^+ from the soil. Correctly labeling composts could decouple the concerns over high EC composts and the benign effects from composts with an EC < 5 dSm^{-1}. Best

practice application methods of compost as an organic amendment will need to be evaluated individually due to the variance of soil type, crops being grown, and irrigation potential.

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Introduction

Compost is a product produced through controlled aerobic, biological decomposition of biodegradable organic materials. The product undergoes microbial action at both mesophilic and thermophilic temperatures, which significantly reduces the viability of pathogens (AAPFCO, 2017). Compost can have a wide range of chemical characteristics, such as nutrient composition and pH, depending on the composting method applied and the composition and origin of the biodegradable materials used **(**Asses et al., 2018; Grigatti et al., 2011; Michel & Reddy, 1998). Traditionally, compost was comprised of waste plant material; however, more recent composting operations include agricultural waste, biosolids, yard waste, source-separate food waste and municipal solid waste (Gomez 1998, Zhang et al., 2018). These wastes are being recycled at increasing rates and their potential to pollute air, water and soil highlight the need to dispose of or utilize them in an environmentally-friendly fashion is becoming more socially desirable (Ahel et al., 1998; Düring and Gäth, 2002; Kumar et al., 2004; Mor et al., 2006). Incorporating these organic wastes into compost allows composters to recycle and reuse elements with agronomic significance that would otherwise end up in landfills and be of no reuse value. Recycling of these elements reduces dependency on finite resources, and therefore is critical to establish sustainable agricultural practices (Gomez, 1998; Qadir & Oster, 2004)**.**

The primary nutrients within compost are forms of nitrogen (N), phosphorus (P) and potassium (K). A number of forms of N can be used by plants, with the most common being nitrate (NO_3^-) and ammonium (NH_4^+). Orthophosphate (($H_2PO_4^-$) is the most available form of P for plant use in soils, and potassium oxide (K_2O) for K (NCRS, 2007; Penn State, 2017). In addition to these primary nutrients, salts, micro- and macro-nutrients, heavy metals, and other contaminants may also be present.

Application of compost can alter the physical and chemical properties of soils that in return enhance the soil's ability to promote growth (Chang et al., 2007; Tejada et al., 2006).

Although compost is comprised of various nutrients, it is not considered a fertilizer and hardly resembles the material that it originated from (USCC, 2010). Despite the documentation of the benefits associated with applying compost, some compost use has been met with skepticism due to its high salt concentrations and not understanding that many soluble salts are beneficial. Regions that are experiencing escalating problems with soil salinity and sodicity may be reluctant to apply compost to their fields because of the phytotoxicity associated with high concentrations of soluble salts present in composts (Mahmoodabadi et al. 2013; Reddy & Crohn 2012; Wu et al. 2000)

Sodicity refers to the amount of sodium (Na^+) held in the soil. NaCl accumulation is the most common cause of sodic soils, and plants grown in them suffer from burnt leaf margins that reduce overall plant vigor and crop yield (Grattan & Grieve, 1998)**.** Salinity refers to the measurement of soluble salts in the soil. High salinity in soil reduces the uptake of nitrogenous molecules into plants and therefore limits the plants growth and yield (Grattan & Grieve, 1998). The limiting growth factor for plants growing in low- or non-sodic environments is nutrients, including salts, while plants growing in environments rich in nutrients may be limited by high salinity, high sodicity, or both (Bernstein 1975).. Sharpley et al. (1992) found that the presence of excess salts decreases the overall P in plant tissues resulting again in reduced plant vigor and crop yield. These studies suggest that there is an optimal nutrient concentration range that provides a plant with an ideal amount of nutrients. When nutrients are outside of this optimal range, the plant can experience nutrient-induced deficiencies or nutrient-induced toxicity (Grattan & Grieve, 1998). Unfortunately, defining this range of optimal nutrient concentrations is problematic due to the variability present within soils, plant salt tolerances and the composition of available nutrients.

Concern over whether or not the high salt concentrations in compost would have a negative impact on soil and agricultural yield is reasonable. Therefore, the objective of this paper is to review current literature to determine which soluble salts are present in compost, the effects of those salts upon soil and plants, and identify gaps in knowledge regarding compost application to soils. The overarching goal of this review is to provide a reference for compost users so they can make better informed decisions regarding the application of compost.

Electrical Conductivity in Compost

A variety of ionic elements found in soil and compost pertain to the definition of a soluble salt. Soil and compost salinity is influenced by the presence of Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2+} ions and some micronutrients. The soluble salt content of a compost or soil is measured by determining the electrical conductivity (EC). This is done by passing an electrical current through a sample of compost or soil mixed with water, giving a reading in decisiemens per meter (dSm^{-1}). Other related units of measurement may also be used such as millisiemens per cm ($mScm^{-1}$) and micro-millisiemens per cm (μScm^{-1}). An EC measurement is the accumulation of all types of salts present in a compost sample, not just NaCl. Composts used in studies reviewed in this paper exhibited EC values with a range from 1.0 dSm^{-1} or less to 16 dSm^{-1} or greater, while EC values in non-saline soils commonly range from 0 to 1.5 dSm^{-1}. Saline soils and saline-sodic soils are characterized as having an EC value greater than 4.0 dSm^{-1}, while high salinity in soil can be defined as soils with an EC of 16 dSm^{-1} or greater.

Confusion regarding EC levels in composts and soils arises due to the different methodologies used to measure them and the inability to directly compare the measured results. Soil EC is measured using a method known as EC_e. EC_e is the measurement of EC from a saturated paste of the soil (1:1 water:compost), while compost EC is measured using a method referred to as EC_5. EC_5 measures EC using extracts from a 5:1 water-to-compost mixture to compensate for the elevated concentrations of soluble salts in compost (Thompson et al 2001).

Both of these methods produce a measurement of EC; however, they are not comparable and thus must be converted to be compared. The development of equations to convert EC_e to EC_5 have not been perfected due to the complexity of the equations (Reddy & Crohn, 2012). In addition, methods using other ratios by volume of water:medium have been used in various studies, which adds further confusion when comparing results across the literature (McLachlan et al., 2004).

A chemical analysis can be done to further determine the specific types of salts causing a specific EC reading (CSU, 2015). After identifying and determining the specific concentrations of soluble salts present in a compost, an agricultural index (commonly referred to as Ag Index) can be calculated. The Ag Index is an analytical measurement of a compost macronutrient mass (g) ($N + P_2O_5 + K_2O$) divided by its sodium chloride mass (g) ($Na + Cl$) (Crohn, 2016). Composts with an Ag Index above 10 are considered high quality due to the high ratio of macronutrients to sodium chloride. Values of 2 or lower are considered poor quality due to the high concentration of NaCl or lack of macronutrients in the compost. Reference to the Ag Index of a compost can alleviate some of the concerns about composts having high Na^+ and Cl^- concentrations that would be potentially detrimental to soil and plant yields.

Unfortunately, few studies have investigated the specific type of salts present in composts and how different combinations of mixtures of these salts affects plant growth. This lack of analysis contributes to the lack of knowledge regarding the quantity and proportion of soluble salts in compost that should be applied (Reddy & Crohn 2012). There also may be a lack of understanding about the Ag Index, and therefore, educating compost end-users and farmers on how to reference the Ag Index would be beneficial. In addition, requiring composters to properly label their compost with a corresponding Ag Index would further promote awareness of this useful information.

Reducing EC in Compost

According to the US Composting Council (2001), composts that contain high amounts of soluble salts may be ideal for application in situations where crops are not present or planted immediately after application. If high EC levels in compost is a concern, leaching a compost and/or producing a leachate can reduce the total number of salts present, as well as a thorough watering to help alleviate salt stress in crops at the time of planting (Ksheem et al. 2015; Pant et al. 2012; Qadir & Oster 2004). A leachate is created when a composter captures the water that has percolated through the compost. Leaching can be done before or after a compost is applied to the soil. Fornes et al. (2010) leached three different composts with an initial EC_5 of 8.3, 4.82, and 7.19 dSm^{-1}. After eight leaching events, the EC_5 of these composts were 0.35, 0.35 and 0.90 $dSm^{-1,}$ respectively. Irrigation, in combination with organic amendments such as compost, can then help leach excess salts in highly saline-sodic soils, particularly Na^+. This will be discussed further in the organic amendments section.

One concern of leaching compost is the loss of the nutrients N, P, and K in the process. Ksheem et al. (2015) found that the majority of Na^+ was leached in the first few leaching events, while Ca and magnesium (Mg) were mostly retained in the compost. The subsequent leachates retained satisfactory amounts of nutrients (N, P, and K) and therefore were still appropriate to use as a soil amendment. However, discarding the first few leachates in a way that doesn't negatively affect the environment through surface and/or groundwater contamination presents a problem. More intuitive ideas on discarding or utilizing these leachates are needed.

The high EC values in composts are a result of the composted materials or feedstocks used. Zhang et al. (2018) found that increasing the proportion of the organic fraction of municipal solid waste in a co-composting mix increased the EC of the mixture. However, the composting process reduces the EC present in the finished product. Said-Pullicino et al. (2007) found that the EC dropped from 7.1 to 5.0 dS/m^{-1} after 250 days of pile composting under aerobic conditions. Therefore, the feeedstock used in composting operations play a significant role in the EC of the finished compost. In attempts to reduce the EC in compost, some have investigated the potential of incorporating other materials into the compost such as zeolite. Zeolite is a microporous crystalline composed of hydrated aluminosilicate of alkali and alkaline earth cations. The crystalline structure of the zeolite allows it to readily absorb cations and thus has a high cation exchange capacity (Ramesh & Reddy 2011).

Chan et al. (2016) investigated the potential of zeolite, a natural mineral, in reducing EC in composted food waste supplemented with Mg and P salts. The additional Mg and P salts conserved the N levels in the compost by forming struvite (i.e. magnesium ammonium phosphate); however, this increased the EC_5 as well. By adding zeolite (10% dry weight), the EC_5 was reduced to 2.82 dSm^{-1} and ammonium ion adsorption increased, resulting in higher total N content in the final product. Compost supplemented with Mg and P salts not treated with zeolite had an EC_5 of 6.45 dSm^{-1}. Compost with neither Mg and P salts nor zeolite treatment had an EC of 3.6 dSm^{-1}. Turan (2007) also found that the addition of zeolite reduced the EC_5 of compost made up of poultry litter. The composted poultry litter EC_5 was reduced from 15.71 to 5.24 and 1.74 dSm^{-1} by adding 5% to 10% zeolite (volume to volume), respectively.

Additionally, numerous studies have shown that the addition of zeolite to compost made with municipal solid waste decreased the concentration of heavy metals present in the final compost (Kosobucki et al. 2008; Turan & Ergun 2008; Zorpas et al. 2000). Zeolite is able to reduce the salinity and heavy metals during composting due to its high cation exchange capacity, yet it is not as effective at a low pH (Chan et al., 2016). The inclusion of zeolite into compost appears to be beneficial by means of reducing the EC and the presence of metals. Further study on the long-term effects of applying compost with zeolite to fields is needed to better understand how nutrient and metal concentrations change over time (Ramesh & Reddy 2011).

Soluble Salts and Plant Nutrition

The effects of high Na^+ in soil on plants and their ability to tolerate them has been the focus of research for some time (Liang et al. 2018, Deinlein et al. 2014, Mudgal et al. 2010). Again, the major ions contributing to high salinity in soil are Na^+, K^+, Cl^-, Ca^{2+}, SO_4^{2+}, and Mg^{2+}. An increase of these ions in the soil can trigger an increase in osmotic pressure which decreases the potential plant water availability, leading to a cascade of events that reduce the plant's potential growth. A plant's relative yield plotted as a function of the average root-zone salinity is defined as a plant's salt tolerance. The variability in salt tolerance among plants is a result of the plant's evolutionary history, and therefore, the interactions described below are generalizations or acknowledged trends found amongst multidisciplinary studies investigating the effects of salts on plants.

A plant in a saline environment usually has difficulty absorbing K^+ ions due to the high levels of other ions in the environment. Plants under salt stress in soil with high levels of Na^+ tend to accumulate Na^+ in their tissues due to the plant's K^+ transporters inability to distinguish Na^+ from K^+ (Mudgal et al. 2010). Plants that can maintain higher cytosolic K^+/Na^+ ratios are more capable of tolerating salt stress (Liang et al. 2018). The soluble salt K^+ is essential for plant growth by contributing to the turgor-pressure-driven solute transport in the xylem of plants (Marschner, 2012). Plants will respond to salt stress by synthesizing soluble sugars and other osmolytes in an attempt to balance the osmotic pressure at the cellular level (Liang et al. 2018). The diversion of energy to combat salt stress is thought to be the main driver of reduced plant growth in plants experiencing salt stress.

An excess accumulation of Cl^- in a plant can also trigger phytotoxic effects. The negative effects caused by Cl^- are less understood than the adverse effects caused by Na^+, despite the anion and cation being commonly bound together (Teakle & Tyerman, 2010). Cl^- is considered an essential micronutrient because of its role in regulating pH, turgor, enzyme activities in the cytoplasm, and photosynthesis (Marshner, 2012; Teodoro et al., 1998; Xu et al., 2000). When Cl^- is abundant in the soil, the NO_3^- transporter mechanism selects for Cl^- due to its inability to distinguish them (Teakle & Tyerman, 2010). This interaction is likely very similar to that of Na^+ and K^+. Thus, plants that can better control the amount of Cl^- entering the roots and being transported to its shoots are more capable of managing salt stress triggered by excess Cl^- (Teakle & Tyerman, 2010). Further research investigating how Cl^- is stored and transported throughout the plant is needed to expand current knowledge of how plants manage salt stress.

The plant's ability to respond to osmotic stress is highly coupled with Ca^{2+} gated channels that may act as osmotic sensors (Deinlein et al., 2014). Ca^{2+} is also an essential mineral nutrient for plants, yet even in low salinity soils, uptake of Ca^{2+} may be inhibited due to high pH or cation competition (Geraldson, 1957). In general, Ca^{2+} is needed as a structural component to plant membranes, cell wall structures and to regulate ion transport within cells (Rengel, 1992; Hepler, 2005).

The uptake of Ca^{2+} into plants can be negatively affected by excessive ion interactions and precipitation in soils from salinity, thus reducing the availability of Ca^{2+} and its usefulness in plants when other salts are present (Cramer et al., 1986). This competition and hindrance of uptaking ions is why Na^+ is detrimental to plant growth (Lynch et al., 1987) Additionally, studies have shown that the application of NH_4^+ rather than NO_3^- results in reduced uptake of both K^+ and Ca^{2+} mineral nutrients in plants, mainly due to the high pH of NH^{4+} (Martinez & Cerdá, 1989; Osawa, 1962). These interactions result in a positive feedback loop due to the plant's increased nutritional need for Ca^{2+} arising while the availability of Ca^{2+} is reduced (Grattan & Grieve, 1998).

Sulfur (S) is perhaps one of the most significant essential nutrients for plant growth due to its role in the formation of the photosynthetic apparatus and electron transport system (Marshner, 2012). Sulfur is found in various metabolic compounds including amino acids, enzyme proteins, vitamins and antioxidants. S is also involved in mitigating salt stress by improving the cytosolic K^+/Na^+ ratio through its role in the antioxidative systems (Fatma et al. 2013). Deficiencies in S are correlated with a reduction in chlorophyll and therefore can hinder metabolic processes including photosynthesis (Takahashi et al. 2011). Organic matter plays a vital role in the mineralization of S, which can be readily uptaken by plants. Soils with <5% organic matter typically require sulfur fertilization to produce crop yields (Eriksen, 1994). In addition, Ali et al (2012) demonstrated that an increase in S availability was correlated with increased growth of plants under salt stress.

One of the more overlooked essential elements for plants growth is Mg. Mg is a central atom in the chlorophyll molecule and is also needed to transport carbohydrates in the phloem in the plant's leaves to other actively growing areas such as the roots. Plants experiencing Mg deficiency may experience a reduction in root growth and chlorosis, or yellowing of the plant tissue, which can ultimately lead to plant yield reductions (Cakmak & Yazici, 2010). The uptake of Mg is influenced by the availability of other soluble salts such as Ca^{2+} and K^+ (Romheld & Kirkby, 2007). Nutrient imbalances in soil solutions result in cation competition, which can limit the uptake of Mg (Gransee & Führs, 2013). This nutrient imbalance can be characterized by too many or too few cations, which suggests that there is an ideal ratio of cations in solution for uptake of nutrients such as Mg. However, little is known about the relationship between Mg and organic matter, and how it affects nutrient uptake by plants (Gransee & Führs, 2013). More research is needed to understand availability of Mg uptake by plants, Mg mineralization, and fixed soil Mg stocks in relation to organic matter (Gransee & Führs, 2013).

Essential micronutrients, such as copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), boron (B), nickel (Ni), and zinc (Zn) have been shown to positively affect plant growth in saline soils for certain species. Zayed et al. (2011) found that rice and grain grown in saline soils treated with Zn^{+2}, Mn^{2+}, and Fe^{2+} exhibited significantly increased plant growth and yields. Soils with high cation exchange capacity and low Na^{+} are more fertile because they make Mn, Zn and other positively charged ions more available for plants to absorb, resulting in improved growth (Khattak & Jarrell, 1989; El-Sherif et al., 1990). However, depending on the species, Fe, Mo and Cu may either increase or decrease plant growth based on the salinity of the soil (Grattan & Grieve, 1998).

Compost can serve as a critical source of the nutrients mentioned above in the form of soluble salts. Good quality composts have limited amounts of Na^{+} and Cl^{-} in them, and therefore, should not cause the phytotoxic effects that have been described, as long as they are properly applied. Compost can also have significant concentrations of phosphorus, potassium, calcium, magnesium, and sulfate, which can either be readily absorbed by the plant, or be transformed by enzymatic activity to readily available forms (Reddy & Crohn, 2012; Gransee & Führs, 2013; Takahashi et al., 2011; Guangming et al., 2017). Finally, many compost products can provide the essential micronutrients for plant growth and a significant source of organic matter.

Effects of Soluble Salts in Compost on Plant Growth and Yields

The preferred soluble salt concentration depends on the type of plant being grown, availability of irrigation and soil type (USCC, 2001). For example, EC_e values from 2-4 dSm^{-1} can significantly reduce plant growth and potentially kill salt sensitive crops, such as strawberries and lettuce. Salt tolerant crops, such as some wheats and ryes, can tolerate EC values as high as 7 dSm^{-1} (Mass & Grattan 1999). Therefore, determining the ideal compost to apply can be difficult due to a wide range of range of factors, including soil type, irrigation, compost and plant species.

Herrara et al. (2008) investigated the effects of different combinations of peat and composted municipal solid wastes (CMSW) on plants and found that a mixture of CMSW with peat (30% - 60% respectively) performed better than other mediums for growing tomatoes (*Lycopersicon esculentum)* (Herrara et al., 2008). The compost used during this three-year study had a range of EC_e values from 11.4 to 19.8 dSm^{-1}. Overall, the nursery substrate ranged from 1.0 to 22.0 dSm^{-1} at the beginning of the study. By the end of the growing periods the EC_e of the nursery substrate treated with CMSW ranged from 1.0 to 5.4 dSm^{-1}. The tomatoes grown in peat-only exhibited significantly higher rates of emergence (number of tomato plants emerging each day) than the tomatoes grown in mixed medias. However, the tomatoes grown in mixed medias exhibited an emergence rate greater than 85%. Despite the lower rate of emergence and percentage of emergence, the plants grown in the 30% CMSW mixtures exhibited enhanced growth in terms of height, stem diameter and height of first node (Herrara et al., 2008). These results suggest that composts with mixed medias are not ideal for seedling emergence; however, they are ideal for growing plants. Therefore, transplanting plants to compost mixed medias, or treating soils with compost after the plants have reached an appropriate size, could be beneficial.

A similar study done by Cai et al. (2010), using mix medias composed of composted biosolids and leached composted bioslids, found that the 1.1 to 1.45% (content of water soluble salts,%, dry base) salinity is ideal for seedling growth of cucumber, *Cucumis sativus L.,* and pepper, *Capsicum frutescens L*. The mixtures with a soluble salt concentration of 1.45% or greater reduced growth, and resulted in similar growth characteristics as plants grown in the control media, which was composed of commercial peat and perlite.

Chang et al. (2007) studied the effects of compost and fertilizers on plant growth and soil characteristics over a three year period. Composts with a range of EC_5 of 4.6 to 18.7 dSm^{-1} were applied to plots at different rates and tilled into the soil at a depth of 15 cm. After tilling, a variety of 24 vegetable crops including pak-choi, *Brassica camesttics,* lettuce, *Latuca sativa*, and amaranth, *Amaranthus tricolor,* were transplanted to plots designated with different treatments. The different treatments included four different application rates of composts; 1 set of plots was treated with inorganic fertilizer, and another set was a control with no treatment.

Plants grown in the plots treated with compost exhibited heightened yields and growth. Crops grown in plots treated with inorganic fertilizers only outgrew and produced higher yields than the crops grown in compost-treated plots during first year of the study. However, during year two and three, crops grown in compost-treated plots grew more and produced higher yields than crops grown in plots treated with inorganic fertilizers (Chang et al., 2007). This suggests that the benefits of adding compost are not immediate and longer observation periods are required to observe their benefits. This is likely due to the slow release of nutrients from the compost in the soils (Miller & Miller, 2000). The experimental plots with the highest rate of compost application exhibited EC_e values greater than 4 dSm^{-1}. The plants grown in these plots did not express any negative effects from the elevated EC_e values; rather, they grew vigorously and obtained high yields. However, the growth of these plants was not significantly higher than plants grown in plots with a one-quarter to one-half reduction in compost application. This suggests that there is an optimal level of soluble salts in soil and exceeding that range doesn't produce significant increases in plant yields.

These studies and others suggest that soils or media amended with compost with EC_e values in the range of 1 to 5 dSm^{-1} are suitable for plants (Walker & Bernal, 2008; Chang et al., 2007, Herrara et al., 2008**)**. Applying compost with EC_5 values of 5 dSm^{-1} or greater to soils and media has been shown to enhance the growth and yield of plants grown in them. Therefore, the literature suggests that the application of compost with high EC_5 values and limited NaCl concentration will not induce negative effects as long as the soils they are applied to do not exceed an overall EC_e of 4 dSm^{-1} after application. If the EC_e does exceed 5 dSm^{-1}, then it is recommended that the soil be irrigated to leach excessive salts. Further scientific study examining how overall EC_e of soil mixed with composts with high EC_5 impacts plant growth is needed.

Studies examining the phytotoxicity of soluble salts at concentrations greater than 4 dSm^{-1} to those found in compost have shown that when these composts are not diluted in other medias, the plants grown in them do experience negative effects from salt stress (Cai & Gao, 2011; Chong, 2000). Germination of seeds should be done in soils that have an EC_e of 2.5 dSm^{-1} or less to optimize the rate and overall emergence of seedlings. There are likely exceptions to these findings due to the high variability of salt tolerance amongst plant species. The development of a proper application method is critical to optimize the benefits from applying compost and avoid negative impacts. Compost application should also consider the substrates they are being applied to and the species of plant being grown (Reddy & Crohn, 2012).

Applying Compost to Saline-Sodic Soils

As previously stated, there is a concern that applying compost with high EC to saline-sodic soils will result in detrimental effects to the soil and the plants grown in that soil. Saline soils are likely the result of improperly-managed fertilizer application and irrigation with water high in Na^+ (Qadir & Oster, 2004). The excess of soluble salts causes clay to swell and disperse, which causes a decrease in soil permeability, available water capacity, and infiltration rate (Lakhdar, 2009). These adverse conditions are then amplified in arid regions where good, quality irrigation water is scarce and water evaporation occurs quickly (Mahmoodabadi et al., 2013; Qadir & Oster, 2004). In addition, saline-sodic soils are becoming increasingly abundant throughout the globe, posing a serious threat to agricultural systems by reducing access to fertile land (Mahmoodabadi et al., 2013; Qadir & Oster, 2004). As a result, there is an increasing need to reclaim these soils and return them to a more favorable condition for crop production.

The main principle to reclaiming these soils is to reduce the overall Na^+ concentration by replacing the exchangeable Na^+ by Ca^{2+}. This is commonly done by applying gypsum ($CaSO_4$), sulfuric acid (H_2SO_4), and organic matter. Addition of organic matter to soils increases the cation exchange capacity due to the increase in organic carbon stock, which makes more nutrients available for plants as well (Diaccono & Montemurro, 2010). The increase in the cation exchange capacity of the soil also increases the chelating ability (i.e. the ability to form several bonds with a metal ion) of Ca^{2+} and Mg^{2+} in the soil, which enables them to replace Na^+ from the cation exchange complex. This decreases the soil's ability to absorb Na^+ by reducing the sodium absorption rate (Lakhdar et al. 2009). The Na^+ concentration in the soil is therefore reduced because it allows Na^+ to be disbursed and leached. However, the application of these amendments is becoming increasingly associated with high financial costs and environmental pollution concerns. Interests in environmentally-friendly and low-cost alternatives to these amendments have prompted the question of whether or not compost could be used instead.

Tazeh et al. (2013) investigated the effects of applying municipal solid waste compost and cow manure to a saline-sodic soil in soil columns in a controlled experiment. The EC of the compost and manure was measured in a 1:2.5 ratio of water to media and was calculated to be 19.6 and 16.7 dSm^{-1}, respectively. The EC_e of the soil was 15 dSm^{-1}. The soil and amendments were thoroughly mixed together and packed into PVC columns that were 50 cm in length and 15 cm in diameter. The EC_e and soluble ions concentrations were monitored over a five-month period where various treatments of leaching were applied. Both amendments reduced the EC_e of the soil to about 5 dSm^{-1}. In most instances, the rate of leaching resulted in no significant difference in the EC_e between amendments. Furthermore, there was little difference in EC_e between months four and five of the experiment.

This experiment by Tazeh et al. (2013) demonstrated that the high EC found in the organic amendments did not result in an overall increase in EC_e of the soil. On the contrary, the organic amendments reduced the EC_e and aided in the remediation of the soil. Other long-term studies lasting nine years or more have also demonstrated that compost application reduces Na^+ concentrations and maintains or increases organic matter and essential nutrients K, N and P in the soil (Diacono & Montemurro, 2010; Miller et al., 2013). A more detailed review of the effectiveness of compost use in salt-affected soils can be found at Lakhdar et al. 2009.

Planting crops with high salt tolerance, such as wheat and barley, can be beneficial to the soil reclamation process. Planting such crops may provide a salable crop and may provide some degree of bioremediation. Qadir & Oster (2004) suggest that the roots will improve the soil aggregation and hydraulic properties of the soils, which will enhance the root's respiration ability. Furthermore, the symbiotic relationship between soil bacteria and roots may make Ca^{2+} more available, which will enable more Na^+ leaching from the soil (Qadir & Oster 2004). Qadir et al. (1997) showed that bioremediated plots exhibited an increase in P, Zn and Cu; however, N decreased in all plots except for those where N-fixing sesbania (*Sesbania aculeata*) was planted. In conclusion, coupling compost application with the planting of salt-tolerant crops may expedite the soil remediation process and produce a more profitable crop in the meantime.

Discussion/Conclusion

Quality compost can serve as an effective soil amendment that provides essential nutrients to plants and enriches the health of soils. The negative effects of high concentrations of Na^+ in soils and composts on plants have been well documented. There is a need to continue the study of phytotoxicity from soluble salts other than Na^+ which are present in compost. Further research is needed to understand how salt tolerance is affected by different mixtures of soluble salts present in compost rather than a singular effect. This research will lead to a better understanding of salt tolerances and plant ability to select anions and cations based on different charge balances (Teakle & Tyerman, 2010). Understanding salt tolerances during plant growth will help users of compost understand the how the nutrients in compost can be better utilized for specific applications.

The overall feedstocks used to make compost significantly impact the physical and chemical properties of the compost (Zhang et al. 2018). The addition of zeolite or creating a leachate are effective strategies at reducing the EC of composts (Chan et al. 2016; Fornes et al. 2018). By incorporating these strategies into the composting process, targeted EC values could be achieved. In addition, zeolite appears to be particularly capable at transforming contaminants such as metals into an inert form (Kosobucki et al. 2008; Turan & Ergun 2008; Zorpas et al. 2000). This could be especially useful when municipal wastes are being incorporated into compost operations. Further investigation into the long-term effects of using such compost is needed.

To direct the efficient use and optimize the potential benefits from compost, further understanding of how and when to apply and mix composts into soils is needed. Furthermore, understanding how nutrients become available temporally and spatially in the soil would also be beneficial. This research needs to take into consideration the effects of agricultural practices, organic matter, soil enzyme and microbial populations that affect the availability of nutrients to plants.

Measurement of EC values for soils and composts needs to be standardized. Different methodologies used to measure EC across the literature make it difficult to compare results and make informed decisions. Standardization of EC measurement methods will alleviate this problem, and as a result, make more literature available for scientific reasoning concerning compost and soil (McLachlan et al., 2004; Reddy & Crohn, 2012). This standardization can be in the form of Seal of Testing Assurance (STA) guidelines for laboratories doing compost analysis through that program.

After reviewing the literature on soluble salts in compost, it seems clear that composts should not be limited to an EC_5 value of 5 dSm^{-1} or less. The literature suggests that the application of composts with high EC_5 values can be beneficial to plant growth and yields when properly applied. However, if not properly applied and/or managed, the applications of these composts to soil could result in a negative impact on seedlings and plant growth. Again, it seems clear from the literature that the addition of composts with a high EC and limited concentrations of NaCl will be beneficial for plant growth as long as the EC_e of the soil doesn't surpass 4 dSm^{-1}. Having said that, additional scientific study is required to elucidate the precise benefits achieved by these additions.

The limiting of composts to an EC of 5 dSm^{-1} or less may inhibit the ability of farmers to remediate saline-sodic soils, which are predicted to increase in abundance in relation to climate change (Komatsuzaki & Ohta, 2007; Zuazo & Pleguezuelo, 2008). There is an upper limit to EC_5 values in compost that needs to be identified to reduce the risk of negatively affecting crops and causing environmental harm. It is critical that the high EC present in these composts is not due to high concentrations of NaCl. This will reduce the chance that application of composts will not increase the soils salinity and/or cause negative effects to crops being grown.

Including an Ag Index on composts with an EC_5 value greater than 5 dSm^{-1} will be advantageous to the consumer and developing best application practices. By doing so, the USCC can decouple low-EC_5 composts from the concerns associated with high-EC_5 composts and restore confidence in the benign properties of low-EC_5 composts. Educating farmers and compost users about the Ag Index and the benefits associated with applying composts with a high EC_5 will likely prove advantageous to increasing the amount of composts applied. Therefore, the proper labeling of composts should also be standardized in an attempt to educate agriculturists on the negative effects if improperly applied.

By labeling composts with an EC_5 of 5 dSm^{-1} or greater with an Ag Index, the industry acknowledges that these composts should be managed in a similar manner as inorganic fertilizers are. The International Plant Nutrition Institute states in their Plant Nutrition Manual (2012) that fertilization needs to follow the “Four R’s,” which are: the right nutrient, at the right rate, at the right time, and in the right place for the selected crop. The creation of best-use protocols--with these guidelines in mind--will need to be developed to ensure that these composts are properly applied and managed. These best-use protocols will need to be applicable to various soils and will have to consider access to irrigation and the crops being grown. Some progress has been made in these areas by Reddy and Crohn (2012), who developed a prediction method to estimate how the application of compost will affect the soil’s EC_e. The expansion of these predictive models to other soils will prove beneficial to those concerned with plant growth and yield and soil remediation.

There is a need to address the increasing amount of saline-sodic soils worldwide and the increasing need to feed growing populations (Reddy & Crohn 2014). The application of compost has the potential to address these problems in a timely and sustainable manner. Other proposed solutions to these problems, such as genetically modified foods or inorganic fertilizers may not be as cost-effective, locally available, nor as suitable as the use of compost. Attempts to cultivate plants with higher salt tolerances has had limited success due to the genetic complexity of salt tolerant genes (Flowers, 2004). Genes that enable plants to tolerate higher salt concentrations have been identified; however, there is much work to be done before genetic engineering can transfer these genes into crops so that they will be salt tolerant and still produce edible yields (Deinlein et al., 2014). Furthermore, these crops would not be available to organic farmers due to their genetic modification.

The application of compost to soil is a viable method to increase nutrient availability, organic matter present in these soils in order to increase plant yields. Furthermore, their application will increase the efficiency of nutrients used in agricultural and municipal systems. Best practices must be developed to ensure the proper management of composts. Overall, the potential of compost to alleviate problems regarding organic recycling and reuse, saline-sodic soils, and environmental pollution by recycling nutrients back into the soil and agricultural systems is promising. The proper application of composts will increase plants yields, restore soil health and encourage farmers to use more sustainable farming practices.

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