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Review

Effectiveness of compost use in salt-affected soil

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ABSTRACT

Soil degradation and salinization are two of the utmost threat affecting agricultural areas, derived from the increasing use of low quality water and inappropriate cultural practices. The problem of low productivity of saline soils may be ascribed not only to their salt toxicity or damage caused by excess amounts of soluble salts but also arising from the lack of organic matter and available mineral nutrients especially N, P, and K. Concerns about salinization risk and environmental quality and productivity of agro-ecosystems have emphasized the need to develop management practices that maintain soil resources. Composted municipal solid waste (MSW) was commonly used to enhance soil productivity in the agricultural lands and rebuild fertility. However, their application could be also a promising alternative to alleviate the adverse effects caused by soil salinization. MSW compost, with high organic matter content and low concentrations of inorganic and organic pollutants allow an improvement of physical, chemical and biochemical characteristics and constitute low cost soil recovery.

Contents

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1. Introduction

Soil salinization and nutrients poorness are a severe problem throughout the world and around 20% of the world's cultivated land and 50% of cropland are affected [1]. In addition the increasingly uses of low quality water and conventional agriculture practice continue on worsening the problem [2,3]. The excessive salt amounts adversely affect soil physical and chemical properties, as well as the microbiological processes. Tejada and Gonzalez [4] showed that increasing electrical conductivity in saline soil decreases structural stability and bulk density. Excessive exchangeable sodium and high pH favors swelling and dispersion of clays as well as slaking of soil aggregates through the decrease soil permeability, available water capacity and infiltration rate [5]. In addition, in the arid zones the intense evaporation tends to accumulate salts in the upper soil profile, especially when it is associated with an insufficient leaching or where soluble salts move upward in the soil profile from a water table instead of downward [6]. These modifications may further compromise the yield of crops growing on such soils via toxicity and perturbation in water nutrients balance [7,8].

The maintenance of adequate soil physical chemical properties in saline land may be achieved by using good quality water, rational use of soil fertilizers, and appropriate cultural practices [9]. In addition, many different methods are used on reclamation, as physical amelioration (deep ploughing, subsoiling, sanding, and profile inversion), chemical amelioration (amending of soil with various reagents: gypsum, calcium chloride, and limestone), electro-reclamation (treatment with electric current) [10]. Alternatively, growing salt tolerant species may be the only cost effective means of revegetation, even though this means a significantly different species mix to that which existed before disturbance [11,12].

Input of organic matter conditioner becomes common practices in such salt-affected area the last decades and according to Melero et al. [13] constitutes an important way of soil regeneration and the enhancement of fertility. Studying the effects of organic fertilization on chemical and biochemical properties of a Mediterranean soil under dryland agriculture, these authors showed that compost amended soil exhibited increases in quantity and quality of total organic carbon, nitrogen and phosphorus nutrients, microbial biomass and enzymatic activities. In the same way such amendment use have two principal beneficial effects on reclamation of saline soil: improvement of soil structure and permeability thus enhancing salt leaching, reducing surface evaporation and inhibition of salt accumulation in surface soils, and release of carbon dioxide during respiration and decomposition [10]. However, irrational or low quality uses of compost may causes potential threat thereby release of organic and inorganic pollutant in the soil which can adversely affect organisms and ecosystems [14]. Therefore, it is of the utmost importance to have stringent quality requirements for the materials to be applied in order to achieve the expected beneficial effects that these amendments create for the long term. This paper focuses the effectiveness of compost as valuable soil conditioner to alleviate the increasingly soil degradation due to salinization.

2. Progression of salt-affected soil

It is estimated that about 15% of the total land area of the world has been degraded by soil erosion and physical and chemical degradation, including soil salinization [15]. Salt-affected soils occur in more than 100 countries of the world with a variety of extents, nature and properties [16]. According to Tòth et al. [17], the total area of salt-affected soil is about one billion hectares. They occur mainly in the arid and semiarid regions of Asia, Australia, Africa and South America. In addition, soil salinity affects an estimated 1 million hectares in the European Union, mainly in the Mediterranean countries, and is a major cause of desertification. Nowadays, 10–15% of the irrigated land (45 Mha) suffers with different level of salinization problems and 0.5–1% of irrigated area are lost every year [18]. Table 1 shows the potential risks of salinization in all over the world.

Table 1
Percentage of salt-affected soils.

Country	Salt-affected area	References
Australia	30% total area	Rengasamy [16]
Egypt	9.1% total area	Mashali et al. [19]
Hungary	10% total area	Varallyay [20]
Iran	28% irrigated land	Khel [21]
Kenya	14.4% total area	Mashali et al. [19]
Nigeria	20% irrigated land	FAO [22]
Russia	21% agricultural land	Dobrovol'skii and Stasyuk [23]
Syrie	40% irrigated land	FAO [22]
Thailand	30% total area	Yuvaniyama [24]
Tunisia	11.6% total area	Mashali et al. [19]
USA	25–30% irrigated land	Wichelns [25]

3. Benefits of compost use in saline soil restoration

Because the reclamation, improvement and management of salt-affected soils necessitate complex and expensive technologies, all efforts must be taken for the efficient prevention of these harmful processes. Permanent care and proper control actions are required. Adequate soil and water conservation practices, based on a comprehensive soil or land degradation assessment, can provide an "early warning system" that provides possibilities for efficient salinity (or alkalinity) control, the prevention of these environmental stresses and their undesirable ecological, economical and social consequences.

Concerning affected soils, a wide array of organic soil amendments, with varying levels of processing and characterization are used for their reclamation. Compost amendments most frequently are used to provide essential nutrients (such as N and P and K) [3] to rebuild soil physic-chemical properties, and re-establish microbial populations and activities [26].

3.1. Physical and chemical effect

It is commonly known that compost application improves soil properties, which is connected with an increase in the organic carbon content. Repeated application of MSW (municipal solid waste) compost consistently increased soil organic matter content and soil C/N ratio to levels greater than those of unamended soil [27–29]. Fig. 1 shows the prediction of future changes in soil organic matter content calculated in Taiwan under different soil management systems. Chemical fertilizer keep the soil organic matter pool at 60 mt ha^{-1} in 2050, however compost addition manage to enhance this pool more than double of the conventional tillage system without fertilizer. Organic amendments may improve soil properties for years after application [30], as only a fraction of the organic material is initially degraded and made available to plants and soil microorganisms [31].

The beneficial effects of composts on affected soil properties depend on soil texture and moisture conditions, as well as on the origin of organic matter [32,33]. In saline soil, Na^+ constitutes a highly dispersive agent resulting directly in the breakup of aggregates [34,35]. Exchangeable Na^+ in the soil solution and at the exchange sites contribute to repulsive charges that disperse clays particles (Fig. 2a). The application of organic matter in salt-affected soil promotes flocculation of clay minerals, which is an essential condition for the aggregation of soil particles and play

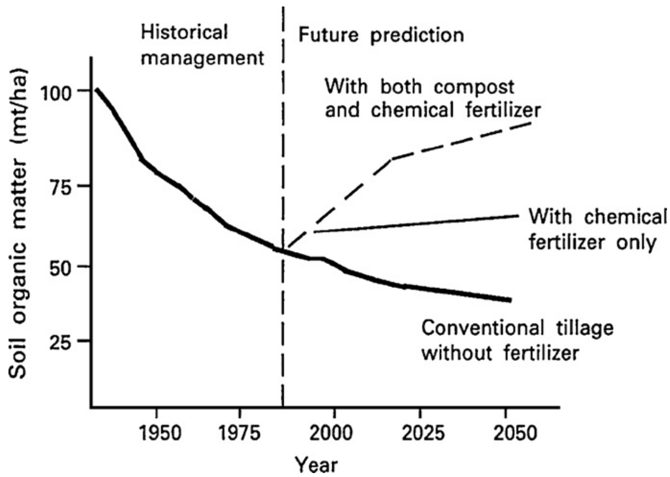

Fig. 1. Changes in soil organic matter content (mt/ha) calculated in Taiwan under different soil management systems with long term application of composts or fertilizers [132].

an important role in control of erosion. The added organic matter aid to glues the tiny soil particles together into larger water stable aggregates, increasing biopores spaces which increase soil air circulation necessary for growth of plants and microorganisms [36,37] (Fig. 2b). In same way, Khaleel et al. [38] found a direct correlation between organic carbon additions and decrease of bulk density. Bronick and Lal [35] and Courtney and Mullen [39] reported this decrease to a dilution effect caused by mixing of the added organic material with the more dense mineral fraction of the soil. Thus, allowing an enhancement of soil porosity and aeration [40]. As a consequence an improvement of saline water leaching was observed by Kahlown and Azam [41] in the soil mixed with organic matter. Moreover, Qadir et al. [42] and Walker and Bernal [43] reported an acceleration of Na^+ leaching, decrease the exchangeable sodium percentage (ESP) and the electrical conductivity (EC). These authors reported that less oxidized, higher molecular weight humic matter is more important in the process of aggregate stabilization than more oxidized humic substances of lower molecular weight. Thereby resulting an enhancement the chelation ability of Ca^{2+} and Mg^{2+} in soil solution to effectively replace Na^+ from the cation exchange complex particularly at alkaline pH values as well as and reducing the sodium adsorption ratio (SAR) of the saline soil [44].

It is well known that salinity soil limit soil fertility. In fact, most salt-affected soils are deficient in nitrogen (N), phosphorus (P), and potassium (K) [3]. Addition of compost in such soil enriches the rhizosphere with micro- and macro-nutrient elements and counteracts nutrient depletion [3]. This amendment constitutes a valuable slow release nitrogen source and its availability in MSW compost has been estimated at 10% in the first year after application [46]. While, Iglesias-Jimenez and Alvarez [47] found that 21% of the total N in MSW compost was available as NH_4NO_3 6 months after application. Pathak and Rao [48] reported the stimulus of nitrogen mineralization observed in the salt-affected soil to the increase of solubilization of organic matter at high pH, which provides increased amount of carbonaceous substrates for microbial growth. In same way, Weber et al. [49] reported that the continuous release of nitrogen from compost into the soil improves not only the soil fertility, but also the conditions of organic matter mineralization. In fact they found an increase of humic acid/fulvic acid ratio (C_{HA}/C_{FA}) in compost amended soil which might be partly inherited from the original composition of humic substances in the composts, where humic acids always predominate over fulvic ones. Hargreaves et al. [50] stated that compost organic nitrogen mineralization dependent on many factors including C/N ratio of raw material, composting conditions, compost maturity, time of application, and compost quality. As well increased KCl and K_2SO_4 salinities had a stimulating effect on organic matter mineralization [51]. Unfortunately, the compost application could promote nitrification process and consequently a possible groundwater contamination [43], especially when there are not crops that can take up the mineralized nitrate. However, compared with mineral fertilization, the soil amendment reduces nitrogen leaching, decreasing the possibility of nitrate groundwater contamination [52,53].

Phosphorus is one of the most essential plant nutrients. Salinity and sodicity can affect forms and dynamics of this nutrient in soil [54]. The bioavailability of P is strongly tied to soil pH [55]. The pH between 5.5 and 7 constitutes the optimum range for P release [56]. There is considerable evidence in the literature dealing with the increase phosphorus solubility following organic material application [57]. In saline soil Muhammad et al. [58] found an increase of $NaHCO_3$-extractable P following 1% of compost amendment. Presumably while decomposing organic matter releases humic acid, which in turn convert unavailable soil phosphates into available forms. Such being the case, compost or other organic if applied with high-grade phosphate minerals must work as very effective phosphate fertilizers [59]. Humus, since it is normally negatively charged, is not thought to retain much P by itself in soils, however, in association with cations provided by amendment such as Fe^{3+}, Al^{3+}, and Ca^{2+}, it is able to retain significant amounts [60]. These authors reported also that 1 t of compost, on an average, contains 50 kg P_2O_5. In addition, MSW compost supplies similar amounts of P as inorganic fertilizer (NPK) [61], nonetheless compost effect remains for long term [62,63]. Frossard et al. [64] showed that composted organic solid wastes contained between 2 and 16% of their total phosphorus as rapidly exchangeable inorganic phosphorus, between 40 and 77% of their total phosphorus as slowly exchangeable.

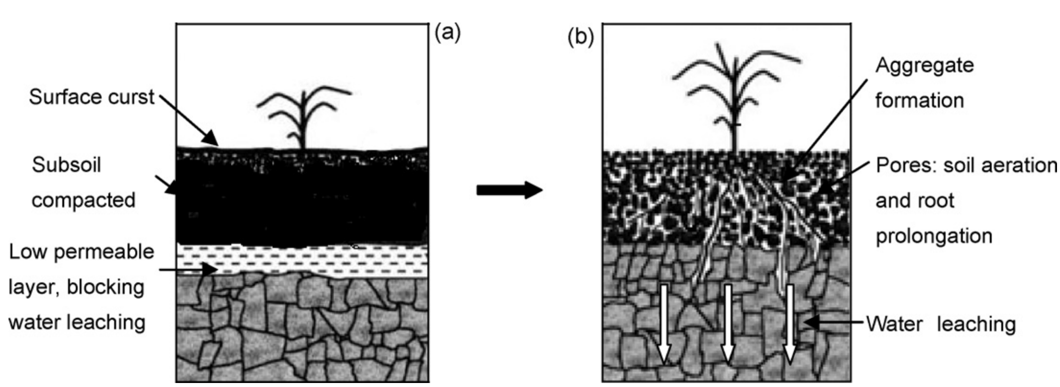

Fig. 2. Schematic representation of the soil before (a) and after (b) organic amendment addition.

Moreover, organic matter plays an important role in determining potassium dynamics in soils, as organic colloids possess negative charges that arise from the dissociation of carboxylic and phenolic groups during organic matter decomposition [65]. These authors found high residual potassium content in compost amended soil bounded by clay minerals and organic matter and not immediately replaceable. The residual potassium becomes more available due to the action of organic acids liberated during decomposition of organic matter [66]. Under saline soil, mineralization of compost increase plant available potassium fraction through the increase occurred in CEC [43]. In addition, the high content of non-exchangeable fraction indicated that the organic matter could supply available K^+ and increase the K^+/Na^+ selectivity ratio in plant [67].

The enrichment of the exchange complex in Ca^{2+} and Mg^{2+} as reported by Walker and Bernal [43] can be particularly relevant in the reclamation of saline–sodic soils, since it could decrease the proportion of Na^+ in the exchange complex, improving soil physical properties. The quantity of other macro- and microelements in compost products depends on the feedstock's type and origin and the method of compost production. Their availability is also controlled by mineralization or compost decomposition rate.

3.2. Biological effect

The importance of microbial biomass of compost amendment return to the essential role of soil microbe in nutrients cycling ecosystems [68]. The amendment of saline soil with compost enhances their subsequent mineralization with microflora with a concomitant increase in CO_2 release and consequently soil aeration [58] presumably owing to a their enzymatic activities stimulus. During the microbial degradation and humification of residues, the residual carbon is released to the atmosphere as CO_2. Microflora generally control the mineralization of organic carbon in soil, however, some authors have reported that microbial activity and microbial biomass were not related to soil salinity or high pH [69], thus contradicting many above-mentioned studies reporting negative or positive effects of salinity on organic carbon mineralization in soil. Chandra et al. [51] reported that at low concentrations salt had a stimulation effect on carbon mineralization; while at high concentrations may become toxic to the organisms. However, Pathak and Rao [48] found a steady evolution of CO_2 throughout 3 months of high salinity treatment showing a high activity of the heterotrophic microflora. As well, Xiaogang et al. [70] related the decomposition of organic matter under salt stress to the soil water content. In fact using tow salt NaCl or Na_2SO_4 they found a greater cumulative CO_2 at 17% (w/w) than 25% (w/w).

The incorporation of organic manure including compost, into soils significantly stimulates soil microbial biomass and activity, due to the high quantities of readily utilizable energy sources introduced [71]. The enhanced soil enzyme and biological activities are believed to be direct indicators of the enhancement of soil fertility resulting from the incorporating organic manure [72,73], which helps increase N and P uptake by plants. In saline soil, Stehouwer and Macneal [74] found an increase of microbial activity reported to both: inoculation of previously sterile soil and providing a reduced C energy source for microbes. The additional organic material, which provides additional substrates in the salt-affected soil for the microbial population, may also relieve osmotic and pH stress on the microorganisms [48]. Soil basal respiration rate, a parameter used to monitor microbial activity, was also increased for 8 years after MSW compost application as compared to a control [75]. Liang et al. [67] reported that soil urease and alkaline phosphatase activity, and respiration rate as well as salt tolerance of plants were significantly stimulated by incorporation of organic amendment in rice–barley rotation system. Incorporation of organic materials influences enzymatic activities in the soil because the added organic fractions may contain intra- and extracellular enzymes [73,76], which stimulate microbial activity in the soil [77]. In the same way, microbial metabolic quotient (qCO2) is used as indicator of biological activity through estimating the efficiently of microbial biomass to utilize available carbon for biosynthesis [78]. After 1 year of incubation, Pascual et al. [79] observed a sharp increase in qCO2 in an arid soil amended with an amount of municipal solid waste sufficient to raise its organic matter by 1.5%. The general opinion is that microorganisms living in a stressed environment put up defense mechanisms by increasing their respiration per unit biomass, so increasing qCO2 [80].

Pascual et al. [75] demonstrated that an 8-year amendment of an arid soil with the organic fraction of a MSW at two different rates (6.5 and 26 $t\,ha^{-1}$) had a positive effect on the activity of enzymes involved in the C, N, P cycles as well as on biomass C, constituting a suitable technique to restore soil quality. In fact, even if microbial activity is depressed by salts, biochemical mineralization by soil enzymes (amidases and deaminases) could still proceed provided the activity is not adversely affected at high salinity and alkalinity [48]. Different enzymatic activities were commonly used in monitoring soil quality. Due to their sensitivity, these properties provide rapid and accurate information on changes in soil quality. Deshydrogenase is an intracellular enzyme related to oxidative phosphorylation processes constitute valuable indicator of the overall microbial activity in soils [81]. The incorporation of organic amendments to soil stimulates its activity [82,83]. This increase is attributed to the availability of a high quantity substrates added to the affected soil [84] especially, the mineralization activity seems to be not affected by salinity [58]. Garcia-Gil et al. [85] found a high increase of oxireductase enzymes, such as dehydrogenase and catalase, under MSW compost treatments by 730 and 200% respectively. They reported also a high correlation between deshydrogenase activity and soil biomass. In the same way, Crecchio et al. [86] observed in 2-year experiment that MSW compost increased organic C and total N contents, dehydrogenase activity. The activity of such enzymes basically depends on the metabolic state of the soil biota [85]. Organic matter incorporation under high salinity or sodicity can provide a buffer to the soil solution and to soil microbiological properties [87].

Phosphatase is the enzyme responsible P mineralization and P turn-over, involved in catalyzing the hydrolysis of both ester and anhydride forms of phosphoric acid in soils [88]. According to Tripathi et al. [89], phosphatase activity responded more to pH than to the differences in soil salinity. Under high pH alkaline form predominates. Ozur et al. [90] observed obvious increase of this enzyme activity following compost treatment. Since, higher plants are devoid of alkaline phosphatase, the alkaline phosphatase of soils seems to be derived totally from microorganisms [91]. Consequently, such amendment could stimulate phoshatase activity under saline media. Microbes can produce and release large amounts of extracellular phosphatase due to their large combined biomass, high metabolic activity and short life cycles [92]. In addition, direct relationship was observed between phosphatase activity and soil organic C and P [88]. However, after reaching its maximum value, phosphatase activity remains constant stimulating the transformation of organic P incorporated with MSW compost into inorganic and available form [93]. Garcia et al. [94] related this stimulation in the synthesis of this enzyme, as well, to the demand for P by plants and soil microorganisms. However the combined application of chemical fertilizers and compost accelerated the decrease in the organic P fractions, presumably due to the promotion of microbial activity in the plough layer, even though a high amount of organic P was inputted by compost [95].

β-Glucosidase is one of the most important glucosidases in soils because it catalyzes the hydrolysis of carbohydrates with β-

D-glucosidase-bonds, such as cellobiose. As a result, this enzyme contributes to the mineralization of cellulose, the main cog compound in nature [96]. According to Landgraf and Klose [97], β-glucosidase activity is governed by the amount of easily mineralizable organic C and soils can be classified with respect to their β-glucosidase activity [98]. Urease and protease activity (related to the N cycle) hydrolyse nitrogen compounds to ammonium, using urea and low molecular weight protein substrates, respectively [85]. In the same way, Lauchli and Epstein [5] showed appreciable stimulation of these enzymes and they related this to higher microbial biomass produced in response to high doses of organic amendment. Pathak and Rao [48] found a stimulation of nitrogen mineralization under saline medium in the later stages of experiment. Indeed, with time of incubation the early adverse effect of pH on nitrites is relieved due the remedial influence resulting from organic matter decomposition (reduction of pH and ESP). As well, the application of vermicompost, sheep manure, poultry manure, pig manure, and urban waste at the level of 1% to soil characterized by high exchangeable sodium percentage increased the rate of urea hydrolysis [99]. Accordingly, the composted olive oil mill wastes are characterized by high organic load and a substantial quantity of plant nutrients (N, P, K, Ca, Mg and Fe) that could increase both soil fertility [100,101] and crop production [102].

4. Use risks

Saline and sodic soils can be managed by incorporating compost in upper soil layer, however, the influence of organic matter on soil properties depends on its amount and composition [103]. Immature composts may become anaerobic which often leads to odors and/or the development of toxic compounds, as well as bag swelling and bursting. Continued active decomposition when these composts are added to soil or growth media may have negative impacts on plant growth due to reduced oxygen in the soil-root zone, reduced available nitrogen, or the presence of phytotoxic compounds [104]. Low quality compost also arises from an excess of heavy metals and salt and a low degree of stabilization [105]. According to the EU Commission, the main limiting factors of amendment applications to soils are related to the eventual addition of organic and/or inorganic pollutants and microbial contaminants [106]. Depending on feedstock, certain composts have been shown to contain elevated concentrations of metals including Pb, Cd, Cu, and Zn [106]. Feedstocks which contribute organic pollutants included pesticides, household wastes such as oils and solvents, and paper products [107]. The chemicals that have been recognized as problems in amendment derived sewage sludge include are heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins and furans (PCDD/Fs) [108]. Surfactants and some of their metabolites are not readily biodegraded in non-aerated environments and may cause adverse environmental impacts when they enter sewage systems in high loads and accumulate in sludge [109]. Municipal and commercial wastes reported that under 0.5% by weight is hazardous and researchers indicated that phthalate esters are likely the most abundant xenobiotic present in MSW compost [110]. Furthermore, the use of immature amendments can cause phytotoxic effects, as well as nitrogen (N) deficiency and reduction in plant yield [111].

5. Compost quality

Composting is defined basically as biological processes occurring in favorable conditions (good aeration, temperature, moisture, etc.) and allowed to transform the raw initial material probably unsanitary or with phytotoxic properties to stable and mature end product [112]. As it shown the incorporation of this amendment improves salt-affected soil in the presence of good compost quality. However, the criteria's to evaluate compost quality are very complex and depend on the original organic matter and the politics of each country. While, general chemical, physical and biological properties are:

5.1. *pH corrective*

The pH plays a large role in the availability of plant nutrients. In fact, a basic or an acid pH can induce elements deficiency. Compost apparently functioned to buffer the pH of saline and alkaline soil [113]. Soil pH often decreases with compost amended due to effects of nitrification [114]. Conversely, compost have the potential to raise pH of acidic soils or mitigate the acidification process of soils receiving N fertilizer [115]. The recommended range of pH is between 6 and 7.5 [116].

5.2. *Total soluble salts*

Total soluble salts (also expressed as electrical conductivity level) it is a measure of water soluble salts (or salinity) present in compost or soil to which plant roots will be exposed. The recommended range of electric conductivity in compost is <2500 μS/cm (1:1 soil to water) [116]. However, application of compost on such affected soil helps to diminish salinity thereby improving soil characteristics, mainly by the increase of salts leaching.

5.3. *Bulk density*

Compost amendment reduces saline soil bulk density through increasing aggregation. The range of bulk density of MSW compost reported by He et al. [117] is between 0.22 and 0.74 $Mg\,m^{-3}$.

5.4. *Cation exchange capacity (CEC)*

The addition of compost can increase the soil CEC from 20 to 70% of the original CEC [118]. However it depends of the compost pH, thus care should be taken when comparing the CEC of composts with different pH.

5.5. *Temperature*

The temperature is a consequence of the microbial activity during biodegradation process. It can be divided into three phases namely mesophilic, thermophilic and maturation phase [119]. These authors stated an increase of temperature to 45 °C in the first 7 days of composting, then it progressed until 55 °C and remained around 70 days. This rapid increase indicates an intensive microbial activity reflecting a higher degradation rates occurring during the first stage. Finally, temperatures decreased and stabilised at 35 °C during the maturation phase.

5.6. *Organic matter*

It is well known that organic matter application plays a key role in the soil system and is an important regulator of numerous environmental constraints [120], mainly salinity [84]. In fact, the solubilization under alkaline medium into colloidal form increased substrates availability, thus relieving the pH stress on microflora [48]. There is no absolute value of organic matter, which is ideal for compost, however according to EPA waste-licencing system it is required that compost contain at least 30% organic matter on a dry weight basis.

5.7. C/N

The C/N ratio is typically used to assess stability maturity and decomposition of organic matter by microorganisms, and for this reason, the organic matter added to saline soils plays an important role in the positive effect observed in microbial activity and enzymatic activities such as urease, alkaline phosphatase and dehydrogenase [84]. The EPA acknowledges this and specifies within a waste license that the C/N ratio of compost must be below 25.

5.8. Element fertilizers (N, P, K, Ca, Mg)

Nutrient contents of compost are often moderate but vary among sources due to differences in waste materials and processing methods [121]. To report compost as having fertilizing capabilities and for it to be used in agriculture the total nitrogen (TN) content must be over 1% DW (dry weight) [122]. If compost contains TN of less than 1%, supplemental nitrogen fertilizer will be required if the compost is to be used as a soil improver.

Immobilization $<$ 1% compost TN $>$ 1% mineralization

The typical range of TN in compost is 1.0–3.0% DW. Compost over 3% TN is usually found to be immature and ammoniacal [122].

The decomposition of organic matter release gradually plant available phosphorus [123]. The range of phosphorus that has been found in MSW composts is between 5 and 35 g kg^{-1} DW [50]. The availability is closely related to soil pH (5.5 and 7.0), while, the suggested P concentration in soil solution should be above 0.2 mg/L to meet the needs of the crop [124]. Concerning potassium, typical range of total content is between 0.6 and 1.7% DW and the typical range of available potassium in this compost is between 620 and 2280 mg/L, fresh weight.

Compost contain calcium and magnesium which act as bases when they exist as oxides, hydroxides and carbonates when applied to soil, and may counteract soil acidification and vary pH levels making soil nutrients more available to plants [125]. As a consequence of increased Ca^{2+} concentration in soil solution, Na^{+}–Ca^{2+} exchange at the soil's cation exchange sites, leaching of the exchanged Na^{+} in percolating water and subsequent reduction in soil sodicity [126]. The typical range of calcium in compost is between 1.0 and 4.0% DW and the typical range of magnesium is 0.2–0.4%, dry weight.

5.9. Germination

The Cress Germination test is recognized by the EPA (Environmental Protection Agency) [127] as another method of determining compost maturity. Under the requirements of a waste license, germination of cress seeds in compost must be greater than 90% of the germination rate of the control sample. Under saline soil the germination rate can be reduced, however, compost application retrieve this effect; in fact Stehouwer and Macneal [74] recorded an increase of germination and fescue seedling establishment after the first leaching event as a response of the salt decrease following compost amendment.

5.10. Pathogenic agents

As pathogenic organisms may be present in the compost feedstock, the compost itself may also contain pathogenic organisms and, as a result, may pose health risks. To adequately reduce these health risks, the compost shall conform. According to Herity [128], the European Directive specifies that the concentration of faecal coliforms must be below 1000 MPN/g (MPN: most probable number) and that there must be no salmonella present in 50 g of total solids.

5.11. Heavy metals and organic pollutant

Low quality compost essentially arises from an excess of heavy metals and salt and a low degree of stabilization [105]. However, humic substances richness, which constitutes a major part of the OM of compost, can reduce metal solubility by formation of stable metal chelates [129]. Differences with respect to effects on metal availability between amendment treatments can be related to differences not only in the OM (humification), but also in the mineral fractions (salt content, pH) and cation exchange capacity (CEC), as well as changes in the redox conditions of the soil [130]. The presence of organic toxins is another cause of the damage noted on the application of low quality compost to the soil. Organic manures incorporation into soils at excess dosage may result in an accumulation of reduced and toxic substances due to anaerobic decomposition of organic manure [67]. A number of organic pollutants, such as hydrophobic persistent organic contaminants and surfactants, are known to accumulate in organic wastes [109]. Behavior of organic pollutants during composting and digestion indicate degradation during composting for PAHs and predominant resistance to breakdown for more recalcitrant compounds such as PCBs or PCDD/F. However estimates on the yearly loads of some organic pollutants released to the total Swiss agricultural area have shown that the load originating from compost application is of minor importance compared to the loads induced by aerial deposition as well as by application of farmyard manure and sewage sludge [131]. Compost utilization in agriculture is legislated in the way to prevent harmful effects on soil, vegetation, animals and human health, thereby encouraging the correct use of biosolids and protect the environment. However the regulations differ between countries largely with respect to requirements of organic waste quality and the quantities of pollutants which can be added to the soil [109]. Table 2 shows the limit premised of inorganic and organic pollutant for compost use according to European Union.

In conclusion, compost uses does not completely solve the underlying cause of the salinity problem. However, the use of compost on saline soils still improves soil physic-chemical properties, microbial biomass and growth of plants. Therefore, compost use can offer a short-term reprieve for farming on soils with medium to high salinity, or soils with temporary high salinity. As well, high application of compost may be a very useful tool for ameliorating severely salt-affected areas through the establishment of plant cover, including deep-rooted crops.

Table 2
European limits values for land application of potentially toxic elements in organic waste (expressed in mg kg^{-1}).

Compound	Limit			
	pH 5.0–5.5	pH 5.5–6.0	pH 6.0–7.0	pH >7.0
(a)				
Zn	200	200	200	300
Cu	80	100	135	200
Ni	50	60	75	110
Cd	3	3	3	3
Pb	300	300	300	300
Hg	1	1	1	1

Compound	Limit
(b)	
AOX (absorbable organic halogens)	500
LAS (linear alkybenzene sulphonates)	2600
DEHP (Di-2-ethylhexyl Phthalates)	100
NPE (nonylphenolethoxylates)	50
PAH (polycyclic aromatic hydrocarbons)	6
PCB (polychlorinated biphenols)	0.8

Sources: (a) UK (1989) regulations [133]. (b) European Commission, Sludge Working Document Brussels [134].

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