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Effect of Salinity on Soil Microorganisms

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1. Introduction

Whilst the majority of countries have criteria to evaluate the quality of the air and water, the same does not occur for the quality of the soil. Traditionally soil quality is associated with productivity, but recently it has been defined in terms of sustainability, that is, the capacity of the soil to absorb, store and recycle water, minerals and energy such that the production of the crops can be maximized and environmental degradation minimized. Thus preservation of soil quality is a critical factor for environmental sustainability.

A significant decline in soil quality has occurred throughout the entire world as a result of adverse changes in its physical, chemical and biological properties. According to Steer (1998), in the last decades of the last century, about 2 billion of the 8.7 billion agricultural lands, permanent pastures, forests and wild native lands were degraded. The global grain production growth rate fell from 3% in the seventies to 1.3% in the period from 1983-1993, and one of the main reasons for this decline was inadequate soil and water management. Inventories carried out on the soil productive capacity in the last decade indicated that 40% of the degradations of arable land were induced by man as a result of soil erosion, atmospheric pollution, intensive cultivation, over-grazing, deforestation, salinization and desertification (Oldeman, 1994).

Soil degradation processes constitute a serious problem on a worldwide basis, with significant environmental, social and economic consequences. As the world population increases, so does the need to protect the soil as a vital resource, particularly for food production, .

The soil is a dynamic medium, constituting the habitat of abundant biodiversity, with unique genetic patterns where one can find the greatest amount and variety of living organisms, which serve as a nutrient reservoir. One gram of soil in good conditions can contain 600 million bacteria belonging to 15,000 or 20,000 different species. These values decrease to 1 million bacteria encompassing from 5000 to 8000 species in desert soils (Informativo Capebe, 2010). Depending on the amount of organic matter present in the soil, the biological activity eliminates pathogenic agents, decomposes organic matter and other pollutants into simpler components (frequently less noxious), and contributes to maintaining the physical and biochemical properties required for soil fertility and structure.

However, soil is not an inexhaustible resource and consciousness of this, allied to knowledge of the need to maintain or increase the capacity of this agro-ecosystem, directing its multiple functions in an adequate way, is increasing, as also changes in the overall perception of its importance as an environmental component.

As an open system, the soil is dynamic and in constant interaction with the atmosphere, the hydrosphere, the biosphere and the lithosphere. Depending on the intensity with which these factors act, soil can present differentiated characteristics which define its potentialities for exploitation by man. Its structure is defined as the aggregation of primary particles in compound particles, separate from adjacent aggregates. However its structure implies in an arrangement of the primary particles (sand, silt, clay) which, by way of cementing agents, can group together forming aggregates with certain structural patterns, which necessarily include porous space.

Alterations in the chemical conditions of cultivated soils, such as the concentrations and types of ions in solution in the soil, variations in pH and in the critical flocculation concentration of the particles, can cause modifications in the dispersion of the clay fraction, degrading the original soil fraction. The sodium ion, being monovalent, increases the width of the diffuse double layer on the surface of the clays, reducing the attractive forces between them with a consequent increase in particle dispersion. The consequence of this dispersion of the clay is also shown by a reduction in stability of the soil aggregates, which are thus easily transported by rain or irrigation (Almeida Neto, 2007).

Although soil structure is not considered as a plant growth factor, it exerts an influence on the air and water supplies to the roots of the crops, on nutrient availability, on the penetration and development of the roots, as also on the movement of the soil macro-fauna. It also influences the loss of agrochemicals by way of erosion and leaching and can have considerable importance on the negative environmental impact of some agricultural practices. According to Machado (2002), inadequate soil use has been causing a gradual loss in their productive capacity.

The main threats to soil are erosion, mineralization of the organic matter, reduction in biodiversity, contamination, water proofing, compacting, salinization, and the degrading effects of floods and landslides. Soil degradation produces deterioration of the plant covering and the hydric resources. In addition, by mean of a series of physical, chemical, biological and hydrological processes, it causes destruction of both the biological potential of the land and of their use to sustain the population connected to it.

2. Soil salinization

Soil salinity is part of the natural ecosystem in arid and semi-arid regions and an increasing problem in agricultural soils the world over. In temperate, moist climates salinity occurs on a smaller scale, principally in salt water marshes, at the side of highways and in salty effluent discharges (Pathak & Rao, 1998; Keren, 2000; Qadir et al, 2000; Wichern, 2006).

Salinization consists of an accumulation of water soluble salts in the soil. These salts include the ions potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and sodium (Na^+). Sodium accumulation is also called sodification. High sodium contents result in destruction of the soil structure which, due to a lack of oxygen, becomes incapable of assuring plant growth and animal life.

Salt affects crop germination and density, as also vegetative development, reducing productivity and, in the most serious cases, leading to generalized plant death, limiting nutrient absorption and reducing the quality of the available water. For example, elevated salinity weakens plants due to the increase in osmotic pressure and the toxic effect of the

salts. In addition, salinization affects the metabolism of the organisms present in the soil, drastically reducing soil fertility and increasing water proofing of the deeper layers, impeding cultivation of the land. In an indirect way, soil salinization can adversely affect plant growth, due to destruction of the soil structure and its consequent compacting. This occurs due to a dispersion of the clay particles caused by substitution of the calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions present in the complex by sodium (Na^{+}), resulting in an increase in soil sodicity, that is, in the percentage of exchangeable sodium (PES), which, in the last instance, is the main factor responsible for the deterioration of the physical properties of salt-affected soils (sodic, or alkaline, and saline-sodic). Saline soils show the following physical-hydric characteristics: low permeability, low hydraulic conductivity and aggregate instability (Freire, 2009).

On a world wide scale, the production by approximately 400 million hectares of arable land is being severely restricted by salinity (Bot et al., 2000). In the European Union salinization affects about 1 million hectares, mainly in the Mediterranean countries, constituting one of the main causes of desertification (Iannetta & Colonna, 2011). The most affected soils are situated in Hungary, Romania, Greece, Italy and the Iberian Peninsula (Agricultura..., 2011). About 8.1 million hectares are salinized in India, of which 3.1 million are in coastal regions (Triphati et al., 2007). In Nordic countries, the use of salt to remove ice from highways produces localized salinization phenomena (Agricultura..., 2011). Considering the increasing temperatures and decrease in pluviosity which have characterized climates in recent years, the salinization problem has increased.

Salinization results from natural or anthropogenic factors, constituting a process of soil degradation which, in some cases, is responsible for irreparable losses in their productive capacity, with great extensions of arable land becoming sterile.

2.1 Natural soil salinization and sodification factors

The natural factors influencing soil salinity are:

- geological phenomena which increase the salts concentration in groundwater and consequently in the soil;
- natural factors capable of bringing groundwater containing elevated salt contents to the surface;
- infiltration of groundwater in below sea-level zones (micro-depressions with reduced or absent drainage);
- drainage of waters from zones with geological substrates capable of liberating large amounts of salts;
- action of winds, which, in coastal zones, can transport moderate amounts of salts to the interior.

The weathering of primary minerals (which make up the rocks or the original soil material) is the indirect source of nearly all the salts present in soils, although there are only a few cases in which this results in sufficient accumulation of salt (primary or pedogenetic salinization) to form saline soils. The areas of lands salinized by such natural processes, from which salt-affected soils could arise, such as Planossolo Solódico, Solonetz Solorizado, Solonchack Solonétzico, do not increase so drastically when compared to the increasing growth intensity of the extension of land salinized by anthropic activity.

In general, the salinization process occurs in soils situated in regions of low rainfall and which have a water-bearing stratum near the surface. In coastal zones, salinization could be

associated with the over-exploitation of groundwaters due to the demand induced by increased urbanization, or by industry and agriculture. The over-extraction of groundwaters can result in a lowering of the normal water-bearing stratum levels, leading to the intrusion of sea water.

2.2 Secondary factors leading to soil salinization and sodification

The most influential anthropogenic factors are:

- irrigation with water containing elevated salt contents;
- rise in phreatic water level due to human activities (infiltration of water from unlined channels and reservoirs, irregular distribution of irrigation water, deficient irrigation practices, inadequate drainage);
- use of fertilizers and other production factors, namely for intensive agriculture in land with low permeability and reduced possibilities for leaching;
- irrigation with residual waters with high salt contents;
- elimination of residual waters with high salt contents by way of the soil;
- contamination of the soil with industrial water and sub-products with high salt contents.

Soils affected by salts commonly appear in irrigated areas due to inadequate management of the irrigation and other practices, such that important extensions of fertile, arable land are becoming more and more saline. This is due to management practices that do not aim at conserving the productive capacity of the soil, such as, for example, the non-existence of an efficient drainage system, the use of inadequate quality water in inadequate amounts, and also the incorrect and excessive use of chemical fertilizers.

Irrigation is an ancient agricultural practice, widely used throughout the world, principally in tropical regions where hot, dry climates prevail, such as, for example, the semi-arid region in northeastern Brazil, where the evapotranspiration rate exceeds the rainfall throughout the better part of the year. In these areas, where there is not sufficient water available to supply the hydric needs of the crops throughout the whole vegetative cycle, irrigation assumes a fundamentally important role in order to guarantee good agricultural harvests. Since all natural waters contain variable amounts of soluble salts, be they of meteoric (rain), surface (rivers, lakes, dams, etc.) or subterranean (aquifers) origin, the application of water to the soil by irrigation implies necessarily in the addition of salts to their profile.

Thus salinization of a soil depends on the quality of the water used for irrigation, on the existence and level of natural and/or artificial drainage of the soil, on the depth of the water-bearing stratum and on the original concentration of salt in the soil profile. The basic principle to avoid soil salinization is to maintain the equilibrium between the amount of salt provided to the soil by irrigation and the amount of salt removed by drainage. In arid or highly ventilated climates, evaporation of the water enriches the soil with solutes, increasing the danger of salinization. In the same way, soils with limited permeability tend to concentrate salts. In irrigated zones, the low rainfall, elevated evapotranspiration rates and the soil structure impede leaching of the salts, which accumulate in the surface layers.

Estimates by FAO indicate that of the 250 million hectares of irrigated land in the world, approximately 50% already show salinization and soil saturation problems, and 10 million hectares are abandoned annually due to these problems (CODEVASF, 2011).

The excessive amounts of salts provided by irrigation waters can have adverse effects on the chemical and physical properties of the soils and on their biological processes (Garcia & Hernandez, 1996; Rietz & Haynes, 2003; Tejada & Gonzalez, 2005). These effects include mineralization of the carbon and nitrogen and the enzymatic activity, which is crucial for the decomposition of organic matter and liberation of the nutrients necessary for sustainability of the production (Azam & Ifzal, 2006; Wong et al., 2008). In addition, the agricultural practices can increase or reduce the microbial population, thus altering the activity, source and persistence of the enzymes in the soil (Parham et al., 2003).

Organic fertilizers are considered useful for crops due to their nutritive value, principally of nitrogen (N), and for their merits in improving the physical properties of the soil (Jackson & Bertsch, 2001; Garbarino et al., 2003), but their salt content is usually ignored, which could prejudice plant growth and soil quality after continued application. The flow of nitrogen (N) and phosphorus (P) from the application of animal manure is considered to contribute to non-precise pollution (Parker, 2000; Anderson & Xia, 2001; Ekholm et al., 2005; Allen et al., 2006). Salinity is considered as a non-precise source of pollution, but the secondary salinity induced by the application of organic fertilizers has not been considered as particularly worrying. Li-Xian et al. (2007) evaluated the effect of applying poultry manure and its ionic composition on soil salinization. The authors showed that the increase or decrease in the concentration of a determined ion in the soil depended on its concentration in the manure, the application rate, the removal of the crops and to leaching. The ionic composition of the soil salinity changed according to the types and doses of the fertilizers used and to their applications. The results also showed that, even in humid regions, the potential for the risk of secondary soil salinization exists with the successive application of animal manure.

3. The effect of salinity on the soil microorganisms

The microbial communities of the soil perform a fundamental role in cycling nutrients, in the volume of organic matter in the soil and in maintaining plant productivity. Thus it is important to understand the microbial response to environmental stress, such as high concentrations of heavy metals of salts, fire and the water content of the soil. Stress can be detrimental for sensitive microorganisms and decrease the activity of surviving cells, due to the metabolic load imposed by the need for stress tolerance mechanisms (Schimel et al., 2007; Yuan et al., 2007; Ibekwe et al., 2010; Chowdhury, 2011). In a dry hot climate, the low humidity and soil salinity are the most stressful factors for the soil microbial flora, and frequently occur simultaneously.

Saline stress can gain importance, especially in agricultural soils where the high salinity may be a result of irrigation practices and the application of chemical fertilizers. Research has been carried out on naturally saline soils, and the detrimental influence of salinity on the microbial soil communities and their activities reported in the majority of studies (Batra & Manna, 1997; Zahran, 1997; Rietz & Haynes, 2003; Sardinha et al., 2003).

The effect is always more pronounced in the rhizosphere according to the increase in water absorption by the plants due to transpiration. The simple explanation for this is that life in high salt concentrations has a high bio-energetic taxation, since the microorganisms need to maintain osmotic equilibrium between the cytoplasm and the surrounding medium, excluding sodium ions from inside the cell. As a result, energy sufficient for osmo-adaptation is required (Oren, 2002; Jiang et al., 2007).

3.1 Fungi

The composition of the microbial community may be affected by salinity (Pankhurst et al., 2001; Gros et al., 2003; Gennari et al., 2007; Llamas et al., 2008; Chowdhury et al., 2011) since the microbial genotypes differ in their tolerance of a low osmotic potential (Mandeel, 2006; Llamas et al., 2008). In fungi, a low osmotic potential decreases spore germination and the growth of hyphae and changes the morphology (Juniper & Abbott, 2006) and gene expression (Liang et al., 2007), resulting in the formation of spores with thick walls (Mandeel, 2006).

Fungi have been reported to be more sensitive to osmotic stress than bacteria (Pankhurst et al., 2001; Sardinha et al., 2003; Wichern et al., 2006). There is a significant reduction in the total fungal count in soils salinized with different concentrations of sodium chloride. Similarly, with an increase in the salinity level to above 5%, the total count of bacteria and actinobacteria was drastically reduced (Omar et al., 1994). Van Bruggen & Semenov (2000) reported that on a long-term basis there is a decrease in the genetic diversity of fungi as a result of stress. On the other hand, Killham (1994) mentioned that the filamentous fungi are highly tolerant of hydric stress. However they have to deal with the increase in osmotic pressure and may therefore change their physiology (Killham, 1994) and morphology in response to this (Zahran, 1997). Two strategies used by microorganisms to adapt to osmotic stress were described by Killham (1994), both of which result in an accumulation of solutes in the cell to counteract the increase in osmotic pressure. One is the selective exclusion of the solute incorporated (for example, Na^+ , Cl^-), thus accumulating the ions necessary for metabolism (for example, NH_4^+). The other cell adaptation mechanism is the production of organic compounds that will antagonize the concentration gradient between the soil solution and the cell cytoplasm. This adaptation finally results in a physiologically more active microbial community, and, in consequence, reduced substrate use efficiency. However these mechanisms are known for single microorganisms, but little has been studied at the community level.

According to Oren (2001) and Hagemann (2011), while sensitive cells are damaged by the low osmotic potential, some microorganisms can adapt by accumulating osmolytes (including amino acids in bacteria and polyols in fungi), that help retain water (Beales, 2004). Nevertheless the synthesis of osmolytes requires large amounts of energy: 30 to 110 ATPs, when compared to the 30 ATPs required to synthesize the cell wall (Oren, 1999), representing a significant metabolic responsibility for the microorganisms, and reduces the energy available for growth.

In order to better understand what happens to the microbial biomass and its activity in saline soils, one must also consider the water potential (osmotic potential + matrix potential), especially the low water content when the salt concentration in the soil solution increases. Since the water content changes, the microorganisms will be subject to different osmotic and water potentials, even though the modifications in the electrical conductivity (EC) measurement are small. Thus the EC is an indicator of little importance with respect to microbial stress in saline environments. According to Chowdhury et al. (2011), microorganisms have two strategies to respond to the water potential. A decrease in this potential to up to -2MPa damages a proportion of the microbial population, but the remaining microorganisms will adapt themselves and be active. For lower water potentials, the adaption mechanisms are not sufficient and, although the microorganisms survive, they do so with reduced activity per unit of biomass. However more studies are required in

different soils and, in particular, in saline soils, in order to discern which effects can be generalized.

Considering the forecast for an increase in saline and sodic areas, an understanding of the effects of salinity and sodicity on the soil carbon (C) stock and flow is fundamental for environmental management. Wong et al. (2008) evaluated the effects of salinity and sodicity on the microbial biomass and on soil respiration, under controlled conditions, submitting perturbed soil samples to leaching after receiving different salts concentrations. The highest soil respiration rates were observed in soils with low salinity, and the lowest in soils with medium salinity, whilst the microbial biomass was greater in the treatments with high salinity and lower in those with low salinity. According to the authors, the results can be attributed to a greater availability of substrate in high salt concentrations, or by an increase in the dispersion of the aggregates of soil or from the dissolution or hydrolysis of the organic material in the soil, which can compensate, at least in part, the stress to which the microbial population is submitted in high salt concentrations. The apparent disparity between the evolution of respiration and that of the biomass could be due to a change induced in the microbial population from one dominated by more active microorganisms to one dominated by less active microorganisms.

The microbial biomass is an important labile fraction of the soil organic matter, functioning both as an agent of transformation and recycling of the organic matter and soil nutrients, as also of a source of nutrients for the plants. It is also a potential source of enzymes in the soil. High salinity reduces the microbial biomass (Tripathi et al., 2006; Wichern et al., 2006), affects amino acid capture and protein synthesis (Norbek & Blomberg, 1998) and respiration (Laura, 1974; Pathak & Rao, 1998; Gennari et al., 2007) and causes increases and decreases in C and N mineralization (Pathak & Rao, 1998; Wichern et al., 2006).

Since the soil organic matter, and consequently, the biomass and microbial activity, are generally more relevant in the first few centimeters at the surface of the soil, salinization close to the surface can significantly affect a series of microbiologically mediated processes. This is a considerable problem, since the microbial processes of the soil control its ecological functions and fertility.

The availability of nutrients for plants is regulated by the rhizospheric microbial activity. Thus any factor affecting this community and its functions influences the availability of nutrients and growth of the plants. One of the microbial responses playing a significant role in plant growth is the internal recycling of nitrogen (N) by way of immobilization and re-mineralization. In the majority of studies, the immobilization of $\text{NH}_4^+\text{-N}$ is reported as being quicker than that of $\text{NO}_3^-\text{-N}$, whilst the re-mineralization of the N immobilized in NH_4^+ is slower than that immobilized in NO_3^- (Herrmann et al., 2005). However, little has been reported about immobilization/re-mineralization in the two forms of N under conditions of salinity. Since nitrification is more or less inhibited in the presence of salts (Laura, 1977; Sethi et al., 1993) resulting in an accumulation of $\text{NH}_4^+\text{-N}$, the cycling of the two forms of N will have a significant impact on the dynamics and availability of N for the plants. According to Azam & Ifzal (2006) the presence of NaCl retards the N immobilization process. Both re-mineralization and nitrification were significantly retarded in the presence of NaCl, maximum inhibition occurring with 4000 mg NaCl kg^{-1} of soil. The inhibitory effect of NaCl on N re-mineralization was relatively higher in soils treated with NH_4^+ . The results of this study suggest greater sensitivity to NaCl by microorganisms that have assimilated NO_3^- . However, N re-mineralization in the

population that had assimilated NO_3^- was less affected by salinity when compared to the population that had assimilated NH_4^+ .

3.2 Effect on enzymatic activities

Since the greater part of soil biochemical transformations are dependent on or related to the presence of enzymes, an evaluation of their activities could be useful to indicate if a soil is adequately carrying out the processes closely connected to its quality.

Soil enzymes carry out a fundamental role in the ecosystems, acting as catalysts of various reactions that result in the decomposition of organic residues, cycling of nutrients and the formation of organic matter in the soil, in addition to taking part in intercellular metabolic reactions responsible for the functioning and maintenance of living beings, quite apart from their biotechnological potential, with various applications in the industrial and environmental areas. They generally originate from microorganisms, but can also have animal and vegetable origins.

Amongst the diverse soil enzymes, dehydrogenase, β -glucosidase, urease and the phosphatases are important in the transformation of different nutrients for plants. The activity of dehydrogenase reflects the total oxidative capacity of the microbial biomass (Nannipieri et al., 1990) and is involved in the central aspect of metabolism. β -glucosidase is an important enzyme in the land carbon cycle, in the production of glucose, which constitutes an important energy source for the microbial mass (Tabatabai, 1994). Thus, the determination of β -glucosidase activity, amongst other hydrolytic enzyme activities, has been suggested as a good indicator of soil quality (Dick et al., 1996). The phosphatases play an important role in the transformation of organic phosphorus into inorganic forms more appropriate for plants. Phosphorus (P) is one of the essential nutrients for a plant, and the greater part of soil phosphorus occurs in the organic form.

Urease predominates amongst the enzymes involved in the N cycle of the soil (Tabatabai & Bremner, 1972; Cookson, 1999). It catalyzes the hydrolysis of urea into ammonia or the ammonium ion, depending on the pH of the soil and carbon dioxide. Urease and catalase are the enzymes responsible for the decomposition of vegetable residues. The activity of these enzymes transforms the residue into humus, which is then completely decomposed into the free nutrients (Ahmad & Khan, 1988). On the other hand, amylase hydrolyzes the polysaccharides, converting them into simpler constituents. The activity of this enzyme is associated with high productivity of the crops (Ahmad & Khan, 1988).

Under laboratory conditions, salinity influenced soil enzyme activity negatively, although the degree of inhibition varied according to the enzyme analyzed and the nature and amount of soil added (Frankenberger & Bingham, 1982). Dehydrogenase activity was severely inhibited whereas the hydrolases showed a milder degree of inhibition. The reduction of enzyme activity in saline soils could be due to the osmotic dehydration of the microbial cells that liberate intracellular enzymes, which become vulnerable to the attack by soil proteases, with a consequent decrease in enzyme activity. The salting-out effect modifies the ionic conformation of the protein-enzyme active site, and specific ionic toxicity causes a nutritional imbalance for microbial growth and subsequent enzyme synthesis (Frankenberger & Bingham, 1982). Ahmad & Khan (1988) and Rietz & Haynes (2003) obtained similar results. According to Rietz & Haynes (2003) the increase in salinity due to an influx of salty water under controlled conditions, decreased the carbon content of the soil microbial biomass and enzymes. Other researchers, for example Omar et al. (1994) and

Jialiang (2008) also indicated the effects of soil salinity on the carbon of microbial biomass and on enzyme activity. Garcia & Hernandez (1996) and Ghollarata & Raiesi (2007) showed that an increase in soil salinity inhibited the enzyme activities of benzoyl argininamide alkaline phosphatase and β -glucosidase, and also microbial respiration. Invertase and urease activities were also severely reduced by an increasing concentration of sodium chloride (NaCl) during incubation. In addition, the effect was inhibitory of nitrate reductase in the majority of the treatments (Omar et al., 1994). On comparing the enzyme activities of saline soil with those of normal soil, Ahmed & Khan (1988) also observed a decline in amylase, catalase, phosphatase and urease activities with increasing salinity. Controlled conditions (laboratory) do not usually reflect the natural situation prevailing in coastal region soils, where the salinity varies temporally. Tripathi et al. (2006; 2007) studied the influence of the salinity of arable soils in Indian coastal regions on the microbial biomass and the following enzyme activities: dehydrogenase, β -glucosidase, urease, and acid and alkaline phosphatases, in three different seasons of the year. The microbial and biochemical parameters were adversely affected by the salinity, and the most extreme situation occurred in the summer. Of the enzymes studied, the activity of dehydrogenase was the most affected.

Another particular ecosystem is the mangrove swamps, areas restricted to zones between coastal seas and islands in tropical regions, associated with estuaries, bays and lagoons in places protected from the impact of waves, where the salinity is between 5 and 30‰, but can reach 90‰ (Museu do Una, 2010). This is a highly degraded natural environment for a variety of reasons, amongst which the discharge of domestic and industrial effluent. Variations in the salinity of this environment can affect the retention of the pollutants and the microbiological responses as a function of the discharge of effluent. On investigating such areas, Tam (1998) observed that the addition of effluent to mangrove swamps, independent of their salinity, stimulated microbial growth and increased the activities of the enzymes dehydrogenase and alkaline phosphatase. According to the author these effects were due to supplementation with additional carbon sources and other nutrients, provided by the effluent.

4. Recovery of saline soils

The low productivity of saline soils can be attributed not only to their toxicity due to the salt or to the damage caused by excessive amounts of soluble salts, but also to low soil fertility. The fertility problems are usually evidenced by a lack of organic matter and of available mineral nutrients, especially N and P (Shi et al., 1994). These soils are also usually characterized by a reduction in the activities of some key soil enzymes, such as urease and phosphatase (Shi et al., 1994, Yuan et al., 1997), which are associated with biological transformations and the bioavailability of N and P. The adverse effect of soil salinity on crops depends both on their tolerance and on other factors with important roles in the selection of the natural soil microbial flora during salinization, such as: soil composition, organic matter, pH, heavy metals, water and oxygen availability (Ross et al., 2000).

4.1 Organic amendents

Recently various organic supplements, such as ground coverings, manures and compounds, have been investigated for their efficiency in recovering saline soils. It has been shown that

the application of organic matter can accelerate the leaching of NaCl, decrease the percentage of exchangeable sodium and the electrical conductivity, and increase water filtration, the water holding capacity and aggregate stability (El-Shakweer et al., 1998).

In soils affected by salts and showing low productivity, the adoption of adequate agricultural practices is of fundamental importance for the success of their exploitation, including modifications in the organic fertilization (Garcia et al., 2000). For example, supplementation with organic matter improves the quality of saline soil and neutralizes the negative effects of the salt, since the microorganisms profit from the greater availability of substrate and can thus deal better with the high salinity. Supplementation also leads to a differentiation in the soil microbial community, with bacteria dominating the surface of the substrate (Wichern et al., 2006).

The application of decomposing cow manure, straw or decomposing stable manure significantly increased the productivities of rice, wheat, barley and sorghum, cultivated in saline soils (Swarup, 1985; Gaffar et al., 1992; Aich et al., 1997). The incorporation of sewage sludge and the epicarp-mesocarp of the almond tree fruit into saline soil increased the N, P and K concentrations in the soil and in tomato fruits (Gomez et al., 1992), and the iron and manganese concentrations in rice (Swarup, 1985). In contrast, the addition of stable manure reduced the sodium adsorption ratio (SAR) (Gaffar et al., 1992). Tejada & Gonzalez (2005) showed that an increase in the organic matter content of saline soils increased the soil structural stability and density and, consequently, the microbial biomass.

The C/N ratio is an extremely important property in the decomposition of organic matter by microorganisms, and for this reason, the organic matter added to saline soils performs an important role in the positive effect on the microbial activity and enzyme activities.

The incorporation of rice straw, swine excrement or rice straw plus swine excrement significantly increased the activities of urease and phosphatase and the rate of respiration of the soil (Liang et al., 2003), coinciding with previous reports on the incorporation of other organic matters in saline soils (Blagodatsky & Richter, 1998; Luo & Sun, 1994).

Other organic residues with differentiated chemical compositions were studied by Tejada et al. (2006): one a compound obtained from a cotton de-stoner and the other non-composted chicken manure, in two different doses. The application of both in the doses studied, under dry climate conditions, improved the physical, chemical and biological properties of the saline soil. These organic treatments also favor the appearance of spontaneous vegetation, which protects the soil and contributes to its correction. The alterations tested improved the soil structure, reducing the percentage of exchangeable sodium and promoting an increase in various enzyme activities. However, whereas the cotton compound had a greater effect on the physical properties of the soil and the percentage of exchangeable sodium, the chicken manure mainly increased the soil enzyme activity.

However, the excessive use of organic manure should be avoided, especially in areas flooded for long periods, in order to reduce the risk of toxic effects from reduced intermediates, which accumulate from the anaerobic decomposition of organic manure (Liang et al., 2003).

The use of residues as a soil corrective or conditioner is an economically and environmentally interesting practice, and coconut powder stands out amongst the organic materials that could be used to recover saline soils, since it is abundant in the Northeastern region of Brazil due to the great consumption of coconuts. It represents a solution for the use of discarded coconut shells, which are constituted of one fraction of fibers and another

known as powder, which is aggregated to the fibers. Silva Junior et al. (2009) evaluated the basal respiration of soil incubated with different concentrations of coconut powder, submitted to different levels of salinity. The incorporation of organic matter increased the amount of C-CO₂ mineralization, even at high salinity levels. It also caused a reduction in the negative effect of salinity on microbial activity.

4.2 Plant remediation strategies

Another solution used for the recovery of saline soils in agricultural systems or salinized, abandoned areas is the use of plants (Hatton & Nulsen, 1999). The use of plants to remediate saline and sodic soils is a low-cost, emergent method, but with little acceptance due to its low profitability. However, some farmers have improved the salinity condition of their soils by planting salt-tolerant trees (Marcar et al., 1995) or forage shrubs (Barrett-Lennard & Malcolm, 1995; Porto et al., 2006).

Various plant species (halophytic plants) grow naturally at the coast and in salinized areas, and can survive in salt concentrations equal or greater to that of sea water. The compartmenting of the ions in the vacuoles, the accumulation of compatible solutes in the cytoplasm and the presence of genes for salt tolerance, confer salt resistance on these plants (Gorham, 1995). The re-vegetation of salinized areas with halophytic plants is an example of pro-active phyto-remediation (Porto et al., 2001; 2006).

The introduction of the halophyte *Glycyrrhiza glabra* in the recovery of saline soils and restoration of the subsequent crop systems in irrigated agriculture has been demonstrated in various studies (Mihailova, 1966; Kerbabaev, 1971; Pauzner, 1971). From results presented by Ravindran et al., (2007), the authors concluded that of the six vegetable species evaluated, *Suaeda maritima* and *Sesuvium portulacastrum* L. exhibited a greater accumulation of salt in their tissues and greater salt reduction in the soil. Rabhi et al. (2009) compared *Sesuvium portulacastrum* L. (Aizoaceae) with two other native halophytes: *A. indicum* and *S. fruticosa* with respect to their abilities to desalinate saline soils. The authors showed that of the three species studied, *Sesuvium portulacastrum* L. was the most convenient for use in the leaching of salts from the rhizosphere in arid and semi-arid regions, where the rainfall is low.

In the same way, the creation of high productivity plant forage systems by establishing palatable halophytic plants showed that it was possible to remediate a saline/sodic soil and provide extra income for the farmers at the same time (Hyder, 1981; Helalia et al., 1992; Dagar et al., 2004). Species of the saltbushes *Atriplex* have been used both as forage and to rehabilitate degraded areas (dunes, salt-mines, saline soils). They are dominant in many arid and semi-arid regions of the world, particularly in environments combining relatively high soil salinity with aridity (Ortiz-Dorda et al., 2005).

Quantifying the recovery of the biological activity of soils remediated with plants has been the focus of few studies. Silva et al. (2008) evaluated the effect of irrigation with the desalination waste from pink tilapia production tanks, on the chemical and microbiological properties of soils cultivated with *Atriplex nummularia* Lindl. The authors found that although the irrigation with saline waste affected the physical and chemical properties of the soil, cultivation of the halophyte favored microbial activity. Similar results were obtained by Pereira et al. (2004) studying soil cultivated for three years with *Atriplex nummularia* Lindl., and irrigated with saline waste. In the dry periods, the values for pH, electrical conductivity, fluorescein diacetate hydrolytic activity and alkaline phosphatase

activity were higher than in other areas. However, a negative correlation was observed between the values for microbial carbon and the metabolic quotient.

Carvava et al. (2005) studied the influence of the following eight halophytes: *Asteriscus maritimus* (L.) Less, *Arthrocnemum macrostachyum* (Moric.) Moris, *Frankenia corymbosa* Desf., *Halimione portulacoides* (L.) Aellen, *Limonium cossonianum* O. Kuntze, *Limonium caesium* (Girard) O. Kuntze, *Lygeum spartum* L., and *Suaeda vera* Forsskål ex J.F. Gmelin, on the microbiological and biochemical properties of the rhizosphere and aggregate stability of a saline soil. There was good correlation between the enzyme activities, the C of the microbial biomass, colonization of the roots of the eight halophytes and the levels of stable aggregates. The results also showed that the microbial activity and the soil properties related to the microbial activity, as also the aggregate stability, were determined by the type of halophytic species. The modifications in microbial activity caused by the vegetation were also related to the variation in the activities of protease, phosphatase, urease and β -glucosidase (Ceccanti & Garcia, 1994). In the case of the halophytes *Arthrocnemum macrostachyum* and *Sarcocornia fruticosa*, when grown in a salty swampy area contaminated with metals, whose roots were colonized by arbuscular mycorrhizal fungi, it was found that the salinity and heavy metals negatively affected the degree of colonization by fungi and some of the parameters indicating microbial activity, such as dehydrogenase, urease, protease, phosphatase and β -glucosidase (Carrasco et al., 2006).

4.3 Consequences of remediation activities

The principal objective of the recovery of soils affected by salts is to reduce the concentration of soluble salts and of exchangeable sodium in the soil profile, to a level that does not prejudice the development of crops. A decrease in the degree of salinity involves the process of dissolution and consequent removal by percolation water, whereas a decrease in the exchangeable sodium content involves its displacement from the exchange complex by calcium before the leaching process. Since it is of low cost and relatively abundant in many parts of the world, plaster is the corrective most used to recover sodic and saline-sodic soils (Oad et al., 2002; Barros et al., 2004; Gharaibeh et al., 2009). The substituted sodium is leached from the radicular zone by way of excess irrigation, a process that demands an adequate flow of water through the soil (Qadir & Oster, 2004; Qadir et al., 2006).

There are reports in the literature that the efficiency of washing the radicular zone was higher when irrigation was carried out by dripping rather than by other methods (Bresler et al., 1982). The key question in the recovery of soils affected by salts using irrigation by dripping, is that a reasonable irrigation regime must be carried out to guarantee not only normal growth of the crops, but also an excess of water to leach out the salts. Recently, Kang et al. (2008) reported the recovery of heavy-textured saline soils using irrigation by dripping. However, the alterations in the soil properties during recovery are still not well defined. The physical, chemical and biological alterations occurring in a saline soil during the recovery process with a corn crop and irrigation by dripping were reported by Tan & Kang (2009). The results showed that the soil density in the first 0-20 cm decreased from 1.71 g cm⁻³ to 1.44 g cm⁻³ after three years of rehabilitation. The water content in the saturated soil of the 0-10 cm layer increased from 20.3 to 30.2%. Both the soil salinity and pH value decreased significantly after three years of recovery. The organic matter contents reduced, whereas the total nitrogen, total phosphorus and total potassium tended to increase after cultivation and

irrigation. The amount of bacteria, actinobacteria and fungi increased according to the number of years of rehabilitation, with a tendency for a homogenous distribution in the soil profile. The activities of urease and alkaline phosphatase also increased, but the activity of invertase altered little.

Lin et al. (2006) observed that the bacteria, actinobacteria and fungi increased 2.3, 4.3 and 71 times, respectively, by planting *Suaeda salsa* L. and irrigating by dripping in coastal saline soil. There was a reduction in soil salinity and improvement in fertility.

The low solubility of Ca^{2+} during remediation could limit its efficiency, and thus the possibility of using it with microorganisms is being explored so as to provide more active Ca^{2+} from plaster. Experiments carried out with blue-green algae and plaster resulted in greater solubility of the plaster, thus providing recovery of the sodic soils (Subhashini & Kaushik, 1981). However, Syed et al. (2003) reported successful experiments in the recovery of saline-sodic soils when a mixture of different microorganisms was applied, without the prior application of plaster.

Sahina et al. (2011) studied the effect of microbial application in four different saline-sodic soils with saturated hydraulic conductivity, and treated with plaster. Suspensions of three fungal isolates (*Aspergillus* spp. FS 9, 11 and *Alternaria* spp. FS 8) and two bacterial strains (*Bacillus subtilis* OSU 142 and M3 *Bacillus megaterium*) were mixed with the leaching water of the soil treated with plaster, and subsequently applied to the soil columns. The measurement of the saturated hydraulic conductivity of the soil columns after treatment, indicated that it increased significantly ($P < 0.01$) in the saline-sodic soils after application of the microorganisms. The data suggest that the microorganisms tested could have the potential to help improve water circulation through saline soils.

Carter (1986) suggested that the addition of plaster caused a decrease in microbial activity, but tended to increase the microbial biomass in the soil. The effect of salinity on the carbon dynamics, with respect to the accumulation or loss of C is not well documented. The rate of C accumulation or loss depends on the balance between the amount entering and leaving. The entrance of C depends on the plant and the accumulation of biomass, when the organic carbon levels of the soil are dominated by the deposition of vegetable and root residues. The entrance of C into saline soils decreases with the decline in growth of the vegetation, due to the direct effect of the toxic ions and of the increase in osmotic potential, and the indirect effect of the structural decline of the sodic soil.

Wong et al. (2009) investigated the flow of C in saline soils to which plaster and organic matter were added. The microbial biomass was lower in the untreated saline soil, but the effect of adding plaster was insignificant. The accumulated respiration was greater in the soils receiving the organic supplement, whereas the addition of plaster decreased the accumulated respiration rate when compared to the addition of organic matter and of organic matter and plaster. The lowest respiration rate and microbial biomass was attributed to the soil with the lowest rate of organic carbon, resulting from the little or absent entrance of C into the soil due to the high salinity, responsible for the lack or absence of vegetation. There was an increase in respiration and in microbial biomass with the addition of organic matter, independent of the adverse environmental conditions of the soil. The results suggest that the microbial biomass of a hibernating population of salt tolerant microorganisms was present, and multiplied quickly when substrate became available.

5. Conclusions

According to estimates made by the United Nations, the population projected for 2050 is one of 8.9 billion inhabitants, which would exacerbate the challenges of agriculture to meet the food demands of this population. In the past the main directive was to increase the potential for food cultivation and its productivity in the field. These days the paradigm has changed, and now demands that the increase in productivity must be accompanied by sustainable management. Sustainable agriculture involves the management of agricultural resources respecting human needs, the maintenance of environmental quality, and the conservation of natural resources for the future. Soil salinity is widely reported as the main agricultural problem, particularly in irrigated agriculture, and approximately 20% of arable land and 50% of agricultural land in the world are under saline stress. According to statistics from UNESCO and FAO, the area of saline soils in the world is of 9.5×10^7 km². Salinity causes, directly or indirectly, a harmful influence on the maintenance of soil quality, since it affects the physical, chemical and biological properties of the soil. Research has reported the detrimental influence of salinity on the microbial communities of the soil and their activities. Thus the recovery of soils affected by salt has an important role in the sense of mitigating the pressure, especially in agricultural areas. Saline soil is an important land resource for agriculture.

6. References

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Soils play multiple roles in the quality of life throughout the world, not only as the resource for food production, but also as the support for our structures, the environment, the medium for waste disposal, water, and the storage of nutrients. A healthy soil can sustain biological productivity, maintain environmental quality, and promote plant and animal health. Understanding the impact of land management practices on soil properties and processes can provide useful indicators of economic and environmental sustainability. The sixteen chapters of this book orchestrate a multidisciplinary composition of current trends in soil health. Soil Health and Land Use Management provides a broad vision of the fundamental importance of soil health. In addition, the development of feasible management and remediation strategies to preserve and ameliorate the fitness of soils are discussed in this book. Strategies to improve land management and relevant case studies are covered, as well as the importance of characterizing soil properties to develop management and remediation strategies. Moreover, the current management of several environmental scenarios of high concern is presented, while the final chapters propose new methodologies for soil pollution assessment.

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