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THE SALT PROBLEM IN SOIL: AN OVERVIEW

LE PROBLÈME DU SEL DANS LE SOL: UNE VUE D'ENSEMBLE

IL PROBLEMA DEI SALI NEL TERRENO: UN QUADRO D'INSIEME

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Abstract

One of the most serious problems for the agriculture in many countries of the world is represented by the presence of excessive amounts of soluble salts in the soil. Soil salinisation has been identified as a major process of land degradation, and the main cause of land desertification, particularly in arid or semi-arid areas. This phenomenon is mainly due to artificial irrigation with waters of inadapted quality in the absence of adequate drainage systems, especially in arid or semi-arid regions. It was estimated from various available data that the world is losing at least three hectares of productive land every minute because of increasing soil salinity (Abrol et al., 1988). The social and economic repercussions of soil salinisation impact severely impact the populations of arid and semi-arid regions. It is in fact the population of developing countries that is hardest hit by the consequences of this phenomenon.
Keywords: *soil salinisation; alkalinisation; structural degradation*

Résumé

Un du problèmes les plus sérieux pour l'agriculture dans beaucoup de pays du monde est représenté par la présence de quantités excessives de sels solubles dans le sol. Le salinisation de sol a été identifiée comme un des processus les plus importants de dégradation des sols, et la cause principale de désertification des terrains. Ce phénomène est principalement dû à une irrigation avec de l'eau de qualité inadaptée, souvent à cause de sa faible disponibilité, en l'absence de canalisations adéquates, particulièrement dans des régions arides ou semi-arides de la planète. On a estimé à partir de diverses données disponibles que le monde perd au moins trois hectares de terre productive chaque minute en raison de salinité croissante des sols (Abrol et al., 1988). Les répercussions sociales et économiques ce phénomène grèvent sévèrement sur les populations des régions arides et sub-arides du monde. C'est en fait la population des pays en voie de développement qui est le plus durement frappée par les conséquences de ce phénomène.
Mots-clés: *salinisation du sol; alcalinisation; dégradation structurale*

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Riassunto

Uno del maggiori problemi per l'agricoltura in molti paesi del mondo è rappresentato dalla presenza di eccessive quantità di sali solubili nel terreno. Il processo di salinizzazione rappresenta infatti uno dei processi più importanti di degradazione dei suoli e la causa principale di desertificazione delle terre. Questo fenomeno è principalmente dovuto alla messa in atto di pratiche irrigue con l'utilizzo di acque non idonee, spesso a causa della scarsa disponibilità, in assenza di adeguati sistemi di drenaggio, ed è particolarmente rilevante nelle regioni aride o semiaride del pianeta. I dati a disposizione stimano la perdita di aree produttive nel mondo in almeno tre ettari ogni minuto a causa della crescente salinizzazione dei suoli (Abrol et al., 1988). Le ripercussioni sociali ed economiche di questo fenomeno hanno quindi un effetto drastico soprattutto sulle popolazioni delle regioni aride e sub-aride del mondo. È in effetti la popolazione dei paesi in via di sviluppo che è più duramente colpita dalle conseguenze di questo fenomeno.
Parole chiave: *salinizzazione del suolo; alcalinizzazione; degradazione strutturale*

Introduction

More or less relevant amounts of salts are always present in soils even though their origin may be different. In nature the principal source of salts is the ocean which directly contributes soluble materials to coastal areas by tidal action or through spray carried inland by the wind. Indirectly, it provides salts through the weathering of parent material of marine origin. Intrusion of sea water in the aquifers, volcanic emanations, fertilizers, and decaying of organic matter also serve as additional sources of salts. Their progressive accumulation depends however on the different climatic, morphologic, hydrologic, and pedologic conditions prevailing in the environment. In humid regions leaching by rainfall tends to remove salts, so preventing their accumulation in the upper layers of the soil. On the other hand, they remain and accumulated at the surface of the soil in areas where the climate is dry and evaporation of groundwater prevails over the percolation process.

The accumulation of salts in agricultural soils is mostly due to artificial irrigation without adequate drainage systems. There are two kinds of soil salinity which describe areas where soils contain high levels of salts : "dryland salinity" (occurring on land not subjected to irrigation), and "irrigated land salinity". This human-induced phenomenon, also known as "secondary salinisation", represents the most harmful and extended phenomenon among the effects produced by irrigation on soils and environments (Szabolcs, 1986). Irrigation with poor quality waters in the absence of adequate drainage directly introduces salts to soil, and brings about their accumulation by increasing the level of the water-table. Referring to dryland salinity Australian farmers call it the "white death" because it conjures up images of lifeless, shining deserts studded with dead trees. Fears of the "white death" seem therefore justified (NOVA – Science in the News; Australian Academy of Science, January 2004).

Many areas where ancient and rich civilizations flourished in the past, today are characterized by infertile salinized soils. An example is the area of the Ancient Mesopotamia where fertile and extremely productive soils have became barren deserts (Buring, 1960). Nowadays salinisation of soils represents one of the most serious problems for the agriculture of many countries of the world. Salt-affected soils are commonly found in arid or semi-arid environments where artificial irrigation is the only way to create a productive agricultural system (Kovda, 1983). However, many countries of the North and East Europe, and those of the Mediterranean Basin, are seriously affected by this phenomenon even though the causes are widely different. According to Szabolcs (1991), salt- affected soils are found in more than one hundred countries of the world.

The extent of land salinisation

Salt-affected soils are found in arid and semi-arid climates in more than one hundred countries of the world (Szabolcs, 1991). Countries predominantly affected by land salinisation include Argentina, Australia, China, Egypt, India, Iran, Iraq, Pakistan, Thailand, former Soviet Union, and USA, even though the problem of the growing salinisation is observed elsewhere (Kovda, 1980). Based on the FAO/UNESCO Soil Map of the World, Szabolcs (1987) estimated that some 952 million hectares are affected by salinisation and alkalinisation world-wide. Evidences of salt accumulation is also present in some regions of Italy, particularly in the coastal areas, with more than 500 ha of salinized soils, and 400,000 ha of potentially salt-affected soils. Figure 1 and Figure 2 show the global distribution of salt-affected soil in the world and Italy respectively.

Figure 1

Distribution of salt-affected soil in the world

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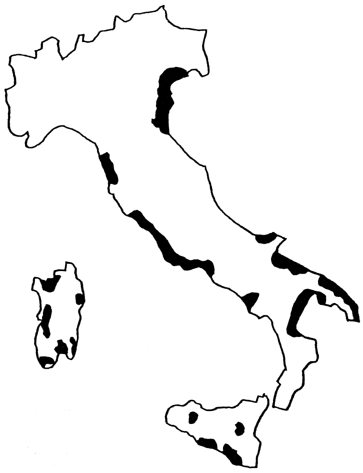

Figure 2

Distribution of salt-affected soil in Italy

The extent of salt-affected soils by continent and sub-continent is also shown in Table 1.

Table 1 - *Regional distribution of salt-affected soils in million hectares*

Regions	Total area	Saline soils		Sodic soils	
	million ha	million ha	%	million ha	%
Africa	1899.1	38.7	2.0	33.5	1.8
Asia / The Pacific / Australia	3107.2	195.1	6.3	248.6	8.0
Europe	2010.8	6.7	0.3	72.7	3.6
Latin America	2038.6	60.5	0.3	72.7	3.6
Near East	1801.9	91.5	5.1	14.1	0.8
North America	1923.7	4.6	0.2	14.5	0.8
Total	12781.3	397.1	3.1	434.3	3.4

In the light of the global warming, resultant from climate changes currently in progress on the whole planet, the reduction of rainfall, and the scarcity of available water resources, the phenomenon of the land salinisation will be continue and irreversible if no valuable measures will be taken by governments and policy-makers all over the world.

Causes and consequences of salinisation

The main factors leading to a progressive accumulation of salts at/or near the soil surface are :

a) high content of salt in the soil profile;
b) salinity of the soil solution;
c) mineralized groundwater
d) high level of the water-table;

e) intrusion of sea-water in the aquifer;
f) irrigation with saline waters;
g) absence of adequate drainage systems

The ions responsible of soil salinisation are essentially :

Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}

Accumulation of salts may be found in many places, particularly in soils and waters of dry areas, and constitute a potential hazard for irrigated agriculture. The other source of salts may be surface waters used for irrigation. In this respect the picture may be different in arid and semiarid regions. In many places, particularly in big rivers, the water is of good quality (low salt concentration). On the other hand, saline waters can be found in places such as small tributaries, lakes, lagoons, and swamps. Sooner or later, when saline waters are utilized for irrigation, secondary salinisation and /or alkalinisation results. Also it should be mentioned that on seashores and in related areas the salt content of sea water has a direct or indirect effect on the salinity of adjoining areas. However, the river waters constitute good-quality irrigation waters in almost all continents, at least insofar as their average values are concerned, even though sharp differences can exist among the chemical compositions of waters of different rivers. In many regions the quantity of airborne salts should be taken into consideration, even though these airborne salts can only cause local salinisation in some desert areas.

The main reservoir of salinity in desert or semi-desert is the ground water. Soluble salts accumulated in the ground water as a results of the geochemical processes can cause salinity problems when these waters are used for irrigation. As long as the groundwater table is deep and moisture cannot rise by capillarity to the soil profile, even saline ground waters do not cause immediate salinisation of the soil. Another possible source of salts Kovda (1980) mentions the biological processes, particularly in arid regions where the ash of halophytes may contribute to the salinity of soils and waters. The natural or artificial drainage of irrigated land, or land to be irrigated, is also a substantial factor in the process of secondary soil salinisation.

Salts in the soil solution give rise to various ionic species whose role is of paramount importance in a oomplex ecosystem such as the soil. Depending on their nature and concentration, they play a fundamental part in determining conditions which can be suitable or dangerous for plant growth. Moreover, salts affect the physico-chemical and structural properties of the soil, often reducing its capability of production. It is well known that an adequate amount of salts is essential to create and maintain a suitable structural state of the soil. Adequate amounts of electrolytes (salts) in fact promote flocculation of colloid particles, thus creating a physical structure which allows the soil to conduct water and air (permeability), also improving those aggregating properties which control the friability of the seedbed. Furthermore, they can exert a direct beneficial action by providing nutrients which are essential to the plants. On the other hand, conditions favouring

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their progressive accumulation will sooner or later cause serious damage to soil fertility, especially when sodium salts prevail in the soil (alkalinisation).
As is well known, the harmful effects of high levels of soluble salts in soil include the limited availability of water for plant growth due to a high osmotic pressure of the soil solution (Bauer, 1978). In addition, excessive amounts of salts reduces the availability of nutrients, and often hinder the emergence of seedlings. The hazard of high sodium concentrations in the soil solution is also well known (alkalinisation). Besides specific toxic effects on plants, dispersion of colloid particles can take place, thus creating an unsuitable structural state of the soil. High levels of sodium at the surface of the soil may give rise to crusts formation, so reducing the infiltration rate (IR) of the water (Agassi et al., 1981; Shainberg, 1985). The ultimate consequence of the accumulation of salts in soil is often the loss of productive land by aridization (Kovda, 1983).
Salinisation has therefore a number of negative impacts on the environment, society, and economy of salt-affected areas as well as the economy of the country as a whole. In its early stage of development, salinisation reduces soil productivity. In its advanced stages it kills all vegetation and transforms fertile and productive land to barren land, leading to loss of habitat and a reduction in biodiversity (Ghassemi et al., 1991).

Effect of salts on soil structure

This section of the paper is dedicated to a simple description of the mechanism by which salts may cause damage to soil structure.
Soil structure may be defined as the “arrangement of particles and aggregates of various shapes and sizes packed together, in various ways, to form a continuous pore space system”. Many factors such as the nature of primary particles, the content of organic matter or other cementing substances, chemical and biological processes, and environmental conditions, all influence the soil structure. The presence of soluble salts and their nature is also of basic importance in determining aggregation or dispersion of soil colloid particles. Maintaining a suitable physical state of the soil is essential to allow water, air, and the roots of plants to penetrate its pore space system, thus creating the best conditions for crop production.
The scientific basis for understanding the interactions between salts and soil particles is the Gouy-Chapman theory of the “diffuse electrical double layer” (Overbeek, 1952). According to this model, the electrical double layer formed at the interface between a colloid particle and an electrolytic solution consists of a surface charge and an equivalent amount of oppositely charged ions in the solution near the interface (counter-ions). These ions are electrostatically attracted by the surface charge. At the same time, they have a tendency to diffuse away from the surface towards the bulk solution, where their concentration is lower, giving rise to a diffuse layer. Cations acting as counter-ions for the negatively charged clay colloid particle surfaces can be replaced by, or exchanged with, other cations added to the soil solution. The distribution of these ions in the diffuse layer depends on both their nature and concentration. A decrease in the thickness of the diffuse layer

will occur when there is an increase in the valency and concentration of ions. If the counter-ions have the same valency the thickness of the diffuse layer is determined by their specific adsorbability, which is related to their polarizability and hydration properties (Voyutsky, 1970). Among ions of the same valency, those of the largest dehydrated radius exibit maximum adsorbability because such ions are greatly polarisable and, at the same time, they are hydrated to a lesser extent; consequently, they are more attracted by the charged surface of soil colloid particles. Divalent cations such as calcium and magnesium are therefore more attracted than monovalent cations like sodium.

When two clay particles approach one another their diffuse layers of counter-ions begin to overlap and repulsive forces develop between the particles which have the same charge. These repulsive forces increase with an increase in the proportion of adsorbed monovalent cations or a decrease of electrolyte concentration in the bulk solution, or both; i.e. when the diffuse layers of counter-ions around clay particles are more extended. The association of individual particles with themselves and other particles, to form units called "aggregates", is therefore encouraged when their diffuse layers of counter-ions are compressed towards the surface of the particles which can approach one another more closely. In this case, the physical structure arising from packing aggregates is more porous than that formed by individual particles, so that the permeability and tilth of the soil will be better.

The electrostatic repulsion between platelets of clay particles also allows water to be imbibed between them, thus increasing the void space between platelets. Correspondly, a decrease in the inter-aggregate pore volume will take place, and reduce soil permeability. This phenomenon (called swelling) is of importance in soils containing expandable layer phillosilicate minerals (smectites such as montmorillonite), especially in the presence of sodium salts (ESP above 15). The basic reason for this is in the higher capability of Na^+ ions to be hydrated to a greater extent than divalent cations. The electrostatic repulsion between platelets will therefore be more effective when sodium ions predominate in the soil solution.

Low electrolyte concentrations and high levels of exchangeable sodium in soils also promote the release of individual platelets (dispersion) and the breakdown of aggregates (slaking) with serious damage to soil fertility (Frenkel and Rhoades, 1978).

Combatting salinisation and alkalinisation of soils is therefore essential to the maintenance of a sound and productive agricultural system.

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