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Salinization: An environmental concern under climate change scenarios

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Soil salinity can be described as a high concentration of ions in the soil solution, a condition that is very restrictive for plant growth, due to the high osmotic potential of the solution that inhibits plant water uptake and the toxicity of specific ions. This definition of soil salinity centred on the plant differs from that used in soil classification, which is more focused on features permanently recognizable in a profile. Salinization is a progressive soil and water degradation process, human-caused, affecting aquifers and the most productive agro-ecosystems under irrigation in arid and semi-arid regions, representing an increasing environmental concern.

Evidence of global mean temperature increase has been presented by the Intergovernmental Panel on Climate Change (IPCC) and by many authors in the last few years. All sources recognize a large uncertainty in the magnitude and geographical distribution of climate change, as well as uncertainty in the response of plants and ecosystems to climate change.

For assessing the risk of salinization, defined scenarios should be analysed. The risk of salinization will affect the soils at different latitudes in different ways. In the Mediterranean area increasing temperatures, higher evapotranspiration rates and higher evaporation from water bodies are expected, combined with rainfall diminution (less water availability, reduction in water in reservoirs). Changes in precipitation patterns are also expected, with more irregular distribution than at present that will provoke increased runoff versus infiltration and difficulties for caudal regulation and water storage.

Under this scenario the water availability will be reduced, and there will be a need for resource optimization through the adoption of adaptation strategies that counteract the possible worsening in irrigation water quality due to an increasing demand that will force the use of alternative water sources. Special effort will be required for the maintenance of crop production under salinization risk and for the expansion of irrigated areas.

The correct analysis and prevention measures require scientific background provided by a critical mass of scientists, an increased effort in research and measurement, development of new conceptual models and the analysis of scenarios under different hypotheses. This will allow the design of new technical and policy approaches.

Soil salinity in the southern Pre-Caspian lowland as related to climate peculiarity and anthropogenic effects

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ABSTRACT

The main objective was to assess the modern state of soil cover and soil salinity in the region, namely the Western Ilmen region of deltaic-marine origin occupied by Baer's mounds, and the Volga Delta region.

Soils subjected to natural salinization were crusty Solonchack, brown semi-desert soil, meadow and swampy meadow soils with the different degrees of salinization. Soils subjected to secondary salinization were also studied. They were alluvial meadow soils with different degrees of salinization located in former irrigated lands, at present withdrawn from agriculture. The results of our investigations were: a) accumulation and redistribution of salts in the soils of the studied region are complex processes and depend on periodical change in the Caspian Sea level and on anthropogenic loads; b) primary (initial) soil salinity has only remained in the Western Ilmen region; c) in the Volga Delta, the salt-affected soils have extremely variegated composition of salts. Soils which were irrigated have a specific salt profile where the upper part of soils is free from salts and sulfates prevail; d) the cessation of irrigation on many plots changed the hydrological regime of the soils and initiated the development of secondary soil salinization; and e) micromorphological studies identified trends in the salinization-desalinization processes and enabled the differentiation of the salt and gypsic neoformations according to their age.

Keywords: initial salinization, desalinization, cessation of irrigation, salt and gypsum pedofeatures.

INTRODUCTION

A considerable part of agricultural production in Russia (about 80%) is concentrated in arid regions of the country. The most severe climatic conditions are inherent to the Pre-Caspian lowland, where the aridity coefficient of desert and semi-desert zones is estimated as 0.11-0.30. Our study has been conducted in the southern part of the Pre-Caspian lowland including the Volga Delta and the Western Ilmen region (Figure 1). Ilmens are hollows with saline lakes and fresh channels between sandy Baer's mounds.

The aim of this paper is to assess the modern state of the soil cover and soil salinization processes in the Volga Delta, 46° 14' 10" N, 48° 11' 15" E and in the Western Ilmen Region (to the west of Astrakhan), 46° 13' 06" N, 47° 40' 07" E.

Salt-affected soils in the studied area were shaped under the impact of a combination of several factors. Three major sources of soil salts can be specified: (1) salt-bearing deposits of the Caspian Sea, (2) salts transferred by wind with seawater drops (impulverized salts) and (3) salts from groundwater. Filtering and evaporating river waters may also serve as an additional source of salts under condition of the arid climate. Astrakhan oblast is the driest part of European Russia. The climate is sharply continental, with summer temperatures up to 45–50 °C and winter temperatures as low as -40 ºC. The daily amplitude of temperatures in the summer is also very high. The mean annual precipitation is about 180–200 mm, and the potential evaporation is much higher.

The specificity of soil salinization in the Caspian Lowland is that the intensity of salt processes is largely controlled by fluctuations in the Caspian Sea level. In the past century, several transgression and regression stages took place, which could not but affect soil morphology. Another important factor is irrigation. The development of irrigation and, then, a considerable decrease in the irrigated area within the past 20 years altered the hydrological regime of the soils and facilitated the development of secondary salinization, particularly on the fields removed from irrigation in the recent decades.

OBJECTIVES AND METHODS

We studied both virgin and abandoned (under long-term fallow) salt-affected soils in two distinctly different geomorphologic areas: (I) The area of il'mens (lakes in the hollows between Baer's mounds) in the south-western part of the Caspian Lowland representing the ancient delta–sea plain complicated by Baer's mounds and (II) The area of the modern Volga Delta subdivided into the central plain part(1) and hilly (with Baer's mounds) western part(2) on alluvial deposits and the coastal marshland overgrown with reeds and composed of sea deposits(3).

The methods are: the water extractions and micromorphological method.

RESULTS AND DISCUSSION

Characterization of the major types of salt-affected soils

I. The western il'men area represents alternating Baer's mounds and hollows (often, with lakes) between them. The following types of virgin soils were studied in this area: Crusty Solonchacks in the dried hollows, zonal Brown Semi-desert soils on the tops and slopes of the mounds and Meadow and Meadow-Swampy soils on the footslopes of the mounds.

The highest degree of salinization is typical of Crusty Solonchacks at the bottoms of dried il'men lakes. Pit 1a represents an example of such soils. This pit characterizes the soil on the dried bottom of the former lake. The barren soil surface is covered by a whitish salt crust. Chloride salts predominate (Figure 2A). The distribution of salts in the profile points to a continuous input of salts from the highly saline groundwater with sodium and magnesium chlorides; these salts are concentrated at the evaporative barrier in the crust layer and in the upper part of the soil profile. Despite the predominance of chlorides, the salt profile also contains gypsum accumulations that are clearly seen in thin sections. Interpedal voids reveal practically complete infillings of large gypsum crystalls, the surface of which is corroded, what speaks about the process of their destruction (Figure 2B).

The Brown Semi-desert soil studied on a recent fallow plot on the top of a Baer's mound is specified by an indistinct horizonation of the profile, the absence of clear soil structure, the slight salinization in the lower part of the profile, and the presence of carbonates. The Brown Semi-desert soils of Baer's mounds are characterized by a relatively coarse (sandy) texture.

Meadow and Meadow-Swampy soils with different degrees of hydromorphism and salinization are developed on the lower parts of mound slopes and in the hollows between the mounds.

The soil profile studied in pit 8a is slightly saline; chloride salts predominate in the upper horizon, and the chloride–sulfate salinization is typical of the lower horizons. This chemical differentiation of salts points to the evaporative soil water regime.

Thus, salt-affected soils in the studied area are represented by automorphic zonal slightly saline Brown Semi-desert soils and by hydromorphic Solonchacks and Meadow soils with different degrees of salinization and hydromorphism.
At present, the Meadow soils of hollows are used for pasturing.

II. Soils of the Volga Delta. Most of the alluvial soils in the Volga Delta are initially saline. They differ in the degree and chemistry of salinization and in the depth of the salt-bearing horizon.

(1) Saturated Meadow Alluvial soils with different degrees of salinization predominate in the central part of the delta floodplain. Soils of the former irrigation systems were investigated in this area. Soil pit 9a characterizes a recent fallow; this soil is moderately saline with a predominance of sulfate salts in the entire profile, except for the plough horizon, in which chlorides predominate. The buried soil horizon and the underlying layers are slightly saline with a predominance of sulfates. The salinization of the topsoil is due to evaporation of slightly saline (3 g/l) groundwater.
An example of the Dark-Colored Meadow Stratified Alluvial soil under the long-term fallow was studied in pit 10a. Several lithological layers of different textures are seen in this soil profile. The upper horizons are slightly saline with a predominance of sulfates; from the depth of 32 cm down to 300 cm, magnesium chlorides derived from the slightly saline groundwater predominate among soluble salts. The magnesium content is very high; the content of exchangeable magnesium reaches 42% of the cation exchange capacity. Micromorphological analysis showed the presence of salt neoformations both in large infillings and in small intraaggregate voids. This fact serves as evidence of the salinization process. In this formerly irrigated soil, irrigation favored the removal of soluble salts from the upper horizons into the lower layers and into the groundwater. The cessation of irrigation resulted in the development of the secondary soil salinization.

(2) The western part of the delta plain is complicated by the presence of Baer's mounds covered by alluvial deposits from the surface and by numerous hollows with branching channels of the Volga River. The salt-affected soils are represented by the Solonchackous Gleyed Wet Meadow soils and by the Surface-Saline Solonchackous soils. Two plots were studied in a hollow between the mounds. The first plot characterized the soil of an abandoned irrigation system (pit 12a), and the second plot characterized the soil of a former meadow (pit 13a). The soil studied in pit 12a is nonsaline; the groundwater is fresh. The abundance of mollusk shells in the profile points to the deposition of sediments in a shallow-water environment. The soil studied in pit 13a is a typical Solonchack with sulfate salinization, except for the two uppermost horizons, in which chloride salts predominate. It can be supposed that secondary salinization of this soil with ascending groundwater flows containing magnesium and sodium chlorides and sulfates took place after the end of irrigation.
Thus, after the cessation of irrigation, the salt profile of the soils has changed: the initial profile of the saturated meadow alluvial soil (pit 13a) was transformed into the profile of a surface-saline Solonchackous meadow soil due to the evaporative concentration of salts in the upper horizon. The result of hydrogenic salt precipitation is clearly seen in thin sections to speak about the process of salinization.

(3) Marshland soils of the coastal part of the delta are subjected to regular influence of seawater. These soils are characterized by the strong gleyzation and the accumulation of clay particles in the upper horizon. These features are clearly seen in the profile of Marshland Solonchack (Figure 2A). This soil contains chloride salts in the entire profile; gley features appear from the depth of 6 cm. The

groundwater is strongly saline, with a predominance of sodium and magnesium chlorides. The soil adsorption complex is saturated with magnesium. Based upon the micromorphological analysis of the soil fabric it seems to conclude that the interaggregate voids are enriched with gypsum crystals. However, in contrast from the crusty Solonchack profile the gypsum crystals are small in size, their corroded surface is absent (Figure 2B). These microfeatures serve as evidence of salinization process.

- Astrakhan oblast is the driest part of European Russia.
- The climate is sharply continental: summer temperatures up to 45–50 °C, and winter temperatures as low as –40 °C. The mean annual precipitation is about 180–200 mm, and the potential evaporation is much higher.

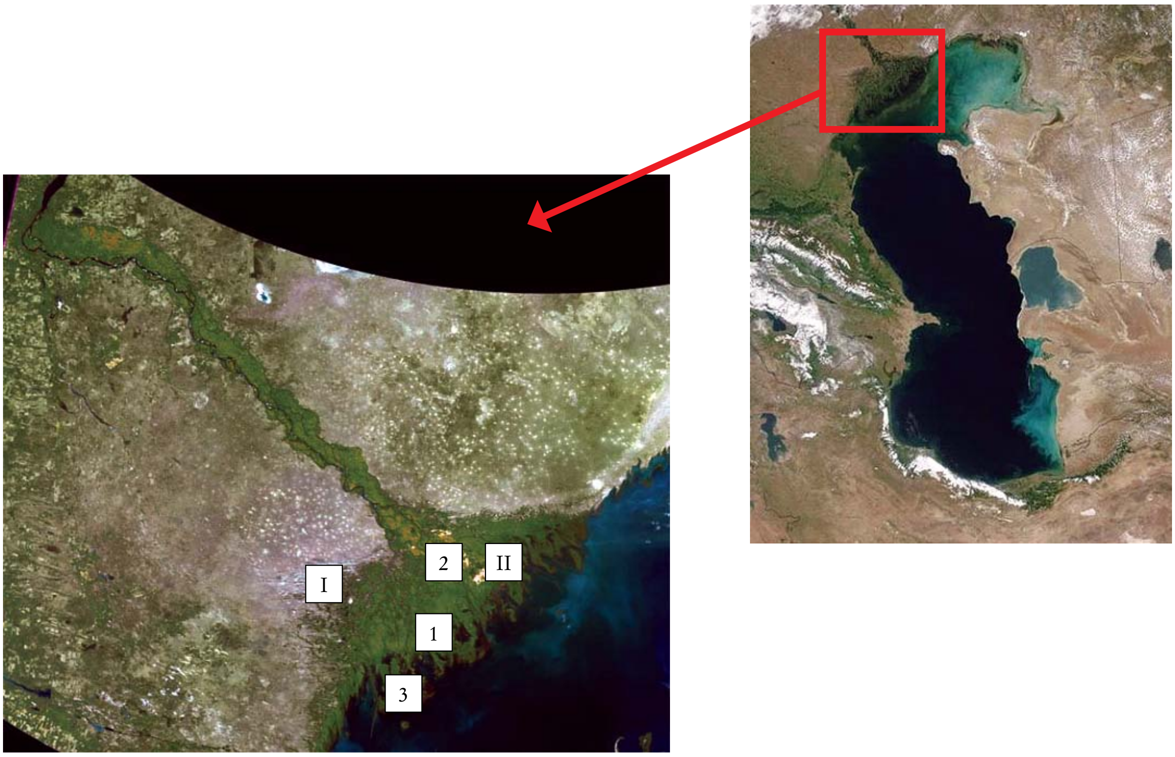
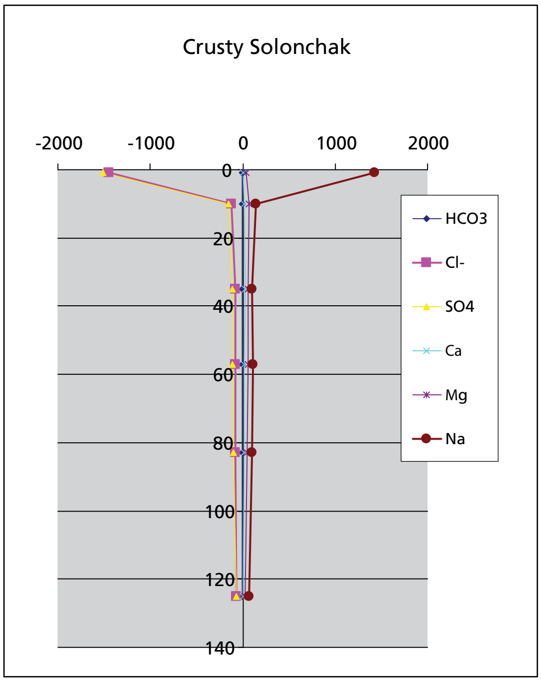
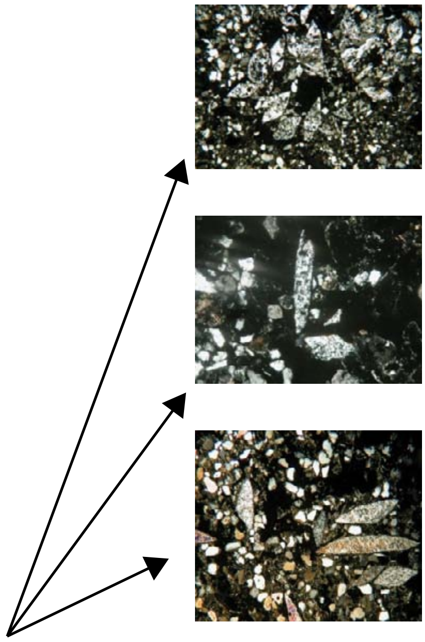


Figure 1.

A

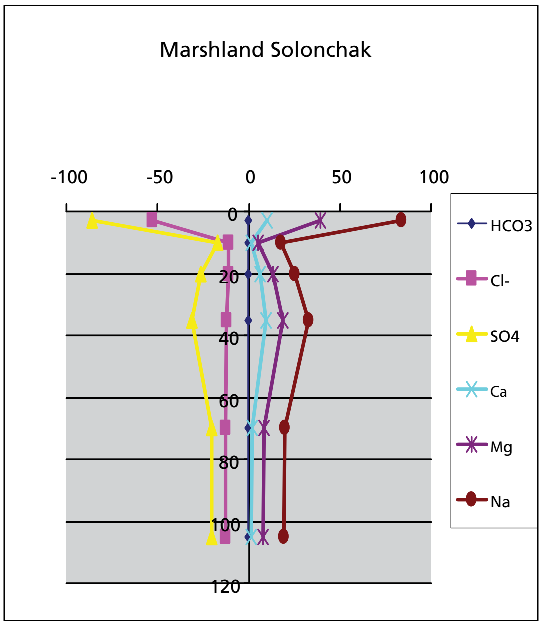


B



corroded crystals of gypsum

A



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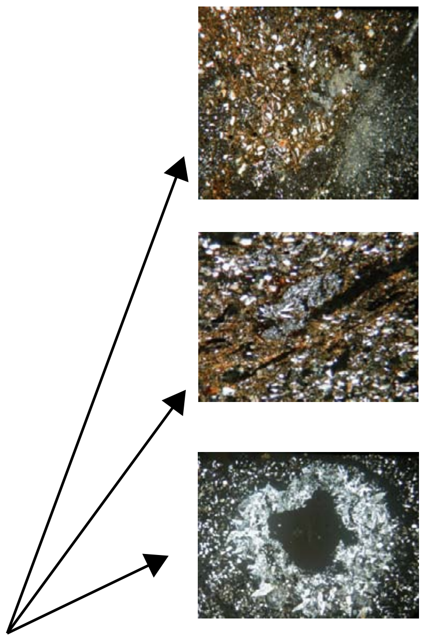

non-corroded crystals of gypsum

Figure 2.

CONCLUSIONS

The accumulation of soluble salts and their distribution in soils of the Volga Delta depend on many factors, including fluctuations in the Caspian Sea level and the anthropogenic loads on soils. The recent rise in the Caspian Sea level has a twofold effect on soil salinization processes. On the one hand, the sea rise is accompanied by the groundwater rise, so that soil salinization due to the ascending migration and evaporation of the groundwater becomes more active. On the other hand, surges of relatively fresh seawater in the Volga Delta favor the removal of salts from the upper soil horizons.

The initial salinization pattern is only preserved in the western il'men area. Hydromorphic meadow and meadow-swampy soils of this area may have different degrees of salinization, up to the formation of Solonchacks. The soils are developed under conditions of a continuous input of salts from the groundwater. The surface soil horizons have the chloride type of salinization.

Soils of the Volga Delta proper are characterized by a great variability of salinization. On the plots subjected to long-term irrigation, soluble salts were washed from the upper soil layer; the initial chloride type of salinization was replaced by the sulfate type in this layer.

The cessation of irrigation on many plots changed the hydrological regime of the soils and initiated the development of secondary soil salinization.

Micromorphological studies permitted to specify the trend of salinization-desalinization processes and to differentiate the salt and gypsum pedofeatures according to their age.

Salt-affected Palaeosols buried under a rampart in the Dry Steppe Zone of the Lower Volga Region as indicators of climate change in the past 300 years

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ABSTRACT

The Dry Steppe Zone in the European part of Russia is one of the best studied territories with regard to the history of interactions between human society and the environment. In recent decades, one of the key factors affecting the character of pedogenesis on the East European Plain in the Holocene is climate change, which has been studied in this area by Russian and European scientists with the use of the pedo-archaeological methods. In essence, it consists of a comparative study of background surface soils and Palaeosols buried under archaeological monuments of different ages with known dates of their construction.

Cyclic changes in the climate of Europe during the past millennium have already been confirmed by Palaeosol data. In particular, changes in the degree of climatic humidity of semi-arid territories are reflected in some labile soil properties, such as the degree and character of soil salinity. In relation to the increased interest in the dynamics of the climate in recent centuries and their impact on the environment and on the economic activity of humans, it is a challenge to search for any kind of evidence for the pattern of climate change.

In this context, ground fortification embankments (ramparts) and the Palaeosols buried under them are of great interest. In the Dry Steppe Zone of Russia, such ramparts were created to protect Russian borders from invasions by Steppe Nomads in the late medieval period and in the 16th–18th centuries. Often, their length reaches tens of km. Archaeological data and written historical documents make it possible to determine the year of their construction. Palaeosols buried under such ramparts are unique objects to trace the history of pedogenesis and the environment in previous centuries.

Keywords: Palaeosols, pedo-archaeological method, dry steppe, salinization dynamics, Solonetzes, Kastanozems, paleoenvironmental reconstruction, climate dynamics.

DISCUSSION

We studied a fragment of a rampart on the Volga–Don interfluve within the zone of dry steppes with chestnut soils (Kastanozems) of different degrees of salinity and Solonetzicity in association with Solonetzes. The studied section of the rampart crosses the valley of the Sakarka River and represents a soil-geomorphological catena stretching for 5 km. The rampart was built in 1718–1720.

Overall, 15 paired profiles of Palaeosols buried under the rampart and their background modern analogues were studied. Soil pits were examined on all the major landforms: tops and slopes of local watersheds, the river terrace, and the low and high floodplains. Thus, the obtained materials make it possible to trace changes that have taken place in the past three centuries in the morphology and salinity of different soil types (chestnut soils with different degrees of salinity and Solonetzicity, Solonetzes, and salt-affected meadow and alluvial soils in relation to the spatial-temporal variability in the conditions of soil formation.

Along with the study of modern soils and buried Palaeosols, we had to estimate the indicative capacity of the latter for the purposes of paleoclimatic reconstructions. It was found that the technology of the rampart construction ensured a good degree of preservation of the buried soil profiles in the intact state. This was confirmed by the analysis of distribution patterns of soluble salts in the rampart body and in the buried Palaeosols. The mean weighted contents of soluble salts and gypsum in a 2 m deep layer of the Palaeosols can be considered to be unchanged since the time of the rampart construction, i.e. they characterize the initial state of the Palaeosol salinity about 300 years ago.

In the modern chestnut soils, the upper boundary of the calcareous horizon is found 20–30 cm deeper than that in their Palaeosol analogues. This leaching of carbonates could take place during the Little Ice Age (1600–1850) with an increased humidity of the climate. This conclusion is confirmed by other methods of paleoclimatic reconstructions. At the same time, the upper boundary of the horizon with soluble salts in the modern Solonetzes is by 70 cm higher than that in their Palaeosol analogues.

The data obtained in this study can be used to predict the development of the soil cover under the impact of climatic changes. They can also be used to estimate the degree of contamination of modern soils under the impact of recent anthropogenic loads.

Soil Salinization as Affected by the Cryoarid Climate in the Permafrost Zone of Yakutia

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ABSTRACT

The genesis and geography of salt-affected soils in the permafrost zone of Yakutia are discussed. These soils are found in three different types of landscapes: in the coastal area of the Arctic Ocean, in river valleys and in thermokarst depressions (alases) within the ancient alluvial plain in Central Yakutia. The chemical composition and genesis of salinization are quite different in these regions. Salt sources and mechanisms responsible for salinization are also different. The geography and genesis of salt-affected soils in Yakutia are highly dependent on local cryoarid climatic, palaeohydrological, lithological and geomorphic conditions, affected by the Arctic Ocean and the presence of permafrost.

Keywords: salt-affected soils, soil genesis, soil geography, permafrost zone, Yakutia.

INTRODUCTION

The paper deals with a problem of geography and genesis of salt-affected soils in Yakutia. The development of salt-affected soils in the northern region within the permafrost zone speaks for itself as a unique phenomenon. Yakutia is located between 105–165° E and 55–77° N and occupies 3 103 200 km^2 in the permafrost zone of Central and East Siberia. The salt-affected soils are found in three different types of landscape with different genesis of soil salinization. Soil salinization is a serious problem for this region, because the salt-affected soils occupy 50.3% of cropland in Central Yakutia.

METHODS

A comparative-geographical method was employed to study regularities in distribution of salt-affected soils at the territory of Yakutia as well as methods to analyse in laboratory the water extracts for determining the chemical composition of soil salinization.

RESULTS

The first type of landscape with salt-affected soils is the coastal area of the Arctic Ocean at about 69–73° N and 120–160° E. This is the vast coastal lowland and the subarctic zone of tundra soils. The area of salt-affected marsh soils is estimated at 7 249 km^2. Marsh Solonchacks occupy the lowermost parts of the lowland subjected to the influence of tides. In the summer the marsh Solonchacks become defrosted to the 1m depth. The soil profile is represented by layers of loamy sand and clay. The soil pH is slightly acid. The amount of soluble salts reaches 1–2%. The formation of a thin salt crust and the salinization of these soils may be explained by ascending movement and transpiration of saline waters in the summer period (Elovskaya *et al.*, 1979). Sodium chlorides predominate in the chemical composition of salts (Table 1, pit N 1064).

With increasing elevation and weakening of the tides, the soddy-gley Solonchackous soils are developed on mesoelevations and low sea terraces. They are characterized by slightly acid and neutral reaction, a weakly expressed salinization degree (with exception of lower horizons). Salinization type is chloride at the surface and sulfate-chloride down the soil profile. These soils are subjected to recent salinization related to the influence of marine deposits containing 0.7–1.2% of salts with predominant sulfates and chlorides of magnesium and sodium. The other source of salts is the saline seawater. Mechanisms of salinization: (1) tidal water; (2) aeolian transportation of seawater drops (impulverization) followed by the redistribution of salts by the local relief with their accumulation in depressions, particularly in the areas with heavy-textured soils. The chloride type of salinization is typical of the marsh zone, and the chloride-sulfate type of salinization is developed on coastal terraces.

The next area of the widespread distribution of salt-affected soils is Central Yakutia. The permafrost thickness here is about 400–600 m. Salt-affected soils occupy only 0.13% of the total area in Central Yakutia. However, in the agricultural zone of Central Yakutia, their role is more significant: 421 600 ha (38.4%), including 56 600 ha (50.3%) of cropland. They are developed in thermokarst depressions (alases) within the ancient alluvial plain, on river floodplains and low terraces in the area of 60–64° N and 120–135° E. This is the area of sharply continental and arid climate: low precipitation, about 200–250 mm, the potential evaporation reaches 350–450 mm/yr. The mean January

TABLE 1
Data of 1:5 water extract and pH of the salt-affected soils in Yakutia

No.	Depth,	The sum of salts				Total alkalinity				pH
pit	cm	%	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^++K^+	1:2.5
			in Mmol-ekv per 100 g of soil							
1064	0–20	1.90	0	0.25	26.75	6.93	0.05	14.75	19.13	7.6
	20–40	1.68	0	0.15	26.00	4.22	0.25	12.30	7.82	8.0
	40–60	0.08	0	0.60	0.05	0.43	0.55	0.35	0.15	7.8
	60–80	2.04	0	0.15	29.85	5.70	0.90	14.15	20.65	7.6
	80–100	1.00	0	0.15	29.50	6.80	0.35	14.80	21.30	7.6
	100–110	1.54	0	0.15	22.05	5.02	0.65	9.40	17.17	7.2
2	0–0.5	12.00	0	1.60	158.53	49.40	24.85	70.00	111.38	8.50
	0.5–5	4.60	0	0.48	76.40	6.20	10.00	24.55	45.70	7.60
	5–18	3.15	0	0.38	29.61	25.00	16.08	14.77	16.32	7.90
	16–57	0.99	0	0.36	15.52	2.00	2.19	4.74	9.41	8.27
	53–85	0.54	0	0.40	7.50	1.56	0.66	0.89	6.55	8.33
	85–100	0.29	0	0.41	3.49	1.08	0.53	0.15	3.11	8.36
	100–130	0.27	0	0.22	1.84	1.90	0.58	0.10	3.63	8.16
	160–170	0.79	0	0.11	5.73	7.46	4.00	3.20	4.61	7.62
18	0–0.5	35.12	4.00	24.88	34.57	476	12.50	377.5	197.8	10.41
	0.5–5	2.44	14.80	22.6	4.85	0.44	0.40	0.20	17.68	9.35
	5–15	0.85	4.56	9.62	2.00	0.14	0.65	0.63	9.70	10.19
	15–50	0.67	2.64	7.7	0.12	0.06	0.85	0.15	6.09	9.98
	50–75	0.28	0.68	3.32	0.06	0.06	0.40	0.60	2.33	9.88
	75–95	0.13	0	1.44	0.04	0.02	0.10	0.40	1.35	9.44
	95–105	0.12	0	1.28	0.04	0.11	0.50	0.55	1.10	9.37
	105–150	0.17	0.2	1.98	0.06	0.02	0.30	0.45	1.46	9.32
	160–170	0.18	0.24	1.98	0.06	0.08	0.10	0.65	1.56	9.50

Pit N 1064: Elovskaya *et al.*, 1979. N 2, 18: original data.

temperature is -43.2 °C, and the mean July temperature is 18–19 °C. The humidity factor is very low. Thus, this area corresponds to the semi-desert zone.

Central Yakutia represents the East Siberian permafrost-affected ultracontinental region of the boreal zone with the middle-taiga subzone of permafrost-affected acid taiga soils and pale soils in the Central Yakutia province (Dobrovolskiy and Urusevskaya 1984). The boreal taiga zone is characterized by the type of pale permafrost-affected taiga soils and meadow-Chernozemic soils of alases. Central Yakutia is located in the ancient Siberian platform and occupies the eastern part of Lena-Yenisei plate. Since Cretaceous period this territory is a depression, enriched with loose continental sediments transferred by water flows from southern mountains and plateaus.

In Central Yakutia, the salt-affected soils are found in two geomorphic positions: in river valleys and in thermokarst depressions or alases within the ancient alluvial plain. Salt-affected soils are developed on the floodplain and two low terraces in river valleys. Sometimes marine outcrops of Cambrian system are met in the valley edges. For instance, in the Amga river valley one can find outcrops of Cambrian age represented by dolomites, limeste, marl, silica and rock-salt (Desyatkin and Romanov 1989). Their largest areas are found within the central floodplain and on the first terrace. They are represented by Solonchacks, Solonetzes, and different variants of Solonchackous soils: meadow-Chernozemic, alluvial, meadow, and meadow-swampy Solonchackous soils.

Sources of salinization are as follows: (1) flood water, (2) groundwater discharge along the edges of river valleys (the existence of cryopegs in permafrost); (3) domestic, farming, and industrial wastewater (technogenic source).

In permafrost are talik zones with unfrozen salt water having subzero temperatures. Also, there are so-called cryopegs. Thus, the discharge of deep saline groundwater onto the surface is possible in the areas of taliks and cryopegs. Upon the rock freezing the salts were squeezed into talik zones and the natural concentration of salts took place in them.

In cities and villages, salt-containing wastewater enters the environment. Technogenic cryopegs with the high concentration of salts (up to 25 g/l) are formed. Sulfates and chlorides of sodium and magnesium predominate among the dissolved salts.

Mechanisms of salinization: (1) the presence of permafrost prevents soil drainage; (2) the evaporative concentration of salts takes place; (3) an important factor is relief: salt-affected soils are found in mesodepressions on floodplains, in which the floodwater is accumulated and then gradually evaporates.

The extremely arid climate of this territory favors the evaporative concentration of salts. Model calculations show that soil salinization with chlorides contained in floodwater in concentrations of about 0.5 meq/l is possible in about 200–300 years.

The chemical composition of soil salinization in river valleys of Central Yakutia is sulfates and chlorides of sodium and magnesium (Table 1, pit N 2); in some areas, soda-saline soils are formed.

It is worth emphasizing that the layers of chloride-sodium salt brines are met at a depth of 50 m in the Lena-Angara artesian basin. It is possible to see stock-like layers of halite (NaCl content 98%) of 140 to 1 000 m thick (early Cambrian) (Dzens-Litovskiy, 1951). Evidently, chloride salinization can be caused by pressure waters flown over aquifuge surface or “hydrogeological windows”. This is also evidenced by a great number of saline chloride-sodium lakes of Kempenday basin.

The third area of the widespread distribution of salt-affected soils is the ancient alluvial plain and ancient river terraces. This is the area of larch taiga forests with a predominance of pale permafrost-affected soils. The thickness of the active layer in them varies from 1 to 2 m. The thickness of underlying permafrost reaches several hundred metres. Within these taiga landscapes, there are thermokarst depressions or alases with a diameter from 10 m to 25 km.

Alases represent geochemically close depressions to be an erosion base and centre of subaqueous accumulation of materials from surrounding territories (Desyatkin and

Romanov, 1989). Such depressions are covered by meadow and steppe vegetation. They can be clearly seen of satellite images. Alas in Yakutian language means a meadow surrounded by forest. Alas depressions represent a very complicated ecological system formed under swampy, meadow-steppe and forest vegetation differed from surrounding interfluve areas occupied by permafrost, podzolized and taiga soils. A series of specific alas soils is formed in such depressions. The lowest part of alas is usually a periodically drying lake, surrounded by a "lake floodplain" with hydromorphic swampy soils. Somewhat higher is the belt of alas semihydromorphic Solonchackous soils and Solonchacks. Still higher along the slope are developed xeromorphic steppized soils and Solonetzes. They are changed by permafrost-affected gray steppe soils and by dark gray and soddy soils at a higher level. The top of alas is occupied by variants of taiga permafrost-affected soils (Desyatkin, 2008). Salt-affected soils are mainly concentrated just in alases of Central Yakutia. In the course of evolution of thermokarst depressions, the area and the degree of soil salinization in them increase. Soda-saline soils are typical for alases.

The genesis of soil salinization in thermokarst depressions is bound up with the mechanism of their formation. In the formation period of the ancient alluvial plain (the 100m terrace of Early Pleistocene) the alluvium accumulated easily soluble salts due to evaporative concentration from groundwaters under warm climatic conditions. Later on, in the Middle and Late Pleistocene the climatic conditions became drastically changed. Permafrost has been formed. Within the ancient alluvial plain, there are areas with extremely ice-rich permafrost contained abundant ice wedges. The loess-ice deposits in such areas are called as the ice complex deposits. Their thickness varies from 3–10 to 60 m. The ice complex was formed in the Middle Pleistocene under extremely cold climatic conditions. In the Holocene, it is subjected to a gradual degradation due to the thawing of ice wedges. The maximum degradation of the ice complex took place during the Holocene climatic maximum. At present, the appearance of new alases is often conditioned by the anthropogenic loads on the soil surface and by fires. The destruction of the peat layer by fires or building works greatly increases the intensity of soil thawing, so that the thawing depth reaches the upper parts of buried ice wedges. Their melting leads to the formation of thermokarst lakes. Under the lakes, new taliks are formed. Gradually, the entire area turns into a large thermokarst depression.

The presence of salts in permafrost serves as evidence of relic salt accumulation. In the Early Pleistocene this area represented ancient river valleys, in which the accumulation of salts removed from the adjacent plateaus composed of salt-containing Paleozoic rocks took place. Gypsum and sodium chloride predominate in the composition of salts within the ice complex deposits. As a result of thermokarst and seasonal thawing the salts are redistributed now within the thawing layer of 1-1.5m thick due to their migration.

Soda ($NaHCO_3$ и Na_2CO_3) is absent in the ice complex deposits, what speaks about its formation at the subsequent stages, in the zone of seasonal thawing.

With the development of alases, these salts are leached off into thermokarst lakes, where their gradual evaporative concentration takes place. Along with soluble salts, the biogenic accumulation of calcium carbonates or calcification of the deposits owing to the shells of fresh water mollusks is developed. Upon the complete drying of the lake, the talik zone under it is subjected to freezing. Often, hydrolaccoliths (pingo) are formed. Thus, the cryogenic concentration of salts is an important factor of salinization. The concentration of salts in talik waters reached 4–10 g/l. Simultaneously, the differentiation of salts occurs because of the precipitation of carbonates of calcium and magnesium, so that soda predominates in the water.

There are several hypotheses about the origin of soda:

(1) organic desulfurization

$Na_2SO_4 + 2C = Na_2S + 2CO_2$

$Na_2S + CO_2 + H_2O = Na_2CO_3 + H_2S$

(2) precipitation of Mg and Ca carbonates; (3) the release of sodium from the weathering of feldspars and its migration with suprapermafrost water flows into the depressions; (4) hydrolytic destruction of silicates with participation of carbon dioxide released from water upon its freezing.

The extreme variation of soda salinization of soils in alases can be observed in the area of Abalakh soda lakes of Yakutia. In summer they are slightly saline, being frozen in winter the lakes reveal high concentrations of soda brine and mirabilite. The soda brine in Abalakh lake, for instance, contains 8-8.5% of salts (Dzens-Litovskiy 1951). These are shallow lakes, and lake mud is used for medical purposes. Soils on the shores of these lakes are strongly saline. This is the area of soda gley Solonchacks (Table 1, pit N 18). Along with a higher content of soda the share of chlorides and sulfates is also rather high in the salt composition of Solonchacks. On slopes of alas depressions, Solonetzes may be formed.

CONCLUSIONS

- The northernmost area with salt-affected soils in Eurasia is the permafrost zone of Yakutia. Salt-affected soils are found in the tundra and taiga zones.
- In the tundra zone of northern Yakutia, salt-affected soils are formed on low sea terraces and coastal marshes. Their area is estimated at 7 249 km^2.
- Sea salts are the major factor of soil salinization in coastal areas within the tundra zone of northern Yakutia.
- MgCl and NaCl predominate in marsh Solonchacks. Solonchackous gley soils on low terraces are enriched with $MgSO_4$ and $NaSO_4$.
- In the taiga zone of Central Yakutia, salt-affected soils are formed on the floodplains and low terraces of river valleys and in thermokarst depressions (alases) within the ancient alluvial plain. Their total area is estimated at 4 216 km^2 (50.3% of the cropland)
- Chlorides and sulfates of sodium and magnesium predominate in the composition of salts in Solonchackous meadow-Chernozemic soils on the floodplains.
- Sulfates of magnesium and soda predominate in the salt composition of the soils in alas depressions.
- Arid climate and permafrost hampering natural drainage of the territory are essential factors favoring salinization in the taiga zone of Central Yakutia.

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River salt loads as influenced by irrigation development in the Bardenas Irrigation Scheme (Spain)

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ABSTRACT

This work used non-parametric methods to assess the trends in monthly flows, salt concentrations and salt loads in the irrigation water, the upstream inflows to—and the outputs from—the Bardenas Irrigation Scheme (BIS, ca. 80 000 ha) in the Ebro River Basin (NE Spain) from the records of the Ebro Basin Authority (CHE) from 1973 to 2004.

The flow decreased and salt concentration increased at all stations. The decrease in flow/increase in concentration was significantly greater in the downstream stations collecting the irrigation return flows (IRF) from BIS (Arba River at Gallur, ARBGAL and Aragón River at Caparroso, ARACAP) than in the upstream stations (Aragón River at Yesa dam, where irrigation water is diverted, and Irati River at Liédena). The increase in concentration was overridden by the decrease in flow causing an overall decrease in the salt loads. The potential uses of IRF in ARBGAL and ARACAP are being impaired by their increasing salinity, but the overall effect of the BIS on the salinity of the receiving Ebro River is decreasing due to the decrease in export loads.

Keywords: Ebro River basin, irrigation return flow, salinity, salt load, trend.

SCOPE OF WORK

Irrigation may help farmers to benefit from warmer climate and longer growing seasons and to cope with irregular precipitations; all three foreseeable effects of climate change in the near future. Thus, an increase in irrigated surface can be expected in semi-arid areas as long as water resources remain available. The higher consumptive water use by irrigated crops will reduce available water resources and increase their salinity, an increase further enhanced by natural soil-subsoil salinity. Therefore, the understanding of the relationship between irrigation development and river salinity is necessary to establish how climate change will affect the salinity of water courses. This work focuses on the flow and salinity (concentration and load) trends in the outflows from the Bardenas Irrigation Scheme (BIS), and its relationship to irrigation development, in order to illustrate the plausible effects of climate change on river salinity through irrigation development.

The Bardenas Irrigation Scheme (BIS), Spain

The BIS is located in the middle Ebro River Basin in NE Spain (42º 20’ N–01º 20’ W) and includes about 22 700 ha in the Aragón River and 59 600 ha in the Arba River basin (up to 98 000 ha in 2004) (Figure 1). Irrigation water is diverted from Yesa Dam on the Aragón River to the Bardenas Canal. The dam became operational in 1959 with the irrigation of 21 000 ha (Bolea Foradada, 1986) and the irrigated area has increased since then, particularly in the Arba basin. The irrigated area in the Aragón basin lies in the left margin of the Aragón River (furnished directly from the Bardenas Canal or through the *Acequia de Navarra*), while two branches of the main canal (*Cinco*

Villas and *Sora*) engulf the irrigated area in the Arba basin (Figure 1). The system was conceived for surface irrigation (with generalized land levelling and low capacity of irrigation ditches) but the new irrigated areas (since the 1980s) benefit from sprinkler irrigation. Also, important sections of the traditional irrigated areas are being converted to sprinkler or drip systems.

The climate in BIS is Mediterranean with precipitation concentrated mainly in spring and autumn and high summer temperatures. The mean annual precipitation ranges from 400 mm to 500 mm; the temperature from 13 °C to 14 °C, and the ET_o (Penman-Monteith) from 1 100 mm to 1 250 mm, with a gradient of decreasing P and increasing T and ET_o from N to S (Basso, 1994).

The Aragón River (like the Irati River, Figure 1) originates from the Pyrenees and provides water with excellent quality for irrigation (mean electrical conductivity, EC=0.35 dS/m). The highest flow in the natural regime in the Aragón River occurs in spring due to snow-melt. On the other hand, the sources of the Arba lie in the pre-Pyrenean ranges and the peak in natural flow takes place in winter, with a marked summer minimum (Masachs Alavedra, 1948). Both natural regimes downstream of the irrigated area have been greatly affected by the development of irrigation in BIS.

Geologically, the irrigated area rests upon Tertiary and Quaternary materials The Tertiary materials include limeste, argillite, siltste and conglomerate: The coarser materials deposited to the North and the finer to the South, the latter were deposited under lacustrine conditions and include some saline and gypsum-rich strata. The Quaternary consists of alluvial clay and gravel along the valley fills and some glacis in the centre of the Arba basin (Martínez-Beltrán, 1978). The main soil types in the irrigated land are the coarse soils developed upon the high glacis (*sasos*) and the silt-clay textured soils along the valley fills. Occasionally, the soils developed upon saline strata have become saline because of the mobilization of geological salts and inadequate drainage (Martínez-Beltrán, 1978).

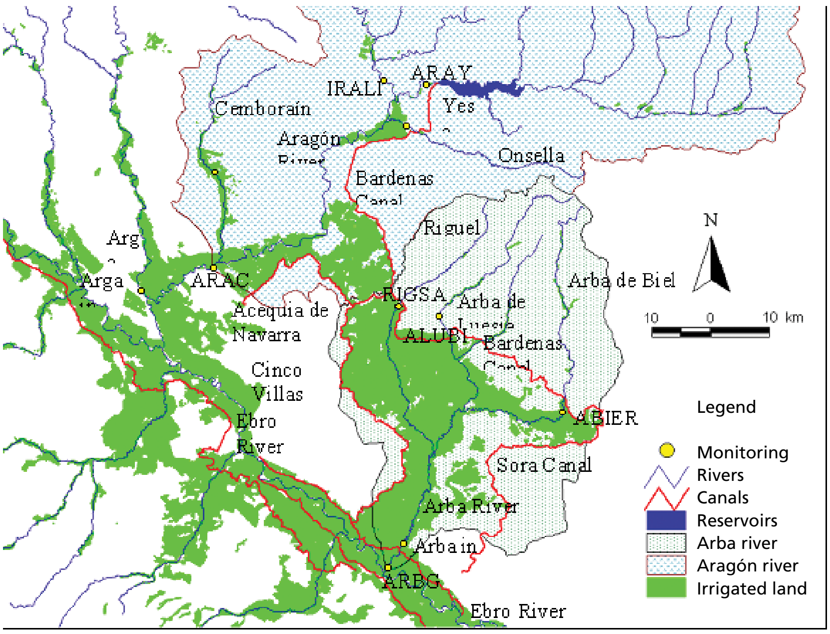

FIGURE 1

The Bardenas Irrigation Scheme: rivers, main canals, monitoring stations used in this work (Aragón R. in Caparroso, ARACAP, Arba R. in Gallur, ARBGAL, Aragón R. in Yesa Dam, ARAYES, Irati R. in Liédena, IRALIE, Riguel R. in Sádaba, Arba de Luesia R. in Biota, ALUBIO, and Arba de Biel R. in Erla, ABIERL) and extent of the Aragón and Arba river basins and the irrigated land.

MATERIALS AND METHODS

Data were collected for 7 stations of the monitoring networks of the Ebro Basin Authority (Confederación Hidrográfica del Ebro, CHE) (Figure 1):

Aragón River at Caparroso (ARACAP) and Arba River at Gallur (ARBGAL) downstream of the irrigated areas in the Aragón and Arba basins, respectively;

Aragón River at Yesa (ARAYES) downstream of the Yesa dam, conveying all the flows in the Aragón River after diversion for irrigation through the Bardenas Canal. This station also features the quality of the water diverted for irrigation;

Irati River at Liédena (IRALIE), the main river flowing into the Aragón River upstream of Caparroso and downstream of Yesa dam. There are two other minor tributaries in this reach of the Aragón R.: the Onsella R. and Cemboraín R., but their flows are quite lower (mean flows 1.6 m^3/s and 0.5 m^3/s respectively), as they do not originate from the Pyrenees and there flow records are not so complete, so they have been neglected; and

The three stations upstream of the irrigated area in the Arba basin along the main rivers draining the basin: Arba de Luesia River at Biota (ALUBIO), Arba de Biel River at Erla (ABIERL) and Riguel River at Sádaba (RIGSAD). For these stations only flow data were available as they are not monitored regularly by CHE, so their EC was taken as the average of the data in CHE (2006) and measurements taken in 2009 (unpublished).

These water quality records were retrieved from the surface water quality control networks of the CHE [1980–2010: CHE (2010); 1974–1980: MOPU (1974 to 1980)]. These sources provided: (i) monthly records of electrical conductivity (EC, dS/m); (ii) two to four complete analysis a year (with all main ions reported: Ca^{2+}, Na^{+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}; mg/l); and (iii) the flows at the time of sampling (Q_i, m^3/s). All EC readings were converted to 25 °C. The total dissolved solids (TDS mg/l) were calculated as the sum of the main ions, and the linear regression relationships between EC and TDS were established for each station to estimate monthly TDS from the more complete EC records.

The daily flow data (Q_d) for all 7 stations were facilitated by CHE and complemented with the data retrieved from CEDEX (2010).

Some missing values of EC were filled by using the best fitting ARIMA model (ARAYES, ARACAP and IRALIE) or from the regression of EC on Q_i (ARBGAL). The Q_d missing in ARAYES were estimated by regression on the Q_d in ARACAP, and the data missing in ARACAP from the regression of these data on the data of ARAYES or on the data of the nearby station of Arba River in Funes, with a similar regime. The missing flows in IRALIE were also obtained from the regression of Q_d in IRALIE on Q_d in ARACAP. All these regressions were used only if the hydrograph in the station with missing data resembled clearly the hydrograph in the other station around the dates with missing data. The missing flow records in ARBGAL were obtained by regression on the nearby station of Arba River in Tauste. Finally, the missing daily flows in the upstream stations in the Arba basin were obtained by regression upon each others.

The monthly salt loads (SL_m) were obtained as the product of the monthly TDS (obtained from EC) by the mean monthly flow (Q_m). Monthly net salt load (NSL) originating inside each irrigation basin was estimated as the difference between downstream (ARBGAL in Arba basin and ARACAP in Aragón basin) and upstream (ALUBIO, ABIERL and RIGSAD in Arba basin and ARAYES and IRALIE in Aragón basin) monthly salt loads. The net salt balance (*SBalance*) in the BIS was estimated as the SL in the two downstream stations - SL in upstream inflows - SL in irrigation water. *SBalance* represented the total salts being removed from the BIS.

Trends were established on salt concentration (EC), mean monthly flow (Q_m); monthly salt load (SL_m) for the stations of ARAYES, ARACAP, ARBGAL, and IRALIE and the Bardenas Canal, monthly net salt load (NSL) for the Arba and the Aragon basins and salt balance (*SBalance*) for the whole BIS. Trends were assessed with the Man-Kendall seasonal test and estimated by the seasonal Kendall slope estimator for each month and for the whole set of data. The significance of the differences in the trends between different stations and seasons (months) were tested with a chi-squared test (Gilbert, 1987).

The salinization of water courses

All the flows showed a clear decrease in the period studied, with significant differences ($P<0.05$) between seasons (months) but not between stations (Table 1). The highest percentage decrease was found in ARBGAL (-2.1%) followed by ARAYES (-1.1%). The volumes diverted (*CanBar*) also decreased along the study period in spite of the increase in irrigated land, pointing to a better water management in BIS along time. The flow reduction in the upstream stations (ARAYES and IRALIE) could be attributed to land use changes in the upper Aragón basin (replacement of pastures and crops by natural vegetation, with higher ET, in the last decades) and could also follow a decrease in precipitation due to climate change. The flow decrease in ARBGAL and ARACAP was higher than in diverted irrigation water showing an increase in the consumptive use in BIS linked to the increase in irrigated area and to crop intensification.

The salt concentrations (EC) increased in all stations, with significant differences ($P<0.05$) between stations but not between months (Table 1). This rising trend in EC has been found widespread over the Ebro River Basin (CHE, 2007). The changes in upstream EC (ARAYES and IRALIE) were lower in absolute value (though higher in percentage due to the lower salinity of inflows) than in the downstream stations collecting the IRF (ARACAP and ARBGAL). The EC increase in ARAYES and IRALIE could follow the same reasons than their flow decrease. The EC increase was particularly high in ARBGAL [+0.020 (dS/m) yr^{-1}] following the increase in irrigated surface, the progressive development of irrigation on soils with high salinity in the left margin of the lower reaches of the Arba River, and the generalization of sprinkler irrigation (with lower drainage than traditional irrigation) in the irrigated areas transformed after the 1980s. The salinity of the downstream station in the Aragón basin also increased [ARACAP=+0.007 (dS/m) yr^{-1}] but the increase was lower than in the Arba basin (higher in relation to the mean salinity of the Aragón River). In the Aragón basin there has been no additional development of irrigation and the increase is attributed to the higher salinity of irrigation water and to enhanced irrigation management (higher efficiency) and consumptive use.

The salt loads (SL) decreased in all stations with significant differences ($P<0.05$) between seasons (months) but not between stations (Table 1). The decrease in the SL of diverted irrigation water (*CanBar*; Table 1) was not significant due to the low decrease in diverted flow. The highest decrease (both in absolute value and percentage of SL) was found in ARBGAL [-389 (Mg/m) yr^{-1}] in spite of the increase in irrigated land in the Arba basin and the higher salinity of the more recently irrigated lands that entail the highest increase in EC in the system. This is explained by the decrease in flow in ARBGAL. The same situation was found in the Aragón basin (ARACAP) but the decrease in SL was much lower (Table 1). Net salt loading, NSL, decreased in both basins, with the highest decrease in the Arba basin [-338 (Mg/m) yr^{-1}]. The *SBalance*, representing the total salts being removed from the BIS, decreased significantly pointing to a lower salt mobilization, due to lower leaching fractions derived from the dominance of sprinkler irrigation in the most recently irrigated areas in the Bardenas basin and to better management of traditional irrigated areas.

TABLE 1

Trends in electrical conductivity (EC), mean monthly flow (Q_m) and mean monthly salt load (SL_m) in the Aragón River at Yesa (ARAYES), Aragón River at Caparroso (ARACAP), Arba River at Gallur (ARBGAL), Irati River at Liédena (IRALIE), and the Bardenas Canal (*CanBar*). net salt load in the Aragón (NSL-Aragón) and Arba (NSL-Arba) basins and salt balance for the whole BIS (*SBalance*).

	EC		Q_m		SL_m		
	(dS/m) yr^{-1}	%	(m^3/s) yr^{-1}	%	(Mg/m) yr^{-1}	%	Period
ARAYES	0.003	1.0	-0.23	-1.1	-120.5	-0.8	1972–73 to 2003–04
IRALIE	0.001	1.4	-0.19	-0.6	-96.4	-0.5	1976–77 to 2003–04
CanBar(1)	0.003	1.0	-0.12	-0.6	-31.3^{NS}	-0.2	1976–77 to 2002–03
ARACAP	0.007	1.7	-0.25	-0.5	-54.8	-0.1	1972–73 to 2003–04
ARBGAL	0.020	1.1	-0.21	-2.1	-389.4	-1.1	1974–75 to 2003–04
NSL-Aragón	-	-	-	-	-176.9	-1.3	1976–77 to 2002–03
NSL-Arba	-	-	-	-	-338.1	-1.1	1976–77 to 2002–03
SBalance	-	-	-	-	-447.2	-1.5	1976–77 to 2002–03

(1) EC in *CanBar* is that of ARAYES

NS Not significant (P>0.05)

CONCLUSIONS

Overall, there was a clear increase in salinity (EC) in the source waters (ARAYES, and also IRALIE), not linked to irrigation management in BIS, but to land use changes and climate change in the Pyrenean region and a higher increase in the collectors of the Bardenas Scheme, particularly in the Arba basin (ARBGAL) linked to the increase in irrigation on more saline environments and to better irrigation management (change to pressurized systems in old irrigated areas and use of sprinkler irrigation in new areas). The flows, however, were lower in all stations overriding the effect of salinity increase and leading to lower salt loads from the Bardenas Scheme (both in ARBGAL and ARACAP). This tendency suggests that higher consumptive use in the Bardenas Scheme, associated to further development of irrigation induced by climate change will lead to higher salinity (limiting the potential use of these waters) but to lower salt loads in the Aragón and Arba rivers (reducing their impact on the overall salinity of the Ebro River).

In the Arba River basin, despite the increase in irrigated land, SL and NSL are decreasing, as a result of decreasing drainage (since there was a clear increase of EC in ARBGAL). The flow decrease and EC increase in ARBGAL derived partially from the decrease in the diversion for irrigation (lower Q); from the growing area with more efficient sprinkler irrigation (lower Q and higher EC); and from the presence of saline soils in the newly irrigated area (higher EC). New irrigation developments should bear in mind the higher salinity of IRF from saline areas and from more efficient irrigation systems.

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The salt-land soil system placement (taxonomy) in relation to global changes and challenges

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The development of new concepts for the improved utilization of soil that best meet the demands of diverse social, economical and environmental needs is the challenge facing scientists and decision makers today.

Global demand for food and fibre to ensure the survival of the increasing population and desired higher standards of living create challenges and may require utilization of scarce soil resources. Food production will need to increase 38% by 2025 and 57% by 2050 if the current global food supply is to be maintained. Nearly all of the most suitable soils are currently in cultivation and this increased demand will require expansion into new areas and reclamation of degraded lands.

In addition to increasing the area of land under cultivation, there is an urgent need to increase the yield per unit area. However, an estimated 15% of the total land area of the world has been degraded by soil salinization and erosion. Productivity must become more efficient as an ever increasing arable area succumbs to degradation.

World Soil Resources (FAO/UNESCO) and other data report that climatic variations are the basis for determining global distribution of saline and sodic soils (>900 Mha). Despite prevailing focus on arid and semi-arid areas, most climo-ecological regions in the world are not free from salinization.

The worldwide soil system is multifunctional, including serving as a source and sink for CO_2 to combat climate change. This system is expected to alter with the warming climatic trend and changing distribution of rainfall. These changes will affect soil dynamics through intensity of weathering, transformation and translocation of minerals, rates of biological activities and chemical reactions. A unique systematic classification and correlation network is required to evaluate these changes, enhance food security, reduce stress on fragile ecosystems and most importantly, monitor the evolution of salinization worldwide.

The FAO/UN and US Soil Taxonomy systems and several others as Remote sensing, GIS, Land sat data, have been applied worldwide for classification/ characterization of saline soils on smaller scales.

However, on the basis of this author's global experiences in teaching, research and mapping soils, sustainable restoration/reclamation of salt-affected soils may not be achieved without development of a unique and "Integrated Classification System". Therefore, it is suggested a new order "SALSODOSOLS" should be created that will be utilized for classifying saline/sodic soils globally. This classification would place soils uniquely to the level of mapping/farmland Units on a global and larger/workable scale.

Utilization of such a system then would allow soil scientists to correlate and harmonize similar mapping units located in unique agro-ecological/physiographic zones under one name, resulting in an effective transfer of knowledge worldwide, enhancing reclamation/ management practices, and improving decision making relative to land use to enhance productivity and meet the demands of growing population.

Keywords: soil system, challenges, salinization, food supply, climate change, soil correlation.

Chernozem and chestnut soils of South Russia long-term vulnerability to irrigation and salinization (learning from past experiences)

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ABSTRACT

A long-term study of irrigated Chernozem and chestnut soils and corresponding rainfed soils of South of Russia was carried out. In the Chernozems, an increase in oozy particles in the arable horizon due to the process of clay formation, profile distribution of silt is observed. In the arable horizon of the Chernozems, humus losses of 15% (stale water from river Don) and 22–23% (mineralized water from Veselovsky storage lake, Manych river) were observed. In chestnut complexes of soils, the geochemical scope of a landscape is up to 4–10 times greater. The total soil salinization increases sharply. Irrigation of Chernozems and chestnut soils results in local hydromorphic formation. The structure of soil cover variability strengthens. Exception of laterally stereotyped vertical convection-diffusion water salt transfer in soil at watering and washing out of a soil continuum is proposed.

Keywords: Chernozem, chestnut soil, irrigation, salinization, past experiences.

INTRODUCTION

The key problem of irrigation is an exception of the imitating approach to a scientific substantiation, development and practice of artificial humidifying and desalinization of soils which basic defect is a general for the soil continuum as a whole mode of water delivery at irrigation and washing out of salts. From the geological point of view the irrigation is an attempt to change instantly the mode of stagnation of biogeosystem, having provided a sharp gain of its bioproduction due to additional humidifying. The homeostasis of such type of biogeosystem usually develops so, that in system there is a future long-term irrigational agriculture the significant reserve of elements of plant nutrition is caused by their accumulation in previous geological stages of lithosphere. From this point of view the adverse consequences of the current stage of irrigation development even under the use of modern subsoil and drop ways of soil humidifying are not individual, but the system lacks of the current irrigation concept. There is a need to discuss the state and prospect of a soil continuum at irrigation on an example of steppe and dry steppe soils of the south of Russia.

MATERIALS AND METHODS

Geographical region: the South of Russia, the Lower Don. Climate continental, 61.7–77 °C, droughty, unstable humidifying. Types of a relief and microrelief are various and advanced. Parent rocks are yellow-brown heavy structural clay, red-brown Scythian clay, lessive loams. The objects of research are the main soil types of steppe zone of

South Russia–Chernozem and chestnut soil. The properties of soils are as follow: calcareous Chernozem–C_{org} 2.3%, exchangeable cations (mmol/kg): Ca 280, Mg 100, Na 7, pH 7.6, $CaCO_3$ 0.9%, clay 61.3%; chestnut soil–C_{org} 1.5%, exchangeable cations (mmol/kg): Ca 260, Mg 70, Na 16.8, pH 7.7, $CaCO_3$ 1.5%, clay 58.9%.

Irrigation methods: superficial, overhead irrigation.

Hydro-geological conditions: the level of subsoil water from 2–4 up to 20 m, differs on individual key sites.

Variants of soils use: constant irrigational culture, alternation of an irrigated and rainfed agriculture.

Term of supervision: between 8 and 50 years on various key sites. The irrigated by standard ways and corresponding rainfed soils long-term regime researches are fulfilled within last 50 years in conditions of soil-meliorative stationary experiments on key sites (32 sites in total).

The geomorphological, physical, chemical and agrochemical properties were investigated by standard methods [1, 2, 7].

RESULTS AND DISCUSSION

Chernozems formed on easy and heavy loams have corresponding mechanical structure. The change of mechanical structure of Chernozem is a result of a long-term irrigation period. It reveals in a top part of arable horizon of long-term irrigated Chernozem enrichment with fine sand particles. As a result of irrigation there is an increase of quantity of oozy particles in the arable horizon [6]. The long-term irrigated Chernozem is characterized by eluvial distribution of silt and eluvial-illuvial distribution of fraction of the aggregated silt occupying a leading position among others subfractions of silt.

In over moistened Chernozem accumulative character of distribution of the silt, the aggregated silt and dominating among aggregated silts subfraction the aggregated silt 1 is observed. Substantial growth of fraction of the aggregated silt 1 in arable and underlaying horizons on 25–33% in comparison with calcareous horizon and parent rock is identified. The merged horizon of over moistened Chernozems has a little bit raised contents of the aggregated silt 2 and 3 subfractions.

In oozy fraction structure of Chernozem the dioctahedron illit, illit-montmorrilonite mixing-layer structures; chlorite and minerals of porcelain clay group are present. A total chemical compound of oozy fractions of Chernozem shows, that the contents of illit, on the basis of reflexes areas revealed, corresponds to distribution of K_2O in a total chemical compound of oozy fraction.

Rectilinear dependence between diffraction intensity of reflections 7.1 and 4.74 Å of initial samples allows to assume, that the properties of both not irrigated, and formerly irrigated Chernozem on easy clay 7 Å minerals are submitted not so much by two-layer structures, but more by chlorites. The true contents of kaolin in structure of oozy fractions is insignificant.

In oozy fraction of Chernozems the kaolin relative accumulation and the quartz contents raise in structure of oozy fraction of the top soil horizons under the influence of irrigation are observed. The intensity of total size of reflexes of clay minerals and an intensity of reflex 4.26 Å ratio testifies an increase of SiO_2 contents and molarity ratio of SiO_2/Al_2O_3 in the top part of a soil profile and in arable horizon of irrigated Chernozem in comparison to not irrigated Chernozem.

The profile differentiation of separate groups of clay minerals of Chernozem calcareous horizons as a result of illitisation processes. Some distortion of structures of mixing-layer illit-smektit in arable and underlaying horizons appears. In long-term irrigated Chernozem formed on loam the probable tendency of soil compaction is revealed. Compaction of arable horizon of irrigated Chernozems and locally over moistened Chernozems is caused mainly by stale irrigation water.

Compaction of the top meter layer of soil increases by 0.13–0.15 g/cm^3, and porosity decreases to 46–48%, compared with 51–52% of non-irrigated soil. In conditions of long-term irrigation the soil water infiltration rate decreases 1.5–2 times.

In long-term irrigated Chernozems a calcareous horizon is formed that is not observed in non-irrigated Chernozem. In the arable and lower horizons of long-term and previously irrigated Chernozems, there is a decrease of CO_2 released by HCl down the soil profile. Some decrease of pH is also observed.

In irrigated Chernozems the dry residue varies from 0.05–0.14% for non-salinized soils to 0.37–0.51% for saline soils. Salinization chemistry type is sulphur-hydrocarbonate. Soils irrigated with mineralized water at key sites had solid residue values of 0.117–0.151% for the 0–25 cm and 0.171–0.287% for the 25–50 cm layer, while pH varies from 7.4 to 8.6. The absorbed sodium of 2.9–8.8% indicates the presence of Solonetzic soils. Under irrigation calcium in soil is especially mobile, and under watering with mineralized waters in which sodium exceeds calcium, the leaching of calcium is significant.

In the arable horizon of Chernozems irrigated for 30 years with stale water from river Don and mineralized water from Veselovsky storage lake (river Manych) the humus losses have been 15% and 22–23%, respectively. As a result of irrigation the humus quantity in the 0–50 cm soil layer has appreciably decreased. Redistribution of humus from arable horizon into the underlaying layers of soil is revealed. Irrigation of soil cover structure (SCS) is caused by humidifying of elements of a surface of soil continuum differentiation, deep moistening of negative forms of a microrelief due to a runoff from an adjoining surface. The high-contrast SCS forms [4]. Biological efficiency of Chernozems after the termination of irrigation within 3–8 years is lower for 15–25%, than that of not irrigated analogues. Non-irrigated chestnut soil is salinized to greater extent than non-irrigated Chernozem.

For complex of chestnut soils the differentiated SCS is peculiar. In the structure of a soil combination the chestnut soil, chestnut Solonetz, meadow-chestnut soil are submitted. As a result of irrigation, especially long-term irrigation in the complex chestnut soils the processes of degradation appear.

In the modern rather dry geological period, readily soluble salts, accumulated in parent rock of chestnut complexes of soils at a depth of 0.5–0.9 m in quantities up to 1–2% during the last geological periods, without an irrigation at the certain degree are isolated from an active water mode of a zone of aeration.

The irrigation of chestnut soil complex the 4–10 time geochemical scope of a landscape grow appears, readily soluble salts now are involved in active geochemical process. Thus the total soil salinization amplifies sharply. Due to influence of intensive lateral component of salt transfer at spatial heterogeneity of a hydrological mode of irrigated territory as a result of lateral heterogeneity of watering of a soil complex and redistributions of water on a microrelief the differentiation of SCS grows.

The heterogeneity of a hydrological mode of irrigated territory is the lateral heterogeneity of watering of a soil complex and redistributions of water on a microrelief. An intensive lateral salt transfer causes the SCS lateral differentiation to increase.

Not submitted to ion complexes, readily movable ions Na^+ and Cl^- migrate with a soil solution to rather low moistened microrelief sites of irrigated territory, in soil complex the local salinization and Solonetz formation increase promotes. Subsoil waters are salinized up to 10 g/l and more, pH=7.8–8.1, have a chloride-sodium chemical composition. Subsoil waters have weak outflow owing to properties of low plain relief of territory. For this reason under the irrigation the level of subsoil waters quickly rises, SCS is deeply differentiated, the landscape degrades, biological efficiency of a complex of soils is reduced, short-term irrigational effect is lost.

Irrigation water is delivered from the River Don, with mineral content of 0.6–1.3 g/l. Hydrological backsoil of landscape is weakly developed. So irrigational losses of water superficial and subsoil drain, are rather appreciable. After start-up of Higher-Sal irrigation systems (about 30 000 ha) in the 1960s the mineralization of water of the river Sal (inflow of the river Don) in summer period in the range line of main collector of irrigation system has decreased from initial data 4–6 g/l down to 1.5–2.5 g/l in the 1990s. This characterizes the situation as an ecological catastrophe [4].

Hydro-geological conditions, caused by application of standard ways of irrigation on the individual soil key sites, renders an adverse influence on a soil salinization degree, both Chernozems, and chestnut soils.

CONCLUSIONS

The examples of biogeosystem sequence under the indignation of an irrigational excess of humidifying are revealed.The irrigation results in adverse changes in soils and landscapes. It demands the search of ways of land use in conditions of soil over moistening and increase of its salinity caused by irrigation. In particular, even the concept of "vagrant agriculture" and its variants are developing. It is offered to allocate a part of the period of operation of irrigating system on restoration of soils, decrease their salinity by translating the irrigation system into not irrigation mode, cultivating not irrigated plants.

Gravitational effects of lateral redistributions of water on nano-, micro- and mesolevel of soil continuum follow the thermodynamics of movement of water in soil. For movement of water the gradient of water thermodynamic potential is necessary. A gravitational pist mode of replacement of water appears.

Reducing irrigation norms to reduce irrigational loss of soil structure were suggested, i.e. some individual improvements of irrigation standard are proposed to apply.

The less is the layer of soil humidifying after watering, the more is contribution of watering into unobstructed physical evaporation of water, both from the top layers of soil, and from its surface. The probability of an irrigational feed of subsoil waters decreases, but loss of water increases for physical evaporation from a surface of soil. Process of irrigational degradation of the top layer of soil is kept without changes.

Feature of a log-term cycle of soil formation at the dry climate, causing small natural salinity of the top layers of the soil generated in automorphic conditions even on salinized parent rock have been mentioned above. Readily soluble salts in geological time sequence are leaching, the horizon of their maximal accumulation is displaced downwards.

The soil salt profile is caused as well by other major feature. The process of migration of salts through a soil profile depends not only on soil humidity, but is caused by ionic structure of a soil solution migrating and parameters of multilevel hierarchy of capillary system of soil. At low soil humidity transfer of ions of salts is determined by their interaction with a soil capillaries surface, the charge of a firm phase of soil and the size of a capillary. It result to that the priority agent of transfer are dipoles and ions of water, and ions of readily soluble salts are late, braked by a superficial charge of capillaries and lag behind the general convection-diffusion mass transfer stream [3].

The state of water into a thin superficies films on soil structural separateness affect the water transfer into soil. Against macrowater, water of thin surface films on soil structural separateness does not dissolve some salt. Besides water at low humidity moves in soil mainly as pair, concentration of readily soluble salts in which is small.

At high humidity of soil in conditions of irrigation an unobstructed intensive convective flow of salts to a zone of evaporation is taking place. The mass transfer in soil at high humidity, salts mass transfer including, is determined by salt concentration of a solution only and goes free. Soil washing out from readily soluble salts, and, especially, prevention of secondary soil salinization at imitating ways irrigation, demands not huge washing norms, or a washing mode of an irrigation, but correct management of soil desalinization process only.

Instability of soil units under over moistening leads to soil water flow direction instability. This flow on a backsoil of the general tendency of descending movement of water in soil gets its stochastic lateral recombination caused by soil units. It results to nano diversity of soil watering, to formation of preferable flows of a soil moisture, to their merge and therefore loss of water from soil deep into the parent rock. The hydrological mode of a soil combination gets lateral heterogeneity which from the point of view of its stability is dangerous [4].

The well known adverse consequences of irrigation are not its individual lacks. Basically, whatever watering ways simulating natural soil humidifying are incapable to overcome sinking mode of watering of soil from its external or internal bottom border, gravitational compaction of over moistened soil, washing away of substances contained in soil, its enrichment by superfluous harmful readily soluble salts.

Therefore irrigation compaction, salinization, humus loss, differentiation of SCS are the system internal defect. Key problem of irrigation is an exception of the imitating basic approach to a scientific substantiation, development and practice of artificial humidifying and desalinization of soils. Dangers to the biosphere from the change of a climate and of fresh water deficiency due to change of the irrigation concept will increase.

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Salt-affected soils and climate change in the Valle del Cauca, Colombia

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ABSTRACT

This study provides an overview of the evolution of soil salinity and the salinity programmess in the Cauca River valley in the period 1980–2009. A description of the environmental conditions in the region studied and the programmes that have been followed for monitoring and control of salinization of soils are presented.

In order to assess the evolution of salinity, pilot projects in areas delimited by rivers flowing into the river Cauca were initiated. The study shows that of the 41 200 ha monitored, 20 830 ha still have some degree of salinity. According to the spatial and temporal assessment of soil salinity in the Cauca River valley, the process of salinization of the sector in general has remained constant, as much in the affected areas and also in the degree of salinity during the period of study. Some local areas showed a slight decrease in saline condition during the study period. It has been found that the region is very sensitive to climate variation events, such as those associated with the El Niño Southern Oscillation (ENSO), which suggests the sensitivity of the region to a change of climate. Among the environmental effects for the study area there is expected to be an impact on soil moisture balance. Several recommendations are given for both the monitoring process of salinization and to promote extension programmess for adaptability to climate change impacts.

Keywords: salinity, Valle del Cauca, climate change, tropical soils.

INTRODUCTION

The Earth's climate is changing, and projected changes, will result in increased economic losses, social and environmental issues in different sectors of production. (Vincent, 2007; Brown and Funk, 2008; IPCC, 2007 a,b,c). Agriculture in the Cauca Valley remains an engine for development, facing new challenges such as soil degradation, climate change, free trade, and development of new technologies, among others. One of the challenges that planners should consider natural resources in the coming years, is that natural resources sector is considered as a means to alleviate poverty and food production needs, (Rahman & Westley, 2002; Dasgupta, 2003), consistent with good agricultural practices that contribute to recovery and sustainable management of soils. This also should be connected with cost-effective alternatives to adapt to the climate variability and climate change.

Due to its proximity to the Pacific Ocean, the Valle del Cauca is one of the regions most affected by climate variability associated with the ENSO phenomenon in its extreme stages. If climate change is added to the scenario, this requires a study to better understand the climate of the region to incorporate into the planning and management strategies. In the region, the warm phase of ENSO is associated with drought, wildfires, energy rationing, reduced production of agriculture, fisheries and livestock (Jiménez *et al.*, 1998; Jiménez *et al.*, 1998), as well as the increase in cases of malaria and endemic diseases. The cold phase (La Niña) is associated with loss of life from natural disasters, such as landslides, mudslides, floods, flooding and erosion and a significant increase in sediment transport in rivers. Several studies indicate the relationship between the extreme phases of the phenomenon and the hydrology in the region. (Mesa & Poveda, 1997; Perez *et al.*, 1998; Carvajal, 2004; Poveda, 2004; Poveda *et al.*, 2001; Carvajal 1998; Doors & Carvajal, 2008).

DESCRIPTION OF THE AREA STUDIED

The study area includes the Cauca River Valley (CRV) having an area of 300 000 ha, is located in the Departamento del Valle del Cauca (VC) in the south-west of Colombia, South America. The flat area of CRV has a bimodal rainfall regime and has two rainy seasons; the first between March and May, and the second from September to November. Normally July and August is the driest time of the year. The mean annual rainfall fluctuates between 1 500 mm in the south and 1 000 mm in the northern zone. The mountainous area has longer and higher rainfall seasons, from March to June and September to December. Some highland areas have most of the rainfall during one season, normally during June to August (Jiménez, 1994).

The soils of this valley originated from alluvial sediments from the quaternary and are deep and fertile. The soils of the region affected by salts, have a poor drainage system, presents a parent material rich in sodium, an also are soils rich in calcium and magnesium salts (Asocia, 1988).

The economy of the zone is supported by the provision of services, followed by industrial and agricultural activities. Among the services, the most important are trade, transport, banking and communications. Sugar cane is the main crop at the region, with about 200 000 ha of the land occupied.

Figure 1 shows the location of the Departamento VC, the study area at the CRV and areas affected by salinizacion.

The selected sector is located at the Palmira municipality, between Frayle and Amaime rivers, both flowing to the Cauca River. The total area is 41 200 ha.

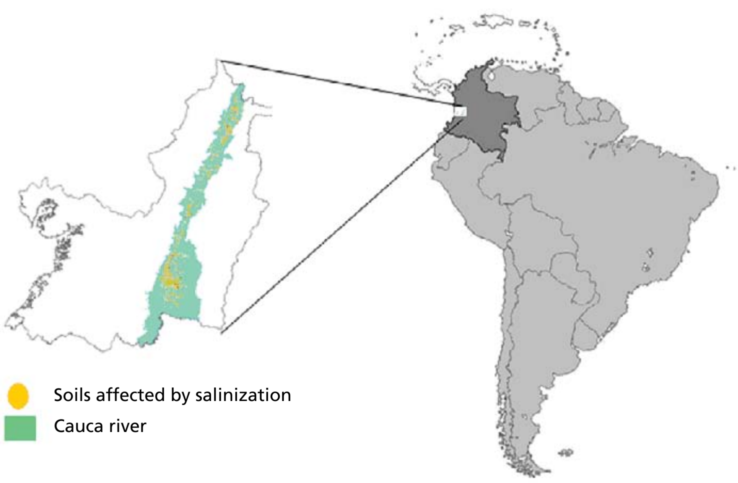

FIGURE 1
Project zone and soils affected by salinization in the Cauca Valley Colombia (Adapted from Romero, 2010).

SALINIZATION EXTENSION RATE

Salinization of soils in the CRV has human and natural origin. The use of salty waters for irrigation, the rise of salts from subsurface layers in areas of poor drainage and fertilizer application are human activities that in combination with natural and climate conditions (high evapotranspiration and low rainfall periods), soil (ferromagnesian and limeste) are conducive to this process. The northern sector of the CRV, has outcrops of salt formations of marine origin, thus exhibiting significant levels of salt-affected in that area. According to the latest monitoring in Valle del Cauca Department are about 65 000 ha affected by some degree of salinity.

DESCRIPTION OF PREVENTION EFFORTS

Efforts to prevent salinization of soils in the CRV have been carried out during the last 30 years, beginning with studies of soil salinity, conducted by local environmental authority the Regional Automous Corporation of Valle del Cauca (CVC). After the initial studies during the 1980s, land reclamation and water management projects were developed for local soil amelioration practices.

Salinity studies

The CVC as environmental regional authority, through the Salinity, Irrigation and Drainage Programme, developed a monitoring programme in order to evaluate the degree of salinity of the soils:

- Collection and selection of analytical information from detailed observations of soil maps at 1:50.000 scale.
- Definition of the classification system based on electric conductivity CE and Percentage of interchangeable sodium PSI, according with local experiences and crops. The values defined to class the degree of salinity and sodicity in the soils are:
  - For saline soils if: CE >4 dS/m, PSI <15%, and pH < 8.5.
  - For sodium affected soils if: CE <4 dS/m, PSI >15% and pH >8.5.
- The analysis was done for two soil layers: 0–50 cm and in 50–100 cm.
- Request for authorization access to the land owners.
- Preparation of photo mosaic: The map of the studies conducted between 1980 to 1994 were scanned and geo-referenced, then proceeded to scan the points with their chemical attributes (Ca, Mg, Na, K, EC, pH, OM, etc. and texture), these points are given coordinates (WGS84) and loaded into a GPS (Arcpad7.01) to arrive to the exact spot and do the monitoring, which consists of an auger to make sure is this at the same point as described textural, and color depths.
- Fieldwork – soil description: After confirming the point location, it starts the opening of a trial pit and a description of the profile as the field manual from the USDA (Field Book for Describing and Sampling Soils.)
- Collection of soil samples for each horizon and special tests for salinity.
- With the results of chemical analysis of monitoring, continues the soil taxonomic classification.
- Interpretation and analysis of laboratory results.
- A comparison with the results of the years 1980–1994 and the present (descriptive statistics) compared using F tests to see if there was a significant change or not.
- Using geographic information systems GIS, in this case the software ArcGIS 9.3 and the Analyst Geostatical module, soil salinity maps are obtained for each period. This allows analysis of the spatial and temporal variation trends for each of one of the characteristics.
- Obtaining of the saline and sodium affected areas, and its variation with the time.

- ➢ Reports and database.
- ➢ Extension practices recommendations.

Land Development Works

During the period of time 1970–1989, different land reclamation projects and dykes for flood protection were developed, mainly to protect the lowlands against the floods caused by the Cauca River and its tributaries. This was followed by the construction of internal drainage works and soil amelioration techniques, such as land levelling and deep ploughing.

Salts leaching

Salt-affected soils in the study area are characterized by difficulties of drainage. For the soils affected by salts, CE >2, salts leaching is enough, in this case an important amount of water is apply, also providing a good drainage system should be functioning. For most of the area the leaching treatment comes with the irrigation practices in the sugar cane crop fields. By the other hand, sodic soils, requires application of gypsum or other amendments, been a costly alternative and still presenting uncertainty.

EVOLUTION OF SALINITY IN THE STUDY AREA

The salinity studies results for the study region, during the period of observation, are summarized in Table 1; it shows the percentage of the lands affected by each degree of salts.

According to the evaluation of salinity for the period 1980–2009, there has been a significant reduction (about 38%) of low (CE<2dS/m) saline areas and also for slightly saline (2dS/m<CE<4dS/m) soils. Territories with higher degrees of salinity did not recover as well. On the other hand, the area of slightly sodic soils for the same region has increased by 21%. Figure 2 shows a comparison of soil pH variation at 0.5 m, for the Palmira sector during the period 1980–2009.

TABLE 1

Salt-affected land area at the Palmira sector 1980–2009 in percentage terms. (Based on Romero, 2010).

YEAR	NORMAL	SLIGHTLY SALT	SLIGHTLY SODIC	SALINE–SLIGHTLY SODIC	MODERATELY SALINE	STRONGLY SALINE	SODIC	SALINE –SODIC
1980	24.8	28.4	5.7	9.3	12.7	6.0	2.0	9.3
2009	38.2	9.1	26.7	12.4	2.6	3.1	1.5	6.4
TOTAL	13.4	-19.3	21.0	3.1	-12.4	-3.1	-0.5	-2.9

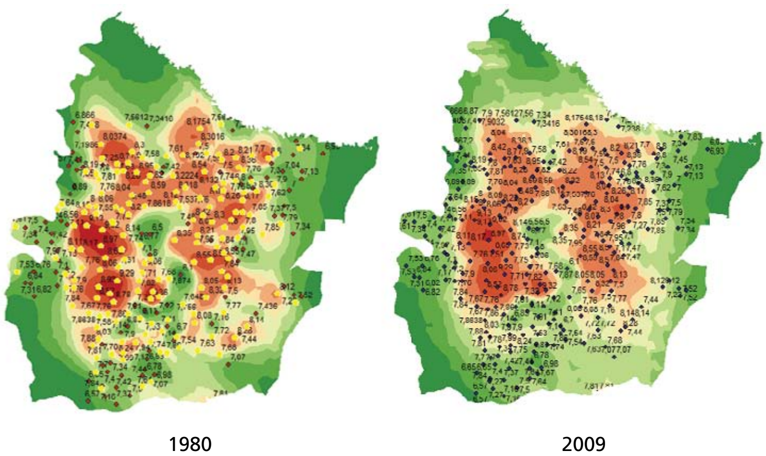

FIGURE 2

Soil pH variation at 0–0.5 m for Palmira sector, 1980–2009.

CLIMATE CHANGE AND SALINE SOILS AT THE CAUCA VALLEY

At first glance, the impact of the CV and climate change on water resources suggest the need to focus in an integrated assessment of climate impacts on soil resources, water and agriculture, because they are very vulnerable to climatic fluctuations. The agricultural sector consumes 70% more water in the world (compared with other sectors) in terms of volume (Ziad and Sireen, 2010). There is, therefore, a need to implement measures for adaptation to water shortages, increased demand for irrigation and land degradation (Carvajal, 2010).

The development of high salinity tolerant varieties could be an important goal to adapt to climate variability/climate change. It is necessary to implement good agricultural practices for the management of saline soils, through engineering and agronomy, to allow a sustainable use. Weather, poor drainage, use of water with high salt content and lack of good agricultural practices, among other important factors, are the main factors that cause severe soil salinization (Chandra *et al.*, 1997). Very dry periods decrease the dissolution and mobilization of salts to deeper profiles, with high evaporation, causing the water table rise, and that the concentrations of salts in solution precipitate in the soil horizons (Arias, 1991).

Some environmentally friendly practices such as monitoring soil characteristics, monitoring plots, cultivation techniques, soil preparation, to achieve uniformity of water on different horizons and to facilitate drainage. Evaporation reduction could be another aspect to working in, preventing capillary rise of salts, as well as deep ploughing encourage percolation and washing operations, the grading and systematization of the soil, prevents the accumulation of water and salts, the implementation of drainage systems, control of fertilization especially those with a high level of salts or frequent use (IPTRID, 2000). In the Cauca Valley region a common action after the harvest, is to apply the agriculture residues, this activity must to be evaluated and controlled, to prevent that the accumulation of salts in organic matter causes the inactivity of fertilizer, and if this does not take place at the right time, can exacerbate the salinity problems.

In the soil surface horizons, it could be useful to keep high moisture level, close to field capacity to maintain a low matrix potential and allow the removal of salts. Irrigation management is one of the main problems due to poor water quality and irrigation techniques used. In this aspect of the water management at the crops fields, there is necessary to improve the soil watering taking into account salts concentration and reaction.

Fertilization is an essential requirement, the successful implementation of the same, in terms of selection and location of manure. We must choose those that contain a lower level of salinity. The accumulation of salts in organic matter causes the inactivity of fertilizer, and if this does not take place at the right time, can exacerbate the salinity problems.

Other factors that should be taken into account in a globalized world, as the increase of energy demand, biofuel production that requires an important amount of environmental services for their row material production, sugar cane for the studied region (Carvajal, 2010; Rajagopal and Zilberman, 2007).

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Genesis of soils with petrocalcic horizons and alkaline soils in a volcanic landscape: Analysis of climate change scenarios on soil use

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ABSTRACT

Diverse types of soils are present in the volcanic watershed of Libres-Oriental, situated in the centre part of the Neo-volcanic Mexican Axe, providing different environmental services according to their properties that can be described, as a whole, under the concept of soil quality. The objective of this work is describing the major types of soils present in a part of the watershed where can be recognized the existing topographical relations that drives the salinization-alkalinization processes appearing in the bottom part of the watershed, discussing their quality in terms of environmental services and making an evaluation of the possible impact of climate change on soil use.

Keywords: salinization, alkalinization, soil use, climate change.

THE STUDY AREA

The area of interest is a part of the watershed of Libres-Oriental within the States of Puebla and Tlaxcala, Mexico. The whole watershed is inscribed into a rectangle defined by the coordinates 14Q 601684E, 209844N and 14Q 694093E, 2180057N, (UTM projection, Datum WGS84), having irregular shape and maximal elongation of 70 km (Reyes Cortés, 1979). Its area is 4 538 Km^2 and its perimeter 374 Km. The major part of the rocks are of volcanic origin, dominantly andesites, rhyolites, basalts and volcanic ashes of different ages and composition (basic and acidic), although some sedimentary rocks like limestes and sandstes are also present in small areas.

The climate of the area is tropical, with a dry season, rainfall concentrated in the summer months, total annual rainfall of 590 mm and average mean temperature of 14 ºC. Table 1 shows the precipitation and temperature by months as well as the number of days with precipitation.

The hydrological scheme (Figure 1) shows the watershed, delineating water courses and water bodies. As can be seen in the scheme, many watercourses disappear after a trajectory in surface, in the points signaled with a dot in the scheme. The final destination of the water volumes that they carry are the underlaying aquifers, some of those feeding laterally and by subsurface the lakes. The lakes also accumulate direct precipitations and runoff water.

Some important waterbodies, recorded at the Archivo Histórico del Agua (CONAGUA, 2008) are the Lake of Vicencio, lake of Santiago Ovando and lake of San Cristobal, all at the South-west of the watershed, lake of Totolcingo in the centre, and lake of El Salado at North-east. The Totolcingo and El Salado lakes are the most extensive waterbodies. Inside and around them are concentrated the problems of soil salinity and alkalinity.

TABLE 1
Climate information (World Meteorological Organization, 2008)

Month	Minimal temperature °C	Maximal temperature °C	Precipitation (mm)	Number of days with rain
Jan	4.6	23.0	9.4	1.2
Feb	5.9	23.8	7.5	1.7
Mar	8.1	25.9	11.5	2.4
Apr	10.2	27.1	23.4	5.8
May	11.7	27.9	87.9	13.1
Jun	12.4	26.4	197.0	17.6
Jul	11.4	25.3	164.7	16.9
Aug	11.4	25.2	155.7	17.4
Sep	11.3	24.8	192.1	17.7
Oct	9.6	24.6	73.9	9.2
Nov	7.3	24.4	12.3	2.4
Dec	5.3	23.5	4.6	1.3

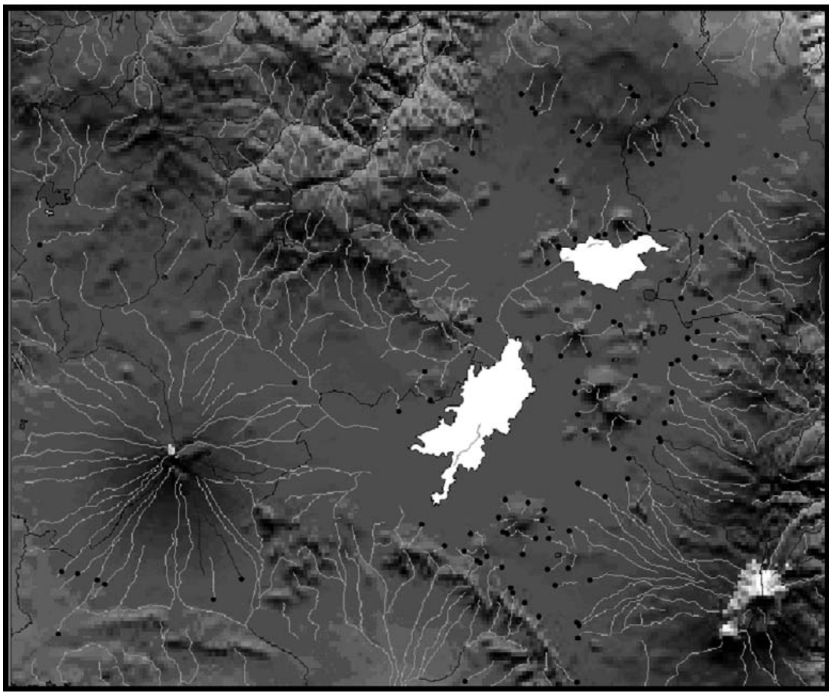

FIGURE 1
The hydrological scheme of the study area.

The natural vegetation has been removed, by forest exploitation and deforestation, in many parts of the watershed, fact that has altered the regulation of the water cycle in the area, with consequences of intense runoff after moderate to intense storms and with flooding as a consequence. Also soil erosion of the soils in the slopes has been exacerbated.

SOILS

Examining the physiographic of the basin, four zones can be delineated with different characteristics clearly associated to their topographical position, mainly related to the altitude (Arriola-Morales *et al.*, 2008):

- Elevations consisting of reliefs of volcanic rocks under weathering. Soils are shallow, with coarse texture and high slopes, not suitable for agriculture.
- Piedmont areas consisting of slope sediments and soils of early development from those sediments, with coarse texture and moderate slopes. Crops, mainly rainfall corn and sprinkler irrigated corn and alfalfa, are limited in yield by soil effective depth in some parts (hard pan occurrence).
- Shallow soils of clay-loam texture, low slopes, periodically flooded, saline, with pH around 10. Only natural specialised plants (halophytic grasses and cactacea) growth under those conditions. Those rangelands are used for livestock grazing.
- Peri-lacustrine saline-alkaline soils of the endorreic bottom area, seasonally flooded, of clayed texture. No vegetation present with exception of halophytes tolerant to alkalinity and to boron toxicity.

The predominant soil moisture regime is Ustic, although in the bottom part of the endorreic area, the soil moisture regime is aquic or peraquic.

A genetic relation can be observed between the soils of certain parts of the watershed. The weathering of the rocks in the upper parts releases Si^{4+}, Al^{3+}, Fe^{3+}, Ca^{2+}, Na^{+} and other ions from plagioclases and other primary minerals, that move downwards and that originate different bands of neoformed minerals, bands that can be conceptually linked in a transport reactive sequence along the slope.

A conceptual model of geochemical differentiation can be linked to the topographical relation between the soils with petrocalcic horizons formed along the slopes and the formation of alkaline soils in the bottom part of a volcanic watershed (Aloirra and Batlle, in press).

SOIL QUALITY AND SOIL USE

The soil quality and the services that each one offers considering the topography and soil type of watershed that appear as consequence of the mineral weathering of the primary rocks, the subsequent transport of solutes downwards and their precipitation as secondary minerals according their relative solubility. At watershed scale, each soil provides different environmental services as a function of properties.

In the two lower soil areas described, soil water infiltration is reduced at surface. The runoff water reaches the bottom of the watershed and feeds an extensive alkaline lake which, in turn, drains to the underlaying aquifer. Groundwater is pumped for sprinkler irrigation, and piezometric levels have been decreased during the past decades, reducing the extent of the lake.

Life is conditioned to the soil quality in many ways. Soils provide very valuable environmental services to the human communities in many aspects. These services can be linked to the capability to regulate the hydrologic cycle, the purification of infiltrated water, to the production of food, biomass and fibres, to the maintenance of biodiversity, to the control of the erosion, the sequestration of carbon, among others.

As noted by Arshad *et al.* (1992), there are not generally accepted criteria for assessing changes in soil quality. This is due fundamentally to that the soil quality is influenced by the interrelationships of multiple factors, which include features and soil properties, physical-biotic and Socio-economic factors. Moreover, these factors and their interrelationships vary or have different significance in each particular situation.

The services that provide the soil can be evaluated using a set of soil properties related to the expected soil behavior. For a soil capable of regulating the hydrological cycle, should have considerable thickness, infiltration rate, penetrability, equilibrated or coarse texture and free drainage as condition of the lower limit.

Aggregate stability, infiltration, penetrability and equilibrated texture are associated with erosion control as a soil environmental service. Soils that can support a greater biodiversity are associated with properties as high microbial activity, high content in organic matter, nitrogen and potassium; free of restrictive conditions developing toxicity. Capacity for food production can be evaluated in function of the soil lower boundary condition, electrical conductivity, thickness, texture, microbial activity, nitrate, organic carbon, potassium and boron. For evaluation of the carbon sequestration in soil as an environmental service the microbial activity, organic matter, bulk density and texture are preferred indicators.

SET OF KEY INDICATORS TO ASSESS A SERVICE

There are several services that can provide the soil, these are related to a set of properties, however, not all the properties have the same value and are unviable measure a large number of them. We have established a set of key indicators which have the greater representation to assess if land can provide these services or not.

A soil that regulate the hydrological cycle, we should evaluate its thickness, the infiltration rate, penetrability, texture and condition of the lower limit. While aggregate stability, infiltration, penetration and texture is associated with erosion control as a environmental service. Soils that can support a greater biodiversity are associated with properties as microbial activity, carbon, nitrogen, potassium and restrictive conditions of toxicity.

Food production can be evaluated if we measure the lower boundary condition, electrical conductivity, thickness, texture, microbial activity, nitrate, organic carbon, potassium and boron. Finally if is wish to offer carbon sequestration in soil as an environmental service we must consider the microbial activity, organic matter, bulk density and texture as key indicators. (Arriola-Morales, 2009).

The hydromorphic conditions are in the lower area of the basin, usually associated with the presence of alkaline soils, although in the south-west zone of Totolcingo Lake there is a large area of soil with a limiting factor, the presence of a shallow water table, non-saline and non-alkaline. These soils generally are devoted to pasture.

Soils with greater limitations to its use are undoubtedly the alkaline soils of the lowlands of the basin. His problems are the infiltration, drainage, toxicity of sodium, boron and other elements, heavy textures, problems of dispersion and stability of the structure, hydromorphic (but severe reduction rarely, as theory predicts) minimal biological activity and severely impaired laminar hydric erosion and wind erosion of surface in dry conditions. But it is a very restrictive specialised ecosystem that contributes to biodiversity by establishing specialised plants on them.

CLIMATE CHANGE SCENARIOS FOR THE AREA

To identify possible scenarios that occur as a result of climate change is necessary know the real situation of the unit of study, in this case the soils of the "Libres - Oriental" basin, identify their properties and assess their quality.

In studies of quality should be paid special attention to soil properties, no deduction for alleged quality auxiliary variables. Certainly not all soils have the same properties as they are based on intrinsic conditions varied and were formed under different factors. Therefore, we must initially identify the service to be evaluated and bases on this set of key indicators, identifying the limiting factors in each case (Arriola-Morales, 2009).

The scale of the cartographic current mapping does not permit adequate mapping of quality, because introduces inaccuracies related to the scale and soil types represented. The conclusions about the quality of the soils of a mapping unit based on the selection of one or more profiles - surveys, should be taken as guidance regarding assessments of their quality multicriteria.

IMPACT OF CLIMATE CHANGE ON SOIL USE

We show in this way that is necessary to know the assessment approach to establish clearly the purpose of assessing the quality of soil, as a function of that objective (Blum, 2000), shall specify the set of indicators required to measure; since interpretation of quality and recommendations of action will be formulated in such terms.

All the analysis of climate change scenarios point towards an increased aridity due to reduction of rainfall and more irregular distribution of precipitations relative to the actual pattern. Under a scenario of extreme drought, the basin in most of its length could not regulate the water cycle. Basin has incipient soil in maxim altitude zones, areas intermedium have a lower boundary condition in many soils having high infiltration or with limitations in the effective thickness, and the low areas do not have infiltration by problems of dispersal and hydromorphic.

Under those conditions it is expected that the geochemical processes will continue within the closed basin: the waters dilution will be lower and the solute concentrations will be higher than nowadays, increasing the salinity-alkalinity of low slope areas, the extension of the lake will be reduced to a minimum, the aquifers recharge will be reduced drastically reducing water availability for irrigation and human consumption, extended areas will be dried and alkaline clayed soils, formerly submerged, will appear as lands with very adverse properties for agriculture, favoring the formation of dust storms, coupled with a loss of control of soil erosion also in the rest of the soils in the basin by a low aggregate stability and surface runoff on slopes caused by a low infiltration. This has a significant impact in macro and microbial activity by reducing the amount of organic material associated with carbon sequestration in soil and biomass. Biodiversity, as a whole, will be reduced.

And under an uneven distribution of rainfall, the most soils in the basin would suffer a severe erosion by water because their infiltration is very slow and some soils that infiltrate better, have a constraint on the lower limit and lower effective thickness, this do not allows us to regulate the hydrological cycle.

The principal population activity in the basin is agriculture: corn, alfalfa and potato principally; some farmers pumped groundwater for sprinkler irrigation and the people said that the piezometric levels have been decreased during the past decades; whether the difficulty to infiltrate water into the aquifer, the decrease of precipitation and/or torrential rain all of them are considered as climate change scenaries. This kind of irrigated agriculture give them the opportunity to sell their products but the consequences are a hard layer in subsoil by the use of tractor and the salinity for groundwater irrigation that are precipitated in this layer.

On the other hand the people that cannot use this technology, practice seasonal agriculture for auto consumption on soils with one or more limited factors (e.g. lower effective thickness, salinity conditions, deep drainage impeded), this soils cannot offer this environmental service because they do not have the inherent properties (before cited) to support agriculture, the owners of this land are conscious of this situation but the economic pressure for food is major, there are a couple of industries where this persons could work. However I observed a marginal condition because they do not have any other option, considering natural resource, to obtain economical resources.

On the lake formed in the lower part of basin endorreic, the references CONAGUA (2008) indicate that the effective surface area was higher, which agrees with the comments of the people. They said that the lake acted as a buffer temperature and humidity, a resting place for migratory birds with the possibility of hunting for food and where salt is dissolved.

Whereas the level has declined in recent years and these environmental services are expiring, a climate change scenario at higher temperatures and lower rainfall the lake could disappear would be the consequences of not only the nullity of the above services but the provision of salts that are dispersed by wind to areas where there is currently no.

Near of Totolcingo Lake (peri-lacustrine saline-alkaline soils of the endorreic bottom area, seasonally flooded, of clayed texture) there is a small city where the population nowadays have health problem associated to breath system, the reason is that the level and surface of this lake is minor and extended areas stayed more time dried and alkaline clayed soils, formerly submerged, will appears as lands favoring the formation of storms clays, reducing the visibility, and the indirect consumption by humans. If this situation is know, the change climate will accent the scenario.

CONCLUSIONS

For the study area the possible environmental impacts derived from the expected scenarios of a changing climate, are related to the water scarcity, to increased soil salinity, to an increased rate of soil erosion and to the loosing of biodiversity, but will have social, health and economic effects as well. An integrated environmentally sound management considering soil quality conservation, soil productivity under sustainable practices, and water resources (both surface water and groundwater) becomes necessary to avoid the collapse of the whole system.

A social-scientific council should give advice to policy makers and decision takers on the guidelines for regulating the adequate use of basin resources, considering some zones as reserves, and planning land use according the land quality and the environmental services that provide.

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Emerging challenges of climate change on salt-induced land degradation and water quality deterioration in peri-urban areas

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The scarcity of fresh water has driven farmers in water scarce countries and regions to use alternative water supplies for irrigation. In peri-urban areas, urban wastewater is often used to irrigate a range of crops in support of urban markets as well as the livelihoods of farming communities. As in many developing countries wastewater treatment is insufficient and the water may contain different types and levels of undesirable constituents. Long-term irrigation with untreated, partly-treated, or diluted wastewater may pose potential health and environmental risks. Emerging events of climate change under such conditions are expected to trigger environmental degradation—extremely low rainfall providing insufficient water to leach salts and other constituents from wastewater-irrigated soils, while high-intensity showers leading to surface runoff and transport of salts and contaminants to nearby good soils irrigated with fresh water or rain-fed. The same applies to surface and groundwater quality.

Environmental impact assessment of peri-urban areas reveals build-up of undesirable constituents in wastewater-irrigated soils and groundwater as a result of changes in rainfall pattern. Salt, nitrate, metal, and metalloid concentrations were found in excess of the critical limits in certain areas as a result of rainfall distribution patterns stemming from climate change events. Therefore, monitoring of water and soil quality in wastewater irrigation schemes is important, particularly where groundwater is used for drinking purposes. In addition, there is a need to develop pertinent models that can predict changes in water and soil quality and to develop management strategies minimizing soil and water quality deterioration in peri-urban areas as a result of climate change.

Keywords: climate change, rainfall distribution, water quality deterioration, soil degradation, salt load, nitrates metals and metalloids, models, soil management.

Temporal changes in the micromorphology of reclaimed Solonetzes in the south-east of European Russia

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ABSTRACT

Modern trends of soil processes in reclaimed salic Solonetzes sampled with an interval of 20 years were estimated with the use of micromorphology. Salt pedofeatures and their microfabrics proved to be sensitive indicators of processes taking place at the interface between the soil matrix and pore space. In 20 years of reclamation of the Solonetzes, an increase in the degree of homogeneity of the plough horizon and its biogeneity, a decrease in the number and diversity of calcareous and gypsiferous pedofeatures, and a general intensification of ameliorative processes took place.

Keywords: soil evolution, sodic soil, salt-affected soils, rainfed agro-ecosystems, forest shelterbelts, micromorphological diagnostics.

INTRODUCTION

One of the challenges of modern soil science is to study the temporal dynamics of soils under the impact of various anthropogenic loads, including soil reclamation procedures. Such studies are often hampered by the lack of adequate data on the particular stages of the development of reclaimed soils. The Dzhanybek Research Station of the Institute of Forestry of the Russian Academy of Sciences is found in the northern part of the Caspian Lowland and represents a unique object, where comprehensive soil studies on the experimental plots have been conducted since the organization of this station in the 1950s.

The development of this semi-desert area with about 50% of salic Solonetzes in the soil cover began in the 1950s. The methods of agroforest reclamation of these soils were tested at the Dzhanybek Research Station (Biogeocenotic Bases, 1974). In essence, they consisted of the deep subsoiling to destroy the Solonetzic horizon and admix gypsum contained under this horizon into the newly formed plough layer. After this, tall grasses were sown to ensure the biological removal of salts, and then shelterbelts with elm (*Ulmus pumila* L.) were created. This led to the additional accumulation of snow and favored the further desalinization of the reclaimed soils. With time, these Solonetzes are transformed into agrozems (Sizemskaya, 1991).

Since the late 1950s, thorough studies of the water and salt regimes of the reclaimed Solonetzes have been performed (Maksimyuk, 1961; Bazykina, 1974; Sizemskaya, 1991). Macro-, meso- and submicromorphological descriptions of soluble salts, carbonates, and gypsum in these soils have been made (Sokolova *et al.*, 1985; Sizemskaya *et al.*, 1985; 1989). However, the micromorphological level of organization of the reclaimed Solonetzes remained poorly studied.

Our work was aimed at revealing changes in the microfabric of reclaimed Solonchackous Solonetzes sampled with an interval of 20 years and to characterize the modern trends of soil processes in them.

METHODS

The Gosfond agroforest plot (10 ha) was organized in 1959. It represents a 200 m wide field crossed by one-row shelterbelts spaced 40 m apart from one another and composed of elm trees. This field was used for growing cereal crops. In 1982 it was used for wheat. In the mid-1980s, perennial herbs were grown. In the 1990s, regular soil treatment and sowing was stopped. In 2002, the studied part of the field was used for wheat growing.

The reclaimed Solonetzes on this field were sampled in 1982 and 2002 in the pits spaced at about 5 m apart from one another. In 1982, two undisturbed samples containing different salt pedofeatures (calcareous nodules (white eyes) and gypsiferous cutans) were taken from the depth of 27–59 cm for their thorough micromorphological examination. In 2002, thin sections were prepared from undisturbed samples taken from the major genetic horizons. Thin sections were prepared in the Laboratory of Soil Mineralogy and Micromorphology of the Dokuchaev Soil Science Institute with the use of polysynthetic resins under conditions of vacuum impregnation, which made it possible to preserve salt pedofeatures without their destruction. The chemical analysis of the reclaimed Solonetzes and their virgin analogues were performed by routine methods.

RESULTS AND DISCUSSION

Morphology and major chemical properties of virgin and reclaimed Solonetzes

Virgin Solonetzes have the following profile: the uppermost slightly humified horizon (2% of humus) of the whitish gray color, with platy structure, and containing no soluble salts and carbonates is underlain at a depth of 3–7 cm by the 25 cm deep reddish brown Solonetzic horizon with columnar structure, 0.5–1.5% of humus, and 30–50% of adsorbed sodium. In its lower part, this horizon may contain small amounts of soluble salts, carbonates, and gypsum. The subSolonetzic horizon (30–50 cm) is pale brown and contains 2% of soluble salts, 3% of gypsum ($CaSO_4x2H_2O$) and 6% of carbonates ($CaCO_3$). The lowermost BC and C (from the depth of 140 cm) are saline, gypsiferous (2–6%), and calcareous (2–5%). Among soluble salts, sodium bicarbonates predominate in the Solonetzic horizon, and sodium sulfates predominate in the deeper horizons.

Reclaimed Solonetzes are characterized by profound transformation of their morphological, chemical, and physical properties. The plough layer (0–44 cm) can be subdivided into the well-mixed homogeneous upper part (0–27 cm) with grayish brown color and crumb structure and the poorly mixed (only once during the deep tillage) lower part of the reddish brown color and prismatic structure. The humus content in the upper part is 1.3–1.4%; carbonates are absent, and the exchangeable sodium percentage (ESP) is very small (1.3%). In the lower part, the humus content decrease to 0.5%; the alkalinity is increased (1meq HCO_3^-/100 g soil), the ESP is about 2%; carbonates and gypsum are absent. Under the plough layer, a nonsaline calcareous and gypsum-bearing horizon is found (44–89 cm). It is pale brown, with clearly seen concentrations of fine-crystalline gypsum and “farinaceous” carbonates. The layer from 89 to 185 cm is represented by the saline (0.8–1.0% of soluble salts), calcareous (3% $CaCO_3$) and gypsiferous (3% in the layer of 89–155 cm and 12% in the layer of 155–185 cm) horizons. Sodium sulfates predominate among soluble salts.

Thus, as a result of reclamation procedures applied to the Solonchackous Solonetzes, the downward migration of soluble salts (from 30 to 90 cm) and gypsum and calcium carbonates (from 30 to 44 cm) took place; the ESP content in the former Solonetzic horizon decreased from 30–50 to 1.3–2.0%, and the content of soluble salts in the layer of 30–160 cm decreased from 2 to 0.4%.

Micromorphology of reclaimed Solonetzes

The study of thin sections prepared from undisturbed soil samples in 1982 and in 2002 (i.e. 23 and 43 years after the beginning of reclamation) showed some common and specific features of the Solonetzes at different stages of their reclamation. In both cases, a good degree of soil aggregation in the upper 50 cm of the profile was observed.

In the Solonetz studied in 1982, rounded aggregates of 0.8–1.0 mm in size predominated, though in some loci, there were abundant smaller rounded aggregates of the presumably biogenic (0.2–0.4 mm) and coagulative (0.05 mm) geneses (Figure 1a). The contents of fine-dispersed carbonates in these aggregates were different. In the aggregates with the lowest content of micrite, the plasma had distinct optical orientation, which could be to the admixture of the material from the former Solonetzic horizon. The low content of such aggregates in the plough horizon allowed us to suppose that the initial Solonetz had a relatively thin Solonetzic horizon (so-called crusty Solonetz).

In the Solonetz studied in 2002, coarser (up to 1.8 mm) rounded aggregates of the grayish brown color predominated in the plot horizon; they consisted of clayey plasma (Figure 1b) with the high degree of optical orientation. Their abundance allowed us to suppose that the initial Solonetz in this place had a thicker Solonetzic horizon enriched in labile clay. In other words, the virgin Solonetzes within the reclaimed field differed in the thickness of their Solonetzic horizons and the presence of carbonates and illuvial clay in it.

The roundness of aggregates of any sizes from the plough horizon in 2002 was much higher than that in 1982, which could be due to a longer duration of soil cultivation. Many small aggregates in the pit studied in 2002 have clear features attesting to their origin from mesofauna excrements. In general, the good degree of aggregation of the soil material and the high macro- and microporosity of the plough layer of the reclaimed Solonetz in 2002 are indicative of the high hydraulic conductivity in this horizon and the absence of clear features of its degradation. Moreover, in 2002, the role of soil invertebrates in the biogenic structuring of the plough horizon increased significantly in comparison with 1982.

Some differences in the contents of carbonates in the studied plough horizon are probably related to the initial differences in their contents in the topmost (above-Solonetzic) horizons of the virgin Solonetzes, which was already noted during earlier studies (Yarilova, 1966).

Differences in the sizes and amounts of the humus-clayey illuviation cutans within the plough horizons also point to the initial differences in the microfabrics of the Solonetzic horizons. In the Solonetz studied in 1982, fine fragments of the former clayey cutans are found inside rounded aggregates, whereas in the Solonetz studied in 2002, coarse fragments of humus-silty-clayey cutans are present as separate aggregates comparable with purely clayey aggregates admixed from the Solonetzic horizon; their sizes are up to 0.8 mm. A higher content of labile clayey material in the plough horizon of the Solonetz studied in 2002 favors the development of the ploughpan. In the Solonetz studied in 1982, no features attesting to the soil compaction and the ploughpan development were observed.

A comparative analysis of the microforms of organic matter in the plough horizons of the Solonetzes studied in 1982 and 2002 indicates a higher diversity of the microforms of humus and plant detritus in the latter soil. Both dispersed and coagulated brown-colored microforms of humus are present in it, as well as plant residues at different stages of decomposition. In the Solonetz studied in 1982, dispersed microforms of brown humus predominated; there were also partly charred and ferruginous coarse plant residues.

The microfabrics of the deeply ploughed horizons (27–44 (59) cm) — the mixture of the former Solonetzic and saline subSolonetzic horizons are somewhat different. In the Solonetz studied in 2002, fragment of clayey cutans inherited from the Solonetzic horizon are smaller, and many of them are incorporated into the intraped mass. The clayey-calcareous material of the former subSolonetzic horizons with a pseudosandy structure becomes more compact, though its porosity is higher than that in the lower horizons. A tendency for some compaction of the subSolonetzic horizon during the same period has also been noted for the virgin Solonetzes (Lebedeva & Konyushkova, 2010), which may be related to some increase in precipitation and the rise in the groundwater level, i.e., to changes in the hydrological regime of the soils. As shown by Rode and Pol'skii (1961), the development of a specific pseudosandy subSolonetzic horizon in the virgin Solonchackous Solonetzes is only possible, if its water content is no less than the wilting point. With an increase in the degree of the soil moistening, which takes place upon the reclamation of the Solonetzes (owing to additional snow retention), the subSolonetzic horizon becomes more compact owing to the leaching of salts into the deeper horizons and shrinkage of the soil material (Pol'skii, 1958). In the durably reclaimed Solonetz (2002), the compaction of the clayey-calcareous material is accompanied by the development of biogenic porosity and microaggregation.

The microfabrics of gypsiferous and calcareous pedofeatures in the compared Solonetzes were also different. In 1982, gypsum concentrations were found in a layer of 27–59 cm; in 2002, their maximum was at a depth of more than 90 cm. Fine spindle-like gypsum crystals predominate and often fill the pores (gypsiferous infillings). Coarse gypsum crystals are present at the depth of 120–140 cm and are characterized by somewhat rounded faces. In the longest crystals (Figure 2a), wavelike faces can be seen.

Elongated gypsum crystals are oriented along macropores, which was also noted during the mesomorphological study (Sokolova *et al.*, 1985; Sizemskaya *et al.*, 1989). Such microforms of gypsum crystals are not typical of the virgin Solonetzes (Lebedeva & Konyushkova, 2010); it is probable that they appear under the impact of reclamation processes.

Specific microforms of salts and gypsum were identified in the studied Solonetzes. The Solonetz studied in 1982 contained coarse gypsum crystals in association with kiserite ($MgSO_4 \times H_2O$) of tablet shape. Modern methods of preparation of thin sections with impregnation under vacuum make it possible to preserve in the thin sections even unstable minerals, such as bassanite and kiserite.

Compact gypsum infillings in the pores of the Solonetz studied in 2002 (89–155 cm) consist of very small and irregular-shaped crystals (Figure 2b). Their appearance in the pores was referred to as thrombosis of the pores (Lim *et al.*, 1985.). These are recent gypsum pedofeatures that have appeared upon the leaching of gypsum from the upper horizons upon the reclamation of Solonetzes.

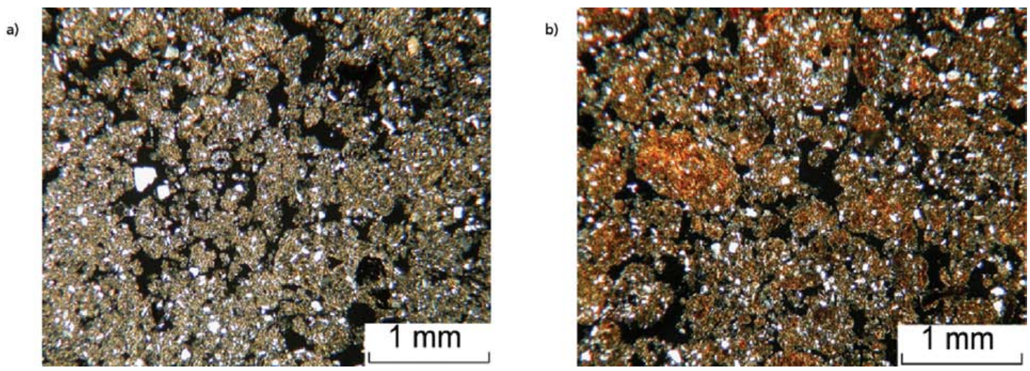

FIGURE 1
Microfabrics of plough horizons in the reclaimed Solonetzes (XN): (a) 1982, a loose and highly porous aggregated material with a clayey-carbonate plasma and single plant tissues; (b) 2002, a loose and highly porous aggregated material with a clayey-humus plasma, with rounded fragments from the former Solonetzic horizon, a great number of coprolites, and with fragments of clayey cutans.

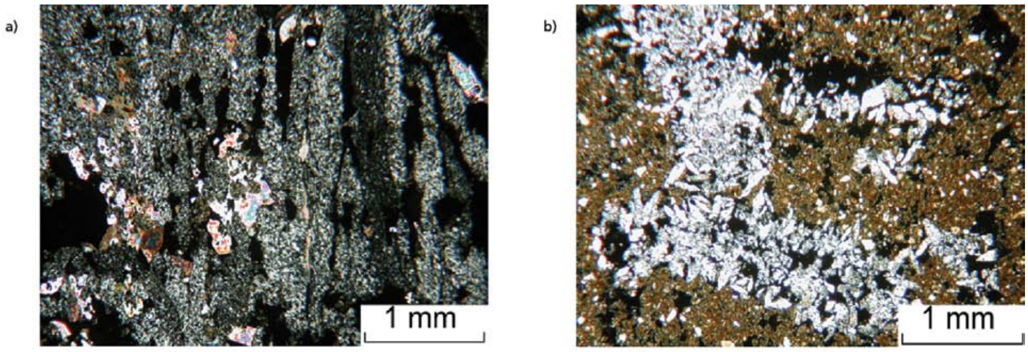

FIGURE 2
Microfabrics of salt-bearing horizons in the reclaimed Solonetzes (XN): (a) 1982, newly formed kieserite crystals of irregular shape between relic elongated gypsum crystals (120–140 cm); (b) 2002, compact pore infillings consisting of fine lenslike and irregular-shaped gypsum crystals (gypsiferous plug in the pore) (90–155 cm).

In the virgin Solonchackous Solonetzes, were observed calcareous nodules and dispersed carbonates in the lower part of the Solonetzic horizon and in the subSolonetzic horizon. In the Solonetz studied in 1982, only irregular distribution of micrite in the soil aggregates was noted. Thus, in about 20 years of reclamation, the leaching of carbonates from the plough horizons without their pronounced accumulation in the lower horizons took place. The mobility of carbonates was favored by the high CO_2 concentration related to root exudates and the activity of biogenic processes around biogenic pores. The walls of oval and rounded biogenic pores were often covered by micritic coatings.

CONCLUSIONS

A significant transformation of the conditions of soil formation in the reclaimed Solonetzes (the rise in the groundwater level, the ageing of elm trees, and additional snow retention) resulted in certain changes in the indices of the structural state, humus conditions, biogenic state, and salt pedofeatures. These changes point to transformation of the soil functioning. The possibility to study reclaimed Solonetzes from the same plot by the micromorphological method with a time interval of 20 years made it possible to assess the trends of pedogenic processes taking place in the reclaimed Solonchackous Solonetzes. The soil microfabric and, especially, the microfabric of salt pedofeatures proved to be sensitive indicators of the processes taking place in the soil matrix and pore space.

The profile of the reclaimed Solonetz studied in 1982 is characterized by the high quantity and great diversity of the microforms of different (carbonate, gypsum, and soluble salts) salt pedofeatures. The presence of newly formed manganese sulfates—kiserite—filling spaces between large gypsum crystals inherited from the previous hydromorphic stage of the soil development suggests that the crystals of kiserite were synthesized from the solutions leached off from the upper (reclaimed) part of the soil. At the same time, the presence of caverns on the surface of large gypsiferous spherolites points to their gradual destruction in the reclaimed Solonetz.

After 20 years (in 2002), the diversity and abundance of salt pedofeatures somewhat decreased. Though gypsum pedofeatures appeared at approximately the same depth as in 1982, their quantity was smaller; they were mainly represented by small irregular-shaped crystals filling the pores, which points to the dissolution and recrystallization of gypsum in the reclaimed Solonetz.

We also had a chance to compare our data with earlier data on the micromorphology of reclaimed Solonetzes (Pol'skii, 1958). In general, during more than four decades of their reclamation, the quality of generally improved significantly, which is seen from the rise in the content of mesofauna excrements, more pronounced biogenic processing of the soil mass, some increase in the amount of coagulated humus microforms, and inn the roundness of fragments of soil material admixed into the plough horizon from the former Solonetzic horizon. Thus, long-term reclamation of Solonchackous Solonetzes increases the thickness of the root zone and improves its water-physical properties owing to the leaching of toxic soluble salts, activation of soil mesofauna, and some lowering of the mobility of clayey-humus substances.

ACKNOWLEDGMENTS

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An ecological approach for proposing and describing a new type of soil salinization

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At present, soil science describes two major types of soil salinization: primary (native) and secondary (anthropic). While the first type is developed due to natural geological, hydrological and pedological processes, the second refers to human-caused factors, mainly as a consequence of improper irrigation management. But sometimes using an ecological-anatomical approach in understanding the interrelations at the level of rhizosphere could reveal new and interesting aspects. For instance, it may be possible that plants induce soil salinization due to a set of anatomical adaptations, allowing them to absorb, conduct and excrete saline solutions. *Tamarix ramosissima* shows the "ideal" example of a plant able to produce soil salinization. This is a halophyte species, being also a phreatophyte, meaning that he has specialised roots that can draw water from deep underground. In addition, the leaves of *Tamarix* posses specialised salt glands, which exude high amount of salts, raising the salt content of the soil, leading to loss of saline-intolerant native plants and pasture. It may be assumed that species with no deep root system, which are not exploiting the salt water table, are exposed to a salinity "provided" by secretory activity of *Tamarix* species. In this way, non-tolerant salt plants are eliminated by the incremental salinity in the rhizosphere. Since salinity occurred as a result of whole plant activity (*Tamarix*) and affecting other species with no salt-copying mechanisms, we suggest that this new type of salinization be called *phyto-salinization*. The place and the relevance of this new proposal in soil science would be specified by further considerations.

Keywords: salinity, halophytes, rhizosphere, salt glands.

Monitoring soil moisture and electrical conductivity (EC) with sensors

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Management of irrigation requires building a picture about how water, nutrients and salts move and accumulate in the soil. This understanding has to be integrated into a more complex farm management scheme, where strategic (slow processes, long term and watershed scale) and tactical (faster processes, short term and plot scale) decisions have to be assessed and made. In a global scenario of increasing food and fibre demands, with important soil degradation problems, and the scarcity of fresh water for irrigation, there is a need for on-farm practical tools for managing water, salt and nutrients in the root zone. Monitoring soil moisture and salts provides an important part of the picture. Relatively new sensors and techniques are available to monitor such variables, such as combined FDR and EC probes and a wetting front detector (WFD). This work shows some basic laboratory exercises done with two commercial products, the 5TE capacitance probe from Decagon devices (Pullman, WA, USA) and the Fullstop® WFD (CSIRO, Australia). These practicum examples may help understanding how these types of instruments work and how to act on the information they provide.

Soil salinity mapping using electromagnetic induction and geostatistics: Case study of Tadla plain, Morocco

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ABSTRACT

The effective control of soil salinity requires the knowledge of its magnitude and its spatial and temporal variability. Soil salinity is determined by measuring electrical conductivity of a saturated paste extract (ECe). Since it is variable, numerous samples are necessary, which makes the conventional procedure laborious and expensive. Alternatively, soil apparent electrical conductivity (ECa) can be measured in field using electromagnetic induction (EMI). The study area covers 2 060 ha in the irrigation district of Tadla, central Morocco. Twelve samples were taken for determination of ECe while 112 ECa measurements were done using the EM38 instrument (Geonics). The calibration equation ECa-ECe was used to convert ECa into ECe. Geostatistics was used for modelling its spatial variability using the variogram and by interpolating to non-sampled locations by kriging. The results showed that the study area presents various degrees of salinity. In conclusion, combined use of ECe, EMI and geostatistics allowed establishing a reliable soil salinity map. This could serve as a basis for any rehabilitation effort of salt-affected soils according to their actual degree of salinity.

Keywords: electrical conductivity, geostatistics, mapping, soil salinity.

INTRODUCTION

Extensive agricultural development under irrigation in the arid zones has allowed improvement of agricultural production. However, this intensification led to degradation of the quality of soils and waters, constituting serious danger for the sustainability of land operating system (Badraoui and Merzouk, 1994; Badraoui *et al.*, 2000; Soudi, 2006).

In the Béni Amir, an irrigated sub-perimeter of Tadla, in Central Morocco, where our study area lies, lands irrigated with salt waters of the Oum Er Rbia River are touched by the salinization of lands and waters. The global soil salinity varies between 0.35 and 13 dS/m (Berrkia, 2003).

It is important to make a characterization of the salt state of lands and waters before exploitation as well as a regular control of their evolution, to end in strategies of their use for a long-lasting agricultural development. Studies carried out in Tadla showed a spatiotemporal variability of soil salinity accelerated under irrigation because of strong mobility of salts; it is mainly localized at the level of the zone of Béni Amir. The conventional methods of laboratory on small samples can hardly report such a phenomenon (Boivin *et al.*, 1988). Methodologies developed in situ are the most adapted, in particular the electromagnetic conductivity assesses in a significant way the salinity on a large volume of soil. It allows an easy, fast temporal follow-up and to collect large number of data for an extrapolation of the global soil salinity.

The data obtained by means of the electromagnetic conductivimeter EM38 (Geonics) and analysis of soil samples for their electrical conductivity from a saturated paste extract (ECe) were analysed by geostatistical methods to map salty zones and to identify spatiotemporal variations of salts. The calibration equation ECe - ECa was established by a simple linear regression. Then, spatial variability was modelled using the variogram. Finally, soil salinity was predicted using kriging.

MATERIAL AND METHODS

The study site is a hydrological irrigated unit of 2060 Ha, a part of Béni Amir, right bank of the irrigated perimeter of Tadla (Figure 1). The topography is generally regular with a height of 400 m.

The climate is arid Mediterranean type with a continental character marked by a cold and wet winter and a warm and dry summer. The dominant soil types are isohumic soils characterized by their well-balanced texture and fersialitic soils averagely deep and rocky in surface resting on red clays.

The electromagnetic induction probe EM38RT (Geonics) is largely used and was validated in many studies (McNeil, 1986). It contains two coils of induction separated by one metre. The transmitter coil sends a magnetic field of low frequency in the soil. The receiving coil gets a secondary field which is as important as the soil is a conductor. We obtain, then, a global apparent electrical conductivity of the soil surface (~ 1 m in the horizontal position and ~ 2 m of depth in the vertical position). However, the ECa also depends on other soil properties other than salinity (temperature, humidity, texture, etc.). For that reason, the probe should be calibrated for every type of soil by soil sampling and measuring salinity in the laboratory (generally ECe).

Two data sets were collected (Figure 2). The first one, called 'data set to be calibrated', contains the field measure of the soil ECa at 112 locations in a pseudo-regular grid of 500 m x 500 m using the EM38RT electromagnetic probe (Geonics). The second, 'calibrating data set', corresponds to 12 soil samples chosen among 112 locations for which ECa was measured. These samples wee taken to a depth of 90 cm with an increment of 30 cm to determine ECe from an extract of saturated paste in the laboratory. The average electrical conductivity on the three depths will be used in this study.

ECe and ECa were analysed using gostatistical methods; in particular variogram supplies information about the spatial variability of soil salinity while maps are drawn from an interpolation by kriging.

The geostatistical procedure of kriging (Webster and Oliver, 2001) allows the spatial interpolation between the sampled locations. It is preferred to other methods of spatial interpolation because it allows exploiting the spatial correlation between nearby observations in the space to predict at the non-sampled locations.

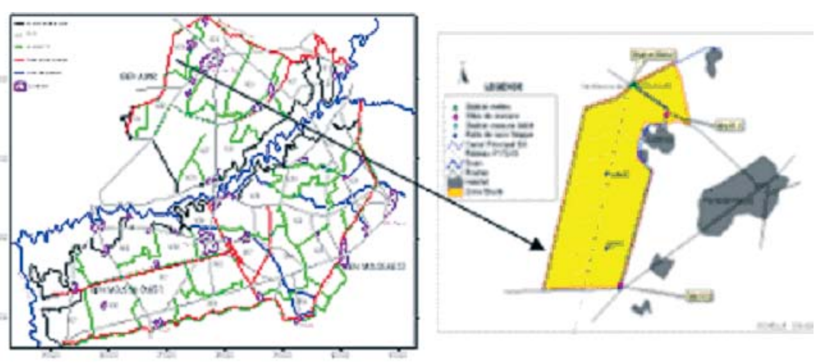

FIGURE 1
Irrigated sub-perimeter of Béni Amir (left) and the study area (right).

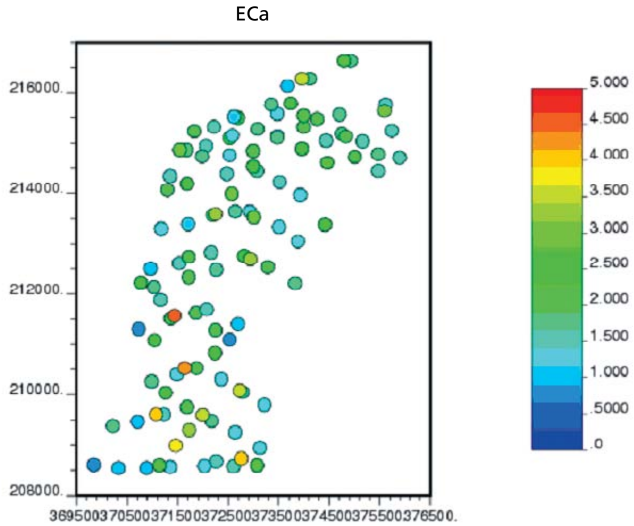

FIGURE 2
Locations of samples were ECa was measured using the EM38RT probe.

This methodology of the use of the electromagnetic conductivity coupled with geostatistics of soil properties allowed to draw reliable maps for diverse soil types (Boivin *et al.*, 1988; Douaik, 2005).

Let ***z(u)*** be the value of the electrical conductivity (ECe or ECa) of soil observed at the non-sampled location ***u*** defined by the x-y coordinates in a two-dimension space. The variogram measures the average dissimilarity between two locations (***u*** and ***u*** + ***h***) separated by a vector ***h*** (direction and distance).

The experimental variogram is calculated, based on the data of the sample, as follows:

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{\alpha=1}^{N(\mathbf{h})} \left[z(\mathbf{u}_\alpha) - z(\mathbf{u}_\alpha + \mathbf{h}) \right]^2 \quad (1)$$

where $N(\mathbf{h})$ represents the number of data pairs separated by the vector **h** and $z(\mathbf{u}_\alpha)$ and $z(\mathbf{u}_\alpha + \mathbf{h})$ are the values of the electrical conductivity observed at the locations $\mathbf{u}_\alpha$ and $\mathbf{u}_\alpha + \mathbf{h}$, respectively, and separated by the vector **h**.

Modelling of variogram is necessary because it allows determining the values of the variogram for any possible value of the vector of separation h. The permissible models, called authorized models, most frequently used are the exponential, the Gaussian and the spherical. To these last ones, the pure nugget effect model may be added.

The prediction by kriging, at a non-sampled location, is made possible thanks to the existence of the spatial dependence between observations resulting from various places and represented by the variogram. The problem consists in predicting the value $z(\mathbf{u}_0)$ for a non-sampled location $\mathbf{u}_0$ based on the observed sample data $\{z(\mathbf{u}_\alpha), \alpha=1, \ldots, n\}$. The most used algorithm is ordinary kriging where the mean trend $m(\mathbf{u}_\alpha)$ is considered to be constant for a local neighbourhood. The ordinary kriging system, which should be solved for the weights $\lambda_\alpha(\mathbf{u})$, is:

$$Z^*_{OK}(u_0) = \sum_{\alpha=1}^{n(u_0)} \lambda_\alpha Z(u_\alpha) \quad (2)$$

where $\lambda_\alpha(\mathbf{u})$ represents the weight assigned to the datum $z(\mathbf{u}_\alpha)$ observed at the location $\mathbf{u}_\alpha$ and interpreted as a random variable $Z(\mathbf{u}_\alpha)$.

or, equivalently:

$$\sum_{\alpha,\beta=1}^{n(u_0)} \lambda_\beta \gamma(u_\alpha, u_\beta) + \psi = \gamma(u_\alpha, u_0) \quad (3)$$

where ψ is a Lagrange multiplier, $\gamma(\boldsymbol{u}_\alpha, \boldsymbol{u}_\beta)$ is the value of the variogram for the separation distance between the two locations $\mathbf{u}_\alpha$ and $\mathbf{u}_\beta$ and $\gamma(\boldsymbol{u}_\alpha, \boldsymbol{u}_0)$ is the value of the variogram at separation distance between a given location $\mathbf{u}_\alpha$ and the location to be predicted $\mathbf{u}_0$.

The corresponding variance of prediction is given by:

$$\sigma^2_{OK}(u_0) = \sum_{\alpha=1}^{n(u_0)} \{\lambda_\alpha \gamma(u_\alpha, u_0)\} + \psi \quad (4)$$

Results

ECe and ECa are strongly correlated, confirmed by the Pearson coefficient of correlation which is 0.88 with the equation of calibration:

ECe=0,5848 + 4,2221 ECa

The histogram and some statistics about ECe are given in Figure 3. It is distributed likely following a normal distribution with some few large values. The average value is 1.92 dS/m and values are ranging between 0.8 and 4.4 dS/m with a coefficient of variation of 39%.

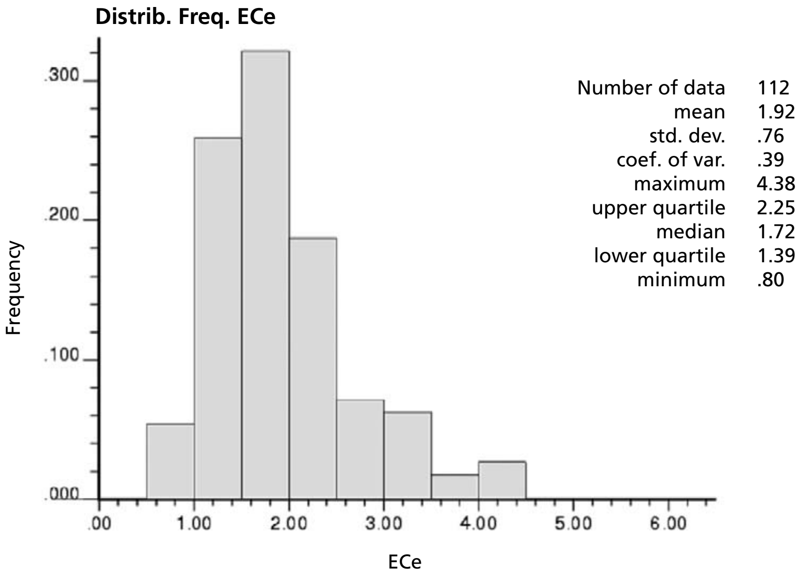

FIGURE 3
Histogram and some descriptive statistics for ECe.

The variogram of ECe is given in Figure 4 and its corresonding parameters are reported in Table 1. A spherical model was fitted to the experimental variogram with the following equation:

$$\gamma(\mathbf{h}) = \mathrm{Sph}(\mathbf{h}/a) = c_0 + c_1[(3/2)(\mathbf{h}/a) - (1/2)(\mathbf{h}/a)^3]$$

if $\mathbf{h} \leq a$

$$c_0 + c_1$$

otherwise, with c_0: variance of the nugget effect; c_1: partial sill variance and a: the range.

TABLE 1
Parameters of the fitted model to the experimental variogram of ECe.

Nugget Effect (dS/m) ²	Range (m)	Partial sill (dS/m) ²	Relative nugget effect (%)
0.312	1 030	0.264	54

The range of the spatial dependance of ECe is 1 030 m with a relative nugget effect (variance of nugget effect/sill variance of 54%, meaning that more than half of the variation in ECe is not spatially structured, i.e. random.

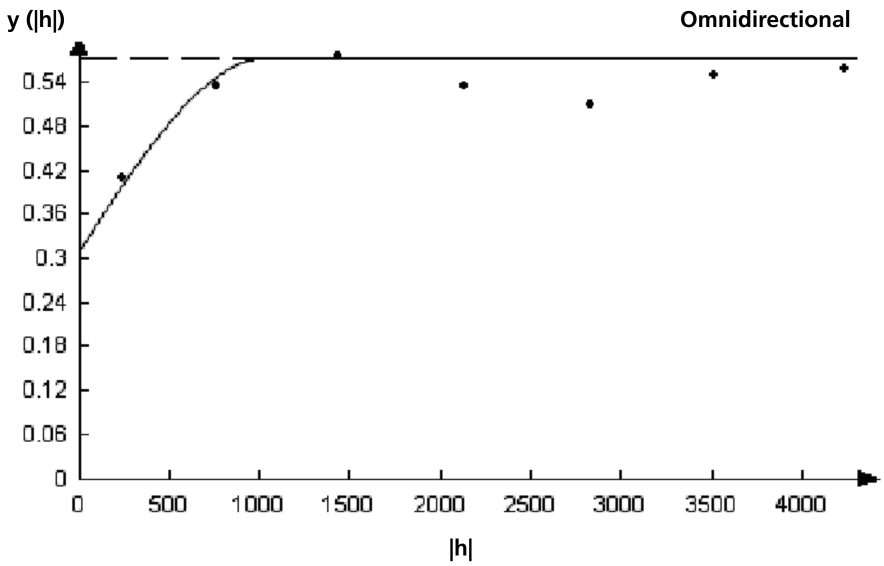

FIGURE 4
Experimental (dots) and fitted (curve) variograms for ECe.

Soil salinity (ECe) was predicted by kriging (Figure 5) using a 30 m x 30 m regular grid. The predicted values are ranging between 0.9 and 3.2 dS/m. Compared to the observed values, the minimal predicted is higher (0.8 dS/m) and the maximal predicted is lower (4.3 dS/m); this proprety is known as the smoothing effect of kriging. The map reflects the spatial distribution of ECe similarly as was noted with the observed values (Figure 4) with, however, a full spatial covering instead of only 112 values.

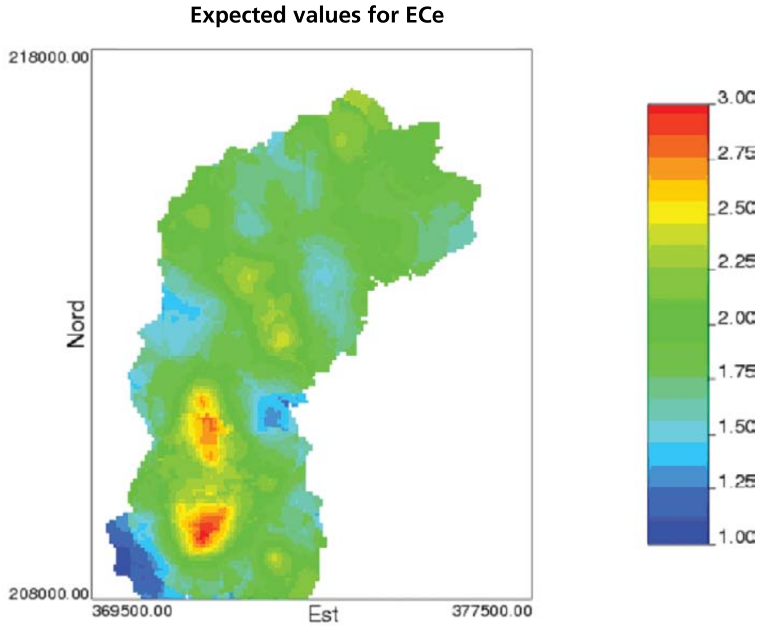

FIGURE 5
Spatial interpolation of soil salinity (ECe).

The prediction errors from ordinary kriging for soil salinity (ECe) are given in Figure 6. This map has a pattern which is function of the sampling intensity: normally, at the observed locations, these errors should be nil and will grow as we move further from these observed locations. In this map, the errors are ranging between 0.6 and 0.8 dS/m meaning that, based on the choice of the interpolation grid, none of the predicted locations coincided with the observed ones.

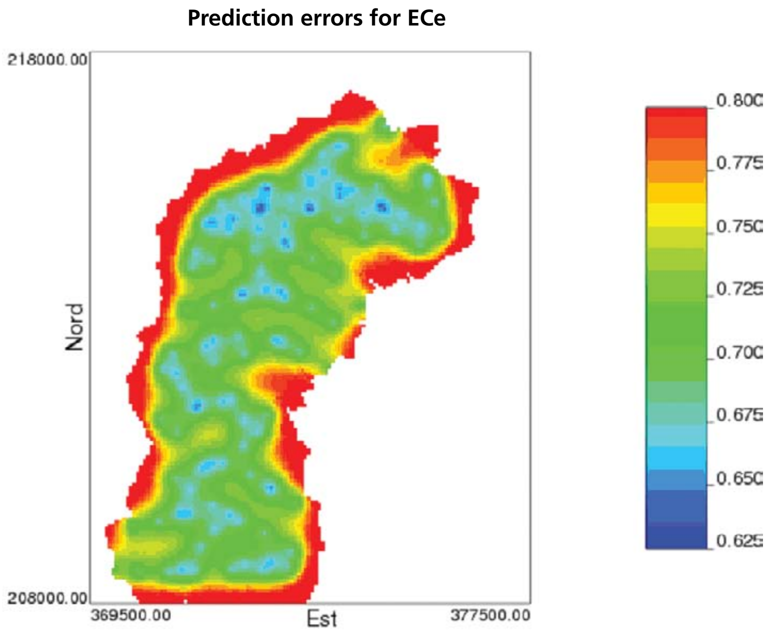

FIGURE 6
Kriging prediction errors for soil salinity (ECe).

CONCLUSIONS

The apparent electrical conductivity (ECa) measured in the field using the electromagnetic induction seems to be a quick and reliable method for assessing soil salinity. Indeed, it allows also monitoring soil salinity effeciently and cost effectively resulting in its widespread use for soil salinity studies. However, since ECa depends on many other factors other than soil salinity, it should always be calibrated with a reduced sample size for determination of the electrical conductivity from a saturated paste extract. Additionnally, geostatistics contributes to the description and modelling of soil salinity in order to integrate this in the spatial prediction at the non-sampled locations allowing mapping the whole study area.

This research work showed the usefulness of using indirect but cheap measures of soil salinity (ECa or possibly salinity indices derived from remote sensing images) for a more reliable mapping of a laborious and expensive soil property (ECe).

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Monitoring temporal stability and/or change of spatial patterns of soil salinity in the context of a changing climate

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Soil salinization is accentuated by climate change, mainly due to spatial and temporal changes in temperature and precipitation. Soil electrical conductivity, obtained from a 1:2.5 soil/water extract ($EC_{2.5}$), was analysed to check temporal stability/change of spatial salinity patterns using Spearman rank correlation and relative differences. Sampling of 20 locations (25 ha) was repeated 19 times (1994–2001). Soil salinity showed strong temporal stability. Rank correlation confirmed persistence of ranking of locations. Using relative differences, three classes of soil salinity were identified: low saline locations which were the most time stable and are associated with waterlogging and/or salt leaching zones; high saline locations which were the least time stable and located exclusively in salt accumulation zone; and locations representative of average field soil salinity which had temporal stability similar to low saline locations and were found in all three zones. Using only two locations, average soil salinity was adequately estimated. The methodology can easily be applied to longer time period and at larger spatial scale for different ecosystems to identify the impact of climate change on soil salinization and select specific locations for monitoring soil salinity with time.

Keywords: Electrical conductivity, rank correlation, relative differences, salt accumulation and leaching, waterlogging.

INTRODUCTION

Soil salinity can be assessed in laboratory by measuring the electrical conductivity of a water-saturated soil paste extract (ECe) or it can be measured in the field using, for example, electrode probes (apparent electrical conductivity, ECa). The latter is easier, less time consuming and cheaper than the former.

Soil salinity is spatially variable and temporally dynamic. This variability is caused by water table depth, topography, parent material, human activities, etc. Thus, measurements from numerous samples from different locations and during different time instants are required. However, if soil salinity does not change noticeably over short time periods in natural conditions, the observed spatial pattern could be time stable and can persist from one instant to another. In this case, sampling could be reduced to a limited number of locations representative of low, average, and high saline conditions.

Vachaud *et al.* (1985) were the first to introduce the concept of temporal stability or persistence. Several other researchers used this concept; among them Comegna and Basile (1994), Castrignanò *et al.* (1994), Gómez-Plaza *et al.* (2000) and Martínez-Fernández and Ceballos (2003). All of these works applied the concept to soil water except Castrignanò *et al.* (1994) who applied it to soil salinity using 28 samples from a small field (2.8 ha) during 8 time instants encompassing two years.

This research work had a first objective of applying the concepts of temporal stability to soil salinity determined by measuring electrical conductivity from a 1:2.5 soil/water extract ($EC_{2.5}$), sampled from a large field (25 ha) and repeated over a long temporal domain (8 years). The second objective was to study the relationship between the salt accumulation processes and their temporal stability.

DATA DESCRIPTION

The study area (Figure 1) covers about 25 ha in the Hortobagy National Park; in the east of Hungary with the central coordinates 47° 30' N and 21° 30' E. Bulk soil or apparent electrical conductivity (ECa in dS/m) was measured in the field, at 20 locations, using a four electrode probe (Rhoades and Miyamoto, 1990) corresponding to the 0–40 cm soil depth. Soil samples from the 20 locations have been collected down to 40 cm, by 10 cm increments. The 1:2.5 soil:water suspensions were prepared in laboratory and electrical conductivity ($EC_{2.5}$ in dS/m) was measured. The latter is a simple proxy of the water-saturated soil-paste extract (ECe), which is the conventional measure of soil salinity (Soil and Plant Analysis Council, 1992). The mean $EC_{2.5}$ calculated over the four depths was considered in this work. The sampling has been repeated 19 times (November 1994–June 2001) with an average temporal lag of 3 months but ranging from 2 to 9 months.

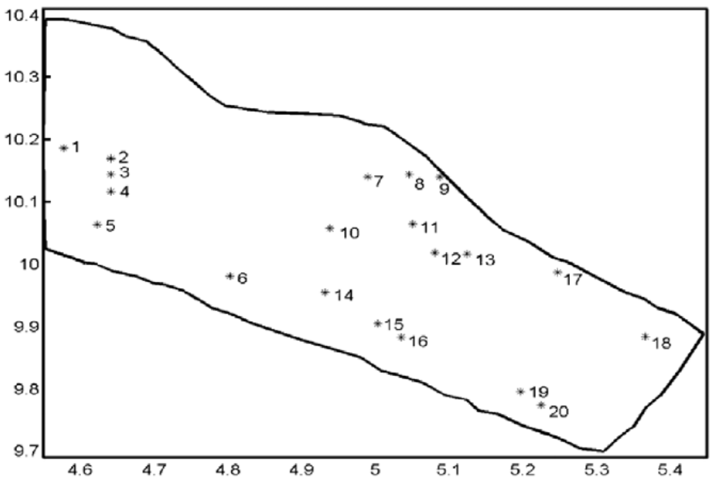

FIGURE 1
Spatial locations where ECa and EC2.5 were measured.

METHODS

The Spearman rank correlation refers to the tendency of $EC_{2.5}$ values, measured at different locations in space, to maintain their relative ranking over time. It is defined as:

$$r_s = 1 - \frac{6\sum_{i=1}^{n}(R_{ij} - R_{ik})^2}{n(n^2-1)}$$

with R_{ij} and R_{ik} the ranks of x_{ij} observed at location i on time instants j and k, respectively. A value of this coefficient equal one indicates a perfect temporal stability between time instants j and k, and thus identity of ranks for any location whereas a lack of temporal stability implies that r_s=0.

Let x_{ij} be the observed value of $EC_{2.5}$ at location i (i=1, …, n) and time j (j=1, …, m). The relative differences δ_{ij} are defined as:

$$\delta_{ij} = \frac{x_{ij} - \overline{x}_j}{\overline{x}_j}$$

with $\overline{x}_j$ being the spatial average for the time instant j.

Using δ_{ij} we can estimate, for each location i, the temporal average:

$$\overline{\delta}_i = \frac{1}{m}\sum_{j=1}^{m}\delta_{ij}$$

and its corresponding temporal standard deviation is defined as:

$$\sigma(\overline{\delta}_i) = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}(\delta_{ij} - \overline{\delta}_i)^2}$$

A zero value for $\overline{\delta}_i$ indicates that the temporal average $\overline{x}_j$ represents the average value over the whole study area at any time. The field average value is overestimated if $\overline{\delta}_i > 0$ while it is underestimated when $\overline{\delta}_i < 0$. A more time stable location will be indicated by a small value of $\sigma(\overline{\delta}_i)$ whereas a high value of the latter is an indication of a less time stable location. The $\overline{\delta}_i$ values can be plotted against their rank with the corresponding temporal standard deviations.

RESULTS

Table 1 gives the rank correlation coefficients for $EC_{2.5}$. These coefficients ranged between 0.46 and 0.96 and were generally greater than 0.85. The table shows that $EC_{2.5}$

TABLE 1
Spearman rank order correlation coefficients for $EC_{2.5}$ at the 19 time intervals

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.65																	
3	0.77	0.72																
4	0.89	0.71	0.94															
5	0.87	0.72	0.96	0.96														
6	0.69	0.66	0.94	0.92	0.94													
7	0.87	0.73	0.92	0.96	0.94	0.88												
8	0.59	0.71	0.85	0.88	0.85	0.89	0.83											
9	0.82	0.79	0.94	0.96	0.95	0.92	0.92	0.94										
10	0.79	0.71	0.89	0.94	0.92	0.91	0.92	0.89	0.95									
11	0.69	0.72	0.95	0.93	0.94	0.96	0.91	0.93	0.95	0.93								
12	0.76	0.67	0.86	0.84	0.87	0.85	0.80	0.85	0.88	0.89	0.88							
13	0.70	0.54	0.85	0.90	0.87	0.90	0.84	0.86	0.90	0.84	0.86	0.80						
14	0.46	0.74	0.88	0.86	0.85	0.78	0.87	0.86	0.93	0.84	0.84	0.71	0.85					
15	0.85	0.74	0.95	0.94	0.94	0.93	0.92	0.87	0.95	0.95	0.95	0.90	0.87	0.85				
16	0.77	0.73	0.92	0.93	0.93	0.91	0.91	0.89	0.96	0.95	0.94	0.90	0.90	0.89	0.95			
17	0.70	0.78	0.89	0.85	0.88	0.84	0.87	0.86	0.95	0.92	0.90	0.86	0.76	0.88	0.94	0.93		
18	0.91	0.64	0.90	0.94	0.95	0.89	0.92	0.80	0.90	0.90	0.89	0.85	0.86	0.82	0.91	0.91	0.79	
19	0.76	0.66	0.82	0.90	0.88	0.90	0.88	0.84	0.95	0.96	0.85	0.87	0.81	0.83	0.90	0.94	0.88	0.87

1 to 19 refer to: Nov 1994, March, June, Sept, and Dec 1995, March and June 1996, March, June, Sept, and Dec 1997, Sept 1998, Apr, Jul and Sept 1999, Apr and Dec 2000, March and June 2001 respectively.

presented time stable spatial patterns across the whole study period. This is indicated by the values of order correlation which were highly to very highly significant in most of the cases. For example, only one of the 171 coefficients was not significant at 5% while 153 coefficients were significant at the 0.1%. Also, the loss of information between two measurement times was small.

The mean relative differences ranked in ascending order are ploted in Figure 2. The corresponding temporal standard deviations (vertical bars represent +/- one standard deviation) were also drawn to indicate the dispersion around the mean relative differences.

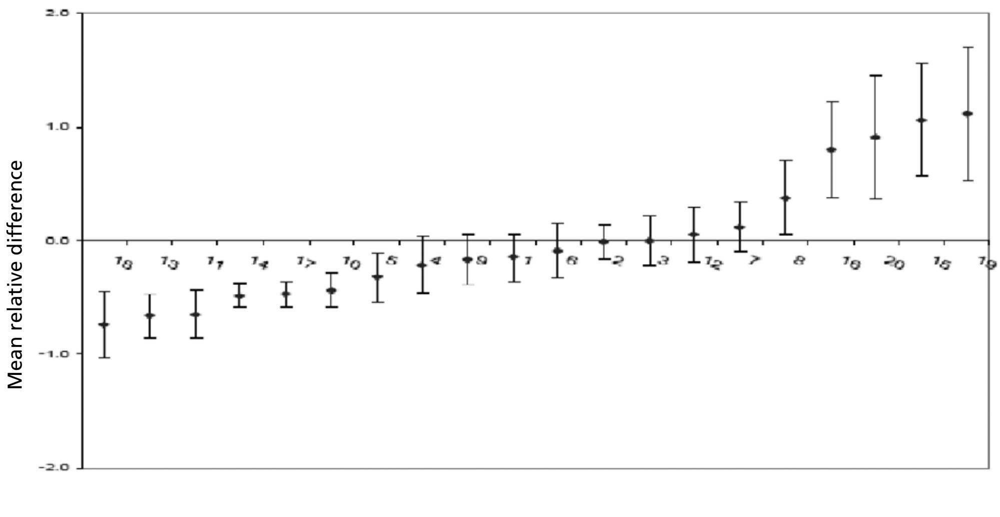

FIGURE 2
Mean relative differences. Vertical bars represent +/- one standard deviation.

The locations representative of the least saline conditions are 11, 13, and 18. They have a moderate temporal stability since their temporal standard deviations ranged between 0.19 and 0.30 dS/m. Locations 15, 16, 19, and 20 are representative of the most saline conditions. They displayed a weak temporal stability; for example, the temporal standard deviation for location 16 is 0.42 dS/m and that for location 19 is 0.59 dS/m. The locations most representative of the average field salinity were 2, 3, 6, and 12. Their temporal stability is similar that for low saline locations and a little bit stronger; for example temporal standard deviation for location 2 is 0.15 dS/m and that for location 6 is 0.24 dS/m.

Taylor *et al.* (2000) considered locations with a temporal standard deviation smaller than the mean relative difference to be consistently different from the mean. They further subdivided this group by separating locations for which the mean relative difference is negative from those for which this mean is positive. Also, they distinguished a third group, locations similar to the mean for which the temporal standard deviation is larger than the mean relative difference and overlapped with the mean value (this is illustrated in Figure 2 by the x axis intersecting with the vertical bars). Based on these definitions, locations were classified as low, average or highly saline (Table 2).

TABLE 2
Classification of locations as low, averagely, or highly saline

Salinity level	Low	Average	High
Location	5, 10, 11, 13, 14, 17, 18	1, 2, 3, 4, 6, 7, 9, 12	8, 15, 16, 19, 20
Proportion from the total	35%	40%	25%

In the study area, elevation is a major factor in the soil salinization. The other factors are the groundwater depth and its chemical composition, which are related to the elevation. All these three factors contribute to the mosaic distribution of the natural vegetation. Based on a *k*-means clustering procedure (Burrough, 1989), the 20 locations were classified into three strata: waterlogging, salt accumulation, and salt leaching (Toth *et al.*, 2001). The waterlogging zone corresponds to the wet area with the lowest elevation and the natural vegetation is a meadow. The zone of salt accumulation is intermediate in elevation, is the most sodic and saline and is covered with short grass. The salt leaching zone has the highest elevation, is the least sodic and the natural vegetation is a tall grass. The three clusters and their locations are given in Table 3.

TABLE 3
Membership of locations to the three salinity strata

Salinity stratum	Waterlogging	Salt accumulation	Salt leaching
Location	2, 10, 14, 17	1, 3, 7, 8, 12, 15, 16, 19, 20	4, 5, 6, 9, 11, 13, 18
Proportion from the total	20%	45%	35%

Based on results from Tables 2 and 3, locations classified as low saline belong to the zones of waterlogging or leaching, the latter being more frequent than the former. Locations classified as highly saline originate exclusively from the accumulation zone while locations representative of the average field salinity encompass the three possible strata with the predominance of the accumulation zone; leaching and waterlogging zones are equally represented but less than the accumulation zone.

The large temporal deviations (less time stable) for locations in the accumulation zone are related to the cracking and the subsequent leaching processes whereas waterlogging and leaching zones showed soil patterns which are strongly time stable.

Based on the description above, it is possible to optimize the selection of locations used to monitor salinity in the future. The selection of the locations should consider the three salinity strata, which can be identified considering the elevation and the vegetation pattern. The characterization of low saline areas will be based on samples taken from the lowest locations covered with meadow (waterlogging zone) or from the highest zones covered with tall grass (leaching zone) while the investigation of highly saline areas considers the locations with intermediate elevations and covered with short grass (accumulation zone). However, if we are interested in characterizing the average field salinity, we will need to obtain samples from the three strata.

Locations 2 and 3 had a mean relative difference approaching zero and the smallest temporal standard deviation. The mean relative difference and its corresponding standard deviation were -0.01 dS/m and 0.15 dS/m for location 2, and 0 dS/m and 0.22 dS/m for location 3. Comparing the two series of means, using either all 20 locations or only locations 2 and 3, we found that they agreed in most of the 19 cases. For example, allowing for a difference of +/- 0.3 dS/m, they agreed for 14 out of the 19 cases, and in all the cases the difference is not more than 0.5 dS/m. The differences would be smaller if locations 2 and 3 had reduced temporal standard deviations, implying if they were more time stable.

CONCLUSIONS

The Spearman rank order correlation showed a temporal persistence of the spatial pattern of $EC_{2.5}$. It indicated the strength and the direction of a rising or falling relationship between measurements made at two different time instants. To find out the locations which were time stable, we applied the technique of relative differences. We found no temporal stability of the complete soil salinity pattern. However, the low saline conditions and the locations representative of the average soil salinity had a moderate temporal stability while the high saline locations were the least time stable. Also, the low saline locations were related to zones of waterlogging and/or salt leaching while the high saline locations were related to the zone of salt accumulation. The locations representative of average soil salinity were present in the three zones. The concept of temporal stability allowed us to select a limited number of locations (as small as two), which were used to estimate the average soil salinity instead of using the 20 available locations. So, this technique can be used to select the locations representative of average and extreme saline conditions, which could be used as 'ground truth' for the calibration and the validation of remote sensing data for the determination, for example, of a soil salinity index. According to the results on the temporal stability of soil salinity in the studied native Solonetzic landscape, the zonation of the toposequence (vegetation pattern and elevation) was a very good indicator of the differences in soil salinity and its temporal stability.

The elaborated procedure is a general one and can be used in different ecosystems (agricultural field, native vegetation like grassland, bushland, forest), for different soil proprieties (moisture, salinity, soluble nutrients), and under different climatic zones (semihumid, arid, semi-arid). The methodology was applied, in this special case study, to a short time period (8 years) and a small spatial scale (a field of 25 ha). The methodology can easily be extended and applied to a much longer temporal series of soil salinity and at a much larger spatial scale with the aim of identifying the impact of climate change on soil salinization and selection of specific locations for monitoring soil salinity with time.

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Indicators of impact of climate change on salinity distribution and land-use in Sudan

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ABSTRACT

As a result of climate changes, there is a negative impact on many countries including Sudan**.** Climate change in some states of the Sudan appears evident from variability in both annual rainfall and distribution with time. This is also reflected in temperature variation. Sudan's economy, like many developing countries, is dependant on agriculture and associated industries, which are contributed to a high extent in the rural development of major farmers groups, who depend on rain-fed agriculture and natural pasture and range. This study is concentrated on the negative impact of climate which leads to drought and consequently to land deterioration which resulted in secondary salinization and vegetation cover degradation. Six locations were selected to represent the effect of climate change on different zones of Sudan: Dongla, Khartoum, Gezira, El-Obeid, Gedarif and Kassala.

Increasing temperatures may result in high evaporative conditions that may activate the capillary rise of salts leading to soil salinization. The results of this study showed a significant increase in salinity in Dongla area in the north where the annual rainfall is the lowest compared to the others in the south, Khartoum and Gezira. Fluctuation and erratic distribution of rainfall together with increase in temperature have an impact on the fertility of soils in the study area and this consequently leads to a reduction in crop productivity and decrease in biodiversity. These factors lead to more degradation of natural resources and displacement of rural people to urban areas. Studies have shown that heat stress, drought and floods have negative impact on animal breeding by reduction of weight gain, food intake and milk production. Sudden heavy rains in different parts of the country including Khartoum, Gezira and El Obeid have caused floods and heavy losses in livestock. A conclusion has to be drawn towards identification of some important research areas aiming at adaptation and mitigation to climate change in Sudan.

INTRODUCTION

The climate of the Sudan is predominantly tropical and continental. The climatic zones range from arid to semi-arid in the North to wet monsoon in the extreme South. The red sea coastal area and its highlands are dominated by Mediterranean climate. The potential evapotranspiration is higher than the actual precipitation in most parts of the country (SNAP, 2006). Sudan is one of the top ten countries regarding the extent of dry land coverage (Figure 1). Climate change affect the Sudan by elevation of temperature and that has consequently change the pattern of rainfall. Climate change affects agricultural productivity of most regions of the country. The IPCC fourth assessment report (2007) concludes that Africa will experience increase levels of water stress and reduced agricultural yields by up to 50% by 2020 because of the climate change. Recently and with other regional countries, Sudan is joining many climate change projects covering many aspects of climate change.

In this study we objected at the assessment of the impact of climate on the livelihoods of people through its effect on crop productivity, livestock, pasture, ecology and animal

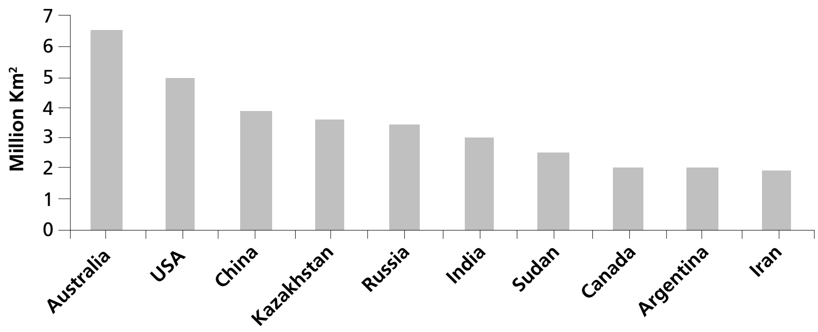

FIGURE 1
Global dry lands and the top ten countries with more than 1.4 million km² of dry land. Source (Abdelhadi & Kawkab, 2008).

production. Moreover, the proposal of research priorities is objected to establish a regional network of climate change involving different stakeholders.

IMPACTS OF CLIMATE CHANGE ON SOME NATURAL RESOURCES AND FOOD SECURITY

Impacts on soil fertility

Effect of global worming is presented in organic matter supply from biomass, soil temperature regime and soil hydrology as well as changes in potential evapotranspiration. In humid and sub-humid the effect of global worming may be reflected in a gradual improvement in soil fertility and physical condition. The CO_2 emissions increase the growth rate of trees and grasses which increase the ground cover. The increase of rainfall would enhance the leaching rates in most cases particularly in well drained soils and this would cause flooding or waterlogging conditions, hence reduction of organic matter decomposition.

Impacts on soil salinity

In arid and semi-arid the higher evaporative demand lead to upward water movement which lead to secondary salinization particularly in heavy cracking clay soils. As a result of accumulation of salty transported material as a consequence of wind erosion was reported for important areas of the northern parts of the semi-arid region of Sudan (dry salinization). In recent soil survey studies, the salt-affected soils are found to extend rapidly from north to south due to high evaporation, low rains and slow salt leaching.

Impacts on livestock

Effect of climate change on animals by heat stress and increase of evaporation from common water sources and pastures prevailing a quick drying and prolonging the dry season which may extend for several months. Some observations in 2005, one of the hottest years since the 1970s, indicates the effect of heat on livestock species in different localities in South Kordofan. Also many other reported indications of different effects of climate change on livestock husbandry and management.

Impacts on Wildlife

The major impacts of climate change on wildlife habitats are changing animals range and distribution. Also it affected habitats quality, the timing of migration and responsibility. Climate change has potential effects on most migratory bird species.

Bird movements include those made in response in food availability, habitat or weather. Water resources may suffer from many crises such as changes in water supply, quality and competition.

Impacts on Agricultural Productivity

Rainfed Agricultural in Sudan contributes to more than 95% of the total cultivated land. The main rainfed crops are Sorghum, Sesame, Millet and Groundnuts, Gedarif state, one of the most important sorghum producing regions, contributes to 30–40% and 40–50% of the total sorghum and sesame production respectively.

In this study the production of sorghum, sesame and cotton for the period 1951–2004 is correlated with annual rainfall of the same period. Results of this study revealed a general trend of reducing crop productivity with erratic rain distribution.

The prevailing reduction in crop productivity could be attributed to the declining in soil fertility as a result of the continuous monocropping of sorghum and also to the lack of crop rotation. Yields have apparently decreased, in Gedaref state as shown in the records of the Mechanized Farming Cooperation (MFC). However, the reason for sorghum yield reduction has several causes but rainfall flocculation has great effect on crop yield. At the start of these schemes establishment the crop production was high and has low correlation with rainfall flocculation and this may be attributed to the high soil fertility of the virgin soils at that time. During the seventies and eighties the crop yield and rainfall flocculation is clear and this can explain soil fertility status was decreased and soil moisture has the main role on crop yield. Although in the last decades the rainfall shows higher amounts but the yield was still low and this can be attributed to the high level of chemical, physical, and biological soil degradation.

Research priorities

The main pattern of climate change on soil variability mainly soil fertility, land degradation and salinization will be identified. The use of remote sensing techniques in detection of land cover degradation over past years is a good tool for studying habitats in different ecosystems as indicators for climate change.

Inventory studies of the current status of habitats, water resources, and wild animal abundance will be compared to old data to detect the factors of change, e.g. historical studies of how climate change and climatic variation in the past have affected species and natural system. Knowing the factors of climate change and their impact on the biodiversity, varied degrees of tolerance of these impacts and species reaction to climate change will help scientists and managers to propose measures for mitigation and adaptation. Climate change impact assessment is also frequently coupled with the identification and assessment of possible adaptive responses to a changing climate. To the extent that adaptation can reduce impacts, the assessment of adaptation measures is part of impact studies.

Joint research programmes are needed to cover gaps in land productivity, animal production and wildlife research topics linked to climate change and to be prioritized first in the government strategies that could be enhanced through development and understanding the change habits for efficient adaptation and mitigation to climatic change.

Evaluation of the spatial variability of soil salinity patterns by using geo-pedological approach: A case study in arid and semi-arid regions

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The spatial prediction of soil salinity patterns in arid and semi-arid regions has a special importance in the understanding of heterogeneity in landscape, the investigation of the causal processes, and the protection of the potentially vulnerable areas from more degradation. The aim of this study was to develop a multifarious exploration into spatial structure of saline soils to deal with different aspects of salinization, forming factors, distribution in landscape, and vertical variability in soil profiles in a GIS environment in Kermanshah, Iran.

The geo-pedological approach developed by Zinck (1998) was implemented to delineate the boundaries between different geomorphic surfaces. Salinity indicator attribute maps (EC, pH, SAR, ESP) were prepared to evaluate their variation in geo-pedological units. The geo-pedological units were distinguished by interpretation of aerial photos, Google earth image along with DEM. The piedmont landscape of the study area consists of apical, medial and distal landforms. According to the salinity heterogeneity, a grid sampling scheme was designed at three depths. Based on fieldwork and obtained laboratory results, the geo-pedological map was prepared and its corresponding legend was constructed.

The ANOVA results indicated that there were great differences in soil properties (EC, pH, SAR, ESP) and clay percentage between different landforms. The average values of EC, SAR, ESP and their extent were raised from apical to distal. Vertical soil salinity decreased in soil profile from topsoil to subsoil, especially in distal part, due to the capillary action of groundwater and water evaporation from the soil surface. The variation of EC, SAR, and ESP in the surface layer (0–20 cm) was significant while the variation of pH was not significant. The distal part was highly affected by salinity due to its location on the lower part of fan, draining the excess irrigation water from upper farms, and soil properties. The apical and medial soil types were classified in Entisols, while the soil of the distal part was under Aridisols order, which approves the effect of geo-pedological processes on soil types. In fact, the salinization process origins from both natural landscape processes (catena model) and anthropogenic sources. The distribution of soil salinity classes was: saline-alkaline (42.7%) and alkaline (0.8%) in surface layer, non-saline-alkaline (31.2%) and saline-alkaline (19.7%) in subsurface layer, and non-saline-alkaline (33.7%) and alkaline (2.1%) in subsoil layer.

According to these results, the pattern analysis in the prediction of soil salinity by using geo-pedological approach can be considered as an appropriate tool to assist decision makers and authorities in environmental management and large scale planning.

Keywords: soil salinity, pattern analysis, geo-pedological approach, arid, semi-arid.

Salinization of soils and aquifers: The case of the Yaqui Valley, Sonora, Mexico

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ABSTRACT

The Yaqui Valley is predominently an agricultural region with an irrigated area of the order of 233 000 ha, where as much surface waters as groundwaters are used for irrigation. The average annual extraction from the system of dams in the Yaqui River is 2 300 million m^3 and that of the regional coastal aquifer is 270 million m^3. The objective of this paper was to analyse the problem of salinized groundwater in the valley and to determine the causes. In periods of drought, when the volume of the water in dams is lower than average, extraction from the aquifer is increased, being on some occasions more than the recharge rate, which corresponds to 450 million m^3/yr. This situation increases the risk of saline intrusion of the coastal aquifer. Also, at times of high precipitation, infiltration from agricultural land may reach the aquifer, elevating phreatic levels towards the surface. Climatic conditions also increase the risk of salinization of waters and soils, since the potential evaporation in this region is of the order of the 2 000 mm/year. This situation induces direct phreatic evapotranspiration, increasing the salinity of the water and of the soils. The salinity distribution of the aquifer identifies an area of saline intrusion (>5 000 mg/l of TDS), which was not generated by encroachment of the hydraulic gradient on the phreatic levels during periods of higher extraction than recharge, but by infiltration of sea water from ponds of shrimp farms on the coast. The aquifer areas of the continental interior that contain brackish water (between 1 000 and 5 000 mg/l of TDS) have their origin in the dissolution of evaporites or from leaking sandy loam strata. The identification of the causes of the problem of salinity in the valley will facilitate the strategies of prevention and remediation of the salinity of the water and soils of the valley. The construction of 2 350 km of agricultural drainage with the complement of other actions has already enabled the recovery of 28 000 ha affected by salts.

Keywords: hydrogeology, hydrology of arid areas, water quality, salinity of water and soil.

INTRODUCTION

Yaqui Valley is located in north-west Mexico, between 26° 45’ at 27° 45’ N and 109° 45’ at 110° 30’ W. It produces 1 211 000 t/yr mainly of wheat, corn, soybean and cotton, as well as 35 600 t/yr of meats of pork, chicken and beef (González and Córdova, 1992). The 468 599 inhabitants live in the municipalities of Bacum, Cajeme, Etchojoa, San Ignacio Rio Muerto and Benito Juarez (INEGI, 2000).

The runoff of the basin of the river Yaqui is stored in three big dams and from 1964 to 2010 have provided 2 329 million m^3/yr of surface water and 262 million m^3/yr of groundwater taken from 335 wells. About 95% of the water is used for the irrigation of 233 000 ha of agricultural lands and the rest is used for industrial supply and drinking water. Other users, such as aquaculture, electric power generation and recreational centres, are exercising pressure for water rights; a situation that forces a more efficient handling of the resource in the valley (Boracio *et al.*, 1970; Díaz, 1993;

De La Peña, 1997; González *et al.*, 1997; González *et al.*, 1998; González and Marín, 2000; González *et al.*, 2001; Díaz, 2001).

The salinity of soils and waters can be caused by physical processes (advection and dispersion) and chemicals (erosion or corrosion and deposition or inlay), where the concentration of salts dissolved in the medium water-soil increases for natural and anthropogenic causes. The salinity is increased in the direction of the groundwater flow, from places of recharge to discharge. The salinity can be of one, or a combination of the following mechanisms: evaporation, evapotranspiration, hydrolysis and leakage between aquifers (Salama *et al.*, 1999).

A third of the agricultural lands in the world and a fifth part in United States of America present problems for accumulation of salts. In England, saline strata of an aquifer are associated to a dissolution process of evaporites. Several saline aquifers in Israel have intrusion of seawater, migration of salinized waters, which results in the contamination of industrial, municipal and agricultural activities in areas where hydraulic communication exists with exploited aquifers (Helweg and Labadie, 1976; Vengosh and Rosenthal, 1994; Tellam, 1995).

In arid and semi-arid climate regions, the absence of sufficient natural washing of the soil promotes the accumulation of salts and of salinized waters. Also, the permeable lands of over-irrigated arid areas will increase their salinity, since large increments can be caused in the elevation of the phreatic level and cause the salinity of soils and shallow groundwater, promoting direct phreatic evapotranspiration. Furthermore, saline infiltration towards the groundwater can happen during the initial washing of desert lands enabled for agriculture and the subsequent handling of the lands irrigated with excessive application of surface water (Helweg and Labadie, 1976; Foster *et al.*,. 1987; Vengosh and Rosenthal, 1994).

The formation and development of irrigation districts results in inherent problems to their evolution, which are often reflected in negative impacts on agricultural exploitation. The most serious problem is the modification of the regime of humidity when subjecting them to an intensive irrigation that results in overwatering due to insufficient natural drainage, causing salinization (Chilt, 1995).

To avoid such a scenario in the Yaqui Valley, which is an extensive and intensive agricultural area located in an arid region in the Provincia Desértica de Sonora (precipitation <100 mm/yr) and the Provincia de la Llanura Costera (precipitation <300 mm/yr), the object of this investigation is to answer the following question: Which is the origin of the salinized water in Yaqui Valley?

ORIGIN OF THE SALINITY OF THE AQUIFER

To explain the causes that give origin to the problem of the salinity, the proposal corresponds to the combination of the following hypotheses:

- Geological stratification of interstitial saline waters contained in pores of clays and evaporite rocks.
- Solute transports from the surface of agricultural lands toward the aquifers by the irrigation waters and the use of agrochemicals.
- Saline intrusion of the sea due to overexploitation of the coastal aquifer.

Regarding the hypothesis of the geological origin, this is based on the formation of the coastal plain during the Quaternary, which generated alluvial fillers and saline deposits from the sea that were caught in places where tidelands existed and that now form evaporitic strata that, as they dissolve, form saline aquifers. Exploratory wells in the higher parts of considerable extensions of the aquifer indicate that they contain between 2 000 and 10 000 mg/l of TDS. The salinity of those wells is generated partly by inter-stratified clays. Other exploratory wells carried out in an area without a hydraulic connection with the sea identified a high saline content in slime-loamy strata in the first 33 m, where to a depth of 20.2 m the montmorillonite clays predominate and are the main cause of salinity in that area (Canales *et al.*, 1987; Canales *et al.*, 1991; González, 1992; González *et al.*, 1998; González *et al.*, 2001).

On the other hand, geophysical explorations carried out from the surface up to 300 m above mean sea level (msl) identified that from the coast until the central area of the valley, there exists geoelectrical resistivity <6 Ωm that correspond to granular materials of fine to medium, possibly saturated with salinized water of marine origin, and in the central area of valley its origin is possibly due to interstitial waters contained in pores of clays and evaporites with resistivity between 6 and 30 Ωm. The favorable area to exploit the aquifer for irrigation and drinking water is between 100 and 300 m above msl, since the resistivity in this interval varies from 30 to 110 Ωm and it corresponds to granular materials of medium to thick, saturated with fresh groundwater (González, 2002).

The confirmation of the hypothesis that relates the combined effect of the geological origin with the solute transports from the surface of the agricultural lands of the valley for the handling of the irrigation water and use of agrochemicals, is based on the concentration-lixiviation from the lands until the aquifer of salts minerals and agrochemicals, since in this region the water irrigation rate is of the order 1 000 mm/yr and the evaporation rate is >2 000 mm/yr, including the direct evaporation from the aquifer in areas with phreatic level <1.0 m of depth (Boracio *et al.*, 1970; Martínez and Hunsgsberg, 1979; PROYESA, 1980; González and Marín, 2000).

The aquifer areas of the continental interior that contain brackish water (between 1 000 and 5 000 mg/l of TDS) have their origin in the dissolution of evaporites; leaking sand-loamy strata; and the irrigation practices associated with faulty drainage. The result of the increase in the salinity in the groundwater shows as a saline front that descends to depth with time due to vertical recharge by irrigation water and the application of agrochemicals in the valley, inducing the transport of nitrates from the surface to the aquifer, reaching the concentrations of up to 69 mg/l at a depth between 21 and 24 m, as demonstrated by exploratory wells carried out in the area (González *et al.*, 1998; González *et al.*, 2001; González and Marín, 2001).

The above-mentioned allows to infer that from the sedimentation process, for that area, the mineral salts stratify and solutes of agrochemical dissolved, they are transported as vertical recharge by infiltration of the irrigation water until the aquifer, as well as it indicates it the elevation in the pesticides concentrations in the aquifer, originating areas of bad quality that have reached to the sources of supply of drinkable water and of irrigation waters (Canales *et al.*, 1991; González, 1991; González 1993; González and Channels, 1995).

The hypothesis of the intrusion of sea water has been discarded, since the hydraulic gradient of the groundwater flow is directed towards the sea. But, it could have infiltration of sea waters from ponds of shrimp farms situated on the coast. Further investigation is required to quantify the contribution of sea water that infiltrates the aquifer from the ponds of the shrimp farms, as a possible source of salinity (Díaz, 1993; De La Peña, 1997; González and Marín, 2000).

This identification of the causes of salinity in the valley can facilitate the strategies of prevention and remediation of the water and soils. The construction of 2 350 km of agricultural drainage with the complement of other actions, has allowed the recovery of 28 000 ha affected by salts.

CONCLUSIONS

The extensive and intensive irrigation in an arid region like that of the Yaqui Valley alters the hydrological regime and the high salinity of waters and soils are a consequence of this. Losses from infiltration of the irrigation system produce a vertical recharge of the aquifer. In areas where the natural recharge is low, the infiltration of the irrigation water elevate the phreatic levels and they cause salinity in the water-soil system, affecting the quality of the lands and of the water, reducing yields.

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Assessing the relationship between the soil dielectric constant and electrical conductivity using 5TE sensors in the field conditions

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ABSTRACT

A theoretical model to describe a linear relationship between bulk electric conductivity and dielectric constant is frequently used in the litreature. Some authors recommend an offset of that linear relationship of 4.1 for most soils. In our preliminary field experiments (loamy sand soil) two 5TE probes (measuring water content, temperature, and bulk EC) were used to show that the calculated offset of a linear model including bulk electrical conductivity and dielectric constant, differs according to the water content.

Keywords: bulk EC, water pore EC, 5TE sensors, linear regression, offset.

INTRODUCTION

Rhoades *et al.* (1990), Mualem and Friedman (1991) studied the empirical relationship between water content, electrical conductivity of pore water σ_p and bulk electrical conductivity σ_b, these methods contain one or several soil-specific parameters. Malicki *et al.* (1994) discovered a high degree linear correlation between dielectric constant and bulk electrical conductivity values measured using time domain reflectometry for most of soil types. Hilhorst (2000) took advantage of this relationship and enabled to convert σ_b to σ_p by using a theoretical model describing a liner relationship between bulk electrical conductivity σ_b, and dielectric constant ε_b. The 5TE probes are commercially available measure ε_b and σ_b nearly simultaneously in the same soil volume. The company that produces these sensors uses Hihorst (2000) model to get water pore EC from bulk EC.

The Linear σ_p-water content -σ_b Model

The pore water conductivity can be determined according to Hilhorst (2000) from the equation:

$$\sigma_p = \frac{\varepsilon_p {}^* \sigma_b}{\varepsilon_b - \varepsilon_{\sigma_b=0}}$$

ε_p is the dielectric constant of the pore water and $\varepsilon_{\sigma_b=0}$ is the ε_b when ε_b=0.

However, $\varepsilon_{\sigma_b=0}$ appears as an offset of the linear relationship between σ_b and ε_b. Hilhorst (2000) found that the parameter $\varepsilon_{\sigma_b=0}$ depends on the soil type and it was the range of 1.9–7.6 for the soils used in his study, and he recommended that ε_b=4.1 can be used as a generic offset.

Many available sensors are able to measure instantaneously the soil bulk electrical conductivity σ_b, temperature and soil water content. σ_b is a measure of the overall conductivity of the solid, liquid and air phases. For agricultural applications it is beneficial to get information on the pore water σ_p. Since it is a good indicator of soil solute concentration, which including the equilibrium of ions in the pore water and soil exchange complex interface.

Water content and temperature have a significant effect on the EC (σ_b) Roger (2010). Previously to measure the pore water σ_p it is necessary to calculate an offset value. This offset removes the contribution of soil surface electrical conductivity and permittivity of dry soil.

The objective to this contribution is to derive an offset value from field data set that would ensure the accurate prediction of σ_p in the soils of this area.

By other hand, the influence of soil water content in the bulk electrical conductivity could be evaluated.

MATERIAL AND METHOD

Data used are come from an experimental plot cultivated with horticultural crop (5 km south of Barcelona, NE Spain) irrigated by furrow system (water quality 1.2 dS/m).

Two 5TE sensors (A and B) equipped with a datalogger were installed in central part of the experimental plot (600 m^2) at 0.10 m depth and separated 45 m. Data were taken each 60 minutes during three months.

The 5TE probe uses an electromagnetic field to measure the dielectric permittivity of the soil. The probe supplies a 70 MHz oscillating to the probe prongs that charges according to the soil dielectric, and uses two electrode array to measure the soil bulk EC, it has also surface–mounted thermistor to take temperature reading.

Data set consist of 3 139 data (1 652 from sensor A and 1 487 from sensor B) measurements of water content, temperature, ε_b and σ_b for each point respectively. Tables 1 and 2 illustrate the summary of values from each point.

Data are grouped according to its water content. The data of the A and B points are divided into 5 and 3 water content intervals, and the relationship between ε_b and σ_b was plotted. Tables 3, 4, 5, 6 and 7 show slope and offset values of the linear regression between ε_b and σ_b.

RESULTS

TABLE 1
Summary analysis of the A point data (1652 observations)

	Volumetric water content m^3/m^3	Bulk electrical conductivity dS/m	Temperature C°	Dielectric constant (Unitless)
Min.	0.22	0.24	10.00	11.76
1st Q	0.28	0.37	14.70	15.78
Median	0.32	0.45	17.70	18.12
Mean	0.31	0.42	17.28	17.27
3rd Q	0.34	0.48	20.00	19.30
Max	0.37	0.54	24.20	22.42

TABLE 2
Summary analysis of the B point data (1487 observations)

	Volumetric water content m^3/m^3	Bulk electrical conductivity dS/m	Temperature C°	Dielectric constant (Unitless)
Min.	0. 23	0.30	20.30	12.32
1st Qu	0.23	0.38	23.30	12.64
Median	0.25	0.44	24.40	13.52
Mean	0.25	0.43	23.80	13.85
3rd Qu	0.27	0.46	24.70	14.64
Max	0.37	0.83	25.70	21.94

TABLE 3

Linear regression analysis between measured dielectric constant and bulk electrical conductivity in A,B points

Sampling point	Water content	Slope	Offset	r^2	N°.ob
All population	0.220–0.37	25-00***	5.02***	0.44	3139
A	0.220–0.370	29.07***	5.06***	0.88	1652
B	0.220–0.360	21.73***	4.49***	0.72	1487

'***' Significant (p<0.001), '**' Significant (p<0.01) '*' Significant (p<0.05)

TABLE 4

Results from the linear regression analysis between measured dielectric constant and bulk electrical conductivity in the A point (Five intervals of water content)

Point	Water content	Slope	Offset	r^2	N°.ob
A	0.220–0.250	24.04***	6.1***	0.93	221
	0.250–0.280	29.59***	4.34****	0.74	148
	0.280–0.310	13.99***	10.8****	0.52	268
	0.310–0.340	6.45***	15.57***	0.11	703
	0.340–0.370	-1.57*	20.84***	0.014	309

'***' Significant (p<0.001), '**' Significant (p<0.01) '*' Significant (p<0.05)

TABLE 5

Results from the linear regression analysis between measured dielectric constant and bulk electrical conductivity in the A point (Three intervals of water content)

Point	Water content	Slope	Offset	r^2	N°.ob
A	0.220–0.270	23.20***	6.35***	0.96	328
	0.270–0.330	21.44***	8.04***	0.74	691
	0.330–0.370	2.45***	18.40***	0.022	630

'***' Significant (p<0.001), '**' Significant (p<0.01) '*' Significant (p<0.05)

TABLE 6

Results from the linear regression analysis between measured dielectric constant and bulk electrical conductivity in the B point (three intervals of water content)

Point	Water content	Slope	Offset	r^2	N°.ob
B	0.220–0.260	6.37***	10.29***	0.31	810
	0.260–0.300	8.20***	14.19***	0.32	631
	0.300–0.340	10.80***	12.67***	0.39	29

'***' Significant (p<0.001), '**' Significant (p<0.01) '*' Significant (p<0.05)

TABLE 7

Results from the linear regression analysis between measured dielectric constant and bulk electrical conductivity in the B point (five intervals of water content)

Point	Water content	Slope	Offset	r^2	N°.ob
B	0.220–0.250	2.78***	11.61***	0.08	710
	0.250–0.280	7.36***	11.06***	0.09	616
	0.280–0.310	10.61***	10.67***	0.19	131
	0.310–0.340	7.99	13.84***	0.27	13
	0.340–0.370	2.98	19.04***	0.087	19

'***' Significant (p<0.001), '**' Significant (p<0.01) '*' Significant (p<0.05)

TABLE 8
Summary analysis of the A point data with water content (0.22- 0.25)

	Volumetric water content m^3/m^3	Bulk electrical conductivity dS/m	Temperature C°	Dielectric constant (Unitless)
Min.	0.22	0.24	15.60	11.76
1st Qu	0.22	0.24	19.80	11.92
Mean	0.23	0.26	20.41	12.35
3rd Qu	0.24	0.27	21.40	12.70
Max.	0.25	0.32	22.80	13.36

TABLE 9
Summary analysis of the B point data with water content (0.22–0.25)

	Volumetric water content m^3/m^3	Bulk electrical conductivity dS/m	Temperature C°	Dielectric constant (Unitless)
Min.	0.23	0.30	20.30	12.32
1st Qu	0.23	0.38	24.00	12.36
Mean	0.24	0.39	23.87	12.69
3rd Qu	0.24	0.41	24.70	13.02
Max	0.25	0.45	25.10	13.36

DISCUSSION AND CONCLUSIONS

The results from the linear regression between dielectric constant and bulk electrical conductivity show that there is a good linear relationship between them (see Tables 3, 4, 5, 6 and 7).

The results show that changes in water content induced changes in slope and offset values. It shows also that in some intervals of the water content, the dielectric constant and bulk electrical conductivity are explained by a linear regression model in a good way (e.g. in Table 3 when the relation in the A population included all the data, and also when the relation in the B population include all the data). Otherwise, in some intervals of the water content, other variables should be included to fit the model (e.g. Tables 6 and 7).

For example, the same level of water content in the two population (0.22–0.25), the A population depict a good linear regression model between the bulk electrical conductivity and dielectric constant with r^2=0.93 with a slope=24.04 and offset=6.1 (see Table 4), but in the B population the linear regression model gives a r^2=0.08, offset=11.61 and slope=2.78 (see Table 7).

Take a look on the mean bulk electrical conductivity in the both population, A and B at that level of water content, it was 0.26 in the A point (see Table 8) and 0.39 (see Table 9) in the B point, maybe this values could interpret the difference in the results of linear regression analysis for the two population.

So it seems that there are an interaction between the level of water content and the mean of bulk electrical conductivity, and that interactions influence on the offset of the linear relationship between dielectric constant and bulk electrical conductivity.

The experiment has been made in the field conditions under furrow irrigation system. It is known that the salts differ in its distribution and concentration between the furrow and the ridge, and in each one according to the depth Chhabra (1996). So it is interesting to get information on the accurate prediction of σ_p beneath the furrow and ridge at the root zone area.

Now the experiment are expended to include 9 5TE probes, they are installed in the furrow and in the ridge at various depths (0.10, 0.20, 0.35, 0.50 and 0.60 m) and (0.12, 0.32, 0.47 and 0.72 m) respectively. The expected results are to get an offset and slopes differ for each depth at specific water content intervals, to fit the linear regression between the dielectric constant and bulk electrical conductivity. Moreover, laboratories experiments are needed to control the variables that could affect on that relationship to determine a good offset to apply Hihorst (2000) model.

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Climate change, salinity and irrigation in southern Italy

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ABSTRACT

The climatic changes induced by global warming are expected to modify agricultural activity and consequently the other social and economical sectors. In this paper, a three-year Project, funded by three Italian Ministries (University, Agriculture and Environment) and involving Italian Research Institutions of Agricultural National Council is described. After presenting the different types of methodologies that we are applying, the results will be presented with particular reference to the first workpackage (WP). The objective is to characterize two areas in the southern part of Italy subjected to intensive agricultural activity. The characterization of the two areas is based on spatially distributed data concerning the soil, the climate and soil use. Several techniques of data spatialization, clustering, geostatistical analysis and GIS are utilized in order to achieve homogeneous areas. Informative layers of GIS about land use, soil properties and climate are produced to describe the two areas.

Keywords: crop yield, soil salinization, irrigation requirement.

DESCRIPTION OF TOOLS AND INFORMATION SYSTEMS

Human activities are affecting the composition of the atmosphere due to increase of emissions of carbon dioxide (CO_2) and other greenhouse gases, causing an increase of the global average temperature. The Mediterranean region is considered particularly vulnerable and the temperature increase is expected to be higher than other regions. Concerning the rainfall, there is a great uncertainty with the projections by the various climate models, which frequently differ in both sign and magnitude for a given region. The phenomenon is complex because the temperature affects soil evaporation, plant transpiration, cloud characteristics, storm intensity, etc. Consequently, some regions can expect an increase in the amount of precipitation. In other areas, especially where water deficit has been experienced already, the forecasted decrease of rainfall will substantially affect the quantity and/or the quality of the water resources for agricultural activity.

For a particular region the forecasted warming is expected to depend strongly on several factors, such as the morphological and geographical characteristics. For Italian lands, some authors predict a reduction in winter precipitation, in particular for the regions of southern Italy.

The climatic change induced by global warming is expected to modify plant productivity and the agricultural activity in general. For the determinant herbaceous crops, the increase of temperature could shorten the cycle and cause a decrease of yield. The opposite will happen for crops with indeterminate cycle if the irrigation water availability were to increase. The temperature increase could expand the area suitable for plants requiring high temperatures, e.g. grapevine (Olesen and Bindi, 2002). The impact of climate change on yield and product quality of cropping systems will depend on the complex relationships between increase of CO_2 and temperature and changes in evapotranpiration rate and rainfall, depending on average, variability and intensity of precipitation.

Considering the cropping systems, the agronomical strategies of adaptation can include: (1) crop substitution; (2) changes in sowing date and sowing depth; (3) cultivar choice; (4) adjusting of fertilizer applications and pesticides treatments; and (5) conservative tillage for reducing soil evaporation and runoff and increasing water infiltration.

In areas where a reduction of water resources is expected, the adoption of localized irrigation methods, the optimization of irrigation scheduling and the continuous monitoring of soil water status could be the useful strategies in order to increase water use efficiency (WUE) of cropping systems (Ventrella *et al.*, 1996).

The objective of this paper is to describe the tree-year project "Evolution of cropping systems as affected by climate change" (CLIMESCO) and to present the first results for the spatial and climatic characterization of two areas subjected to intensive agricultural activity located in southern Italy.

In a context characterized by climate change, high evaporative and transpirative demands, poor availability of water resources and/or decreasing of water quality for irrigation, the overall objective of the project is to identify integrated approaches for optimizing water resources use by maximizing the cropping systems WUE, approaches that could be utilized by political stakeholders in land planning activity. CLIMESCO is founded by three Italian Ministries and involves Italian Research Institutions of Agricultural National Council, Research National Council and Universities.

The research is being carried out in two reference areas in southern Italy: the Capitanata area in Apulia and the Diego Nivolelli basin in Sicily.

The Capitanata area, the second largest plain in Italy (about 4 000 km^2), is located in the Northern part of Apulia region. It is one of the most important areas for Italian agriculture. The most widespread crops are winter wheat (rainfed), sugar beet, tomato, vegetables, grapevine and olive orchard. The climate is semi-arid, with hot and dry summers (annual rainfall is about 550 mm) and short and temperate winters.

The Delia-Nivolelli basin, with an area of about 60 km^2, is located in the south-western Sicily. The climate of the area is semi-arid, with dry summers and short, temperate winters. The annual evapotranspiration is always greater than rainfall, determining drought conditions that make irrigation necessary for agriculture. The main crop is the grapevine, covering about 83% of the cultivated area and 93% of the total catchment area. Other crops present in the area are olives and citrus.

The project is structured in four workpackages (WP) with specific objectives of a high degree of interaction and information exchange.

WP1: Identification of homogeneous areas

The objective is to characterize the two areas. The characterization is based on spatially distributed data concerning soil, climate and land use. Several techniques of data spatialization, clustering, geostatistical analysis and GIS are being used in order to achieve homogeneous areas. Informative layers of GIS have been produced to describe the two areas and manage the data for the other WPs.

WP2: Climate change

The first objective of this WP is to provide temperature, precipitation and radiation scenarios according to forecasted greenhouse-gas emissions by using the General Circulation Models (GCM). The GCMs are complex models that consider mass and energy exchanges between ocean, land and atmosphere of the whole planet, providing temperature, precipitation and radiation scenarios, according to projected greenhouse-gas emissions.

Regional models have been used in several climate impact studies for many regions of the world. The regional climate models obtain sub-grid scale estimates (sometimes down to 25 km resolution) and are able to account for important local forcing factors, such as surface type, land use and elevation. Therefore, the aim of this WP is to estimate local weather forecast for several decades at daily scale according two method of downscaling (regionalization techniques): (i) dynamic, increasing the spatial resolution in the reference areas or adopting global cells as boundary conditions and (ii) statistical, based on the identification of statistical correlations between meteorological variables at global and local scales.

WP3: Optimization of water resources

The topics of this activity involve the irrigation management of water resources that are expected to become increasingly the main limiting factor for agricultural activity. In particular, research at field scale is being carried out for agronomical studies regarding the following irrigation studies: (1) irrigation management with saline water in Mediterranean environments at high desertification risk, (2) cropping systems and water requirements, (3) agronomical strategies for soil leaching (4) temporal evolution of crop coefficients (Kc) and crop resistance depending on climate change and (5) evaluation of new procedures to determine hydrological soil parameters used in soil water balance models.Another important issue of this WP is to parameterize the simulation models for crop growth and photosynthesis translocation, soil water fluxes and solute transport.

WP4: Scenarios analysis

This is the conclusive WP. Using the information derived from WPs 1 and 2, simulations are run both at field and regional scales by using numerical models for simulating crops and cropping systems. In particular, calibrated and tested crop and hydrological models are utilized in order to evaluate the effects that the future climatic scenarios will have on crop yields and to identify the best agronomical strategy to optimize the use of water resources.

In order to select the models to be used in the framework of CLIMESCO, a comparison has been carried out taking into account the modelling approaches than can be applied to crop water management. The models DSSAT (Jones *et al.,* 2003), CropSyst (Stockle *et al.*, 2003), EPIC (Williams *et al.*, 1989), and SWAP (Van Dam *et al.*, 1997) have been selected.

APPLICATION OF THE STUDY

The Geographic Information System (GIS), realized in the framework of CLIMESCO, represents the possibility to manage the information of different features with the objective to characterize the agro-environmental parameters. The GIS is an essential tools for capturing, managing, analyzing, and displaying all forms of geographically referenced information. The implementation required to collect data of different types of information related to CLIMESCO. All the data were checked and homogenized to the same measurement units, temporal and spatial resolution and their variances. Moreover, the same geographical reference system was utilized.

The Capitanata Area

The GIS was characterized by 5 features: (1) geography, (2) remote sensing, (3) geo-lithology, (4) soil and land use and (5)climate. The Figure 1 shows the geographic area of Capitanata with the surface hydrography. Remote sensing Images from LANDSAT TM were utilized with a resolution of 30 m related to two dates in April and July 2006.

The soil in the Tavoliere area is mainly constituted by continental and marine sediments. A preliminary study based on the interpretation of the official geological maps of the area allowed to group different geological units in seven lithological classes outcropping over the area: Cretaceous Limestes, Plio-Quaternary clays, Plio-

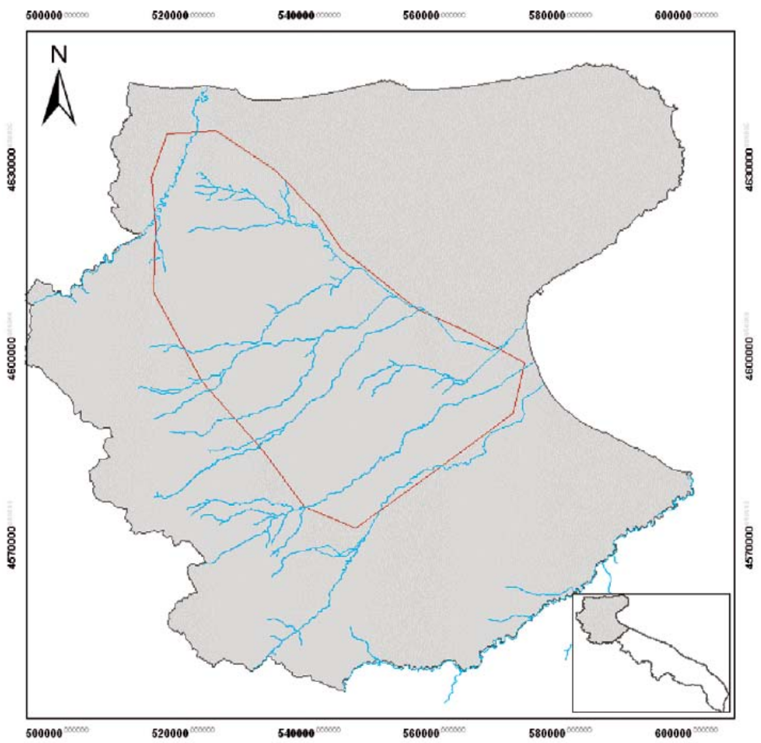

FIGURE 1
The Capitanata area in the Apulia region.

Quaternary Sands, Plio-Quaternary Gravelly Deposits, Terraced Marine Deposits, Terraced Alluvial Deposits and Actual River-Bed Deposits. The most diffusely outcropping lithology is represented by the alluvial deposits, composed of terrains with heterogeneous grain size and texture.

The soil database includes 1 353 pedological profiles distributed in the area of Foggia district. The data characterize two layers of 0-40 cm and > 40 cm.

The Landsat images with 2 400 points of ground inspection were utilized to yield a land use map applying a procedure based on "maximum likelihood" and the geostatistical tool of Indicator Kriging. The land use included 4 classes: cereal crops (67%), tree crops (11%), vegetable crops (10%) and vineyards (12%).

The climatic feature is composed of data from 20 meteorological stations homogenously distributed in the Foggia district. In particular, the database includes data of precipitation and temperatures (minimum and maximum) at monthly scale. The "climatological unit" of CLIMESCO (WP2) IS utilizing these data in order to apply the statistical downscaling methodology.

The Delia-Nivolelli basin

The Delia-Nivolelli basin is located in the south-west of Sicily, near the city of Mazara del Vallo in the Trapani district.

The GIS is organized in 5 layers, geo-referenced with the UTM system (longitude zone 33° N with datum ED50): (1) geography and topography, (2) remote sensing images, (3) Geo-lithology, (4) soil and land use and (5) climate.

The geographical layer is constituted by (1) physiographic and administrative features useful for the geographical location and topographic data for obtaining the DTM elaboration. In particular, starting from the national cartography (1:25 000), the following geographical features were digitalized and stored in shape files: (1) regional administrative boundaries, (2) study area boundaries and (3) hydrographic network.

In order to realize the DTM model, another GIS layer was implemented by digitalizating 3 591 elevation points collected from regional topographic maps (1:10 000). In particular, a first sampling of 2 364 elevation points were extracted from the 1:5 000 technical topographic maps and a further sampling of 1 227 elevation points were carried out from the 1:10 000 technical topographic maps for increasing the DTM resolution.

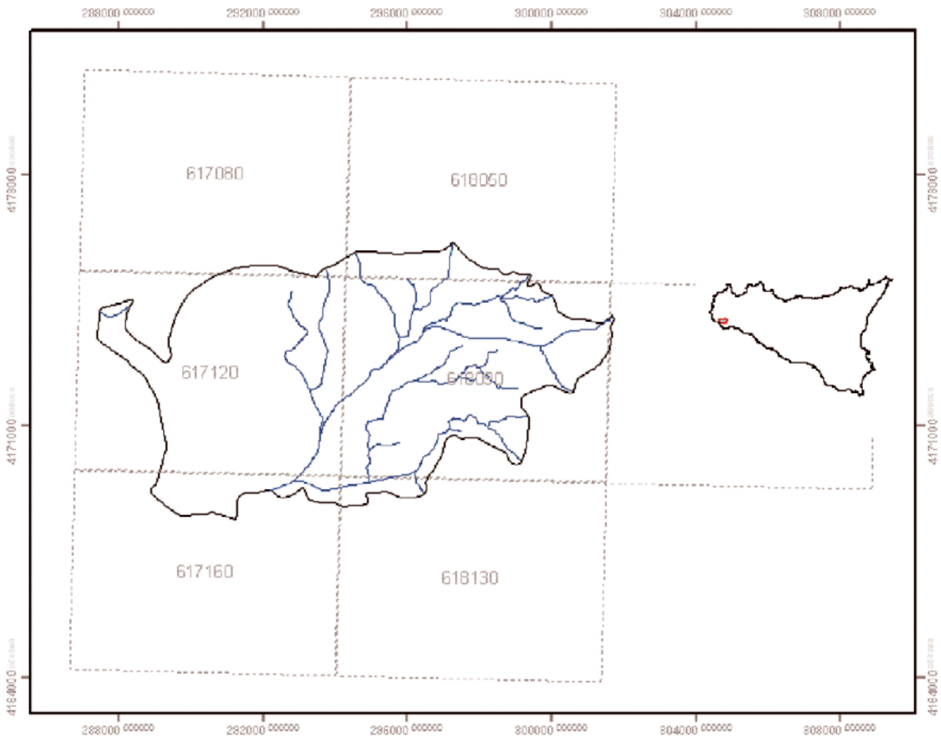

FIGURE 2
The Delia-Nivolelli basin in Sicily.

The remote sensing layer includes orthophoto strips with a resolution of 1.5 m. They were utilized for identifying the vineyard cultivated areas.

In the Delia-Nivolelli area the earth materials are composed by continental and litoral deposits, belonging a Miocene and Quaternary sedimentary sequence, which covers the evaporitic rocks of the gypsum-sulphuric formations. The older lithology outcropping in the area is represented by the Marly Clays, upper Miocene in age. In the western sector, the clay deposits are covered by the Plio-pleistocene Litoral Deposits, constituted by gravelly and calcareous deposits, with organogenic detrital and local clayey-sandy levels. The eastern sector of the area is characterized by Olocene alluvial deposits with a variable grain sizes.

The soil feature is represented by maps of pedological characteristics, hydraulic and chemical soil parameters and land use. The pedological map was obtained by digitalizing of the Sicily soil maps (1:250 000) enhanced by information from 10 further soil profiles. Four soil classes, according to USDA classification, were recognized and acquired in the GIS: Lithic Xerorthens, Typic Chromoxerert, Vertic Xerochrept and Vertic Xerofluvent. In order to characterize accurately the soil hydraulic properties, the following data, from 330 sampling points of two soil surveys were utilized for implementing the soil GIS layer: soil electrical conductivity (by EM38 and laboratory determinations), textural data and bulk density, soil water content, pH organic matter, soil water retention and hydraulic conductivity (Crescimanno, 2001; Crescimanno *et al.,* 2002). Data from five meteorological stations distributed in the Delia-Nivolelli basin constituited the climatic layer.

To synthesize the results and spot the areas jointly affected by the factors promoting soil salinization, we performed factorial kriging analysis. Omitting the regionalised factors corresponding to nugget effect and shorter range, because the former is mostly affected by measurement errors and the latter explains a small component of the total variance, we focused on the factor 1 at longer scale, which accounts for more than 92% of the total variation at this spatial scale and is positively correlated to all variables. To make the interpretation of the factor1 map easier, we preferred an even class representation (Figure 3), where the study area has been divided into three zones of equal extension as a function of the scores of the factor 1, positively related to the clay content and EC values along the soil profile: the first one (high), at high risk of salinization, extending within a central strip of 1 500 m width and in some zones to east, where remediation action would be recommended; the second one (medium) extending on the whole area in restricted zones, where the salinity levels in the soils should be under continuous monitoring so that a wiser management of soil and water resources could be planned; and the third zone (low) including a wide area in the western part, nearer the coast, and a large strip in the eastern part.

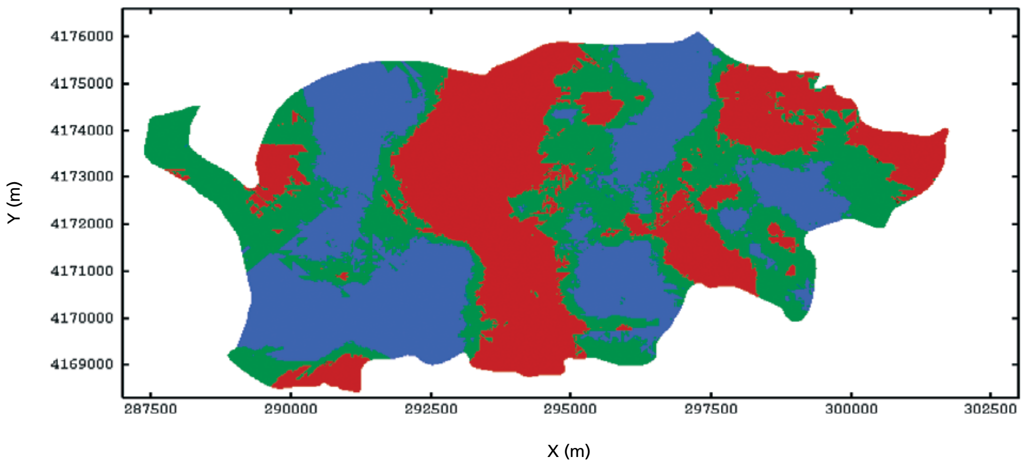

FIGURE 3
Map of salinization hazard.

These areas could be classified as safe and the production of grapes should not suffer significant reduction. This partition of the area is mostly affected by the lithological and textural properties. However, other covariates, more related to topography and management, may have contributed to determine the actual degree of salinization of the soils.

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TOPIC II: PREVENTING AND MANAGING SALINIZATION UNDER CLIMATE CHANGE THREATS: LEARNING FROM PAST EXPERIENCES, INTRODUCING NEW TECHNOLOGIES AND FACILITATING THE EXCHANGE OF KNOWLEDGE

The effect of salinization and climate change on the biomes of South Africa

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ABSTRACT

South Africa is both a climatically sensitive and water-stressed country. Much of the country is arid or semi-arid and is subject to droughts and floods. Any variation in the salinity, rainfall or temperatures would thus exacerbate the already stressed environment. Through the whole debate about climate change the underlying view is that the world's climate should stay exactly as it is. The soil and geological records tell us that this is a vain and naïve hope. Instead, it tells us that dramatic change is to be anticipated. Long-term global trends in late Cenozoic climate/oceanographic/sea level evolution are mediated by fundamental geological processes such as the changing configuration of landmasses. However, the underlying forces driving some major trends remain obscure.

There is considerable evidence for several humid cycles, with intervening arid episodes, during the latter part of the Pliocene and the Pleistocene. It was during such humid cycles that pedogenesis and bioturbation occurred within older colluvial or aeolian sediments to form transported sandy soils of mixed origin over large areas of South Africa. Lower winter rainfall conditions in the western part of South Africa are of fairly recent origin. These changes are partially preserved in deep weathering profiles, often capped by paleo-features that are out of phase with present day conditions, such as silcretes or ferricretes in the western arid regions of South Africa. Salinity is in some areas clearly not solely a function of present day climate, therefore the prediction of future salinity conditions in a biome or region is problematic.

Keywords: salinization, biomes, climate change.

DISCUSSION

The opening of the Drake Passage is probably the geological event in the recent past in the southern hemisphere that has had the most significant effect on salt-affected soils and climate change. The opening of the Drake Passage and the resulting circum-polar circulation resulted in the expansion of the Antarctic ice sheet and cooling of the Southern Ocean. The separation of South America from Antarctica is widely believed to have influenced Cenozoic cooling because these events enabled the development of the Antarctic Circumpolar Current. In the atmosphere, a strong, semi-permanent high-pressure system established over the South Atlantic Ocean, producing offshore drift of water off the west coast of southern Africa. This gave rise to the Benguela up-welling system. Cooling of the ocean water along the west coast radically changed the climate of southern Africa. Whereas previously, moist air was supplied to the subcontinent from both the Indian and Atlantic Oceans, producing relatively moist conditions on both sides of the continent, the up welling of cold water on the west coast cut off the moisture supply from the Atlantic. The west coast became very arid, the Namib Desert formed, and the rainfall gradient from the east to the west coast was established.

South Africa is ranked third in the world in terms of biological diversity. The country encompasses a range of vegetation types, from arid shrubland and semi desert, through savanna and woodland to coastal forest and alpine forest. These 68 vegetation types are classified into 7 biomes (Figure 1). Biodiversity is important for South Africa because it maintains ecosystem functioning has proven economic value for tourism and supports subsistence lifestyles. The combined effect of climate change, rising human population, and increasing per capita consumption will result in major changes to biodiversity. Climate change and the resulting loss of biodiversity has the potential to harm the tourism sector, which currently contributes $ 70 billion each year to the economy. It is estimated that if South Africans do not immediately act to adapt to the effects of climate change, it could cost the country about 1.5% of gross domestic product by 2050.

When internationally agreed scientific models are used to explore the potential impacts of climate change on South Africa over the next 50 years, a broad reduction of approximately 5 to 10% of current rainfall is predicted, but with higher rainfall in the east and drier conditions in the west of South Africa. Climate change modelling suggests major changes in biome distribution and also that South Africa's plant biomes will experience a reduction of the area covered by up to 55% in the next 50 years due to warming and aridification trends. For example; the succulent Karoo Biome could possibly be completely lost within 50 to 100 years, and only the hardiest plants of the biome will be able to survive.

The Desert and Succulent Karoo Biomes in the arid regions of South Africa are clearly saline if the median electrical conductivity is used as an indicator of salinity (Table 1 and Figure 2). The Grassland and Indian Ocean Coastal Belt Biomes in the higher rainfall regions on the other hand are clearly non-saline (Table 1 and 2).

The biomes with the highest electrical conductivity are found in the western parts of South Africa (North 28°, South 34°, East 22° and West 16°) with the lowest rainfall and highest aridity index (Table 1 and 2). Climate change would probably result in a decrease in salinity for the Savanna, Grassland and Indian Ocean Coastal Belt Biomes, because of higher rainfall and lower aridity index. An increase in salinity in the Desert, Succulent Karoo, Nama-Karoo and especially in the Fynbos Biome, because of lower rainfall and higher aridity index, would probably occur in the future (Table 1). The effect of an increase in salinity would be less dramatic in the Desert, Succulent Karoo, Nama-Karoo Biomes, because the biomes are already classified as arid or hyper-arid.

The Cape Floral Kingdom (Fynbos Biome) has been identified as one of the global biodiversity hotspots in the world and it will be hit very hard by climate change and an increase in salinization. Drought, increased intensity and frequency of fire and climbing temperatures are expected to push many of these rare species in the Fynbos Biome towards extinction. The effect of climate change on salinization in the Fynbos Biome would probably be mitigated be geological material in some areas that do not contain high levels of salt.

TABLE 1
Current electrical conductivity and possible future trends in electrical conductivity of the different biomes in South Africa

Biome	Count	Average dS/m	Median dS/m	Future Change in EC
Desert	66	8.30	1.59	>
Succulent Karoo	516	8.29	1.68	>
Nama-Karoo	1 268	3.11	0.49	>
Fynbos	977	1.91	0.36	>>
Albany Thicket	572	1.68	0.59	=
Savanna	8 041	0.99	0.32	<
Indian Ocean Coastal Belt	525	0.43	0.24	<
Grassland	7 946	0.42	0.21	<

Climate change would also cause changes in the temperature, salinity, sodicity and alkalinity of aquatic systems affecting the survival of biodiversity.

TABLE 2
Annual rainfall of the different biomes in South Africa

Biome	Median Annual Rainfall (mm)
Desert	35
Succulent Karoo	147
Nama-Karoo	207
Fynbos	450
Albany Thicket	481
Savanna	615
Grassland	755
Indian Ocean Coastal	1 015

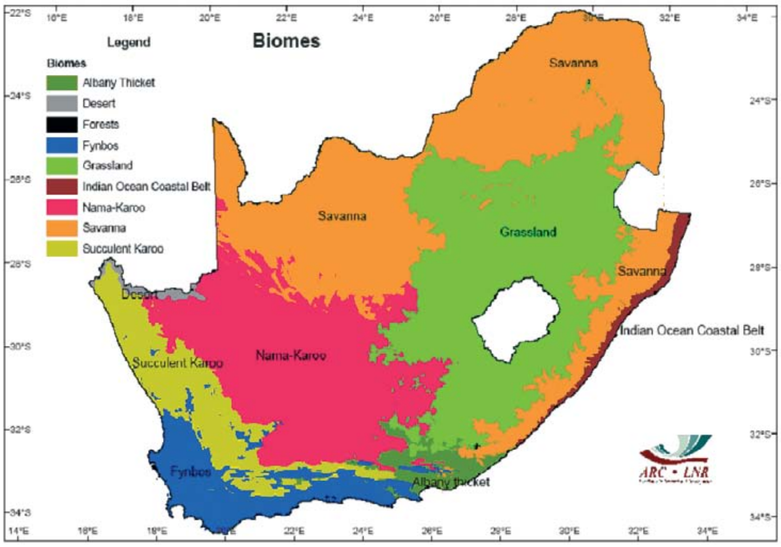

FIGURE 1
Biomes of South Africa.

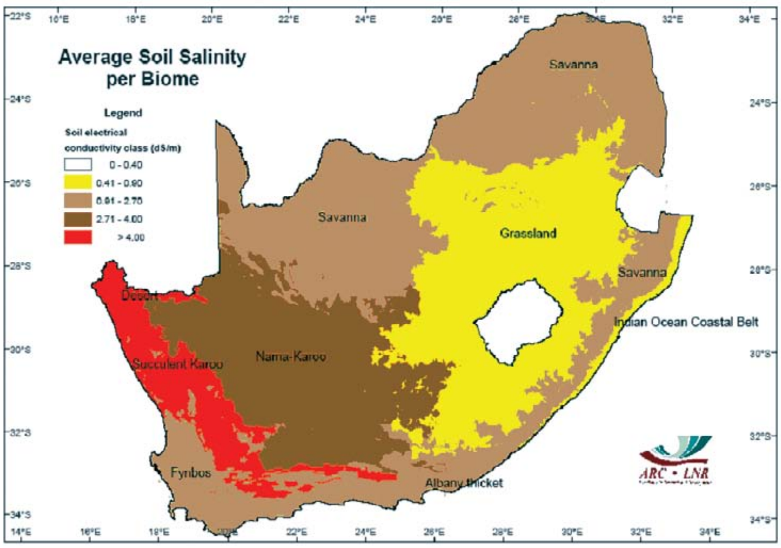

FIGURE 2
Average soil salinity (dS/m) per biome.

Effects of an alternative water source and combined agronomic practices on soil salinity and irrigated cotton in coastal saline soils in China

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ABSRACT

The ongoing experiment for cotton crop (*Gossypium hirsutum L.*) was conducted at the Zhongjie Farm, Huanghua city of Hebei province in the coastal salinity-affected areas in North China Plain, to determine the effects of an alternative of irrigation water sources/methods and agronomic practices on the changes in soil water salt contents and soil pH during cotton growth stages, and also on seedling emergence and yields of cotton. The experiment was set-up using split-plot design with two water sources as main treatments (well water/desalinized sea ice water); two irrigation methods (+PAM (Polyacrylamide) /-PAM); and four fertilization modes: check (CK), mineral fertilizer (F), mineral+organic fertilizer (FM), and mineral fertilizer+gypsum (FG).

The 10 cm top-soil salt contents at seeding decreased by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea ice water irrigation, respectively, as compared with PAM-untreated CK. Using PAM-treated irrigation, the 10 cm top-soil salinity significantly decreased to about 2.3–3.9 g/kg from 4.6–8.6 g/kg (PAM-untreated). The top-soil salt contents at seeding stage also adversely affected seedling emergence (r=-0.71**), and resulted in yield reduction (r=-0.50**). PAM-treated irrigation, either using well water or desalinized sea ice, in combination with gypsum, shows the best practice for soil desalinization, and hence seedling emergence and cotton yields, and could be acceptable for crop irrigation in the coastal saline areas.

Keywords: coastal areas, cotton, fertilization, irrigation, polyacrylamide.

INTRODUCTION

The coastal area surrounding the Bohai Sea (including 3 provinces and 2 cities, i.e. Hebei, Liaoning, Shandong, Tianjin and Beijing) is one of the important regional economic development belts and food production bases in China. Fresh water shortage is the most limiting factor to crop production in the coastal areas surrounding the Bohai Sea, thus searching for usable water resources and effective water-saving irrigation methods for improvement of crop production on the salinity-affected land has been of a great interest in recent years. The use of “new water” through desalinization of seawater or brackish water for crop irrigation has been also receiving great attention in water-starved countries throughout the world (Fang and Chen 1997; Wolff and Stein 1999; Pereira *et al.*, 2002; Qadir *et al.*, 2003; Qadir and Oster 2004; Li *et al.*, 2008; Zhao *et al.*, 2008).

Recently in China, the sea ice resource of Bohai Sea has been considered to be a potential resource of fresh water (Shi *et al.,* 2003; Li *et al.,* 2005). Shi *et al.* (2003) observed in the investigated area in Behai Gulf that salt separation from sea ice by freezing results in lower salinity (about 1.4–4.0 g/l) in sea ice with an average of 2.64 g/l, far less than that of sea water (about 26–29 g/l). The salinity of refrozen sea ice water decreases further to 0.5–2.0 g/l, close to the salinity of freshwater (Shi *et al.,* 2003).

Using melted and desalinized sea ice water for crop irrigation has been tested with simple and low-cost desalinization techniques (by sea ice freezing-melting processing through temperature control) under recent research project support in China (Xu *et al.,* 2006; Zhang *et al.,* 2006; Hu *et al.,* 2009; Zheng *et al.,* 2009). However, under the saline conditions, influenced by capillary up-flow from salt-rich shallow groundwater, irrigation should meet both the crop water requirements and the leaching (or desalination) requirements (Minhas, 1996). Thus, an integrated irrigation management, when combined with other agronomic practices, including hydraulic, physical, chemical, biological and engineering practices, may help both increase the efficiency of infiltration and use of irrigation water, and improve the efficiency of the reclamation, amelioration and utilization of salt-affected soils. Whether sea ice can be used as freshwater also depends on the salinity and alkalinity of the thawed sea ice (Shi *et al.,* 2003). However, the changes in soil water salt contents, and salinity and alkalinity relationship when the sea ice water used for crop irrigation are still unclear.

The objective of the research is to determine the effects of various irrigation (water sources/water additives by PAM) and fertilization practices (soil amendment additions by gypsum or organic fertilizer combined) on the changes in soil water salt contents and soil pH during cotton growth stages, and on cotton seedling emergence and yields, to provide an assessment of using desalinized sea ice water as an alternative irrigation water source and integrated agronomic practices of soil water salt management for cotton production in the salinity-affected and freshwater-limited coastal areas of the Bohai Sea in China.

METHODS

The ongoing field experiment was carried out at the Zhongjie Farm, Huanghua city of Hebei province (38° 19'–38° 29' N, 117° 23'–117° 29' E, located in dry semi humid region of northern China), on a loamy-clay soil with a moderate–high salinity level, in the coastal area near the Bohai Sea in China. The initial 20 cm layer salt contents ranged from 4 to 11 g/kg due to field flooding in 2006. Soil pH was about 8.4. The groundwater level is around 0.9-1.6 m deep. The average annual rainfall is about 620 mm. Spring cotton (*Gossypium hirsutum* L.), one crop per year, is one of main crops. Spring drought, accompanying high salinity at the soil surface inhibits seed germination and seedling emergence, which in turn adversely affects cotton growth and yields. Thus, irrigation is necessary to alleviate both water and salt stress

The experiment was set-up using split-plot design with two water sources as main treatments: well water and desalinized sea ice water; two irrigation methods as sub-treatments (+PAM (Polyacrylamide)/-PAM); and four fertilization methods as sub-treatments: 1) CK, 2) mineral fertilizer (F), 3) mineral + organic fertilizer (FM), and 4) mineral fertilizer + gypsum (FG). The salt contents of well water and desalinized sea ice water were about 1 and 3 g/l, respectively. Mineral fertilizer applications were 180 N (urea, 46% N), 150 P_2O_5 (superphosphate, 12% P_2O_5), and 90 K_2O kg/ha (Potassium fertilizer, (K_2SO_4, 50% K_2O). Commercial organic fertilizer application was 4 500 kg/ha. The contents of organic carbon, total N, total P, total K and moisture were 38%, 2.35%, 1.39%, 1.25% and 42.9%, respectively for organic fertilizer. Gypsum and PAM applications were 5 000 kg/ha and 10 ppm, respectively. Plots of 6 x 5 m^2 were laid down randomly in triplicate.

The pre-field experimental preparation for cotton crops was conducted in April 2007. To lower the groundwater level in order to avoid soil waterlogging and salt-rising, drains were installed in the experimental field site. Irrigation water (about 55.5 mm) and fertilizer treatments were implemented before cotton crop planting (27 April). The second irrigation treatment was on 6 July. Cotton was seeded on 2 May, in rows at distances of 60 cm and 80 cm between rows and at 30 cm within the rows. The local salt-tolerant spring cotton (*Lumianyan* No. 21) variety was used. To prevent evaporation and salt-rising, a plastic film cover was placed on the seeded soil surface at sowing.

Soil samples were collected at depths of 0–10, 10–20, 20–40, 40–60, 60–80 and 80–100 cm for soil moisture, salt content, and pH value determination taken at seeding and main growth stages of cotton. Electrical conductivity (EC) and pH value were measured in 1:5 (by weight) soil-water extract using an EC/pH meter WM-22EP. Soil salt content can be converted by the relationship of total dissolved salts (TDS) to EC as follows:

$$\text{TDS (mg/l)} = \text{EC } (\mu\text{S/cm at } 25°\text{C}) \times 0.6 \qquad (1)$$

Seedling emergence and cotton yields were measured at seedling stage (29 May) and harvest (23 October), respectively. Statistical analysis was done with the GLM/REG procedure of the SAS Institute (2004).

RESULTS

Changes in top soil salt contents and pH at cotton growth stages

Mean soil salt contents and soil pH in the top 10 cm layers changed during the cotton growing periods as shown in Table 1. Mean 10 cm top-soil salt contents changed greatly, from 4.8 g/kg (ranging from 1.8 to 15.5 g/kg) at seeding to 2.3 g/kg (ranging from 1.0 to 6.3 g/kg) at harvest with increased seasonal rainfall between July and September, while mean 10 cm top-soil pH slightly changed from 8.5 (ranging from 7.9 to 9.1) at seeding to 8.4 (ranging from 7.95 to 8.93) at harvest.

The large variation in top-soil salinity at seeding was related to the top-soil redistribution because of pre-field preparation in April 2007, and flooding in 2006 (in which cotton yields were heavily lost due to waterlogging and salinity). The salt contents of the 10 cm top-soil at seeding were also influenced by various irrigation and fertilization treatments, decreasing by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea ice water irrigation, respectively, as compared with PAM-untreated CK (data not shown). Either using well water or desalinized sea ice water irrigation with PAM application, the 10 cm top-soil salt contents significantly decreased to about 2.3–3.9 g/kg (+PAM) from 4.6–8.6 g/kg (-PAM) ($P<0.05$).

TABLE 1

Statistic data for cotton yield (kg/ha), soil salinity (g/kg) and pH in 10 cm top-soil layers (n=48) measured during the period of May 2 at seeding to Oct 27, 2007 at harvest

	Salinity May 2	Salinity July 10	Salinity Sept 15	Salinity Oct 27	pH May 2	pH July 10	pH Sept 15	pH Oct 27
Min.	1.8	1.2	1.7	1.0	7.90	7.91	7.50	7.95
Max.	15.5	18.9	13.9	6.3	9.09	9.06	8.74	8.93
Mean	4.8	5.9	5.6	2.3	8.51	8.38	8.10	8.40
SE.	0.4	0.6	0.4	0.2	0.04	0.04	0.04	0.03
SD.	2.9	4.2	2.9	1.1	0.27	0.25	0.30	0.23
CV(%)	59.8	70.3	53.0	45.5	3.1	3.0	3.8	2.8

Relationships between cotton seedling emergence/yields and top soil salinity/pH

Relationships between cotton seedling emergence/yields and the 10 cm top-soil salt contents/pH are shown in Table 2. The 10 cm top-soil salt contents during cotton growth stages, especially at seeding stage (2 May) adversely affected seedling emergence (r=-0.71**), and significantly resulted in yield reduction (r=-0.50**). Cotton yields significantly decreased with a reduction in seedling emergence (r=0.62**), related to the 10 cm top-soil salt contents at seeding, but not to the top-soil pH values. Apparently, the 10 cm top-soil salt content at cotton seeding is the most important yield-limiting factor. Although generally there were significantly negative relations between the 10 cm top-soil salt and pH during cotton growing periods, they have less impact on cotton yields than the soil salt contents at seeding stage.

TABLE 2

Correlation coefficients (r) for cotton yields (kg/ha), seedling emergence (%), and the 10 cm top-soil salt contents (g/kg) and soil pH measured during the periods of May 2 to Oct 27, 2007

	Cotton Yield	Seedling emergence	Salinity May 2	Salinity July 10	Salinity Sept 15	Salinity Oct 27
Seedling emergence	0.624**					
Salinity May 2	-0.499**	-0.708**				
Salinity July 10	-0.400*					
Salinity Sept 15	-0.278					
Salinity Oct 27	-0.079					
pH May 2	-0.297	0.141	-0.428**			
pH July 10	-0.057			-0.689**		
pH Sept 15	0.104				-0.440**	
pH Oct 27	-0.125					-0.703**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

Relationships between profile soil salinity and moisture/pH

The correlation coefficients (r) between soil moisture and salinity at seeding show positively significant relations when PAM treated, but insignificant relations when PAM untreated in the 0–10, 10–20, and 20–40 cm soil depth (Table 3). Soil moisture contents in the top 0–10 and 10–20 cm were also positively related to the deep soil salinity when PAM treated, showing that PAM-treated irrigation promoted salt downward transfer with irrigation water movement due to increased infiltration rate.

The relations between profile soil pH and salinity at seeding were not significant when PAM treated, while negative significantly relations between them were found in the 0–10, 10–20, 20–40 and 40–100 cm soil depth when PAM untreated (Table 4). This

TABLE 3

Correlation coefficients (r) for soil salinity (g/kg) and moisture (%) /pH in the 0–10, 10–20, 20–40, 40–100 cm soil profile at seeding (May 2, 2007)

Irrigation method	Soil salinity	Soil moisture				Soil pH			
		0–10 cm	10–20 cm	20–40 cm	40–100 cm	0–10 cm	10–20 cm	20–40 cm	40–100 cm
+PAM	0–10 cm	0.355*				-0.116			
	10–20 cm	0.631**	0.436*			0.158	-0.348		
	20–40 cm	0.599**	0.549**	0.452*		0.200	-0.187	-0.025	
	40–100 cm	0.410**	0.502*	0.372	0.194	0.178	-0.050	0.253	-0.166
-PAM	0–10 cm	-0.275				-0.792**			
	10–20 cm	0.145	-0.081			-0.262	-0.588**		
	20–40 cm	0.049	-0.162	-0.335		-0.617**	-0.350	-0.612**	
	40–100 cm	-0.144	-0.271	-0.328	-0.298	-0.508**	-0.200	-0.417	-0.652**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

indicated that declined salt contents in soil profiles with PAM-treated irrigation did not cause significant increases in profile soil pH values.

CONCLUSION

The PAM-treated irrigation, either using well water or desalinized sea ice, combined with gypsum, shows the best practice for soil desalinization from top to deep soil layers, and hence seedling emergence and cotton yields. The desalinized sea ice water used as an alternative water source for crop irrigation in the salinity-affected coastal areas could be effective by using an integrated agronomic practice (such as PAM-treated irrigation combined with gypsum application).

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Molecular characterization of shoots and roots protein contents of salt-stressed barley seedlings inoculated with *Azospirillum brasilense* NO40

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ABSTRACT

The present work was performed to study the effect of inoculation with *Azospirillum brasilense* NO40 on the protein pattern of shoots and roots of the seedlings of two barley cultivars (Giza 123 and Giza 2000) which are known for their different tolerance to salt stress. A greenhouse experiment was conducted to evaluate the effect of this inoculation on the molecular masses of the protein contents of both studied barley cultivars cultivated under 350 mM NaCl through the determination of SDS-PAGE protein profile of shoots and roots. The results showed that the salt stress, bacterial inoculation and the interaction between them resulted in noticed change in the protein patterns of the shoots and roots in all treatments.

INTRODUCTION

Salinity is an increasing problem in many irrigated, arid and semi-arid areas of the world, where rainfall is insufficient to leach salts from the root zone, and it is a significant factor in reducing growth and crop productivity (Ghoulam *et al.*, 2002). Salt stress affects all the major physiological processes in plants such as growth, photosynthesis, protein synthesis, and energy and lipid metabolism (Parida and Das, 2005).

Plants develop a plethora of biochemical and molecular mechanisms to cope with salt stress such as accumulation of nitrogen-containing compounds like proline, activation of the antioxidant defense mechanism and expression of many genes leading to the formation of stress proteins (Sairam and Tyagi, 2004).

In a previous publication (Omar *et al.*, 2006) we found that inoculation with *Azospirillum brasilense* NO40 significantly alleviated the deleterious effects of salinity stress on the photosynthetic apparatus of the two barley cultivars Giza 123 (salt sensitive) and Giza 2000 (salt tolerant), through increased pigment contents, reduced accumulation of the osmoregulator proline, and reduced activities of antioxidant enzymes. However, it was interesting for us to understand the effect of the inoculation with *A. brasilense* NO40 on the formation of stress proteins in plants under salt stress.

The aim of the present work was to study the effect of *A. brasilense* NO40 inoculant on the protein pattern of the shoots and roots of 30 day old seedlings of two barley cultivars, Giza 123 (salt sensitive) and Giza 2000 (salt tolerant) cultivated under salt stress.

MATERIALS AND METHODS

Grains were soaked in water for 24 hr (to accelerate the germination process) before coating with *Azospirillum brasilense* (NO40). Grains were sown in each plastic pot and irrigated every other day with 350 mM NaCl, or with tap water as control, the pots were drained with water once a week. Each treatment was represented by six plastic pots. The seedlings were left to grow for 30 days at 25 ± 2 °C in a relative humidity of 65% and 16 hr photoperiod. From each treatment seedlings were taken and kept frozen in liquid nitrogen till further analysis.

Characterization and molecular mass determination of proteins were carried out using one dimensional SDS-polyacrylamide gel electrophoresis (SDS-PAGE) as described by Laemmli (1970).

RESULTS

The effects of salt stress (350 mM NaCl) with and without *A. brasilense* (NO40) inoculation on SDS-PAGE protein extract of shoot of 30 day old barley seedlings are illustrated in Table 1

The response of expressed proteins to the interaction between the salt stress and the bacterial inoculation was varied among the two cultivars. Shoots of the inoculated salt stressed Giza 123 and Giza 2000 were characterized by the synthesis of 7 kDa polypeptide. The formation of the two polypeptide bands with molecular masses of 68 and 37 kDa was inhibited in the shoots of the inoculated salt stressed Giza 123 plants if compared with the un-inoculated treatments. In cultivar Giza 2000, inoculation with *A. brasilense* (NO40) strain resulted in the disappearance of three polypeptide bands with molecular masses of 37, 21 and 19 kDa in the shoots of the salt stressed plants if compared with the un-inoculated treatment.

As shown in Table 2 the electrophoretic separation of protein extract of roots of 30 day old seedlings of two barley cultivars (Giza 123 and Giza 2000) cultivated under

TABLE 1

SDS-PAGE protein extract of shoots of 30 day old barley seedlings of two cultivars (Giza 123 and Giza 2000) cultivated under 350 mM NaCl with and without Azospirillum brasilense (NO40) inoculation (M=Marker, MM=molecular mass, +=present, --=absent).

M (kDa)	MM (kDa)	Giza 123				Giza 2000			
		Un-Inoculated		Inoculated		Un-Inoculated		Inoculated	
		Control	350 mM NaCl	Control	350 mM NaCl	Control	350 mM NaCl	Control	350 mM NaCl
--	73	+	+	--	+	--	+	--	+
--	70	--	--	+	--	+	--	+	--
66	68	--	+	--	--	--	--	--	--
	62	+	--	--	--	--	--	--	--
--	57	--	--	--	--	+	+	+	+
--	55	+	+	+	+	--	--	--	--
--	52	--	--	--	--	--	--	+	--
45	46	+	+	+	+	+	+	+	+
	40	+	+	+	+	+	+	+	+
--	37	--	+	--	--	--	+	--	--
--	35	--	--	+	--	+	--	+	--
--	32	+	+	+	+	--	--	--	--
29	29	+	+	+	+	+	+	+	+
--	27	+	+	+	+	--	+	+	+
--	25	+	+	+	+	+	+	+	+
--	23	+	+	+	+	+	+	+	+
20	21	+	--	+	--	+	+	+	--
	19	+	+	+	+	--	+	--	--
--	17	--	--	--	--	+	--	--	--
14	14	--	--	+	--	--	+	+	+
--	11	+	+	+	+	+	--	--	--
--	7	--	--	--	+	--	--	--	+
--	5	+	+	--	+	--	+	+	+

TABLE 2
SDS-PAGE protein extract of roots of 30 day old barley seedlings of two cultivars (Giza 123 and Giza 2000) cultivated under 350 mM NaCl with and without Azospirillum brasilense (NO 40) inoculation (M=Marker, MM=molecular mass, +=present, --=absent)

M (kDa)	MM (kDa)	Giza 123				Giza 2000			
		Un-Inoculated		Inoculated		Un-Inoculated		Inoculated	
		Control	350 mM NaCl	Control	350 mM NaCl	Control	350 mM NaCl	Control	350 mM NaCl
--	101	+	+	+	+	+	+	+	+
--	86	+	--	--	--	+	+	+	+
--	81	--	--	--	+	--	--	--	--
--	76	--	--	--	--	--	+	--	+
--	71	+	+	--	--	--	+	--	--
--	69	+	--	+	+	+	--	--	--
66	67	--	+	--	--	--	--	--	+
	65	+	+	+	+	+	+	+	--
--	63	--	--	--	--	--	+	--	--
--	59	--	--	--	--	+	--	--	--
--	55	+	+	+	+	--	+	+	+
--	50	--	+	--	--	--	--	--	--
--	48	+	+	--	+	+	+	+	+
45	45	+	--	+	--	--	--	--	+
--	43	--	--	--	--	--	+	+	--
--	40	--	--	+	+	--	+	--	+
--	37	--	+	+	+	--	+	+	+
--	34	+	--	--	--	--	--	--	--
29	32	--	+	--	--	--	--	--	--
	28	+	+	+	+	+	+	+	+
--	26	+	+	+	+	+	+	+	+
--	24	+	--	+	+	--	+	+	+
--	22	--	+	+	+	+	+	+	+
20	20	+	--	+	--	+	+	--	+
--	19	--	+	--	+	--	--	--	--
--	17	--	--	--	--	+	--	+	--
14	15	--	+	+	--	--	+	--	--
	13	--	--	+	+	+	+	+	+
--	11	+	+	+	+	+	+	+	+

350 mM NaCl revealed that inoculated salt stressed seedling of cultivar Giza 123 was characterized by the presence of a polypeptide band with molecular mass of 81 kDa in the roots. Some new synthesized polypeptide bands with molecular masses of 69, 40, 24 and 13 kDa were formed in the roots of the inoculated salt stressed Giza 123 plants if compared with their corresponding un-inoculated counterparts. On the other hand, some of the polypeptides which where detected in the roots of salt stressed Giza 123 plants as polypeptide bands with molecular masses of 71, 67, 50, 32 and 15 kDa were never formed after the bacterial inoculation in the same treatment. In cultivar Giza 2000 the interaction between bacterial inoculation and salt stress resulted in the synthesis of two polypeptide bands with molecular masses of 67 and 45 kDa polypeptides in the root and disappearance of another polypeptide bands with molecular masses of 71, 65, 63, 43 and 17 kDa in the roots compared with the un-inoculated salt stressed plants.

DISCUSSION

Expression of stress proteins is an important adaptive strategy of environmental stress tolerance. They are highly water soluble and heat stable, associate to cytoplasmic membranes and organelles and act as molecular chaperones. (Wahid and Close, 2006). In the present study it could be demonstrated that stress-protein expression was induced in both shoots and roots in the seedling of barley plants exposed to 350 mM NaCl. The expressed stress proteins were different among the two cultivars, but the molecular mass (MM) of the new formed polypeptide bands in the shoots of both cultivars were usually in the same ranges of molecular mass (MM) which were from 27 kDa to 37 kDa and from 65 kDa to 75 kDa. Similar protein patterns were obtained in the shoots of spring wheat by Ashraf and O'Leary (1999) they found that three new polypeptide bands with molecular mass of 29, 48 and 72 kDa were formed in the shoots of spring wheat cultivated under 125 mM NaCl. The results of the present study also show that salt stress induced the formation of several polypeptides in the roots of the two cultivars. The molecular mass of the formed polypeptides were found to be in the ranges of 30 to 43 kDa and 50 to 76 kDa. These results are in agreement with those reported by Goncalo *et al.* (2003) who found that several new proteins with molecular masses of 35 and 61 kDa were formed in the roots of rice plant during its exposure to 170 mM NaCl. Formation of several polypeptides belonging to HSP family (60–100 kDa) in NaCl and/or heat stress-treated seedlings was confirmed in many crop plants such as wheat, rice and barley (Lee and Vierling, 2000). Grene (2002) demonstrated that sHSPs can protect against oxidative through increasing the antioxidant defense system in the cellular levels. The present results indicated that bacterial inoculation was able to prevent the synthesis of most of the formed stress polypeptides band in shoots and roots of both cultivars under salt stress. It could be demonstrated that the formed polypeptides with molecular masses of 68 and 37 kDa in shoots of cultivar Giza 123 with 350 mM NaCl were inhibited after inoculation with *A. brasilense* (NO40) in the same treatment.

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Data mining on soil salinity analysis

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Soil salinity is considered as one of the most serious environmental problems in arid and semi-arid regions which limit sustainable development. For this reason, the development of early warning systems for monitoring and reducing salinity impacts is an important global issue. The lack of up-to-date and available ground observations necessitated the use of remote sensing images for monitoring. The human mind cannot deal with considering each image individually, analyzing it and understanding its relationships with other images at various time steps. Hence, for solving such problems, issues of processing large sets of remotely sensed data using automatic techniques become important. But the understanding of salinity and the use of appropriate methods for extracting information from available remote sensing data is very important in the processes of automated salinity monitoring. In this study, the main objective was to develop a framework that applies image mining techniques for monitoring soil salinity automatically.

In the developed framework a soil salinity indicator (EC) was used to identify soil salinization from remote sensing data. As the central part of Iran is highly affected by the salinity, this area was selected as a case study during the period of 1989 to 2003. To achieve the objective, freely Landsat ETM+ in dry season (from Jun to September) were acquired between the mentioned time periods. 72 soil surface samples as a representation of the Kavir-Lout plain were collected to measure the surface soil salinity. The high correlation between the collected field data (measured EC) and the remotely sensed data (ETM+ band 3) was expressed by an exponential equation ($y=0.0021 \exp(0.049x+0.04)$) with the correlation coefficient of $R^2=0.63$.

For validation thirty soil samples were used to assess the accuracy of the created soil salinity map. The overall accuracy of soil salinity map was 85% with the Kappa index of 53% which is an acceptable accuracy for this classification. Fuzzy set implemented to overcome the low accuracy of prepared map. For evaluation of the spatio-temporal changes of soil salinity, the obtained equation was applied to band 3 of each Landsat image to create soil salinity maps of different years. To characterize the spatial soil salinity, the identified membership function based on measured EC was applied on the series of TM images. In extraction process, the tracking of salinity objects was facilitated depends on salinity object definition. In this study the definition was kept at pixel-level object. An algorithm has been automated to extract all possible salinity objects from the images. To perform the spatio-temporal analysis of salinity, the salinity objects were traced based on two criteria; intensity and temporal continuity at locations. The consideration of these two criteria in salinity analysis helps to delineate the severity of salinity not only based on intensity but also on duration.

EC by itself does not indicate saline or non-saline soil surface, in the process of understanding salinity from the images the deviation values was calculated to identify the severity of salinity on soil surface as the deviation of current EC values from their corresponding long-term mean EC values. For each location, this deviation was calculated. For validation of the developed algorithm, the outputs were compared with the reports describing salinity on the region and the previous prepared soil salinity maps. The result revealed the proposed framework can be considered as cost and time effective tool in large scale planning for assessment of the spatio-temporal characteristics of soil salinity. The software used in the study were ILWIS 3.3, ArcGIS and PYTHON.

Keywords: data mining, soil salinity monitoring, EC, fuzzy classification.

Global Response to soil and water salinization in agricultural landscapes

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ABSTRACT

The global population is projected to exceed 9.1 billion by 2050 and the food production will need to increase by more than 50% to feed the increased population. As land becomes increasingly scarce, the additional food needs to be produced through crop intensification. In arid and semi-arid regions sustainable management of land and water resources is of concern as a result of crop intensification. Poor irrigation and land management causes widespread soil and water salinity across regions of South Asia, Central Asia, Arabian Peninsula and North Africa and reduced crop productivity and livelihood of rural population. Recent estimates suggest that up to 50% of irrigated land became saline in some of these regions.

This paper focuses on the extent of and response options to soil and water salinization in arid and semi-arid regions. The response options discussed in this paper include integrated soil, water and crop management to prevent further salinization (mitigation) and sustainable use of salt-affected soils and saline water for crop and forage production (adaptation), and principles and practices for using salt-affected soils and saline waters.

Keywords: salinization, arid and semi-arid regions, salt-affected soils, saline water, halophytes.

EXTENT OF SOIL AND WATER SALINIZATION

Currently around 4 million km^2 (3%) of land area has been affected by salinity to various degrees (Figure 1) and most of these salt-affected lands are located in arid and semi-arid regions of the world from North Africa to East Asia, Central Asia and South Asia (FAO, 2006; Corbishley and Pearce, 2007).

It has been estimated that more than 75 Mha of land has been salinized as a result of human induced activities (e.g dryland and irrigation induced salinity) of which more than 50% occurs in irrigated landscapes. On average, 24% of the world's irrigated lands have been salinized as a result of poor irrigation and soil management practices and this figure could reach to more than 50% in Central Asia (Qadir *et al.*, 2009). Such soil salinizations have also impacted water salinization (Vincent and Russell, 2007). About 53% of the global groundwater and 45% of surface water resources in lakes and wetlands have been salinized to some extent (Palaniappan and Gleick, 2009). It is expected that water salinity levels in some rivers will exceed the 800 µS/cm electrical conductivity thresholds for desirable drinking water quality in the next 50–100 years (MDBC, 1999).

Severe declines in crop productivity have been observed on about 24 Mha of irrigated land. Reports showed that salinization (more than 2 500 mg salt/kg soil) affects crop productivity in 28% of irrigated lands in the US, 23% in China, 21% in Pakistan, 11% in India, and 10% in Mexico (Umali,1993).

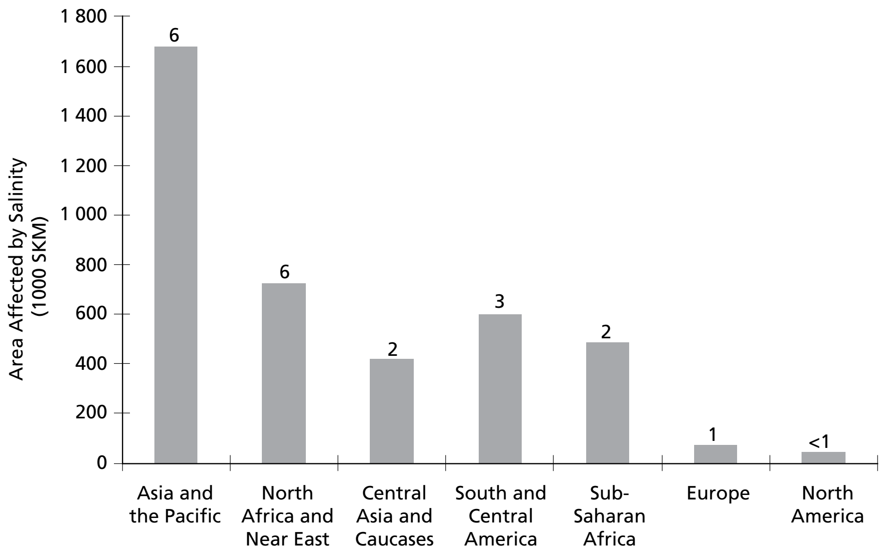

FIGURE 1
Land area affected by salinity in different regions of the world. Numbers on top of the bar represent% area affected by salinity (source: FAO, 2006).

CLIMATE CHANGE AND SALINIZATION

The global climate change accelerates soil and water salinity through the following processes:

- Unpredictable evaporation and transpiration: Climate change alters the evapotranspiration and water balance at the land surface, and changes the groundwater recharge. In shallow aquifers, the groundwater responds to these changes quickly and moves towards the surface bringing salt with it and accelerates soil salinization (Yu *et al.*, 2002).
- Reduction in rainfall: Current best estimates suggest that in arid and semi-arid catchments, a reduction in rainfall due to climate change will result in up to double the reduction in run-off from catchment and river flow. Under such conditions the river salinity will increase as a result of reduced river dilution (CSIRO, 2008).
- Influence of tidal waves: In coastal areas, the risk of soil and water salinization under climate change is even higher because the increased sea level and frequency of tidal waves brings salt water along the river to inland and lost to groundwater making it saline. In low lying areas the salty river water moves to the land surface and causing soil salinization (Nicolls *et al.*, 2007).
- Disconnection between floodplains and rivers: Continuous drought in some arid and semi-arid regions accumulates irrigation driven salt in floodplains. At the end of drought cycle the accumulated salt mobilized and released to river and making the water saline. The process may continue for years and affect environmental assets downstream of irrigated landscapes (Junk and Wantzen, 2003).
- Bangladesh, Indonesia, Egypt, countries in Arabian Peninsula and small island countries and atolls in the Pacific are particularly vulnerable to soil and water salinization as coastal areas of these countries are affected by increased tidal waves (Bindoff *et al.*, 2007).

ECONOMIC IMPACTS OF SALINIZATION

Globally the economic losses due to salinization of agricultural land are estimated at US$11.4 billion per year in irrigated land and US$1.2 billion in non-irrigated areas (Ghassemi *et al.*, 1995). In Australia, the economic losses of soil salinization were estimated at AUS$200 million in 2000 due to losses in productivity and soil quality. These losses are projected to increase to AUS$300 million per year by 2020. The offsite impact (downstream water quality for domestic, recreation and fisheries uses), of salinization cost around AUS$90 million in 2000 and projected to increase to AUS$150 million per year by 2020 (NLWRA, 2000). For Colorado River Basin in USA, the estimated damage due to salinity run up to US$300 million per year. The total annual cost of crop losses from salinity in Pakistan has been estimated between 270 and 960 million dollars (Corbishley and Pearce, 2007). This is in addition to the 270 million dollars estimated to have been lost from the land that has been rendered unproductive (Corbishley and Pearce, 2007). Of the one Mha of land affected by irrigation induced salinity in North-west India about 50% is located within the State of Haryana and the annual losses in land productivity due to salinity, its associated impact on soil structural degradation and the subsequent influence on waterlogging was estimated at US$39 million in this region alone (Datta and de Jong, 2002).

RESPONSE OPTIONS FOR ADDRESSING SOIL AND WATER SALINITY

Soil and water salinity can be addressed through improved irrigation and agronomic practices that reduce further salinization (mitigation) and the sustainable use of salt-affected soils and saline water to grow salt-tolerant crops and forage (adaptation).

MITIGATION

To control soil salinity in irrigated agriculture, it is essential that water application is controlled and reduced based upon the crop water demand. Accurate irrigation scheduling based on soil water monitoring using sensor technologies improves crop irrigation efficiency, soil water storage and control salinity (Howell, 1996).

The following seasonal management of water depth through correct irrigation scheduling and appropriate drainage system can help reduce soil salinization (Fang and Chen, 1997): (1) the water depth is maintained between 2 and 3 m during dry seasons to prevent salt accumulation in surface soil, (2) it is maintained between 4 and 6 m to increase rainwater storage and recharge before rainy seasons, and (3) during the rainy season the water depth should be kept between 0.5 and 1.0 meter to allow the excess rain water to drain within two days.

Permanent raised bed technology can be used to reduce soil salinity. This technology has the potential to improve crop productivity (10–30%), reduce irrigation water requirement (20–40%) and lower the risk of groundwater recharge (Akbar *et al.*, 2007).

Improved soil management practices including reduced tillage, incorporation of crop residues, gypsum and manure application, crop rotation and growing cover crops increase soil organic matter, soil water holding capacity and infiltration, and remove sodium from cation exchange sites and the subsequent removal of sodium from upper soil layer through leaching (Zhang *et al.*, 2005).

Depending upon the climate, hydrology, economic and social conditions many different approaches can be combined to provide satisfactory management practices that reduce further salinization of soil. Key management principles include: (1) manage soil and water for preventing further increase in soil salinity levels, and (2) manage crop under saline conditions.

Important considerations for soil water and crop management include:

- ➢ Construction of appropriate drainage systems to remove excess water from soil;
- ➢ Occasional leaching of salt from crop rooting zone with freshwater or low saline water;
- ➢ Alternate use of saline water with freshwater; and
- ➢ The irrigation type, scheduling and intensity that minimise water stress in crop rooting zone.
- ➢ Information on soil, water and salinity within the crop rooting zone, plant growth and salinity of drainage water need to be obtained periodically to identify problem areas and to monitor the effectiveness of management practices
- ➢ Growing suitable salt-tolerant crops, managing seedbeds and grading fields to minimise local accumulation of salts.
- ➢ Selection of appropriate crop genotypes and planting procedures for satisfactory yield under existing and predicted saline conditions are important.

Isotopic and nuclear techniques play an important role in monitoring the performance of technologies and management practices.

ADAPTATION

Worldwide a number of regions and individual countries have been using saline water for irrigation, including the USA, Australia, North Africa (Egypt and Tunisia), South Asia (India, Pakistan and Bangladesh), Arabian Peninsula and Central Asia. In some countries water with salinity up to 6 000 mg total dissolved solids (TDS) per litre of water have been successfully used for crop production (Table 1).

TABLE1
Saline water irrigation and crop produced for selected countries/regions.

Country	Crop grown	Salinity of water used (mg TDS/l water)	Reference
United States of America	cott, sugar beet, small grains and alfalfa	6 000	Kaffka *et al.*, 2005
Australia	Rice, wheat and sub clover	3 000	Thompson *et al.*, 1997
India	Rice and wheat	5 000	Boumans *et al.*, 1988
Israel	Cott	5 600	Bustan *et al.*, 2004
Tunisia	Date palm, sorghum, barley, alfalfa, rye grass and artichokes	5 000	Stenhouse and Kijne, 2006
Egypt	Rice, Clover, barley, cotton and squash	4 000	Rady, 1990
Central Asia	Cotton and wheat	2 500	Toderich *et al.*, 2008

Salt-tolerant plants and halophytes (salt-loving plants) respond differently to water salinity levels compared to salt-sensitive crops (Figure 2). The IAEA through its Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and other International Research Centres (e.g. IWMI, ICARDA, ICRISAT, ICBA) have been involved in promoting successful technologies using an integrated approach that combines better soil and water management practices together with salt tolerance crops and halophytes.

The IAEA inter-regional model project involving Morocco, Algeria, Tunisia, Egypt, Jordan, Syria, Iran, United Arab Emirates and Pakistan for a period of 10 years has (1) demonstrated that long-term sustainable production from salt-tolerant plants growing in saline (up to 6 000 mg/l) waters and salt-affected (up to 10 600 mg/kg) soils, and (2) developed capacity of Member States on the use of isotopic and nuclear techniques to assess and monitor soil and water salinity.

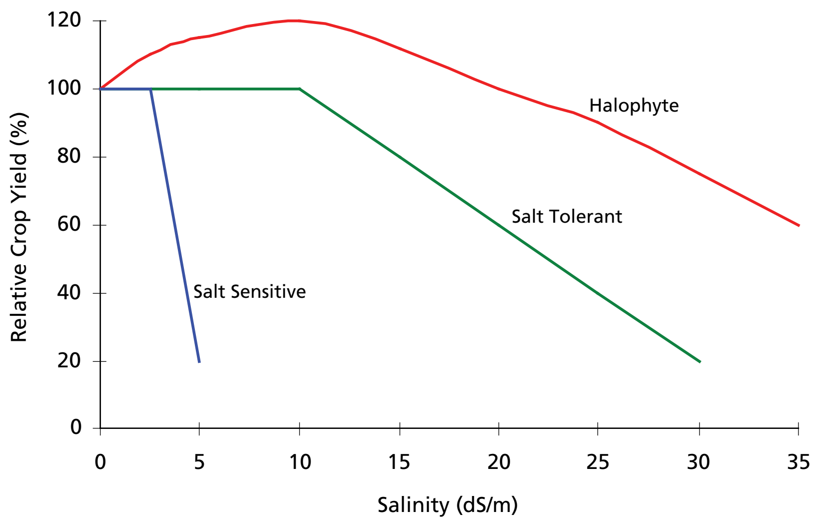

FIGURE 2
Growth response to salinity by salt sensitive, salt-tolerant and halophytes plants.

The IAEA through the Soil and Water Management and Crop Nutrition sub-programme is currently using ^{18}O, ^{2}H, ^{15}N, ^{32}P and soil moisture neutron probe to assess water movement and its relationship to nutrient (nitrogen), soil and water salinity.

The ICBA is currently involved in promoting the use of salt-affected soils and saline waters by providing technologies and methodologies for growing halophytes in Central Asia, North Africa and West Asia. Field trials conducted in Central Asia, South Asia, North Africa and the Arabian Peninsula showed adaptation of forage crops including sorghum, pearl millet, and fodder beet (Kushiev *et al.*, 2005; Toderich *et al.*, 2008). Varieties of pearl millet (for forages and seed production) and alfalfa have proved to be far better than all local genotypes in Central Asia and Arabian Peninsula. Kallar grass has been adapted to high (5 700 mg/l) saline conditions in Pakistan.

CONCLUSIONS

A number of countries in arid and semi-arid regions have been affected by soil and water salinity and the global climate change is expected to accelerate this salinization. Soil and water salinization can be addressed through both mitigation and adaptation. Reducing the extent of soil and water salinization include improved irrigation and agronomic practices. The use of salt-affected soils and saline waters for agriculture is important for many countries in arid and semi-arid regions as there are not enough freshwater resources available to meet the agricultural water requirements and part of arable land is saline. A multi-country regional programme to exchange technologies and methodologies for germplasm development and testing for halophytes is important for food security and poverty alleviation. Transfer of technologies and methodologies of ICBA in planting perennial and annual halophytes are a new approach that should be tested in many countries that have been affected by soil and water salinity.

With economically useful plants are grown on salt-affected soils using saline water, more food and feed can be made available globally and abandoned land re-used because the soil that has become saline can be put in to use.

Crop diversification under saline soil conditions sustains agricultural productivity in salt-affected lands and will improve profit for farmers. The introduction of new species and varieties of forage crops, grasses and legumes are important for the restoration of salt-affected soils.

Monitoring soil and water salinities within and beyond crop rooting zone under irrigation is important for both mitigation and adaptation to identify the performance of new technologies and management practices.

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Progress towards DSS-SALTIRSOIL: monthly calculation of soil salinity, sodicity and alkalinity in irrigated, well-drained lands

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ABSTRACT

The development of a decision support system (DSS) based on SALTIRSOIL for the precise management of irrigation water, crop and soil in agricultural lands under risk of salinization, sodification and alkalinization needed SALTIRSOIL to be able to calculate soil salinity, sodicity and alkalinity at monthly intervals. The new monthly SALTIRSOIL model has been developed and validated in three citrus orchards in the Almenara irrigitation area in Valencia (Spain). Comparison of simulations and measurements of electrical conductivity and sodium adsorption ratio in the saturation extract and pH in the saturated paste indicated the SALTIRSOIL is able to give reliable predictions of soil salinity, sodicity and alkalinity when the soil drainage is not impeded. Furthermore, the SALTIRSOIL model gives these reliable predictions in a cost-effective way because only a few basic water quality, climate, soil, crop and irrigation management information data are required to run the model.

Keywords: soil salinity, agriculture, modelling.

DESCRIPTION OF THE SALTIRSOIL MODEL

The assessment of water quality for irrigation purposes under risk of salinization is widely performed, either explicitly or implicitly, through the use of Soil-Vegetation-Atmosphere-Transfer (SVAT) models. SVAT models can be classified as steady-state or transient, being UNSATCHEM (Suarez and Simunek, 1997) and WATSUIT (Rhoades and Merrill, 1976), respectively, paradigmatic examples of each class. Steady-state models, though simpler than transient, are regarded as valid enough for most cases, mostly when precipitation and dissolution reactions such as calcite and gypsum equilibria are taken into account in the model development (Corwin *et al.*, 2007). This is true for WATSUIT, which use and application to the farm level was presented by Rhoades *et al.* (1992) in the FAO Irrigation and Drainage Paper 48. This latter contribution adequately supplemented the guidelines for water quality assessment in agriculture by Ayers and Westcot (1985) in the previous FAO Irrigation and Drainage Paper 29. As WATSUIT, SALTIRSOIL (SALTs in IRrigated SOILs) is a deterministic, static and functional (capacity-type) process-based model for the prediction of soil salinity, sodicity and alkalinity in irrigated well-drained lands (Visconti *et al.*, 2006). The SALTIRSOIL model development started from the model concepts used in WATSUIT, and then, it has expanded its calculation capabilities trying to attain the maximum accuracy using available, or if not, at least affordable water, climate, soil and crop data. This has been carried out by the inclusion of i) a detailed conceptualization of irrigation and crop management practices such as crop rotations, monthly irrigation schedulings, etc, ii) the FAO model for evapotranspiration assessment (Allen *et al.*, 1998), iii) new algorithms for water stress coefficient assessment and iv) new developments in electrical conductivity calculation, and all integrated with an easy-to-use graphical user interface (GUI).

The SALTIRSOIL yearly model has been described previously (Visconti, 2009; Visconti *et al.*, 2010a). Here the SALTIRSOIL monthly model, from now on the SALTIRSOIL, will be outlined.

SALTIRSOIL calculates the monthly major inorganic ion composition and electrical conductivity at 25 °C of the soil solution at saturation, field capacity, field moisture and of the drainage water. SALTIRSOIL is composed of two primary modules (Figure 1).

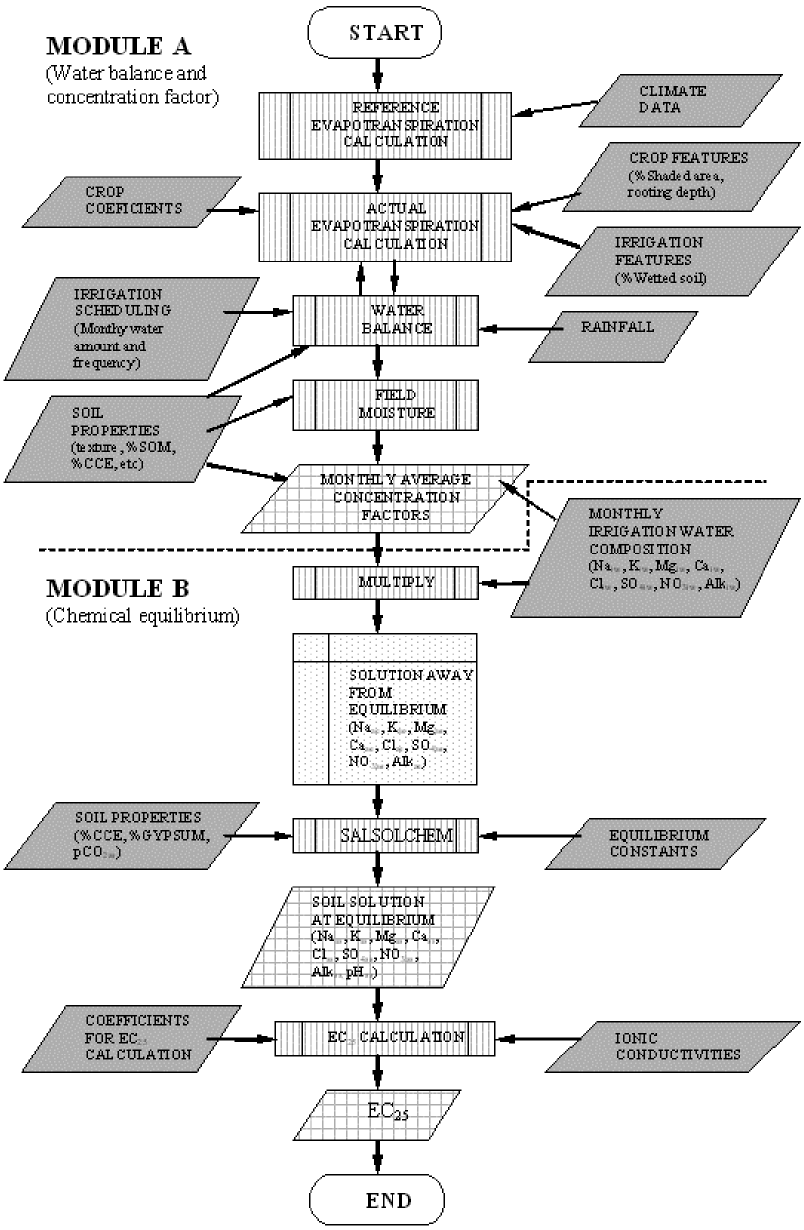

FIGURE 1
Flowchart of the monthly SALTIRSOIL.

Module A calculates the soil water balance and as a consequence the relative concentration of the soil solution at field moisture with regard to the irrigation water. This variable, called the concentration factor at field moisture (f_{FM}), is an average value calculated from the soil surface to the specific soil depth chosen by the user. From this factor, the soil water content at field moisture, at field capacity and at saturation, the concentration factors at field capacity and at saturation are calculated (f_{FC}, f_{SE}). The concentrations of the major inorganic ions in the irrigation water are multiplied by these concentrations factors and the composition of a solution away from equilibrium is obtained. This composition along with three chemical soil properties namely: percentage of calcium carbonate equivalent (%CCE), gypsum (%Gypsum) and soil solution carbon dioxide partial pressure (log pCO_2) are the input to a chemical equilibrium module called SALSOLCHEM (SALine SOLution CHEMistry). This calculates the major inorganic ion concentrations at equilibrium. Finally, the electrical conductivity at 25 °C is calculated from this composition using the equation developed by Visconti *et al.* (2010b).

The monthly SALTIRSOIL model has been programmed in Visual Basic 2005 and runs in a Microsoft Windows© environment. The data required by the model is organized in a database in Microsoft Access© in several tables according to the type of data required: water quality, irrigation management, climate, soil and crop. Once the data has been set up the software is called from the Windows menu and a user-friendly GUI from which the application is managed is displayed (Figure 2 and Figure 3).

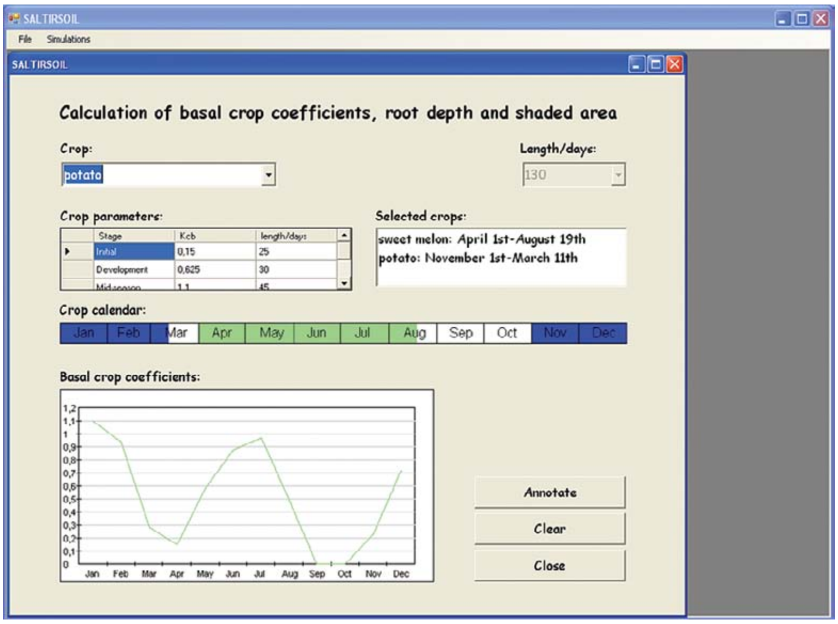

FIGURE 2

SALTIRSOIL form where the user sets up a crop rotation, e.g. sweet melon and potato.

SCALE OF APPLICATION AND EXAMPLES OF AREAS WHERE SALTIRSOIL HAS BEEN USED

Study area

The SALTIRSOIL model has been used for the monthly calculation of electrical conductivity, and sodium adsorption ratio in the saturation extracts (EC_{se} and SAR_{se} respectively) and pH in the saturated pastes (pH_{sp}) of three citrus plots, namely S3, S4 and S5 located in the lower Palància river basin in Valencian Community near

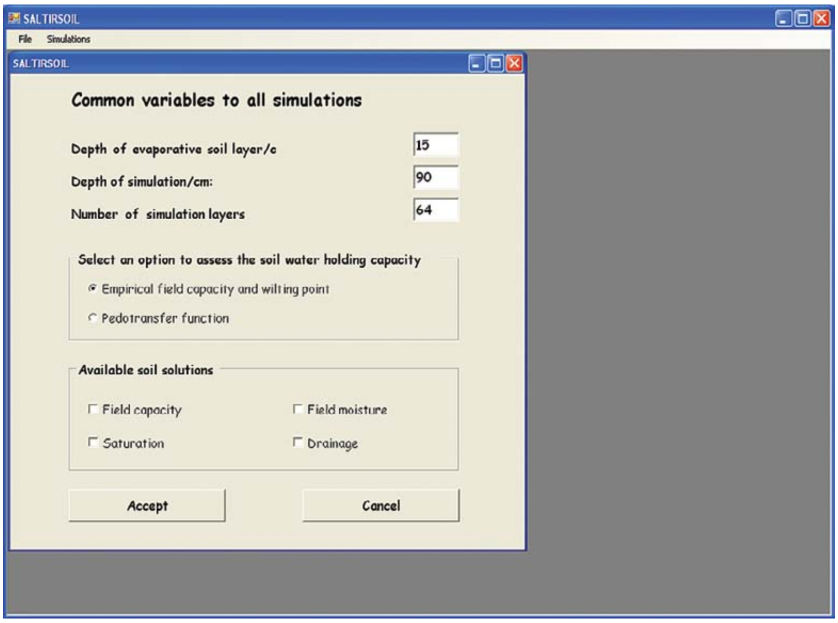

FIGURE 3
SALTIRSOIL menu where the user sets up the simulation parameters.

the Mediterranean coast of Spain (Figure 4). The climate is characterised by high evapotranspiration (~ 1000 mm yr^{-1}) and low rainfall (~ 500 mm yr^{-1}). Irrigation is applied using drip (S4 plot) or surface systems (S3 and S5 plots). The electrical conductivity of the irrigation water varies from low to medium (1–2 dS/m). The experimental plots have been cultivated to grow citrus for a long time. The soil texture is a clay loam (USDA) that has medium amounts of organic matter and high of calcium carbonate.

The experimental plots were sampled from April to November of 2008 at two points: in the surface irrigated plots one near the irrigation water inlet to the plot and another point opposite this downgradient, in the drip irrigated plot the points were randomly located close to emitters. Each point was sampled at three depths: 0–10, 10–30 and 30–60 cm. Soil and water samples were analysed according to validated methods.

Layer-thickness weighted averages ($O_{0\text{-}60}$) for each one of the properties (EC_{se}, SAR_{se} and pH_{sp}) were calculated in each one of the points using Equation 1, where $O_{0\text{-}10}$, $O_{10\text{-}30}$ and $O_{30\text{-}60}$ are their values in the samples from the 0–10, 10–30, and 30–60 cm soil layers,

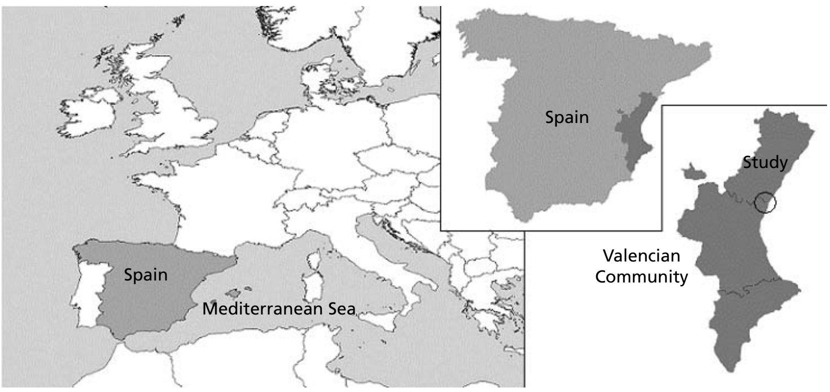

FIGURE 4
Location of the experimental plots.

respectively. The measurements from the two points in each plot were then averaged again to obtain monthly values for EC_{se}, SAR_{se} and pH_{sp}:

$$O_{0\text{-}60=}(O_{0\text{-}10} + 2\ O_{10\text{-}30} + 3\ O_{30\text{-}60})/6 \qquad (1)$$

Soil salinity simulations

The saturation extract composition in the experimental plots was simulated with SALTIRSOIL using the information shown in Boxes 1 and 2. The information for the soil solution concentration factor calculation is shown in Box 1, while the information for the calculation of the final composition in equilibrium with CO_2, calcite and gypsum is shown in Box 2.

BOX 1

Input information for the soil solution concentration factor calculation in 2008

Weather from Benavites SIAR station:

Rainfall of 507 mm yr^{-1}

Reference evapotranspiration of 961 mm yr^{-1} calculated according to Penman-Monteith (Allen *et al.*, 1998)

Irrigation:

Application

Method: surface (S3 and S5) and drip (S4)

Wetted soil: 65, 20 and 90% for S3, S4 and S5 respectively

Quantity and frequency (number of days a month):

Plot	month	Mar	Apr	May	Jun	Jul	Aug	Sep
S3	mm	0	73	0	56	93	118	49
	Freq.	0	1	1	1	1	2	1
S4	mm	40	52	0	38	66	85	33
	Freq.	20	24	0	20	31	31	16
S5	mm	0	100	60	100	100	120	60
	Freq.	0	1	1	1	1	2	1

Water quality: Average compositiona of the irrigation waters during 2008:

Plot	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	NO_3^-	SO_4^{2-}	Alk	EC_{25}	pH
S3 & S5	6.6	0.2	8.4	4.2	13.6	3.6	5.9	4.5	2.87	7.42
S4 b	1.1	1.1	4.5	1.8	2.2	6.7	7.1	-3.3	2.49	2.54

[a] Ion concentrations in mmol L^{-1}, alkalinity in meq L^{-1} and EC_{25} in dS m^{-1}.
[b] Fertigated water.

Crop:

Basal crop coefficients for citrus (Ferrer and Catalan, 2007):

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kcb	0.62	0.63	0.59	0.52	0.59	0.65	0.75	0.70	0.80	0.69	0.60	0.62

Maximum shaded soil: 23, 41 and 53% for S3, S4 and S5 respectively

Maximum rooting depth: 60, 80 and 80 cm for S3, S4 and S5 respectively

Water uptake pattern within the rooting depth: 40:30:20:10*

BOX 1 *(continued)*

Input information for the soil solution concentration factor calculation in 2008

Soil:

Properties:

Plot	Layer/ cm	θg_{sat}/ g g^{-1}	θv_{fc}/ mm mm^{-1}	θv_{wp}/ mm mm^{-1}	ρ_{fc}/ g cm^{-3}	CCE (%)	SOM (%)
S3	0-10	0.400	0.369	0.152	1.27	39.7	4.4
	10-30	0.449	0.332	0.179	1.55	51.4	3.1
	30-60	0.443	0.384	0.183	1.82	46.7	0.5
S4	0-10	0.493	0.388	0.163	1.16	41.6	4.9
	10-30	0.509	0.349	0.167	1.13	42.2	2.5
	30-60	0.578	0.361	0.195	1.10	61.0	4.1
S5	0-10	0.462	0.318	0.161	1.16	40.1	5.7
	10-30	0.457	0.292	0.174	1.43	47.5	5.2
	30-60	0.440	0.342	0.179	1.70	56.6	2.6

Other properties
Ste percentaje: < 5%
Gypsum: < 0.1%

* Percentage of soil water taken by the plant roots from each quarter of the rooting depth from top to bottom

BOX 2

Input information for the chemical equilibrium calculation

Chemical equilibrium constants:
Ion association constants: Lindsay (1979)
Calcite solubility product (pKs): 8.29.
Gypsum solubility product (pKs): 4.62.

CO_2 partial pressure in equilibrium with the solution in the saturated soil paste after 4 hours: 1.6 10-3 atm

Comparison of simulations and measurements of EC_{se}, SAR_{se} and pH_{sp}

The measurements of EC_{se}, SAR_{se} and pH_{sp} were graphed against the sampling dates and compared to monthly simulations (Figure 5). In the three plots the simulated EC_{se} presented a minimum in winter, next it gradually increased during the irrigation season until it reached a maximum in the late summer; afterwards it decreased during the rest of autumn and early winter. During the irrigation season, which takes place since April until September, the tendency in the simulations was more or less followed by measurements with some remarkable exceptions. In the S3 and S4 plots the simulations were on average 19% and 8% less than the measurements. In both plots the measured EC_{se} was characterized by an early summer maximum. This was caused by fertilization, and its sharper shape in the S4 plot was because of the lower salinity of the irrigation water in this plot and because of the fertigation practices.

In the S5 plot the EC_{se} simulations almost matched the measurements during the irrigation season: the average simulated EC_{se} was 1.78 dS/m while the average measured EC_{se} was 1.72 dS/m. However, a peak in the EC_{se} was observed in the early autumn in the S5 plot. This peak matched the rainfall as it is shown in Figure 6. This suggested that in some zones in this area the autumn rainfalls could raise the water table preventing the soils from being effectively drained mostly during the early post-irrigation season (October), when large amounts of drainage water are usually produced as we know from the water balance simulation of the S5 plot for 2008 (Figure 7).

The shape of the curve of the simulated SAR_{se} against sampling date throughout the year matched the shape of the same curve for EC_{se}. Like the simulated EC_{se} the simulated SAR_{se} presented a minimum in winter and a maximum in the late summer. Nevertheless, in the case of SAR_{se} simulations and measurements were in general closer for every plot. Moreover, this was true not only during the irrigation season but also in the early autumn, and particularly in the flood irrigated S3 and S5 plots. In the S3 and S5 plots the average measured SAR_{se} from April to November was 1.42 and 1.46 $(\text{mmol L}^{-1})^{1/2}$ respectively, which were very similar to the simulated SAR_{se}: 1.36 and 1.47 $(\text{mmol L}^{-1})^{1/2}$, respectively. On the drip fertigated S4 plot the measurements of SAR_{se} were significantly less than in the other two plots. The simulations of SAR_{se} were also significantly lower, but much more: the average measured SAR_{se} was 0.65 $(\text{mmol L}^{-1})^{1/2}$, whereas the average simulated SAR_{se} was 49% less, i.e. 0.33 $(\text{mmol L}^{-1})^{1/2}$.

The simulated pH_{sp} hardly fluctuated throughout the year. This is because the carbon dioxide partial pressure is overwhelmingly the most influential variable in the pH calculation according to the preliminary global sensitivity analysis of SALTIRSOIL (Visconti *et al.*, 2010c), and the same value of log pCO_2 was used for every month. The average simulated pH values for the irrigation season and early autumn were 7.79, 7.72 and 7.78 for the S3, S4 and S5 respectively plots, which are equal within two significant figures to the measured values of 7.74, 7.76 and 7.74.

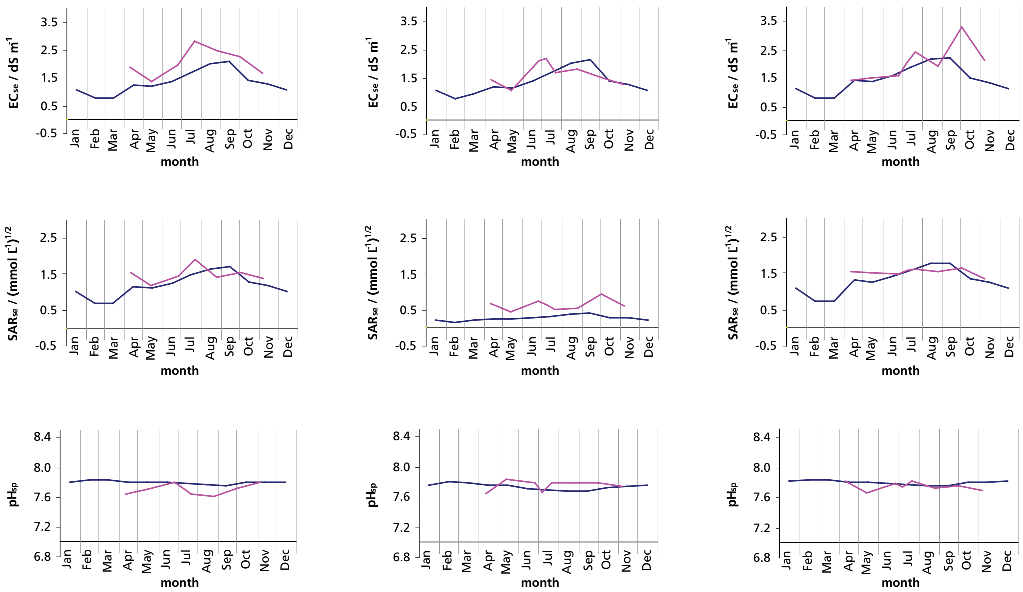

FIGURE 5

Measured and simulated monthly electrical conductivity and sodium adsorption ratio in the saturation extracts (ECse and SARse) and pH in the saturated pastes (pHsp) in each plot.

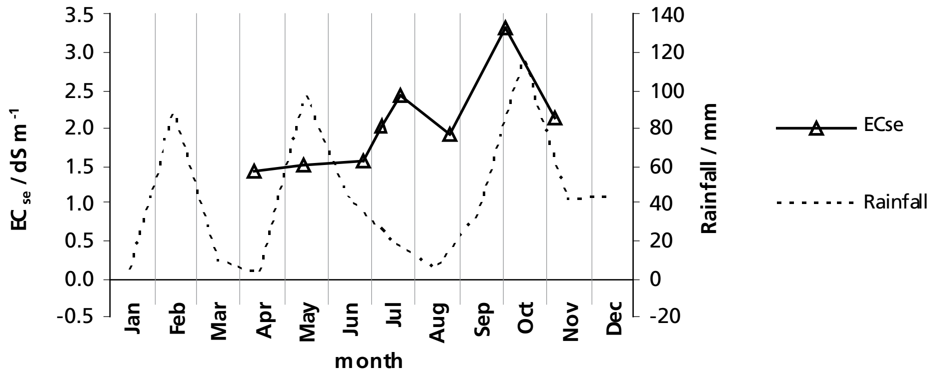

FIGURE 6
Electrical conductivity of the saturation extract against the sampling date and rainfall against month.

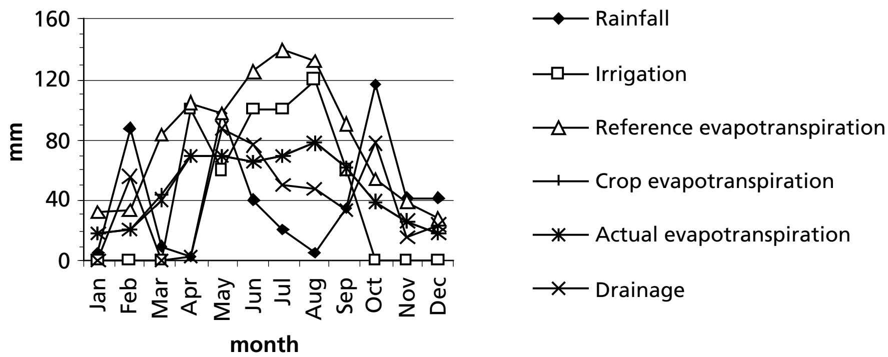

FIGURE 7
Soil water balance for the S5 plot simulated with SALTIRSOIL.

ADVANTAGES OF THE SALTIRSOIL MODEL

Nowadays, there are many models for soil salinity simulation. Practitioners' selection of a model is usually oriented by criteria based on the simultaneous maximization of applicability and reliability (Shaffer and Delgado, 2001). Data requirements are one of the primary criteria to evaluate model applicability. There are models low data-demanding, which are used as screening tools. These models often give coarse predictions of soil salinization risk, usually expressed in an ordinal scale: low, slight, moderate, etc. On the other hand there are models highly data-demanding, which are primarily research oriented. These models are able to give detailed predictions of ion concentrations horizontal and vertically in the soil and along time. These predictions so detailed are not usually needed in land evaluation for soil salinity risk assessment. In fact, whether such detailed predictions were made, they would have to be averaged over soil depth and time to obtain data useful to make decisions. The main advantage of SALTIRSOIL is that it has been devised to maximize the quotient of reliability to data requirements, i.e. the SALTIRSOIL project is aimed at designing a model able to give the most possible accurate predictions of soil salinity using information available through regular land survey and analyses. From the beginning of its development SALTIRSOIL has been subjected to sensitivity and rigorous validation analyses which credit a high enough reliability as it has been shown in the previous section. Another advantage of SALTIRSOIL is its GUI, which allows a rapid learning of SALTIRSOIL.

COSTS OF USING THE SALTIRSOIL MODEL FOR ASSESSING SOIL SALINIZATION

The yearly version of SALTIRSOIL is already downloadable through the website: http://www.uv.es/fervisre/ at no cost. The monthly version of SALTIRSOIL will be soon available.

NEEDS/COSTS RELATED TO THE APPLICATION OF SALTIRSOIL AT DIFFERENT SCALES

The only costs for the application of SALTIRSOIL at plot scale are those derived from its data requirements, which are listed in Table 1. For the costs of application at regional scale see the contribution entitled "GIS-SALTIRSOIL a new tool to evaluate and modelling soil salinity at regional scale: an application to evaluate the climate change effect in an irrigated salinity risk area".

TABLE 1
Minimum and optimum data requirements necessary to simulate the monthly soil salinity, sodicity and alkalinity with the SALTIRSOIL model using pedotransfer functions for soil water content assessment

Class	Variable (abbreviation)/units	Number of data		Observations
		minimum	optimum	
Climate	Monthly rainfall amount (R)/mm month^{-1}	12	12	
	Monthly reference evapotranspiration (ET_0)/mm month^{-1}	12	12	a
	Monthly frequency of rainfall (fR)/day month^{-1}	12	12	
Soil	Clay content (clay)/g (100g)$^{-1}$	1	6	b
	Sand content (sand)/g (100g)$^{-1}$	1	6	b
	Ste content (ste)/g (100g)$^{-1}$	1	6	
	Calcium carbonate content (ECC)/g (100g)$^{-1}$	1	6	
	Soil Organic Matter content (SOM)/g (100g)$^{-1}$	1	6	b
	Gypsum content (gypsum)/g (100g)$^{-1}$	1	6	
	Carbon dioxide in saturated paste (log pCO_2)	1	6	
Crop	Root depth (RD)/cm	1	6	
	Basal crop coefficient (K_{cb})	4	12	c
	Maximum percentage of shaded soil (SS)	1	1	
Irrigation management	Irrigation water amount (I)/mm month^{-1}	4	12	c
	Frequency of irrigation (fI)/day month^{-1}	4	12	c
	Percent of wetted soil (WS)	1	1	
Water quality	Irrigation water composition (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, alkalinity)	8	96	d
TOTAL		**66**	**218**	

a. Monthly ET0 can be assessed within SALTIRSOIL using basic climate information through several methods such as Penman-Monteith, Blaney-Criddle, Hargreaves and Thornthwaite.
b. Clay, sand and SOM can be substituted by the soil water content at saturation, field capacity and wilting point.
c. One datum for each month (12 data) or one for each crop stage (4 data).
d. The year average water composition can be used for every month, i.e. a minimum of 8 data.

ACKNOWLEDGEMENTS

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GIS-SALTIRSOIL: a new tool to evaluate and modelling soil salinity at regional scale; an application to evaluate the climate change effect in an irrigated salinity risk area

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ABSTRACT

Soil salinization in irrigated areas is a soil degradation process that affects both crop productivity and environment. It is predicted that climate change could affect the precipitation pattern and/or increase the average temperature at the Mediterranean region. This new scenario can be simulated with the SALTIRSOIL model to know the effect of climate change in soil salinization. This model was fully integrated within a Geographical Information System (GIS) framework to extend its applicability to the whole irrigation area of Segura and Vinalopo lowland (Spain). Three scenarios were simulated to evaluate the climate change effect in soil salinity: i) non-climate change ii) with climate change iii) same conditions as scenario ii but with an increase of 20% in irrigation rates. A total increase of 28% in soil salinity was simulated when comparing the current climatic conditions with the climate change scenario. An increase of 50 hm^3 of irrigation water could practically offset the effect of climate change in soil salinity.

Keywords: salinity, climate change, model, GIS.

DESCRIPTION OF THE GIS-SALTIRSOIL

SALTIRSOIL (SALTs in IRrigated SOILs, Visconti *et al.,* 2006) is a simulation model able to predict the annual average value of the electrical conductivity, and the ionic components of soil solution in irrigated soils. This model was programmed in Visual Basic.net language. The SALTIRSOIL model was calibrated and validated for several crops and irrigation systems (drip, surface irrigation) (Visconti *et al.,* 2009). Several modules were developed to simulate the water balance and salt concentration factor, and for chemical equilibrium of soil solution at several soil water contents. The yearly SALTIRSOIL was integrated in a GIS framework using the ARCGIS developer engine tool, and new modules to interact between the model and the GIS-database were designed for full integration of the model.

The GIS-SALTIRSOIL model requires information associated to several maps to input to the model. These maps were elaborated and combined to yield a base map with all the information spatially distributed in which run the model at regional scale. These maps are:

- Soil. This map was elaborated from a soil survey in the area in which more than 40 points were sampled and analyse the main characteristics in the lab.
- Climate. The Precipitation/ETP aridity indicator was interpolated using kriging techniques to elaborate this map.

- ➢ Crop distribution. A combination of GIS-citrus and Land use map was used to elaborate this map.
- ➢ Irrigation water quality. Irrigation administrative delimitation was provided by the public institution responsible of the water supply in the region (Confederación Hidrográfica del Segura, CHS)

A graphic user interface (GUI, Figure 1) was designed and implemented in the system to manage the GIS-SALTIRSOIL friendly. Several menus, option butts, listboxes and comboboxes were included in the GUI to manage the map display (zoom), to access the database, make selections, to elaborate printable maps etc. Thanks to this GUI a non-expert user can manage the system to perform the simulations, display the map results, add new maps, measure tools, zoom, and query the attribute database where the simulation results and the input data are stored. In Figure 1 the main menu of the GIS-SALTIRSOIL linkage is shown. A database structure was designed to store the main attribute data associated to the maps. Soil, climate, water quality, crop parameters (crop coefficients, irrigation frequency etc.), equilibrium chemical parameters, model input and output data are stored in this database linked to the maps.

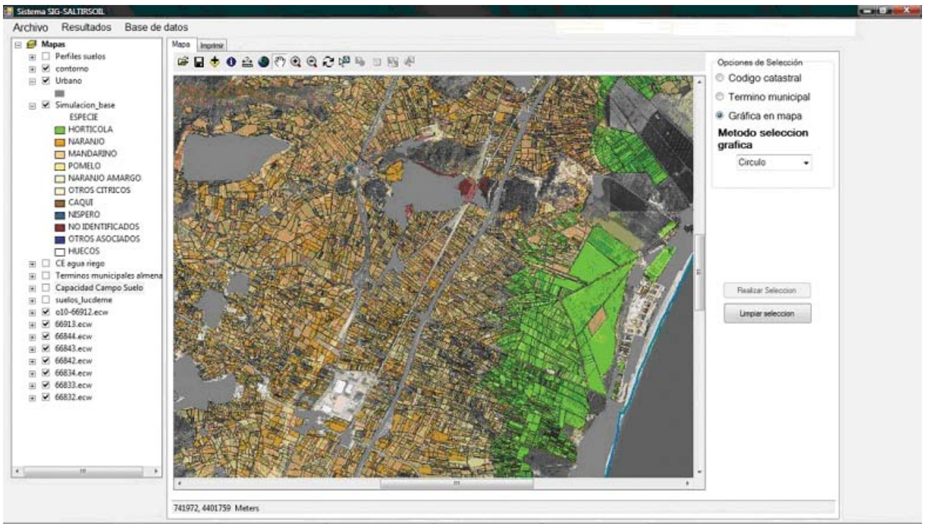

FIGURE 1
Main menu of the Graphical User Interface (GUI) of the GIS-SALTIRSOIL linkage.

SCALE OF APPLICATION AND AREA WHERE THE GIS-SALTIRSOIL HAS BEEN USED

The GIS-SALTIRSOIL version has been used to simulate several scenarios included the climate change scenarios, within the Segura and Vinalopo lowland in Valencia Community (Figure 2).

The irrigated area of this zone occupies 74 000 ha, and 80% of the soils in the irrigated area are salt-affected (de Paz *et al.*, 2010). Farmers use several irrigation water supplies with significant differences in salt contents (Visconti 2009), from good quality such as the Tajo-Segura transfer with a constant EC_{25} of 1.1 dS/m, to worse quality water such as the agricultural return flows, or several groundwaters with an EC_{25} sometimes higher than 8 dS/m. Other irrigation water supplies are the Segura River with an EC_{25} that can reach 3.9 dS/m, and treated waste water with a variable EC_{25} from 2.2 to 3.5 dS/m. The main irrigated crops are citrus (lemon, orange, mandarine), which

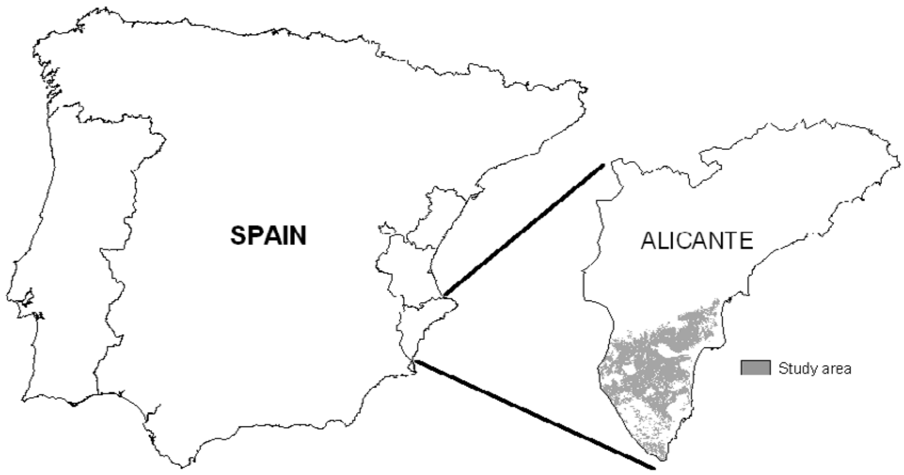

FIGURE 2
Area where the GIS-SALTIRSOIL has been applied to evaluate the climate change effects in soil salinity.

occupy 63% of the area, and vegetables such as Broccoli (*Brassica oleracea* var. *italica)*, artichoke (*Cynara scolymus* L.), lettuce (*Lactuca sativa* L.) and melon (*Cucumis mello* L.), which accounts for 13% of the irrigated area. The average annual precipitation and Penman-Monteith reference evapotranspiration (± 95% confidence interval) within the period 2000–2006 was 280 ± 40 mm and 1210 ± 60 mm, respectively, indicating a semi-arid climate with an important water deficit.

This system GIS-SALTIRSOIL allows us to evaluate the effect of climate change in the soil salinization of the irrigated area regionally. In this work we consider the following three scenarios:

- Scenario 1: With no climate change and the average current climatic conditions were simulated.
- Scenario 2: With climate change in which changes of temperature and precipitation were considered in agreement to the predictions carried out by Giannakopoulos *et al.* (2009) for the Spanish Mediterranean region in the period 2030–2060 using the Hadcm3 model (Table 1).
- Scenario 3: The same scenario than 2, but with an increase of 20% of the irrigation rates to mitigate the effect of climate change in the irrigated crops.

TABLE 1
Projections simulated by Hadm3 model for climate change in seasonal temperature and precipitation for the 2030–2060

Scenario	ΔTemperature (°C)				ΔPrecipitation (%)			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
A2-B2	+1.5	+2.0	+1.5	+1.5	-15%	-20%	+5%	+5%

ADVANTAGES AND APPLICATION OF THE GIS-SALTIRSOIL LINKAGE

The use of the GIS-SALTIRSOIL tool allows us to evaluate and analyse the future effect of climate change in soil salinity in large areas with just a reduced cost in time and human efforts. This system is able to model likely scenarios under climate change and evaluating the effect in soil salinity of irrigated areas. In addition, the system is able to assess the chemical composition of the salts, leaching fraction, salt concentration factor and other useful information about salt accumulation on soil for several scenarios. All this information is provided regionally by the system that can be used to establish management practices particularly for each area, field, irrigation district etc. to mitigate the climate change effects.

In order to demonstrate the utility of this GIS-SALTIRSOIL system to evaluate the effect of climate change in soil salinity, we simulate the three scenarios previously described. The soil salinization was evaluated simulating the annual average electrical conductivity at 25 °C in the soil saturated extract (EC_{se}) for the soil rooting depth (0–60 cm).

As the main result of the simulation, an increase of 28.7% in soil salinity was estimated for the irrigated area, if comparing the no climate change (1) with the climate change scenario (2). This increase of EC_{se} may be reduced up to 7.5% if we increase the irrigation rate by 20% (scenario 3). In this case, the GIS-SALTIRSOIL estimated a 50 hm^3 of extra-water volume needed to reduce the soil salinity in the whole area up to a tolerant level for crop production under the climate change scenario.

Other valuable information provided by the system is the regional estimation of the actual crop evapotranspiration (ET_a). This parameter is the actual water transpired by the crops and evaporated from soils. Comparing the ET_a estimated for the climate change scenario with the current conditions, an increase of 44% was estimated. Additionally, the drainage water was reduced by 24%. These issues lead to a reduction of the salt leached and an increase of salt content in soils within the rooting depth. This information can help to optimize the irrigation rate required to fulfill the increment in crop water demand, and reach a leaching fraction high enough to wash out the salts down to a level within the rooting depth adequate for crop production.

Some other utilities included in the GIS-SALTIRSOIL are the map display and the regional analysis. In Figure 3 the soil electrical conductivity maps for the three scenarios are shown. In these maps we can spatially identify the most salt-affected areas in the region. Comparing these maps we can find out in which areas soil salinity will increase significantly because of climate change. Thanks to this capability we can say that the areas where the climate change effect becomes more evident on soil salinity are those irrigated with the highest salinity water (EC=6 dS/m) (Figure4). There an increase of 45% in the EC_{se} was estimated. On the other hand, in the districts irrigated with low salinity water (EC=1.2 dS/m) the effect of climate change on soil salinity is hardly significant. There just an increase of 8% in EC_{se} was estimated (Figure 4). This indicates that an improvement in water quality would significantly mitigate the likely effect of climate change in the study area. In this sense, a desalinization factory to produce 40 hm^3 $year^{-1}$ of irrigation water by the beginning of 2011 is currently being built in the area.

The system is also able to classify the area in several ranges of electrical conductivity in the soil saturated extract in agreement of USDA classification (*U.S. Salinity Laboratory Staff*, 1954): non-saline (0–2 dS/m), slightly saline (2–4 dS/m), moderately saline (4–8 dS/m), strongly saline (8-16 dS/m) and very saline (>16 dS/m) as shown in Figure 5 for the three scenarios. Using this utility we could estimate that the area with EC_{se} >4 dS/m (moderately to strongly saline), was extended from 19% to 34% when comparing climate change (scenario 2) (Figure 5) with current conditions (scenario 1). This increment of salt-affected areas (EC_{se} >4 dS/m) was reduced to similar levels than current conditions if the irrigation rates increase to 20% (scenario 3). This reveal that under climate change conditions we will need to increase the irrigation rates in 20% with regard to the current water applications in order to combat the likely effect of climate change in the irrigation crops of the Segura and Vinalopo river lowland.

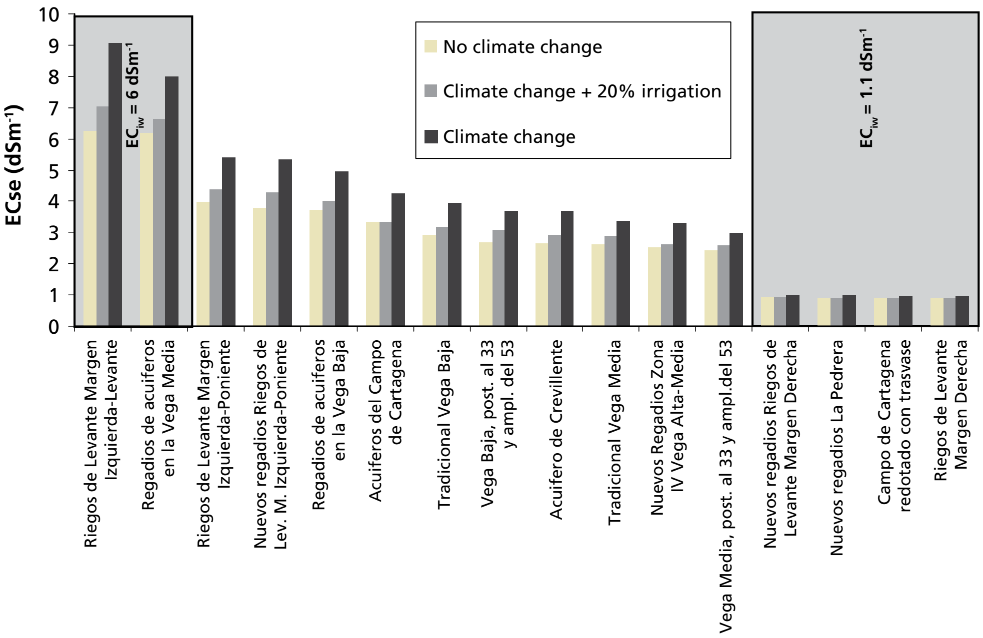

FIGURE 4

Simulated average ECse for each irrigation district in the area and scenario considered. Left grey part of the plot are irrigation districts irrigated with EC=6 dS/m and the right grey part are irrigated with EC=1.1 dS/m.

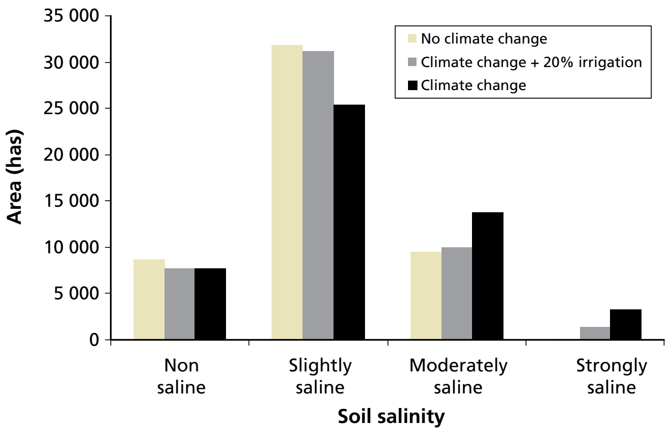

FIGURE 5

Area classified in soil salinity ranges for the three scenarios: non-climate change, with climate change, and climate change with an increase of 20% in irrigation rates.

COSTS OF USING THE GIS-SALTIRSOIL FOR ASSESSING SOIL SALINIZATION

The GIS-SALTIRSOIL will soon be downloadable through the Internet at no cost.

NEEDS/COSTS RELATED TO THE APPLICATION OF THE GIS-SALTIRSOIL AT DIFFERENT SCALES

The information costs of the GIS-SALTIRSOIL depend on the both parts of the linkage. On the one hand the data necessary for the yearly SALTIRSOIL model integrated in

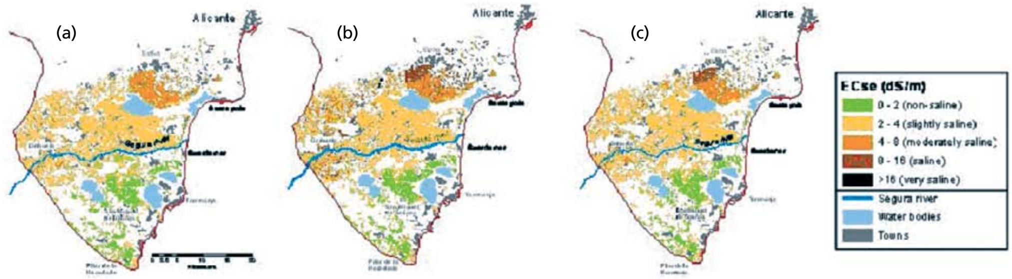

FIGURE 6
Maps of the electrical conductivity in soil saturated extract for the scenarios with no climate change (a), with climate change (b) and with climate change and an increase of 20% in irrigation rates.

the GIS-SALTIRSOIL is very similar to the monthly SALTIRSOIL which is discussed in another contribution (Progress towards DSS-SALTIRSOIL: monthly calculation of soil salinity, sodicity and alkalinity in irrigated well-drained lands). The only exception is for the irrigation water composition. The yearly SALTIRSOIL only needs the year average irrigation water composition, i.e. eight data (sodium, potassium, calcium, magnesium, chloride, sulfate, nitrate and alkalinity concentrations); whereas the monthly SALTIRSOIL logically needs the monthly composition for optimum results, i.e. 96 data. On the other hand the number of data required by the yearly SALTIRSOIL model has to be multiplied by a scale factor, which depends on the detailed needed for the simulations. A georreferenced regional database with all the data required by the GIS-SALTIRSOIL for the whole Valencian Community is being developed at present time: water quality, irrigation management, climate, soil and crop.

ACKNOWLEDGEMENTS

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Floodplain rehabilitation model in Hortobágy-Sárrét

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The biggest unbroken floodzone network of the Carpathian Basin before 19th century river controls lay in Hortobágy-Sárrét (9 331 km², between 46° 48' N and 47° 35' N, and 20° 55' E and 22° 04' E). As a result of the Carpathian Basin being uniquely enclosed in Alföld, at its deepest part, significant material accumulation processes take place. Due to persistant human destruction its indigenous vegetation has almost completely disappeared and 63% of the area characterized as agricultural is involved in cropland farming. The constant lability of the relationship between people and nature is signalled by the dramatic deterioration of social and natural conditions due to secondary salinization. By IPCC, EUN and numerous climatic model impacts of climate change will be negative (decreasing precipitation in growing period, increasing evaporation) in the Great Hungarian Plain (Alföld). The present form of landscape management (almost exclusive monocultural cropland farming) is unsustainable from the point of view of society, economy and ecology. It can be seen that the water management system of the Tisza Valley is incapable of managing floods, drainage water, salinization processes and intensifying aridity.

Our research into environmental history warns us to pay particular attention to forests, i.e. final associations of various floodzone successions. Of all the impacts that floodzone forests have on water circulation, the most examined is their bility to act as an aquifer and to reduce runoff water. We have highlighted the landscape degrading effect of salination so we may point out that the war on salinization in Hungary, as a result of unsustainable and destructive landscape management, has proved unsuccessful and, to date, 25% of the Alföld (ca. 12 000 km²) has fallen victim to salinization. As a result of the intensive water utilization of forests the root zone of trees pump up groundwater lying under them, stabilizing the groundwater levels at a lower level lower than elsewhere in the environment.

If groundwater level sinks below level C of three-phase soil, the streaming of salty groundwater in capillaries and the precipitation of salt in the upper layers of soil also comes to a halt. As a consequence of the geomorphological character of Hortobágy-Sárrét water inundating floodzones nearly every year streamed slowly down the landscape southwards from the north dissolving water-soluble substances, including salts accumulated either on the surface or near to it. Another impact of water coverage is that the saturation of soil with water stops capillary effect and leads to the infiltration of water from above. The only feasible solution against the phenomenon of the flow anomalies in salt-affected soils characterized by almost zero infiltration coefficient is to slacken the structure of salinated soils in the root zone. If the impact of rehabilitated floodzone forests on groundwater and soil structure continues together with the rinsing effect of inundations the process of salinization may be reversed.

Disaster risk reduction efforts and factors affecting flood disaster management: A case study of Katakwi district—Olupe and Ngariam camps

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ABSTRACT

The objective of the study was to establish factors that affected flood disaster management in Katakwi district. The study focused on 238 randomly selected internally displaced camp residents. Key informant interviews were conducted and data qualitatively analysed to assess issues that impeded successful mitigation of flood disasters.

Continued degradation of wetlands for crop cultivation and cattle over grazing were partly responsible for increased flooding during rainy seasons and drought during dry seasons. The absence of accessible micro finance credit schemes to support recovery efforts of the communities' drastically undermined measures to reduce the impact of flood disasters. The district was reported to have lacked contingency plans to show the risks and likelihood of related disasters occurring with potential effects at the community level hence impeding disaster management and preparedness. Both the government of Uganda and the local government of Katakwi district had not practically earmarked emergency funds for disaster response. The affected communities had no storage facilities for emergency relief items like medicine and food. The idea of having community level food stores and granaries died out and this amplified the flood disaster with famine making disaster management difficult. The poor nature of the community's temporary mud bricks and wattle roofed huts exacerbated the impact of the floods since many huts were just washed down prompting more relief items like tents straining the relief efforts.

A lack of awareness at the community level and alternative means of livelihood that do not constrain non-renewable resources have persistently provoked natural disasters in the district.

INTRODUCTION

Disasters are common in Uganda. The earliest recorded disaster is an earthquake in 1897. These disasters have caused a great deal of suffering and loss of property and productive capacity for the peoples of Uganda. In so doing, disasters have contributed to the retardation of social development.

Uganda has experienced a wide range of disasters directly affecting most of the country. The following have been frequent displacement of persons as a result of civil strife, famine as result of drought, earthquakes, disease epidemics, livestock and crop disease, flooding and land slides as a result of heavy rains and injudicious environmental management, and technological accidents as a result of inadequate safety procedures. New on the scene and most frightening is the phenomenon of terrorism.

BACKGROUND INFORMATION ABOUT THE DISTRICT

Katakwi District regained its district status in 1997 through an Act of Parliament. Its earlier status as North Teso District was cancelled in the 1970s. The District was curved out of Soroti District in 1997 and in July 2005 Amuria district was curved out of Katakwi District.

Location and Size

Katakwi District is located in the North-eastern region in Uganda, lying between 1° 38' N–2° 20' N land 33° 48' E–34° 14' E. It shares borders with the districts of Moroto in the North, Nakapiripirit in the East, Amuria in the West and North-west, Soroti in the South-west and Kumi in the South.

The District Headquarters is situated at Katakwi Town Council, a road distance of about 380km from Kampala, the National capital by the most direct route.

District Area:

Total area (sq. km)	: 2 507
Land area (sq. km)	: 2 177
Water area (sq. km)	: 177
Land under cultivation (sq. km)	: 720
Area under forest (sq. km)	: 22.98
Other	: 129.67

Geography

The district landscape is generally a plateau with gently undulating slopes in certain areas. The district lies approximately between 1 036–1 127 m above sea level. The climate is characterized by two seasons i.e. wet season, March–October and dry season, November–February. The mean annual rainfall varies from 1 000–1 500 mm.

The rainy season has a principal peak due around March–June and a minor peak around August–October. December and January are usually the driest months. The recent rainfall has however, been unreliable and unpredictable. The district sometimes registers extremes of both very heavy rainfall and drought. In some cases heavy rainfall is accompanied by hailstes. waterlogging as a result of heavy down pour is sometimes experienced in many areas, especially: Ngariam and Magoro sub counties. Katakwi District records a mean annual maximum temperature of 31.3 °C and a mean minimum of 18 °C.

Relative humidity ranges from 66% to 83% at 6.00 am. This reduces to 35%–57% at 12.00 pm thereby reducing chances of rainfall. The soils are mainly of ferralitic type (sandy sediments and sandy loam). They are well drained and friable. Bottom land contains widespread deposits of alluvium.

The land resource is fertile and productive. The most fertile region being areas lying on the North to Eastern part of the district. The vegetation of Katakwi district largely comprises of savannah grasslands dotted with shrubs and trees. It can generally be described as a wood land/shrub land–grassland vegetation dominated by *Acacia, Conbretum, Piliostigma, Butyrosperum paradoxum and Hyperenia* species.

POPULATION SIZE, GROWTH AND DISTRIBUTION

Population size

In order to formulate present and future development programmes of the District there is need to know the size, quality and growth of its population. The main source of demographic data is the population census and others include the following; surveys, administrative records and the Birth and Death Registration System (BDR) is yet to be operationalised in the District. This will help in proper planning and management of resources in the District.

Population Distribution

The population of Katakwi District according to population census 2002 was 298 950 people. From Figure 1, Katakwi Sub County has the largest population total of 26

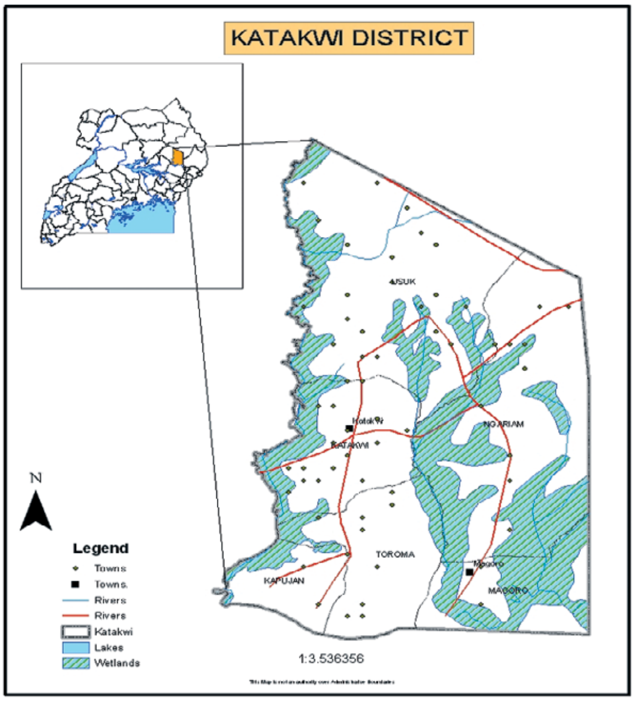

FIGURE 1

Map of Uganda showing the location of Katakwi district.

687 people of which 12 902 were male and 13785 were female. The least populated sub county was Katakwi Town Council with total population of 5 912 people of which males were 2 760 and females were 3 143. Because of insecurity in most parts in the district, most of the communities living in the sub counties bordering Karamoja migrated to Katakwi Sub County hence increasing the population size. Katakwi Town Council has the lowest population size because it was curved out from Katakwi Sub County when Katakwi was granted District status in 1997.

District highlights

- Total population in 2002 was 298 950.
- The average annual population growth rate between 1991 and 2002 was 6.2%.
- Population density was 65 persons per square kilometre.
- Only 2% of the population was living in urban areas.
- The sex ratio was 93 males per 100 females.
- Children below 18 years constituted 55% of the population.
- Children below 15 years constituted 50% of the population.
- The litreacy rate was 58% (of the population aged 10 years and above).
- 5% had a disability.
- The mean household size was 4.6 persons.
- 67% of the households had access to safe water.
- 76% had no access to a toilet facility.
- Only 0.1% of the households had access to electricity.
- Almost all the households (99%) used firewood and charcoal for cooking.
- Only 2% of the dwelling units were constructed with permanent roof, wall and floor materials.
- 72% of the households used "word of mouth" as their main source of information.
- 29% of households owned a radio.
- 44% of households owned a bicycle.

Scope of the study

Flood disasters impact differently the populations affected by it. While others suffer physical harm that result in disability and death, others suffer loss of property and livelihood. In the case of Katakwi district, the impact was felt at all levels and was most explicit in the way the communities were displaced. This mobility from their usual geographical confines was temporary for some people, but has resulted into permanence for others. This change in aspect is considered as a factor accounting for some of the observed practices. In this sense, the study considers populations displaced or resettled, the communities that hosted them and the dynamics resulting from this occurrence, whatever the nature and duration of the displacement.

The two camps that were assessed were the border camps of Olupe and Ngariam both have frontiers with Moroto. The target groups taken into consideration were the mobile populations and all the people interacting with them. Taking into account the differing burdens of floods experienced by the people, the study examined women, youth, children and the men groups.

The objectives of the study were to establish the social, economic, cultural factors that have affected flood disaster management in Olupe and Ngariam Camps and to identify mitigating factors and approaches to flood disaster management in Katakwi District.

METHODOLOGY

Key Informant Interviews

Different types of key informant were identified to cover different points of view on the same theme. Respondents were people such as local government leaders and administrators, as well as NGO and Civil society leaders. They were identified as persons with direct knowledge and experience of the field of the study and were used to identify flood risk reduction efforts and factors affecting flood disaster management.

Focus Group Discussions

We used focus groups to get a rapid and participatory but low cost method of data collection. The themes covered during the groups were the same as those used during the in depth interviews with key informants. The discussion groups were not only used to gain numbers but also to allow for the discussion of important problems by airing the different current opinions.

Participants were found at a focal place in the villages to enable them to remain in a relaxed setting. This not only elicited a higher degree of openness from participants but also enabled us to immediately crosscheck the responses through probing of other group members. In this naturalistic environment, our team members were able to explore many unanticipated issues and diverse experiences.

Wherever possible, focus group discussions were made homogenous so that reserved participants could overcome their shyness and express their opinions. Participants were of the same sex, same age groups (youths, adults or children) and having experienced the same situation of having been displaced or hosted displaced persons. A common ground was always first sought on the language in which both the respondents and interviewer would be comfortable with.

The main disadvantage we found was that the views of most audible respondents overshadowed those of the less talkative. In some issues, those directly affected by problem were more confident than others with different but just as valid opinions.

Data Collection Tools

There were two checklist guides for data collection that were translated into the local languages. One was for focus groups while the other one was for key informant interviews. The questionnaires were used a thematic guides to aid the memory of interviews to ensure that all dimensions of flood disaster were taken into consideration as proposed by the steering committee. The informal approach was meant to keep an interactive flow of the discussion as opposed to a question and answer approach.

As much as possible, interviews were conducted in the language of the informant, or the language mostly used in the area where the study was being conducted.

Prior to the in-depth interviews, the team had selected the general theme of the investigation and elaborated on an interview strategy. Using the above mentioned thematic guide, key informants were interviewed in their area of specialty like flood risk prevention, preparedness, management and response. The strategy was always to go for in-depth information rather than attempting to cover a large scope of study.

Every evening after fieldwork, the team had a debriefing session to summarize findings from the field. Such communication helped them to share, analyse and learn from each other while maintaining a bigger picture of the whole study. New thoughts would stimulate ideas on how to improve on tools and the approach in general during subsequent filed visit.

Target Populations

The targets of the study are classified into three categories:

- The populations in a situation of displacement.
- The population of people that have been resettled.
- The host communities and the social networks in interaction with displaced persons.

All groups included women, men and youth as respondents. Some children groups were also met.

Data Analysis

The management of field data was carried out using the following conventional qualitative data management operations:

- Note taking and recording in the field (during in depth interviews and groups)
- Transcription and typing of data resulting from semi structured and non-structured interviews
- Thematic coding and classifying of the data
- Synthesizing the processed data into a report

FINDINGS

Flood disaster risk reduction efforts

The government of Uganda has put in place a national disaster preparedness policy and institutional framework approved by cabinet in 1999 and revised in 2003. The national platform, locally referred to as the "Inter-ministerial committee" is an initiative whose members are sectoral disaster focal point officers assigned to mainstream disaster risk issues into sectoral work plans and budgets. The sectoral focal point officers chair the sectoral disaster risk working group forums e.g. the government has in place the health sector working group, the water sector working group, the education sector working group, the food security working group and the sanitation working group. Each of these sectors have in place sectoral plans with clear disaster risk features.

Efforts have been made to carry out hazard mapping/assessments and as a result hazard maps for wetlands, environment forests, earthquakes, landslides, drought and floods have been developed to enhance risk monitoring and vulnerability capacity assessments have been done using a community participatory approachInformation on disaster risks such as floods in Katakwi is poorly collected by community level workers, analysed and disseminated through a feed back mechanism to stake holders. This existing disaster risk information management acts as an early warning system.

Factors affecting flood disaster management

Disasters in general and flood disasters management efforts in particular have been affected by a number of factors that include human action, decisions and choices that exacerbate the scale of the disaster. Flood disaster control and management in Olupe and Ngariam camps which are one of biggest internally displaced peoples' camps has failed and intermittent by occurred due to the ever increasing high population constraining the fixed acreage of land that is ever cultivated inevitably resulting into floods when it rains heavily

Poverty that looms high in Katakwi District has left camp dwellers no choice but to harness all available natural resources including cutting green vegetation, deforestation and felling of trees so as to make a living. This practice has interfered with the flood disaster management efforts.

Katakwi wetlands have been drained for crop cultivation. In Olupe camp, continued degradation of wetlands is partly responsible for increased flooding during rainy seasons and extreme water shortages during dry seasons.

The absence of accessibility to micro finance credit schemes to support recovery efforts of communities has drastically undermined measures to reduce the impact of flood disaster.

The local government of Katakwi district has had no contingency plans to show the risks and likelihood of related disasters occurring with potential effects in camp communities. This trend has caused a recurrence of floods and impeded disaster management preparedness and response in Olupe and Ngariam camps.

The government of Uganda and the district local governments have not practically earmarked emergency funds for flood disaster response neither are there community level storage facilities for emergency relief items like medicine and flood. The idea of every household in Olupe and Ngariam camps to have granaries and community food stores has almost completely died out. This has amplified flood disasters with famine making flood disaster management difficult.

Poor temporary building materials in these camps like mud bricks that are sand witched with mud and the huts roofed with wattle has exacerbated the impact of floods since many huts were washed down prompting more relief items like tents for shelter straining relief efforts.

Lastly, flood disaster management in Olupe and Ngariam camps have been stifled by the continued cattle rustling raids by the neighbouring Karamajong communities that have forced the local population into camps sparking competition for scarce resources and in turn regenerate flood disasters during rainy seasons.

DISCUSSION

The displaced people in Olupe and Ngariam left their homes or safely nets due to situations beyond their control, and were forced to disrupt the eco system. The impact of the departures has had an impact on the environmental natural disaster control systems.

The destination was not always what the displaced people in both camps had anticipated the socio-economic contexts in which displaced people in both camps had anticipated the socio-economic contexts in which displaced people found themselves upon reaching the IDP camps, the challenges they were confronted with, social hosting or care networks, the varying forms of exclusion and marginalization compiled with the struggle for already very limited resources degrading the land.

The factors in the findings should be looked at their interrelation. They may be resulted of floods, while at the same tome have the potential for fueling floods. Thus a capacity building approach to preparedness, management and response to floods in Katakwi.

Inherent in this approach is recognition of individual and community resources that form protective factors, and can be strengthened as opposed to creating new introduced structures.

RECOMMENDATIONS

- There is need for continuous sensitization and building capacities of the camp communities on flood issues, if flood disasters have to be minimized.
- The preventive approach to flood management is very appropriate to flood management and should be emulated by Katakwi district so as to reduce floods.
- Early warning systems need to be put in place to warn camp dwellers every time the rainy season is approaching so as to minimize the impact and scale of destruction of property, lives and food.
- A participatory approach is very necessary if communities have to adopt mitigation measures that change their ways of life to some extent.

CONCLUSIONS

Gross lack of awareness at community level and alternative means of livelihood that do not constrain non-renewable resources have persistently provoked natural disasters in these camps. The adoption of a proactive flood preventive approach in the district development plan will ensure sustainable flood management.

Utilization of brackish/saline water and salinization risk in the centre of Tunisia

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ABSTRACT

In Kairouan and Mahdia area (Centre of Tunisia), the irrigated sectors represent about 20% of 400 000 ha irrigated in Tunisia. Most of these areas are irrigated by pumping groundwater from wells. In many cases, water has a high salinity of more than 4 g of salt per litre (between 4 and 6.5 dS/m). The over exploitation of groundwater resources induces a decrease of the aquifer's piezometric level and the degradation of its quality by saline water intrusion from the sea or sebkhats (salt flats). In some farms, irrigation is a new practice and the farmers have not enough experience to use water efficiently and to manage soil, water and plants under saline conditions. After some years, problems related to salinity are observed and decrease in yield is noticed. Studies show the feasibility of using saline water for irrigation in some cases. With regard to soil salinity evolution and salinity risks, soil salinity increases under irrigation until the equilibrium with the irrigation water is reached at about 6 dS/m. Many tonnes of salts are added to the soil but a large proportion is leached to deep layers. In the short term, soil salinity increases with irrigation and decreases with rain. In the long term, salinization of the aquifer may occur. In terms of the crop response, a large decrease in yield is observed, the amount varying with region, farmer and land parcel. This decrease is greater for summer and greenhouse crops than for winter crops.

INTRODUCTION

In arid countries, such as Tunisia, irrigated areas are very important. The increase in production needs a good water quality and soil management because these resources are a limiting factor for agriculture production. The use of saline water for irrigation is feasible, especially when saline water are blended or alternated with good quality water (Rhoades 1987). This is what indirectly happened in case where rainfall is greater than 200 mm (Abdelgawad 1995). For long term, crop rotation must be used under this quantity of rainfall which not enough to leach the salts. There are many regions in the world where soils have been irrigated with saline waters successfully over many decades without degradation. In each instance, leaching and adequate drainage have been the factors that assure success (Rhoades and Loveday 1990; Rhoades *et al.,* 1992; Oster *et al.,* 1996; Hachicha *et al.,* 2000). There are also many cases of irrigation failure (Szabolcs 1994; Bresler *et al.,* 1982).

In Kairouan and Mahdia (Centre of Tunisia), the irrigated areas represent about 20% belong to 400 000 ha irrigated in Tunisia. Most of these areas are irrigated by groundwater pumped from wells. For a long time, the water has had more than 4 g of salt per litre (between 4 and 6.5 dS/m). The over exploitation of groundwater resources induces a decrease of the piezometric level of the groundwater and the degradation of its quality by saline water intrusion from the sea or sebkhats. In some regions, irrigation is a new practice and the farmers have not enough experiences to use water efficiently and to manage soil, water and plant under saline conditions. After some years, problems related to salinity are observed and decrease of yield crop is noticed. Moreover, there are not enough applied researches in the field of brackish/saline water to be transferred to the farmers in particular concerning the small-irrigated areas, which depend on groundwater wells in the Centre of Tunisia. According to that, applied research programme for the utilization of brackish/saline water is begun in 2001 (IFAD/ACSAD). The objective is to improve the production of irrigated systems through an adapted and efficient use of rare and saline water by the farmers. The main activities are (IFAD 2000): transfer the adapted management methods to the farmers, develop local guideline and norms of irrigation by using saline water, add complementary and adapted researches to increase farmer income and strength the institutional and human capacity building.

MATERIALS AND METHOD

The methodology used concerns the transfer of adapted management methods to the farmers and to add complementary and adapted new research methods:

- Selection of two agricultural regions characterised by considerable amounts of brackish/saltwater.
- Selection of one irrigated area per region, where the water quality is more than 4 g of salt/litre (>5 dS/m).
- Selecting three farmers per irrigated area.
- Select for the same season, the same crop in the two regions.
- Take two parcels, one irrigated by the farmer usual way and the second with irrigation scheduling according to the climate parameters and water requirement of the pepper crop and by the irrigation scheduling computer programme developed by ACSAD (Gaibeh *et al.*, 2002).
- Characterize the soil and water for each parcel.
- Control the water quantity by placing water measures devices in each farm of the selected farmers.
- Take periodically samples for water, soil and plant.
- Carry out the chemical and physical analysis of soils as well as the chemical analysis for water and plant samples.
- Data analysis to determinate relations between crop yield, water use and its quantity and soil salinity.

The experimental activities were started in April 2002. In Mahdia, the soil texture between the surface and 1.5 m is loamy sand to sandy loam with about 80% of sand and less than 15% of clay. The water available is low less than 70 mm for 0–1 m of soil depth. The initial soil salinity differs from farmer to farmer between 2 to 5 dS/m. In Kairouan, the soil texture between the surface and 1.5 m is sandier than Mahdia and the water available is lower. The initial soil salinity is between 1 to 5 dS/m.

Concerning the water quality, the electrical conductivity (EC) is high between 5.4 dS/m to 7 dS/m.

RESULTS

Water use

Total water supply varies between the region and the farmers. It is less than 800 mm in Mahdia and higher in Kairouan. For some farmers, it is twice or three times higher. Thus, the water efficiency differs considerably. Accordingly, drip irrigation is the best irrigation system to be utilized when using such water quality, but, in the long term, salt leaching must be realized.

In the other part, the farmers did not consider water quality to manage irrigation (dose and frequency). They have no appreciation of salts leaching. The salinity management concerns only crop rotation because decrease yield is observed when they continue irrigate the same parcel.

Soil salinity evolution

Just after the first irrigation, the soil salinity increases to about 6 dS/m (equilibrium with water quality) and becomes very high in July (more than 10 dS/m). Many tonnes of salts are added to the initial stock. If we estimate the soil salinity at 5 dS/m between 0 and 1 m depth, the average bulk density 1.5 g/cm^3, we can calculate the salt balance. This salt balance shows that about 3 t of salts will be accumulated between soil surface and 1 m soil depth. More than 3 t goes under the arable layer under irrigation but after some months, the total of salts will be leached progressively to deep layers. On the short term, soil salinity increases with irrigation and decreases by rains. On the long term, salinization of the aquifer may occur and also in the low elevation areas are expected and salinity control of these parts of landscape must be studied.

Crop response

The most yields functions related to salinity of irrigation water is that proposed by Ayers and Wescott (1985) on the basis of Maas and Hoffmann (1977) model in the form Y=100-b(ECe-a) where Y=relative crop yield in percent, ECe=salinity of the soil saturation extract in dS/m, a=salinity threshold value in dS/m and b=yield loss per unit increase in salinity. This equation expresses the straight line salinity effect on yield and indicates that plant growth rate decreases linearly as salinity increases above a critical threshold at which the growth rate first begins to decrease. In Tunisia, considering the US Salinity laboratory norms and criteria for water use in irrigation (Richards *et al.*, 1954) not adapted for the Tunisian context, research in saline water use in agriculture was conducted in many experimental stations at the field condition (CRUESI 1970). Yield functions are obtained for many crops for the Lower Mejerda Valley in the North where annual average rainfall is about 450 mm. For the more arid Tunisian region (rainfall between 150 and 350 mm) there are not any yield functions. Concerning the yield of pepper, table 5 shows yield decrease according to water salinity. The main remark is the big difference between Kairouan and Mahdia farmers. If the maximum yield in Tunisia is 34 t/ha obtained in Cherfech Station (North; CRUESI 1970) under furrow irrigation, then the yield decrease is between 17 and 72% in Mahdia and between 64 and 79% in Kairouan. So a good comparison is to be carried out in Kairouan and Mahdia using low salinity water.

CONCLUSIONS

Results show the feasibility of using saline water for irrigation by groundwater pumped from wells in semi-arid region. Saline water could be used for small areas. Many aspects are observed. For saline water management, the water use efficiency indicates the necessity to improve irrigation management. Concerning soil salinity evolution and salinity risks, the soil salinity increases under irrigation until the equilibrium with the irrigation water at about 6 dS/m. Many ts of salts are added to the initial soil salinity but a big quantity is leached to deep layers. On the short term, soil salinity increases with irrigation and decreases by rains. On the long term, salinization of the aquifer may occur and also in the low elevation areas are expected and salinity control of these parts of landscape must be studied. For the crop responses, high yield decrease is observed, variable between regions and farmers and also parcels. This decrease is higher for the summer crops and greenhouse crops than the winter crops. Finally, promise results are obtained now but they need more studies and complementary actions must be carried out in particular to improve water management by the farmers.

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TOPIC III: ALTERNATIVE LAND USE SYSTEMS/ECOSYSTEM SERVICES IN SALT-AFFECTED HABITATS

Plant based management of saline environments

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During the last few decades, net agricultural production has suffered a significant drop, though productivity per unit area has increased. This is mainly due to loss of productive agricultural areas by secondary salinization, among other factors. The three major approaches used to tackle the problem include soil management (mainly reclamation), water management, and plant based approaches. However, none of these approaches can be effective both technically and economically, unless worked out as an integrated measure.

A management strategy is needed to look at soil, water and plant based systems related to salinity conditions, whether on-farm, or at irrigation district or higher levels. A different approach needs to be taken at regional level, based on water quality/quantity, edaphic characteristics, climatic conditions, type of production systems, markets, etc.

Plant based approaches to use salt-affected lands and/or saline water, in economical and environmentally safe ways depend on the salinity ranges of soil, water (and groundwater) and other associated factors. The selected production system(s) not only help in halting further deterioration of the marginal lands, but also have direct commercial uses for food, forage/fodder, livestock industry, medicinal use, wood, etc. In addition to primary products, the use of marginal resources may also provide many secondary and indirect benefits, including bioenergy, carbon sequestration, phytoremediation, etc.

This paper will discuss the different approaches taken by the International Center for Biosaline Agriculture (ICBA) working in different countries and regions that have specific salinity problems. It will describe the salinity problem in the context of the overall water management issue and will focus on different management systems related to production. Case studies will be described from different regions of the world (especially from developing countries) to use marginal and saline resources for different types of agricultural production systems. The paper will also describe the economic and environmental benefits highlighted by the case studies.

Sustainable restoration of salt-affected soil through revegetation of *Leptochloa fusca* and *Sporobolus virginicus*

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Land degradation is a major global issue because of its adverse impact on agricultural productivity and sustainability. Population pressure along with the demand for more food, fodder and fuel has generated a chain of interrelated economic, social and environmental issues associated with land degradation, especially in developing countries in arid and semi-arid regions.

Restoring the productivity of saline lands through improving soil conditions, reducing desertification and raising the fertility of soils is one of the most important tasks. The biological restoration of saline lands by the use of halophytes could achieve this. Halophytes are geologically, physiologically and biochemically specialised plants which are able to function and produce in the conditions of saline soils. Domestication of halophytes will make a promising solution for increasing fodder supply and utilization of the abandoned salt-affected soils, and offers a low-cost approach to reclaiming and rehabilitating saline habitats. For this purpose, two pot experiments were carried out in the halophytic greenhouse of the National Research Centre, Dokki, Giza to study the mutual influence of soil salinity on growth, physiological aspects and some cations content as well as biomass production of *Leptochloa fusca* and *Sporobolus virginicus* plants.

The results showed improvement in the growth characteristics as well as biomass production of both species in the second season due to improvement of the soil salinity. Meanwhile, leaf/stem ratio increased with increasing soil salinity in both seasons. Increasing soil salinity significantly increased Na^+, soluble carbohydrates and proline concentration in the plant tissues. On the other hand K^+, K^+/Na^+ ratio and Ca^{2+} content decreased very slightly compared with the control. No clear effects were recorded for Mg^{2+}.

As for the effect of successive growing of *Leptochloa fusca* and *Sporobolus virginicus* on the soil quality, all cations, anions (except for HCO^{3-}), SAR, and electrical conductivity decreased in the soil by the end of the first season and reached its lowest values by the end of the second season. This may be due to leaching and the accumulation of salts into the leaves' vacuoles followed by excretion through the salt glands. *Leptochloa fusca* showed a greater effect on improving soil quality than *Sporobolus virginicus.*

Keywords: *Leptochloa fusca, Sporobolus virginicus*, soil salinity, growth, yield.

What is stress? Concepts, definitions and implications for plant growth in saline environments

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Salinity imposes "stress" on plants, affecting plant reproduction and productivity, and hence, agriculture and biodiversity. However, there is no clear consensus on what plant stress is, and how to diagnose and assess its severity. Here, we build upon concepts from physics, medicine and psychology to formulate a novel plant stress concept, considering "eustresses" that enhance function, and "distresses" that have harmful effects. Taking the "General Adaptation Syndrome", a tri-phasic biomedical stress concept from 1936, to the molecular level, the "alarm" phase is defined by post-translational modifications and stress signalling involving cross-talk between hormones and reactive oxygen species, resulting in modifications to the transcriptome. Protection, repair, acclimation and adaptation are viewed as the building blocks of the "resistance" phase. The failure of protection and repair mechanisms, depending on dose and time of exposure to stress, results in "exhaustion", comprising cell and plant death. Implications for salt-tolerant and salt-sensitive plants are discussed.

Keywords: Halophytes, hormones, reactive oxygen, salt, signalling, stress.

Maximize the outcome of saline agriculture by integrating fish culture with field crops

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In achieving a more effective use of saline water, farmers could make an important contribution to agricultural industries in arid regions, particularly by maximizing farm production without increasing water consumption. Integrating aquaculture with agriculture has become a channel for increasing the use of limited water resources, decreasing dependence on chemical fertilizers and providing a greater economic return per unit of water. The aim of our study was to use an integrated system that would allow us to determine the effects of fish effluent irrigations on the growth and yield of field crops in an arid region. Our primary site was a tilapia (Oreochromis niloticus) fish farm in Oman that used effluent (EC=3 and 6 dS/m) from the farm to irrigate tomato plants grown in soil-less culture. When tilapia were cultured intensively in tank systems, with low daily water exchange, some dissolved nutrients including magnesium, calcium, sulphur and boron accumulated to approach levels suitable for fertilizing vegetable crops. However, some key nutrients, including nitrogen, potassium and phosphorus were deficient.

There was a significant difference in growth rate of tomato receiving effluent compared to plants receiving fresh water. However, the effluent treated plants did grow significantly larger than plants that received only fresh water with no fertilizer added. Plant growth decreased linearly with increasing salinity of the effluent. The decrease in plant parameters with salinity was mostly due to a linear decrease in water and nutrient absorption.

In a preliminary trial, low-salinity, tilapia effluent was shown to support the early growth of tomato plants in a hydroponic culture system. Integrative methods used in this study may achieve nutrient recycling of otherwise unused waste materials, as well as nutrient and energy recovery; better sanitation; increased natural resource efficiency; low environmental loading; and low dependence on fossil energy inputs.

Keywords: saline irrigation, water nutrients, plant growth.

Combating salt stress in citrus orchards under semi-arid condition in the Negev desert of Israel

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Citrus is well known as a salt sensitive crop (due to their sensitivity to osmotic and toxic effects of salinity). About 37% (7 400 ha) of the Israeli citrus orchards are located within the Negev desert (a semi-arid climate with average precipitation of 280 mm per year) and exposed to salt stress. The origin of the salt is irrigation water (reclaimed waste water containing about 300 mg chloride per litre). While leaf chloride concentration until 1999 averaged 0.3%, it increased to about 0.5% in 2001 (this increase was associated with about 17% reduction in yield).

In the short term programme, a protocol for a soil analysis that allows growers to monitor their soil EC status under field conditions was developed. Additionally, the use of plastic mulch agro-technique proved effective for the reduction of salt accumulation in trees in young orchards (1–3 years old). For the long term programme, we characterized the link between rootstock salt sensitivity and carbohydrate status (a parameter that is strongly affected by scion characteristics and girdling treatment). A salinity/rootstock experiment and a protocol for early detection of salt stress using remote sensing technology are being developed. Different aspects of the various methods developed and their projected usage will be discussed.

An American legume, *Prosopis strombulifera*, as a new model for understanding extreme salt tolerance

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ABSTRACT

The shrub *Prosopis strombulifera* (Lam) Benth is distributed from the Arizona desert (U.S.A) to Patagonia (Argentina) and is especially abundant in the salinized areas of central Argentina. This species showed a halophytic response to NaCl surviving up to 1M NaCl in *in vitro* experiments, but a strong growth inhibition at lower Na_2SO_4 concentrations. These differential responses to the most abundant salts present in most salinized soils make this species an excellent model to study salt-tolerance mechanisms in halophytic plants. This work provides an overview of different salt tolerance mechanisms in the native halophyte *Prosopis strombulifera*, which may be considered a useful new tool to improve crop salt tolerance through two biotechnological strategies: considering *P. strombulifera* as a natural gene donor to improve genetic salt tolerance of low tolerant crops, and considering this species and its rhizosphere as a natural source of Plant Stress Homeostasis-regulating Rhizobacteria (PSHR) capable of improving salt tolerance in crops.

Keywords: halophyte, NaCl, Na_2SO_4, differential tolerance, PSHR microorganisms, biotechnology.

A NEW MODEL PLANT

Improving our knowledge on the specialised physiology and biochemistry of halophytes, which impart their exceptional degree of salt tolerance, still represents a challenge for scientists. The model plant *Prosopis strombulifera* exhibits growth promotion up to 500 mM NaCl and its growth is slightly inhibited at higher salt concentrations such as 700 mM NaCl. This exceptional degree of tolerance makes this species a perfect candidate to deep our knowledge on halophytic salt tolerance mechanisms.

The *Prosopis* genus is considered to have unique terrestrial species with the ability to fix nitrogen and grow under high-salinity conditions (Rhodes and Felker, 1987). The spiny shrub *Prosopis strombulifera* (Lam.) Benth. (Burkart, 1976) is distributed from the Arizona desert (U.S.A.) to Patagonia (Argentina) and is especially abundant in the salinized areas of central Argentina (Cantero *et al.*, 1996). Geographically, the area is located at 33° 43' S, 66° 37' W at an altitude of 400–500 m, with a temperature thermal regime (i.e., an annual average temperature of 15–20 °C). This area is an algarrobo *Prosopis alba* forest located in a saline depression between the annual 300 to 400 mm isohyets in the El Monte phytogeographic region. The soil has a franc-sandy texture, with abundant calcareous material and moderate salinity (8 000 mho/cm^2 electrical conductivity at the surface) (Anderson *et al.*, 1970). The proportions of NaCl and Na_2SO_4 are similar, although, in some samples, Na_2SO_4 was up to three times more abundant (Sosa *et al.*, 2005). This and other recent studies have suggested an increasing need to compare the effects of Na_2SO_4 and NaCl on plant growth in order to better understand plant responses to the major salts found in the salinized soils of several countries such as Argentina, Pakistan, China, India and Tunisia (Iqbal, 2003; Bie *et al.*, 2004; Shi and Sheng, 2005; Naeem and Qureshi, 2005; Manivannan *et al.*, 2008; Tarchoune *et al.*, 2010).

The response of *P. strombulifera* to salinity was different depending on the type of salt used and the osmotic potential in the culture medium. Shoot growth was stimulated up to Ψo=-1.88 MPa (500 mM) NaCl, showing an interesting halophytic response that differs from other *Prosopis* species (Felker, 2007). On the other hand, this species is much less tolerant to Na_2SO_4, showing strong and sustained shoot growth inhibition from the beginning of the treatment, accompanied by senescence symptoms such as chlorosis, necrosis, and leaf abscission (Reinoso *et al.*, 2005; Reginato 2009). Root growth stimulation was also observed in NaCl-grown plants showing a generalized adaptive mechanism to favor water and nutrient absorption. The SO_4^{2-} anion had a detrimental effect on root growth in comparison with the Cl^- anion, which was partially alleviated when both anions were present in bisaline solutions. Few authors analysed growth responses to iso-osmotic mixtures of both salts. Partial alleviation of SO_4^{2-} toxicity by bisaline solutions is an interesting response in our experiments, confirming previous reports on germination of this species (Sosa *et al.*, 2005; Llanes *et al.*, 2005).

Mechanisms of salt tolerance in *Prosopis strombulifera* include:

- Ion exclusion, accumulation and compartmentation
- Sodium exclusion, K^+/Na^+ discrimination and Cl^- exclusion traits have proven valuable in screening germplasm for salinity tolerance. Some halophytes make an osmotic adjustment by accumulating equivalent amounts of Na^+ and Cl^- in vacuoles (Kefu *et al.*, 2003).

Prosopis strombulifera does not allow the entrance of large amounts of Na^+ (compared with Cl^- levels) which correlates with the particular characteristics observed in the radical system, such as precocious lignification and suberization of endodermis for salt exclusion (Reinoso *et al.*, 2004, 2005); this observations would imply that *P. strombulifera* falls within the category of salt-excluding plants given by Yensen and Biel (2005), able to exclude salts from entering their tissues at the roots. Similarly, the economically important relatives *Prosopis* species are Na^+ excluders (Villagra *et al.*, 2010). Nevertheless, Na^+ content in leaves was 2-3 fold higher than K^+ content (0.48 mMol.gDW and 0.185 mMol.gDW, respectively) when optimal growth was observed in NaCl treated plants (ψo=-1.9 MPa, 500 mM), which suggest that would be a sodium exporter like Atriplex. Thus, a good explanation for the unusual salt tolerance of this species maybe a combination of exclusion mechanism in the root and ion accumulation/compartmentation in leaves. It is remarkable that *P. strombulifera* preferentially accumulated Cl^- over Na^+ reaching significant levels of Cl^- anion (2.24 mMol.gDW) in root as well as in leaf tissues without toxicity symptoms when optimal growth was observed in NaCl treated plants (Reginato, 2009).

In Na_2SO_4 treated *P. strombulifera* plants, there was SO_4^{2-} accumulation in roots and leaves from the beginning of salinization, reaching amounts equivalent to those of Cl^- at the highest salt concentration tested in our experiments (530 mM Na_2SO_4, osmotically equivalent to 700 mM NaCl). Chrispeels *et al.* (1999) affirmed that SO_4^{2-} causes acidification of the medium, generating membrane depolarization and favoring SO_4^{2-} uptake. The SO_4^{2-} levels in leaves were lower than those of Cl^- in NaCl-treated plants, but they were sufficient to cause metabolic disorders and visible signs of toxicity, as reported above. In bisaline-treated plants a preferential accumulation of Cl^- over SO_4^{2-} was observed, corroborating the fact that SO_4^{2-} is absorbed slowly by the roots of higher plants (Bie *et al.*, 2004). The deleterious effect of SO_4^{2-} on leaf development and root and shoot elongation may be a consequence of several metabolic reactions, such as excessive sulfide formation in the process of sulfate assimilation in the chloroplast, which could be emitted to the environment or could effectively bind to cytochromes, thus inhibiting mitochondrial respiration (Schmidt, 2005).

On the other hand, Na^+ accumulated in *P. strombulifera* leaves at the expense of K^+ in a quantitatively different manner depending on the salinizing agent used. In roots, SO_4^{2-}-based treatment caused greater Na^+ accumulation at the beginning of salinization limiting sodium's transport to the shoot. Although most plants have an absolute requirement for K^+, and Na^+ is toxic for many biological reactions in the cytoplasm, this does not apply to vacuolar processes, being more suitable than K^+ for osmotic adjustment in several species (Subbarao *et al.*, 2003).

Efficiency in long-distance Na^+ transport to stems and leaves is a required mechanism for salt tolerance in halophytes (Patel and Pandey, 2007). Then, limitation of sodium's transport to the shoot by SO_4^{2-} anion seems to be one of the reasons for the lack of tolerance of this species to SO_4^{2-} treatment, discarding the possibility that unfavorable plant growth in Na_2SO_4 resulted from Na^+ toxicity due to the higher Na^+ concentration in this solution.

Our results demonstrate that NaCl and Na_2SO_4 differentially affect ion accumulation by plants, generating specific distribution patterns of ions in different organs. This fact suggests an important specific anionic effect on membrane permeability. Increasing concentrations of bisaline solutions allowed higher salt tolerance than increasing concentrations of individual Na_2SO_4 solutions through various phenomena such as ionic antagonism and/or mutual competence, which bring about specific physiological responses, confirming previous results (Sosa *et al.*, 2005; Llanes *et al.*, 2005).

Water content

Prosopis strombulifera has the ability to maintain a higher relative water content (RWC) in leaves of seedlings growing in high NaCl concentrations, without succulence. Thus, it appears that the extreme tolerance of this species to NaCl would be due to its capability of osmotic adjustment. Also, the high water content in its leaves helps to ease the impact of the Na^+ accumulation in the tissues, which is also favored by leaf anatomical adaptations such as the particular distribution of chlorenchyma around the leaf veins (Reinoso *et al.*, 2004) and the modifications on stomatal area and distribution (Reginato, 2009) and stomatal conductivity, that enable *P. strombulifera* seedlings to make a more efficient use of water under our experimental conditions. Plants treated with high Na_2SO_4 concentrations (Ψo=-2.6 MPa) failed on making an efficient osmotic adjustment showing extremely negative water potentials in leaves causing water imbalance, which, in comparison with NaCl-treated plants, correlates directly with the marked decrease in individual and total leaf area at Ψo=-1.88 MPa and lower, reaching final values of 30% and 60% inhibition of these parameters respectively. An increase in stomatal density and epidermal cell density with smaller stomata, maybe additional efforts of Na_2SO_4-treated plants to survive (Reginato, 2009). Meanwhile, leaf area was not modified in NaCl-treated plants.

Metabolism protection-compatible solutes production

One of the most common stress responses in plants is overproduction of different types of compatible organic solutes (Serraj and Sinclair, 2002). In *P. strombulifera* seedlings a remarkable proline accumulation occurred under increasing salinity. Indeed, this amino acid increased by 200% since the beginning of all salt treatments in coincidence with the proposal that proline content in plants increases in a linear relationship with conductivity in the medium. Armengaud *et al.* (2004) reported that in *Medicago truncatula,* proline accumulation in response to NaCl stress was higher in aerial parts (13 fold) than in roots (8 fold) compared to controls. A similar effect was observed in *P. strombulifera* where proline accumulation in leaves was much more important than in roots. This fact could be related to the high ion accumulation in salt-treated leaves, raising the need for organic molecules production to counteract osmotic balance and/or ion secuestration, scavenging free radicals and buffering cellular redox potential under stress conditions. Results with NaCl and Na_2SO_4 treated plants indicate that proline would be a stress-intensity signal but not a salt-tolerance indicator, as it increased concomitantly with osmotic potential decrease, independently of the ion composition of the solution (Llanes, 2010).

A number of sugar-alcohols are present in some but not all halophytes from several families, as is the case of pinitol (Arndt *et al.*, 2004). Sorbitol and Mannitol are not widely reported in halophytes, but are present in several families of flowering plants (Koyro, 2006). Mannitol accumulation in *P. strombulifera* seedlings only occurred in leaves of NaCl-treated plants with moderate to high salinity, while in those treated with sulfate and salt mixture, manitol level was lower than in controls. By contrast, sorbitol accumulated in greater amounts in sulfate and salt mixture-treated plants, while under NaCl treatment sorbitol level was similar to controls. Thus, it appears that this species uses mannitol + pinitol for osmotic adjustment in the presence of NaCl, while in the presence of the toxic sulfate it synthesizes sorbitol + pinitol. Thus, sorbitol biosynthesis might be a possible manifestation of a carbon metabolism disorder (Sheveleva *et al.,* 1998).

Antioxidant defence

Salt stress leads to increased reactive oxygen species (ROS) production in plant cells, which are known to produce a secondary oxidative stress under these conditions (Sreenivasulu *et al.*, 2000). To counteract oxidative stress induced by salinity, plants have developed different strategies among which the stimulation of secondary metabolites synthesis, particularly polyphenols, may be involved in cell protective roles such as ROS scavenging (Simic and Jovanovich, 1994). An important increase in tannin content in salt-treated *Prosopis strombulifera* plants was observed. Total phenols, total flavonoids, total flavan-3-ols, condensed tannins (or proanthocyanidins), tartaric acid esters and flavonols analysis showed that salt treatments increased the accumulation of several polyphenols in both leaves and roots. Na_2SO_4 treatment sharply induced an increase in total polyphenols showing the highest levels of these compounds in our experiments, especially flavonoids and total flavan-3-ols. Bisaline treated plants also accumulated high levels of polyphenols. HPLC analysis showed high levels of rutin, catechin, epicatechin and proanthocyanidine in these plants. The increase in total flavonoids and flavan-3-ols, when SO_4^{2-} anion is present in the growth solution, may indicate a role for these compounds in counteracting the oxidative damage induced by severe salt stress (Reginato *et al.*, 2010). Agati and Tattini (2010) reported that antioxidant mesophyll flavonoids, at micromolar range, may effectively avoid reactive oxygen forms generation (e.g. by chelating transition metal ions).

BIOTECHNOLOGICAL APPROACHES

P. strombulifera as a natural gene donor to improve salt tolerance in crops

In *P. strombulifera* seedlings four sequences were isolated and identified in our lab, showing homology with genes involved in salinity responses. They were named *PSALl, PSAL3*, *PSAL11* and *PSAL5*, and were selected for further studies of gene expression and functional analysis with the aim of contributing to understand the mechanisms responsible for the extreme salt tolerance of this species. The isolation of *PSAL1* sequence, which has homology with an ABA-dependent atypical LEA protein, is an interesting result related to cellular protection against osmotic stress (Bray, 2002; Parida *et al.*, 2007). Preliminary studies of this gene expression showed that *P. strombulifera* roots constitutively accumulate high levels of the corresponding transcript whereas gene induction was observed only in Na_2SO_4-treated plant roots at ψo=-1.88 MPa, which coincides with ABA and ABA-GE accumulation. *PSAL5* sequence encodes a myo-inositol-1-P synthase enzyme, which participates in the formation of the pinitol precursor; *PSAL11* sequence shows homology with a potassium and sodium transporter HKT1 from *Mesembryanthemum crystallinum*. Similarly, *PSAL3* sequence shows homology with a sodium/proline transporter, which may play a key role in stress tolerance considering that both, sodium and proline, accumulate largely in this species (Llanes, 2010).

P. strombulifera and its rhizosphere as natural sources of PSHR microorganisms

In addition to the biochemical mechanisms reported above, *P. strombulifera* adaptive success may depend, at least in part, on its ability to establish and maintain effective associations with plant growth-promoting endophytic or rhizospheric bacteria. Studies carried on in our lab (Sgroy *et al.*, 2010) reported for the first time the isolation and molecular characterization of *P. strombulifera* endophytic bacteria (PSHB) as well as their principal Plant-Stress-Homeoregulating-mechanisms under controlled growth conditions. Twenty-nine endophytic strains were isolated from established *P. strombulifera* plants in their natural habit, *Bacillus* sp. representing the 80% of gram-positive isolated strains. The genotypic 16S rDNA sequencing showed a prevalence of 18.8% for *L. fusiformis* (Ps7); 68.8% for *B. subtilis* (Ps8); 6.25% for *B. licheniformis* (Ps14); and 6.25% for *B. pumilus* (Ps19). Gramnegative bacilli were the 31% of isolations, and genotypic identification showed 55% prevalence for *Achromobacter xylosoxidans* (Ps27) and 45% for *Pseudomonas putida* (Ps30).

All strains were able to express *ACC deaminase* activity, to produce high amounts of several phytohormones functionally associated with the abiotic stress tolerance such as ABA and JA, and to immobilize the toxic anion (SO_4^{2-}) (Sgroy *et al.*, 2010). The existence of these plant stress homeo-regulating mechanisms described above in rhizobacteria could be the result of a co-evolutionary relationship regulation, allowing plants to select their most convenient partners to improve their natural capacity to face adverse environmental conditions. Our findings suggest the existence of an "endophytic consensus" among all the strains colonizing the same plant, each of them expressing one or more different interaction mechanisms that jointly determine a global plant response under salt stress.

CONCLUSIONS AND PERSPECTIVES

Halophytes have recently been pointed out as gene donors for genetic manipulation of economically important species. A challenge for salinity tolerance research now is the ability to marry together new molecular techniques with the body of litreature on whole plant physiology. The present work is a contribution to understanding the physiological responses of a native halophyte to salinity, taking into account the chemical nature of the major salts present in soils of several countries. Besides, a new approach emerging from this work is the consideration of halophyte rhizospheres as natural sources of PSHR microorganisms capable to help plants to face adverse environmental conditions, as a new biotechnological tool for inoculants industry.

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TOPIC IV: EVALUATING HE EFFECTS OF CLIMATE CHANGE ON COASTAL AREAS, LAGOONS AND WETLANDS, INCLUDING ECONOMICAL, SOCIAL AND ENVIRONMENTAL ASPECTS

Salinity issues in Portugal: Coastal aquifers

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Salt accumulation in soils is a serious environmental problem threatening plant physiological processes and soil fertility. Whenever osmotic potential reaches certain levels, as a consequence of high concentrations of salts in the soil solution, plant development becomes limited since they experience many difficulties in absorbing all the nutrients and water they need. Salinity also affects the metabolism of soil microorganisms, and alters soil structure, reducing its fertility. This problem is often associated with irrigation in areas where low rainfall, high evapotranspiration rates or soils with poor drainage impede the washing out of the salts. The regular use of water with an excess of salts in irrigation will, in the short-term, may cause or aggravate soil salinization, putting stress on and limiting agriculture.

In Portugal's coastal areas, as in many other areas around the world, poor water management has impacts on aquifers of the region, which end up with salinization. Salinity problems can be related to over-exploitation of groundwater induced by the expansion of human populations, associated industry, and agricultural practices. These pressures, along with pollution events and climate change, are likely to combine to produce a severe decline of suitable water as well as to accelerate salinization.

Excessive water extraction, increase in the population, contamination and salinization of the coastal aquifers will reduce the safe yield of the water that can be supplied. Such a scenario makes water quality and sustainable use of groundwater resources major challenges to the scientific community, managers and stakeholders. In the scope of the Water Framework Directive (2000) and the Groundwater Directive (2006), a good ecological status of groundwater must be guaranteed by 2015. To achieve this goal, we need to develop a better understanding of the prevalence and significance of aquifers through the integration of multi-disciplinary approaches, identify the risks associated with poor management and develop sustainable management strategies to prevent the deterioration of these water bodies and to ensure compliance with the established legal framework.

Keywords: salinization, coastal aquifers, water management, agriculture, WFD.

Integrated management practices for increased crop production: Introducing salt-tolerant crop varieties in the coastal areas of Bangladesh

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ABSTRACT

Bangladesh is a deltaic country with total area of 147 570 km². The major part of the country (80%) consists of alluvial sediments deposited by rivers, e.g. Meghna, Ganges, Brahmaputra, Tista, Jamuna and their tributaries. Terraces with an altitude of 20–30 m cover about 8% of the country, while hilly areas with an altitude of 10–1000 m occur in the southern and northern parts. The coastal region covers almost 29 000 km² or about 20% of the country. The coastal areas of Bangladesh account for more than 30% of the cultivable lands of the country. About 53% of the coastal areas are affected by different degrees of salinity (4.0–25.0 dS/m).

Agricultural land use in the coastal area is very poor, much lower, (62–144% less) than the country's average cropping intensity (175–180%). Salinity causes an unfavourable environmental and hydrological situation that restricts normal crop production throughout the year. The coastal area receives huge amounts of fresh alluvial deposits every year. The land becomes saline as it comes in contact with sea water and continues to be inundated during high tides.

The factors which contribute significantly to the development of saline soil are: tidal flooding during the wet season (July–October); direct inundation by saline or brackish water; and upward or lateral movement of saline groundwater during the dry season (November–June). Salinity problems will be exacerbated by climate change and sea-level rise; decrease of upstream flow due to Farakka Barrage in the upstream of the Ganges River; horizontal expansion of shrimp firms; and due to construction of the coastal embankment. The severity of the salinity problem in Bangladesh increases with the desiccation of the soil. The effect on crops depends on the degree of salinity at critical stages of growth, which may reduce yield and in severe cases causes total yield loss.

Soil reaction values (pH) range from 6.0–8.4 in the coastal region. The organic matter content of the soils is also low (1.0–1.5%). Nutrient deficiencies of N and P are quite dominant in saline soils. Micro-nutrients deficiency such as Cu and Zn are widespread. During the wet monsoon, the severity of salt injury is reduced due to dilution of the salt in the root zone of the standing crop. The dominant crop grown in the saline areas (July–October) is local transplanted rice with low yields. The cropping patterns followed in the coastal areas are mainly fallow–fallow–transplanted rice. The salinity problem in Bangladesh has received very little attention in the past.

Due to increased demand for food crops by an increasing population, it has become imperative to explore the potential of these lands for food security. High potentials of the area for increased crop production can be achieved by introducing salt-tolerant crop varieties and intensifying cropping through salinity control, improved irrigation and drainage systems and better soil and water management practices. Mutation breeding for evolution of salt-tolerant crop varieties coupled with biotechnology in laboratory and field level studies has provided an opportunity to develop salt-tolerant rice and other crop varieties. Isotopic tracer and nuclear techniques have provided the potential for exploiting the saline soil for better fertilizer, soil and water management practices in the coastal area. The findings of this research are that there is a potential for future exploitation of the saline areas to reduce food scarcity and poverty, increasing food security.

Keywords: salinity, crop production, salt-tolerant varieties, soil and water management practices, biotechnology, mutation breeding, tracer techniques, climate change, sea level rise, coastal embankment, upstream flow.

DESCRIPTION OF SYSTEM AFFECTED BY SALINIZATION

The main obstacle to intensification of crop production in the coastal areas is seasonally high content of salts in the root zone of the soil. The salts enter inland through rivers and channels, especially during the later part of the dry season (November–May), when the downstream flow of fresh water becomes very low. Low flow in the rivers is also caused by Farakka Barage in the upstream of the Ganges River. During the dry period, the salinity of the river water increases. The salt enters the soil by flooding with saline river water or by seepage from the rivers, and the salt becomes concentrated in the surface layers through evaporation. The saline river water through intrusion process may also cause an increase in salinity of the groundwater and make it unsuitable for irrigation. The increase in water salinity of southern area has created suitable habitat for shrimp cultivation. Along with other processes, shrimp cultivation played a major role to increase salinity, particularly in the south-western coastal region. Salinity is expected to be exacerbated by climate change and sea-level rise. A direct consequence of sea level rise would be intrusion of salinity with tide through the rivers and estuaries. It would be more acute in the dry season, especially when fresh water flows from rivers would diminish. Acording to an estimate of the Master Planning Organization, about 14 000 km^2 of coastal and offshore areas have saline soils and are susceptible to tidal flooding. If some 16 000 km^2 of coastal land is lost due to a 45 cm rise in sea level, the salinity front would be pushed further inland. The present interface between freshwater and saline water lies around 120 to 160 km inland in the south-west, and this could well be pushed northward.

EXTENT OF SALINITY

Coastal saline soils occur in the river deltas along the sea coast, from a few km to 180 km. The landscapes are low-lying land, estuaries and inland along the coast of Bangladesh. According to salinity survey findings and salinity monitoring information, about 1.02 Mha (about 70%) of the cultivable lands are affected by varying degrees of soil salinity. About 0.282, 0.297, 0.191, 0.451 and 0.087 Mha of lands are affected by very slight, slight, moderate, strong and very strong salinity, respectively. Cropping intensity may be increased in very slight and slightly alkaline areas by adopting proper soil and water management practices with introduction of salt-tolerant varieties of different crops. To mitigate the demand of fresh water for irrigation, especial emphasis may be given to adopt rain water harvest technology.

OBSERVED IMPACTS

This section summarizes the potential impacts of salinization and climate change on key sectors in Bangladesh.

Water resources

Water related impacts of climate change will likely be the most critical for Bangladesh, largely related to coastal and riverine flooding, but also enhanced possibility of dry season drought in coastal areas. The effects of increased flooding resulting from climate change will be the greatest problem faced by Bangladesh. Both coastal flooding (from sea and river water), and inland flooding (river/rain water) are expected to increase. Flooding in Bangladesh is a regular feature and has numerous adverse effects, including loss of life through drowning, increased prevalence of disease, and destruction of property. This is because much of the Bangladesh is located on a floodplain of three major rivers and their numerous tributaries. One-fifth of the country is flooded every year, and in extreme years, two-thirds of the country can be inundated. This vulnerability to flooding is exacerbated by the fact that Bangladesh is also a low-lying deltaic nation exposed to storm surges from the Bay of Bengal. Sea level rise will result in coastal flooding both under ambient conditions (given the low elevations of the coast), and even more so in the event of storm surges. It will also indirectly cause riverine flooding by causing more backing up of the Ganges, Brahmaputra and Meghna rivers along the delta.

Ecosystem

One of the likely adverse impacts of salinity and climate change is the loss of Sundarbans which are the coastal mangroves that straddle the coasts of western Bangladesh and neighbouring India. The Sundarbans were formed by the deposition of materials from the Ganges, Brahmaputra, and Meghna rivers. If the Sundarbans are lost, the habitat for several valuable species would also be lost. A 45 cm sea level rise would inundate 75% of the Sundarbans, and 67 cm sea level rise could inundate all of the system. Extrapolating from this information, a 25 cm sea level rise would result in a 40% mangrove loss. It is not certain whether there will be many adverse effects on the Sundarbans with a sea level rise of a few centimetres, although salinity could increase substantially in many areas. Even if barriers to migration such as physical structures could be moved, it is unlikely that inland migration could make up for losses of mangroves from inundation.

Agriculture

The effect of saline water intrusion in the estuaries and into the groundwater would be enhanced by low river flow, sea level rise and subsidence The adverse effects of saline water intrusion will be significant on coastal agriculture and the availability of fresh water for public and industrial water supply will fail.

Agriculture is a major sector of Bangladesh's economy and the coastal area of Bangladesh is very fertile for growing rice. Increase in salinity intrusion and increase in soil salinity will have serious negative impacts on agriculture. The presently practised rice varieties may not be able to withstand increased salinity. The food production does not seem to have a better future in the event of a climate change. The rice may fall by 10% and wheat by 30% by 2050.

Fisheries

The climate change and sea level rise (CCSLR) is likely to affect the fisheries in Bangladesh. Increased water temperature and salinity may not be suitable for many species. Sea level rise, by reducing the fresh water fishing areas, will cause reduction in fish production. Pond culture in the coastal area will be affected by intrusion of salt water into pond, unless embankments are made around them. Shrimp farming in the coastal area is lucrative business. Increase in salinity is likely to jeopardize the shrimp farming. For the last few decades, more and more attention is being given to sea fishing and brackish water fisheries. The CCSLR may arrest this trend.

REASONS FOR VULNERABILITY DUE TO SALINIZATION UNDER CLIMATE CHANGE

Of the several factors that affect rice production, abiotic stresses limit rice yields in 9 Mha in central and inland areas of the country. In India, water available for agriculture has fallen by nearly 10% during the last decade. While in Bangladesh, about 2.8 Mha of coastal soil has become saline due to heavy withdrawal of surface and groundwater for irrigation and intrusion of seawater. The total saline area forms one third of the 9 Mha of total national cultivated area in Bangladesh.

EFFORTS TO PREVENT SALINIZATION AND REHABILITATION

A wide array of river dredging projects have been completed to reduce siltation and facilitate better drainage at times of flooding as well as to boost dry season flows to critical areas such as the Sundarbans. The Ganges Water Sharing Treaty has been signed with India to boost dry season flows and reduce the threat of salinity, and more sophisticated cyclone early warning systems and protection shelters are being, to some extent, developed. All these measures are likely to contribute to reducing the vulnerability of Bangladesh to climate change impacts. Salt-tolerant crop varieties development is also a potential for rehabilitation to grow in the coastal area using fresh water arrested through rain water harvesting programme.

PREVENTION OF FURTHER SALINIZATION

With regardr to structural adaptations such as coastal embankments and salinity reduction/prevention, even though it is true that many of these measures have already been integrated in development projects and policies in Bangladesh, there remains an ongoing challenge with regard to their durability and sustainability. For example, given the high influx of sediments from the Himalayan Rivers each year (one of the cause of river bed rise), measures such as dredging of waterways are not a one time response but require periodic repetition. Similarly flow regulators on coastal embankments (to protect the non-saline land from development of salinity from tidal flooding) require constant monitoring and maintenance for the life time of such structures. Monitoring and maintenance in turn requires continued government and donour interest as well as participation of the local population far beyond the original lifetime of the project.

CONSEQUENCES IF FURTHER SALINIZATION DEVELOPS

About 10% more land will be affected by salinization and intensity will also be increased by 10%. There will be a decrease in the availability of agricultural land, which will subsequently reduce the productivity or total production. As land is lost due to salinity, total production will be affected which will create increased food insecurity. People in saline areas have been facing the hard reality of drinking saline water for decades. The situation has becomes worse with the introduction of shrimp farming and the consequent intrusion of brackish water far inside the coast. As a result, salinity has seriously affected groundwater. Finding no alternative, most people now use bacteriologically unsafe surface water. In the coastal area, there is already loss of biodiversity, e.g. decrease in tree species and fresh water fish. Every person in the saline area could be found to be suffering from one or more saline water-related disease.

Bangladesh tops the 2009 Global Climate Risk Index, a ranking of 170 countries most vulnerable to climate change compiled by Germanwatch, an international nongovernmental organization that works on environment and development issues. The nation is particularly at risk because it is a vast delta plain with 230 rivers, many of which unstably swell during the monsoon rains. This geology, combined with river water from the melting Himalayan glaciers in the north and an encroaching Bay of Bengal in the south, makes the region prone to severe flooding and salinity problems.

POTENTIAL COSTS FOR REHABILITATION

Bangladesh has so far invested more than US$10 billion to reduce vulnerability to natural disaster by building embankments and cyclone shelters. But it needs billions more to build similar infrastructure in the next 15 years to mitigate the threats, along with enhancing research on climate-resistant agriculture.

CONSTRAINTS FOR AGRICULTURAL DEVELOPMENT

The agricultural development in the coastal saline belt is constrained by various physical, chemical and social factors. In general, the major agricultural constraints identified that impede development are as follows:

- It has been found that constraints increased with increasing intensity of salinity. Soil salinity is the most dominant limiting factor in the region, especially during the dry season. It affects certain crops at different levels of soil salinity and at critical stages of growth, which reduces yield and in severe cases total yield is lost. A substantial area of land is tidally affected by saline water. Appropriate management practice for crop production in this area is not available.
- Fertility status of most saline soils range from low to very low in respect to organic matter content, nitrogen, phosphorus and micronutrients like zinc and copper. The crop yield obtained in these soils are low.
- Scarcity of quality irrigation water during dry season limits cultivation of dry season rice (boro) and winter crops, and rice cultivation during March-July season.
- Variability of rainfall, uncertain dates of onset and recession of seasonal floods and risk drought restrict cultivation of rice both in dry (March–July) and monsoon period (July–October). Uncertain rainfall delays sowing/transplanting and flood damages dry season and monsoon rice.
- Narrow technological and germplasm bases for salt-tolerant crops limit crop choices. On the other hand, due to extensive cultivation of a particular cultivar of crop year after year make the crop susceptible to pests and disease attack. Pests and diseases like hispa, leaf-hopper and tungro virus are prevalent in the region and extensive damage is caused by these almost every year.
- In the coastal saline belt with short winter season, timely sowing/planting of winter crops is essential but this is restricted by late harvest of monsoon season rice.
- Presence of saline groundwater table throughout the year within 1.0 m depth is another factor affecting crop production in the saline belt.
- The texture of most saline soils varies silt clay to clay. Land preparation becomes very difficult as the soil dries out. Deep and wide cracks develop and surface soil becomes hard. These also necessitate deep and rapid tillage operations.
- Difficult communication and remote marketing facilities also retard agricultural development in the region.

STRATEGY FOR MANAGEMENT OF COASTAL SALINE SOILS

The following points could be options for saline land cultivation practices in the long run:

- Protective embankment: Land may be protected from inundation of saline water through establishment of embankment of suitable size. The recommended size should be 1 meter high above the high tide level.

- Provision of sluice gate on the embankment: There should be provision of sluice gate in the embankment system to remove excess water and also to prevent ingress of saline water during high tide.
- Levelling of land: Slight variations in the micro-relief lead to salt accumulation in the raised spots. Land should be properly levelled to prvent accumulation of water in the low-lying patches with shallow groundwater tables and to facilitate uniform drainage of excess water. It will help to apply irrigation water uniformly in the field in winter dry season, facilitate germination of seeds and better growth of crops.
- Storing of excess rainwater for irrigation: Initiatives should be taken to store rainwater which is the potential source of fresh water for irrigation. This water can be used for rice irrigation (during no rain period) during June–October (monsoon) and also during dry winter period (November–May).
- Salt-tolerant rice and non-rice crop varieties: Cropping intensity can be increased in about 0.596 Mha of very slight (2.0–4.0 dS/m) and slightly saline (4.1–8.0 dS/m) areas by adopting proper soil and water management practices with the introduction of salt-tolerant crop varieties.
- Keeping land covered in winter and summer months: Groundwater is saline which present at shallow depth (about 1.0 m from the ground surface). Keeping land fallow promotes salinity build up on the soil surface through evaporation process from the soil. Therefore, it is recommended to avoid fallowing of lands during dry season. Salt-tolerant crop varieties should be chosen to grow in the area to lower the salinity of the soil profile.
- Fertilization of crops: Salt-affected soils are in general poor in fertility with low organic matter content. It is necessary to apply appropriate fertilizers to boost up crop production. Potash fertilizer has an added advantage under soil salinity. It lowers down Na uptakes by plants and of course increases K uptake. Thus K fertilization protects crops from harmfull effects of Na.
- Provision of sub-surface drainage: In many parts of the coastal area, salinity is very high. To grow crops successfully in those areas, it is necessary to bring down the salinity by leaching the salts. It is also necessary to lower down the water table and maintain it below the critical depth to prevent salt effect on crops grown. To achieve the objective, a proper sub-surface drainage has to be installed to keep the groundwater at least one meter below the soil surface. This technology is effective but somewhat expensive.

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Soil water and salinity modelling aimed at sustainable agriculture

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Evapotranspiration by crops and bare soil increases salinity in soils, in particular when irrigation water and groundwater is of poor quality. Critical conditions are defined by threshold values defined in terms of sodicity, above which soil structure is destroyed and thresholds defined in terms of salinity, above which crop yield starts to be reduced. Numerous models for salt and water transport are available and approaches range from steady state to transient process descriptions which are mathematically complex and numerically intensive. Descriptions of crop growth as dependent on salinity are rather more limited in physiological detail. When striving for soil-vegetation models which are balanced in terms of detail, quantitative descriptions of crop physiological responses seem to be limiting the approaches available.

In this presentation, we will give an overview of some currently actual issues in the scientific debate, on water availability from the perspective of the soil physicist and hydrologist. These issues involve whether or not the stresses from water availability and soil water salinity (osmotic effects) should be conceived as additive or multiplicative. This debate is illustrated with detailed mechanistic modelling. Furthermore, we show the effects of soil salinity on the water balance of the rootzone, in a stochastic ecohydrological systems analysis approach, results of which are used to indicate currently unresolved issues in soil water salinity research.

Keywords: osmotic potential, transpiration reduction.

Impacts of climate change and sea level rise on wetlands agriculture: a case study from India

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ABSTRACT

Coastal wetlands face challenges from the changing climate and rising sea level, in addition to increasing anthropogenic activites. The issue is serious in developing countries like India where wetlands agriculture is vital in maintaining food security and where adaptation strategies are not well developed and not properly implemented. The Vembanad-Kol coastal agricultural wetland in India now faces environmental problems affecting the ecosystem and the livelihood of thousands of wetland dependent communities.

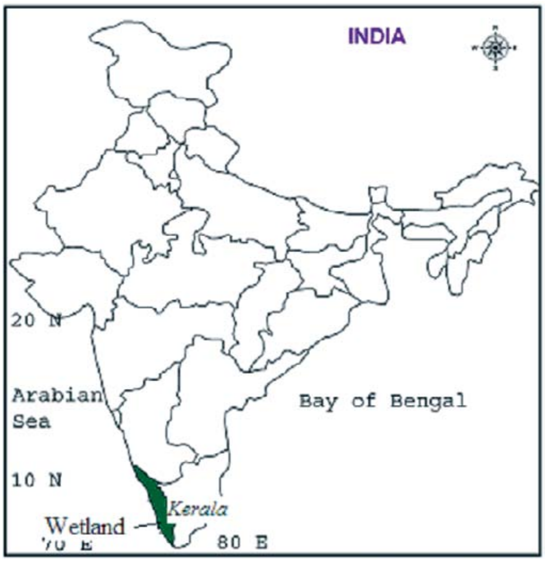

FIGURE 1
Vembanad-Kol coastal wetland.

The Vembanad-Kol (also called Kuttanad) wetlands, the largest designated wetland in India lying in the south-western coastal state of Kerala, are rich in biodiversity, provide hydrological and ecological services and also support the livelihoods of thousands of rural people. It acts as a mechanism for flood control and pollution abatement. It provides income through fisheries, lime shell collection, rice and banana cultivation, duck farming, navigation, port facilities, tourism and the coir (natural fibre extracted from coconut husk) industry. It is a complex wetland system comprising of backwaters, marshes, lagoons, mangrove forests, reclaimed land and an intricate network of natural and man-made canals. The wetland system covers an area of over 1 512 km², of which 500 km² are 0.6 to 2.2 m below sea level. About 30% of its inhabited area was recovered from water. The northern region is more urbanized and industrialized. The five rivers—Pumba, Achenkovil, Meenachil, Manimala and Muvattupuzha—flow through the wetland to join the Arabian Sea. From these rivers, 10 000 Mm^3 water flows into the wetland in a year. In extreme years it can be as much as 15 000 Mm^3. Steep slopes in the eastern hills, the Western Ghats where the rivers originate cause fast flow of water in rainy season and results in flooding in the wetland. This acts as a natural flushing system that removes the wastes and wastewater in the wetlands into the Arabian Sea and minimises saline water mixing. The wetland is of high conservation priority owing to vanishing mangrove patches and declining diversity and population of fishes and other aquatic species and migratory waterfowl. It was declared as a Ramsar site by the Convention on Wetlands in November 2002.

IMPACTS OF DEVELOPMENT PROJECTS AND ANTHROPOGENIC ACTIVITIES

The wetland has been subjected to intense human interventions for agriculture, industrial developments and human settlements. For rice, the State of Kerala largely depends on the agriculture in this region. The paddy fields (550 km^2) cover about 65% of the total rice cultivation area of Kerala. In 30% of this, only single cropping was possible due to flooding and saltwater intrusion in dry months. Cultivation was carried out by constructing temporary dykes in lowlands and pumping out water. Floods used to break the dykes in rainy season, resulting in heavy losses. To avoid this and to make double cropping possible to meet increasing demands, control of floodwater in rainy season and prevention of saltwater intrusion in summer became necessary. With this in view, three major projects were planned and implemented for the overall development.

Thottappally Spillway was completed in 1955 at the south-western part of the wetland to remove floodwater from upper Kuttanad in peak monsoon season. It was designed to transport 19 500 m^3 water per second. But, when completed it could transport only 600 m^3 water per second. This is because of the failure in the completion of leading channels aimed at collecting the floodwater flowing in different directions and then to lead through the upper Kuttanad into the Arabian Sea. Also there was a failure in foreseeing the rising sea level due to strong winds and the sand bars formed parallel to the coast in the monsoon season. This prevents outflow of floodwater and results in severe flooding and so crop failure, in addition to the inflow of sea water. Flow through numerous small canals also was not seriously considered. Now, during December–March seawater leaks inside, as the shutters of the spillway are not properly maintained.

The Thanneermukkam Barrage in the north was partially completed and commissioned in 1975 to control saltwater penetration from the backwater so as to make rice cultivation possible in pre-monsoon season also. During November–December tidal variation is 1.3 m. By December, water flow from rivers is considerably reduced and to avoid saltwater inflow, shutters are closed. The barrage has a length of nearly 1 500 m with 31 shutters on each side to control water flow and two locks to allow water transportation. Even now, it is not completed, as arguments on whether it is a success or failure is continuing. Fishermen and agriculturists are on opposite sides with disputes on the time of opening. Delay in annual closing and lack of timely maintenance of the barrage allow salinity intrusion when the sea level is high. Instead of completion, a sand dyke and road was constructed in the central part so that road transport became possible between the coastal area and the interior.

The A.C Road at the southern boundary was constructed to make access to the isolated regions easy. During construction, proper care was not given to the water flow through canals. This added to water pollution and fresh water scarcity. The new road promoted encroachment and reclamation by the real estate lobby.

Drawbacks in the project worsened the environmental conditions in the wetland region and objectives were not achieved. Salinity increased during the cropping season. Floods became severe during monsoon months. As the natural flushing effect was controlled by the barrage, concentration of pollutants multiplied. This led to the contamination of both surface and groundwater resources, including traditional sources like ponds and wells. Aim to multiply cropping was not achieved, mainly due to untimely opening and closing of shutters. Rice production became half.

A major source of pollution to the rivers and wetland is from agriculture. All the rivers carry pesticides and fertilizers up to 500 to 1000 t per year. This includes organochlorine and organophosphorous and the use is very unscientific and is lot more than actual requirement. As the rivers joining the wetland flow through thickly populated regions, there is tremendous input of detergents and bio wastes from household. There are several small factories and vehicle servicing centres in this region that empty wastewater containing oils and chemicals. In the lowland areas, coir making is the livelihood of many low income people and the coconut husk retting in freshwater has deteriorated the water in ponds and canals. New roads promoted tourism. Pollution from the increasing number of houseboats invited new environmental issues. As natural flushing was obstructed, waterlogging made water unsafe, making the region inhospitable. Vectors grew fast and water-borne and vector-borne diseases became common.

New schemes for river linking and water diversion may reduce summer runoff in rivers, inviting more intrusion of saline water. Overdraft of groundwater and development of aquaculture farms also result in salinity intrusion.

Impact of changing climate

The area receives more than 300 cm of rainfall annually, mainly during the south-west monsoon (June to September). North-east monsoon (October to November) and pre-monsoon (March-May) thunderstorms also bring some rain. There is an increasing trend in rainfall intensity and seasonality (Nair, 2007). Long dry period reduces the runoff in rivers and water level in wetland area. As the barrage is not being operated properly, large quantity of brackish water enter the wetland. Increasing rainfall intensity worsens flood and also cause large input of sediments carried by the rivers.

Studies indicate a trend in sea level rise of 1 cm per decade along the Indian coast (Unnikrishnan *et al.*, 2006). Large area of the wetland is already under water. Sea level rise due to thermal expansion of sea water may add to this. Most of the land that separates the wetland and the Arabian Sea is only around one metre above the high sea level. If the predicted rise in sea level really happens, all the measures to control salinity are likely to fail. There will be inflow of sea water through numerous inlets. The present spillway and barrage may become useless and rice cultivation may totally disappear.

Socio-economic issues

Salinity intrusion in the wetland may create several socio-economic issues in future. Fall in rice production will be a serious threat to food security. Safe water will become a rare and costly commodity that may be unaffordable to the poor. Change in salinity level may affect the existence of aquatic life. Mass migration can be expected to the eastern highlands. As the highlands are already thickly populated, conflicts are likely to develop over land and water resources and over food allocation. Rural unemployment in the agricultural sector may create unrest in society. Large investment will be required for adaptation and to provide basic necessities and infrastructure.

Current policies

Current policies such as the wetland policy, agriculture policy, water policy, environment policy and climate policy and current management strategies are incapable of protecting the wetland from the challenges. Most of the policies are just guidelines and they lack information on how to implement the suggestions successfully and how to enact the regulations properly.

Notification of the Ministry of Environment and Forests (2009) suggests the formation of Central Wetlands Regulatory Authority that includes senior government officials and experts to grant of clearances for permissible activities in the wetlands, to exercise regulatory functions, to determine the zone of influence of the wetlands, to issue broad guidelines for compliance by the State Governments. In addition, there are state level and district level authorities.

The policy restricts activities such as conversion of wetlands to non-wetland use, reclamation of wetlands, industrial development, manufacture, handling, storage or disposal of hazardous substances, solid waste dumping, discharge of untreated wastes, construction of permanent nature except for boat jetties within fifty metres from the mean high flood level any other activity to be specified by the regulatory authorities constituted in accordance with these rules, which may have adverse impact on the ecosystem of the wetland. Prior approval of the regulatory authority is required for withdrawal of water, impoundment, diversion, interruption of sources, harvesting of living and non-living resources, treated effluent discharges, plying of motorized boat, dredging, construction of boat jetties, activities which interfere with the normal runoff and related ecological processes upto 200 m of wetland, construction of bridges and roads, fisheries and any other activity to be identified by the regulatory authorities, which may have adverse impact on the wetlands. However, the policy does not make any constructive suggestions or recommendations for the conservation the wetlands demand.

National water policy (Ministry of Water Resources, 2002) is silent over the key issues related to wetlands and climate change. National agriculture policy (Ministry of Agriculture, 2000) is unable to provide strong guidelines for adaptation strategy in a changing climate. Though the millions living in climate sensitive coastal zones and wetlands make India highly vulnerable to the impact of a changing climate, India was too late to develop a national climate policy (National Action Plan on Climate Change, 2008). The policy also does not provide any strong adaptation strategy for the wetlands. The coastal zone regulation act (Ministry of Environment and Forests, 1991) prohibits any development activities within 500 m of the water bodies. But, there are loopholes in the act which are being cleverly exploited. There are environment policies at the national and state level. They appear to be strong, but their implementation often fails due to several socio-economic reasons, vested political interests and high level of corruption. So, they are always violated.

There are several hurdles in implementing the policies and strategies including lack of finance, lack of public awareness, lack of proper training for professionals, poor information system and unreliable data banks, lack of adequate planning and vision, slow government machinery, weak administrative and legal mechanisms, fragmented organizational structures, non-cooperation among agencies and Government departments and conflict among different groups.

Suggestions and recommendations

Since wetland agriculture is a key factor in maintaining food security for the fast rising population, urgent measures are necessary to control salinity intrusion in the area.

The spillway is to be redesigned to resist inflow of sea water and the leading channels are to be completed to evacuate floodwater. Regulators in the barrage and spillway are to be properly maintained. Opening and closing of the shutters should be based on the climate and water quality conditions and not on fixed time as it is done now. Water quality in the region should be continuously monitored. More water storage reservoirs in the eastern highlands and timely release of water into the wetland can help reduce pollution concentration and saline water inflow during non-rainy months.

Crop varieties capable of growing in saline environment are to be developed and introduced in the region. A better crop calendar to adjust farming with changes in climate is necessary. Crop diversification may become necessary to meet the rising food demands.

Adequate facilities are to be provided for freshwater for domestic purposes. A water treatment plant is the area is ideal. Water harvesting techniques is to be implemented at the domestic level and financial and technical assistance are to be extended.

Environmental laws should be enacted properly to control wetland degradation. Sand quarrying in the rivers and wetland has been a serious environmental problem in this area and it should be controlled. Land reclamation has considerably reduced the area of wetland and connected water bodies and this has adversely affected the water quality and quantity. Prohibition of any more land reclamation is urgent. Possible ecological and hydrological changes should be deeply studied before the implementation of any new projects.

A major suggestion is the construction of a freshwater dike or spillway on the western side of the wetlands parallel to the backwater so that there is no possibility of seawater mixing. Controlled mixing of the salt water from the backwater can solve acidity problems.

India has to develop a comprehensive, frequently updated policy for climate change adaptation and a mechanism for its effective implementation. New management practices and policies to reduce vulnerability of ecosystems are to be identified. Improved observation methods, better international cooperation in research and technology, permanent mechanism to monitor climate change impacts and regionwise, in-depth study of the environmental changes are also necessary. There should be better coordination of different programmes running under different departments. Coastal Zone Regulation Act is to be enacted after removing the drawbacks.

Proper public awareness and participation of NGOs and stakeholders in policy development and implementation can do much in protecting the wetland agriculture from salinity problems. Rights of communities engaged in traditional agriculture and other wetland based activities should be protected.

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Evaluating the effects of climate change on coastal areas, lagoons and wetlands, including economic, social and environmental aspects: A case study from Turkey

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ABSTRACT

The coastal zone is expected to be home to nearly 75% of the world's population by 2025. Nearly half the world's major cities are located within 50 km of the coast and coastal population densities are 2.6 times greater than those of inland areas. Heavy urbanization, demographic and industrial developments around this zone have worsened the situation. The coastal sprawl is highly affected by increases in tourism. In less than one generation, entire swathes of the coast have disappeared under concrete, causing irreversible damage to landscapes and loss of habitat and biodiversity. The effects of a drop in natural sediment input from rivers, illegal extraction of sand and inappropriate construction on the coast are combining to intensify coastal erosion, the economic consequences of which can pose a major threat. Demands on coastal zones are ever increasing leading to severe socio-economic and environmental problems in these fragile ecosystems. Despite growing awareness sustainable coastal management policies remain insufficient. The relative share of protected coastal areas remains low despite a six-fold increase over 25 years.

Climate is one of the two most important physical factors (the other being topography) determining the survival and nature of all living beings, from individuals and communities to populations and entire species, by heavily influencing the coastal ecosystems. This presentation gives a general account of the coastal zone ecology of Turkey and potential impacts of climate change on this zone.

CLIMATE CHANGE IMPACTS ON THE COASTAL ZONE ECOSYSTEMS AND MAJOR CONSEQUENCES

The IPPCC predicts that global mean sea level may rise as much as 88 cm by the end of the 21st century. Sea level rise will have numerous impacts. Flooding of coasts, estuaries, and river deltas can alter the physical structure of habitats and lower habitat availability and suitability. Increased coastal erosion can reduce or remove beach areas and protective barrier islands and interfere with nearshore currents and their physical transport patterns. Subsequent changes in drainage and irrigation patterns and modifications of fluvial flows can reroute sediment transport nutrient runoff into coastal waters. Saltwater intrusion into coastal wetlands, especially estuaries, can negatively affect these ecosystems and contaminate groundwater and other inland freshwater sources.

Global warming adds a significant stress to them. It will increase sea surface temperatures as surface waters absorb heat from higher air temperatures. Such altered temperature regimes can significantly affect the reproduction and survival of species. In addition to heat, the oceans absorb CO_2 from the atmosphere. This process also creates carbonic acid in the seawater. Ocean acidification has a corrosive effect on the corals and shelled organisms that form the basis of marine and coastal food webs. The coastal and marine locations with naturally occurring high CO_2 levels show a high number of invasive species and low biodiversity.

Main coastal formations in Turkey

Turkey has 8 333 km of coastline covering the Black Sea, Marmara Sea, Aegean Sea and Mediterranean Sea, extending from the borderline with Georgia in the North to the border with Syria in the south. The coastline is supported by a large hinterland which abounds in highly productive ecosystems, such as lagoons and wetlands. These provide many benefits and a range of natural services by supporting a variety of habitats. In fact they have a significant contribution in the overall productivity. Sea bream and bass production has shot up, with an average annual growth rate nearing 27% over the same period, to hit 180 000 t in 2006, 80% of which originated in Turkey and Greece. There are 110 dunes distributed along the coast. These dunes are 845 km long, covering an area of 36 601 ha. Turkey's coastal region is a key area of vulnerability. Several of its component sub-regions have consistently been identified as among the most vulnerable to climate change now and in the future.The coastal areas face range of stresses and shocks, the scale of which poses a threat to the resilience of both human and environmental coastal systems, and which are likely to be exacerbated by climate change. The following coastal regions and districts can be distinguished: Black sea region, Marmara region, Aegean region, and Mediterranean region. The usual formations of erosive and sedimentary origin are of four types: muddy coastal swamps, sand dunes, the siliceous dunes and fissured cliffs. The exotic karst formations of corrosive origin predominate along the southern and south-western Anatolian coasts. The coastal karst of this area is also very important biogeographically as it is the main centre of coastal endemism.

Changing Coastal Zone Ecology

Turkey is a rare example among the world coasts, with a relatively low level of coastal exploitation, and consequently many natural coastal ecosystems are still well preserved. However, little scientific interest has been devoted to these zones. Loss and degradation of these ecosystems is affected by several interacting factors like; land-use change, sedimentation, overfishing, point and nonpoint pollution sources, freshwater withdrawal from ground and surface water sources, and shoreline hardening. All these have a profound impact on their existence and productivity by changing the ability of the natural communities flourishing in these ecosystems and push them to get adapted successfully to changing conditions.The degradation has been accelerated by tourism (last 15 years, more than 10,000 ha), reforestation (last 38 years, 10 672 ha), industry (around 7 000 ha), sand extraction (nore or less 3 000 ha), grazing (aiore than 3 000 ha) and mining activities (nearly 1 000 ha). Presently there is no protection for coastal dune vegetation. Agriculture is traditionally the main and often also the only use of the coastal areas in Turkey, and, due to the varied climate and soils, coastal agriculture is also varied. Overall, however, their impact on the dunes is low. Because the Turkish inland is very dry and the coasts more rainy, coastal slopes are important for forestry. Coastal afforestations are especially abundant along the wet-temperate northern coasts, from the Bosphorus to the Georgian border. At the sametime some exotics are moving fast along the Meditarranean region. The coastal urbanization has spread all along the Mediterranean coast and big hotels are replacing the dunes. The industrial estates too have gone up along the aquatic ecosystems alongwith coastal mining carried out in the siliceous rocks of northern and western Anatolia. The really important centres of coastal tourism are those with the numerous ancient monuments and ruins. The coastal ecosystems and vegetation of northern and southern Anatolia are among the best preserved ones in the Mediterranean, and thus of considerable comparative interest. At the same time, the efforts to establish a series of national parks and natural sites have been well accepted by the people.

The coastal zones are rich in plant taxa like *Ammophila arenaria ssp. arenaria*, *Artrocnemum fruticosum*, *Atriplex lasiantha*, *Cakile maritima*, *Calystegia soldanella*, *Centaurea spinosa ssp. spinosa*, *Chenopodium album subsp. album*, *C. murale*, *Cyperus capitatus*, *Eryngium maritimum*, *Euphorbia paralias*, *Halimione portulacoides*, *Halocnemum strobilaceum*, *Hordeum marinum var. marinum*, *Imperata cylindrica subsp. cylindrica*, *Inula crithmoides*, *J. acutus*, *J. maritimus*, *Lagurus ovatus*, *L. bellidifolium*, *L. gmelinii*, *L. sieberi*, *Matthiola tricuspidata*, *Medicago. marina var. marina*, *Otanthus maritimus*, *Pancratium maritimum*, *Petrosimonia brachiata*, *Phragmites australis*, *Plantago coronopus subsp. commutata*, *Polypogon monspeliensis*, *Salicornia europaea*, *Salsola kali*, *Spergularia marina*, *Suaeda prostrata subsp. prostrata*, *Tamarix parviflora*, *T. smyrnensis*, *T. tetrandr* and *Urginea maritima*, and a refuge for the migratory birds, as well as home for the resident birds and other animals. However, their setting within the landscape leaves them especially vulnerable to several physical, ecological, and associated societal disturbances.

The introduction of exogenous species represents a growing threat and, in the long term, global warming could change the marine ecosystem. The underwater prairies so essential to fish reproduction and beach maintenance are being damaged by work at sea, physical pollution and the uprooting caused by the anchors of pleasure craft. It is therefore necessary to assess the impacts of climate change to better understand the vulnerability of coastal zones. An increasing concern stresses that current management practices along the coastal ecosystems are unsustainable.

QUO VADIMUS

Integrated coastal zone management (ICZM) is a dynamic process which takes into consideration ecological, economic and social resources of the coasts. It adopts sustainable measures to reduce negative impacts of natural phenomena, including impacts of climate change. Recently most important Integrated Coastal Zone Management (ICZM) protocol was signed in Madrid in 2008. The evaluation revealed that, despite the positive impact made by the recommendations through its championing of a"more holistic spatial planning", there have been delays and no significant progress. The evaluation report recognized that the environmental degrading of the coasts remains a serious problem, and linked future progress in relation to ICZM with aims at combined environmental information systems. So far as mitigation, adaptation and transfer of technology are concerned, there is need to develop strategies, cooperation and joint programmes to implement the decisions. A regional approach should be implemented at the national level, and all sectors of the economy.

In an era in which the greenhouse effect and desertification are making there presence felt ever more acutely as they pose a serious threat to the coastal and marine ecosystems, we need to look ahead to new organizational structures with a view to integrated planning for coastal regions. The 'usual' offices in the various ministries, regions, prefectures and municipalities that are usually called upon to solve the problems relating to demarcation, protection and administration are insufficient, as a result of which the all-important issues of coordination and cooperation between the bodies involved and the drafting and application of policy are totally ignored. The management by means of a powerful and inspired national programme has not served to redress this state of affairs. In the coastal zone, an area beset by problems of land ownership, it is essential that a special mechanism be put in place for their solution, which will help in the drafting of a well thought-out spatial planning policy for our coasts and provide the means for its application.

The ICZ planning management remains a complex issue and a difficult project requiring systematic approach and data gathering. This will have to lead to the drawing up of a strategy which will be in accordance with and make active use of the favourable provisions included in the international conventions and in the Blue Plan produced by the UN Mediterranean Action Plan to make it possible to protect and develop a valuable natural resource of vast environmental and socio-economic importance.

There is a need for timely adaptation of these ecosystems to global warming. A too much delay will mean that the option of adaptation no longer exists. Serious Socio-economic, technical, political, and ecological problems hamper the planning and implementation of adaptive strategies. The awareness at national level of the impending climate risks, special vulnerabilities of particular populations, and responsibilities of individuals and groups in mitigating climate change and reducing vulnerability are very low. The reason being that interest in economic development of the coastal zone has overridden concerns regarding climate change, natural disasters, or environmental quality. Despite slowly increasing levels of awareness among the general public, the level of debate and discussion is woefully inadequate.

Present understanding of most ecological processes largely derives from individual species, sites, or smaller regions studied over shorter time scales (a few decades). This makes it difficult to connect specific processes taking place in populations and communities with broader climate change affecting whole regions and their constituent ecosystems.

The maintenance of coastal ecosystems is growing in importance as buffers against climate impacts and for sustaining coastal livelihoods. It would be far better if popular awareness and political foresight could engender timely and effective measures to avert the high human costs of global warming than for society to respond only belatedly to climate calamity.

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Vulnerability of a coastal plain of Mexico to climate change

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The Pacific Coastal Plain of north-western Mexico, comprises 445 Mha in Nayarit State. The origin of the coastal plain is related to marine transgressions and regressions which occurred in Pleistocene and Holocene times and controlled the formation of deltas at river outflows and beach ridges that enclose wetlands currently connected to the Pacific Ocean through coastal lagoons and tidal channels. Soil formation occurs under a warm sub-humid climate with tropical forests and mangroves, where Fluvisols, Feozems, Cambisols, Solonchaks and Arenosols are the dominant soil types.

The actual processes of change in the above-mentioned soils are post-Holocene desalinization, net carbon loss and tidal-driven saline intrusion in free aquifers. The future vulnerability of the coastal plain ecosystems and soils will be related to the tendency of sea level rise of 1.9 a 3.3 mm/year, a slight increase in precipitation concentrated over a shorter period, a mean increase of 1 °C on the maximum and minimum temperatures every 30 years, together with the change of regime of river flows due to the potential construction of infrastructure.

Keywords: processes, fluvial plains, beach ridges, salinization, climate change.

DESCRIPTION OF THE SALT-AFFECTED SYSTEM

The Pacific Coastal Plain occupies a small area which is located north-west of Mexico and comprises 445 069 ha in the state of Nayarit (Gonzalez *et al.*, 2009), its origin is related to marine transgressions and regressions occurred during the Pleistocene and Holocene periods. Curray *et al.* (1964, 1969), point out the influence on the plain formation of the increase in sea level during the last glaciation (about 18 000 years) and the onset of regressional relief uplift in the late Holocene, with the subsequent formation of beach ridges. The marine regresion and formation dynamics of this coastal plain have given rise to three major geomorphological landscapes: the deltaic floodplain, coastal lagoons and marshes, which ouflow to the Pacific Ocean are limited by parallel bars of ancient shorelines (Bojorquez *et al.*, 2006). From the Sierra Madre Occidental mountain range, several rivers flow toward a system of coastal lagoons and mangrove fringes, extending over the Pacific North-western coast of Mexico. These regional geomorphologic units were included within the number 732 RAMSAR polygon site in Mexico and a recently-established biosphere reserve named Marismas Nacionales.

The conditions of soil formation in coastal system of Nayarit are controlled by a warm, humid climate, with average annual temperature of 25 to 26 °C and rainfall between 1 000 and 1 300 mm, concentrated in the summer. A regional relief plane whose origin is closely related to a marine transgression occurred during the Quaternary. A later regression of the coastline controlled the deposition rate of deltaic, fluvial deposit and terrace levels, which later determined the development of soils. The evolution and position of sand beach ridges, have enclosed areas of depressed relief and wetlands, influenced by the tides through transversal channels, salty marshes and coastal lagoons. The original vegetation of the coastal system was tropical forests, mangroves and halophytic vegetation. After long periods of anthropogenic influence, the original vegetation was replaced by secondary forests, low forest and crop areas. Thus, the soil types and their main characteristics and processes of change can be described by geomorphologic units within the coastal system of northern Nayarit State (Bojorquez *et al.*, 2006, 2007, 2008).

Alluvial fans and deltaic floodplains where created on the lower watersheds of the currently meandering rivers: Santiago, San Pedro, Bejuco, Rosamorada, San Francisco, Acaponeta and Cañas. Within the formerly active deltas soils development was related to the geomorphology and topographic level and the key process of change taking place on them. Thus, the eastern part of the coast plain mainly influenced by of river depositional processes is characterized by different levels of terraces, where soil types are typically Haplic Fluvisol Fluvic Cambisol. While in the current higher-level inactive floodplains, Haplic Cambisol are registered for the higher plains and vertic Stagnosols in depressed areas flooded during the rainy season. In between, the medium height floodplain has a soil association of Haplic Fluvisol and Fluvic Cambisol.

During the Holocene, dominant processes were the fluvial depositional processes related to the main rivers, local erosion patterns and the beginning of clay formation, with a significant process of humification under the original tropical forests (and the development of the Feozem soil-type). As a result of continuous cropping during the last hundred years, there is an accelerated decline in soil carbon stocks, in addition to post-Holocene leaching of salts already contained in these soils.

Depressions in the medium topographic level of floodplain used to be flooded during the rain season and still support tropical forest cover, dominated by *Orbignea guacouyule*. These depressed sectors have had accumulation of salts in the past—much of it washed naturally—but based on the presence of some exchangeable sodium, the development of an association of Haplic Cambisol (Hyposodic, humic oxiáquic) and Haplic stagnic Solonetz (endoclayic, oxiácuic) has been recorded.

Towards the west, to the coast, a low plain with some tidal influence is a transition area between the active fluvial floodplain and a complex estuarine lagoon system, with influence from meandering flooding and tidal channel. Adjacent to the lagoons, the development of soil type Fluvic Cambisol, endosalic (sodic episiltic) and Haplic Fluvisol (oxiaquic, hyposodic, endoarenic) has been recorded. Within minor depressions and the lagoon surfaces, fine sedimentation takes place, where a combination of Gleyic Stagnosols and Salic Fluvisol were formed. This lower section of the deltaic plain is seasonably influenced by the large flooding of rivers and by the salts input through tidal channels. Vertical movement and capillarity from a shallow watertable also controls the accumulation of salts in the subsoil and temporarly on soil surface in these depressions.

As the coast regressed and beach ridges partially blocked the rivers outflows into the ocean, enclosing part of the runoff, lagoon systems were created. A second geomorphologic region, comprises a saline plain and wetlands around coastal lagoons, where there is direct influence of tidal dynamics, in between the higher beach ridges and deltaic floodplains. Hydrodynamic is mostly influenced by tides, and groundwater flow patterns. Following high precipitation periods, eastern large flooding events force a temporarily unidirectional surface-water flow towards the ocean through a network of channels connecting lagoons and the Pacific Ocean. Within the tidal basins, saline water input is related, mainly, to tidal inflows though the coastal channels. The main channel outflows (or locally known as “mouths”) on the coast are named, from north to south, Teacapán, Cuautla channel, Camichines, Asadero and San Cristobal mouths.

The regular water level on the network of channels and lagoons corresponds to the daily difference of high and low tides. The lowlands with this direct tidal influence represents the sedimentary support of the red mangrove (Rhizophora mangle), which associations creates habitat and wetland ecosystems on the edge of the tidal channels where saline water and river freshwater temporarily merge. Upland the white mangrove (Laguncularia racemosa) grows over the shallow groundwater floodplain, on soil type Hypersalic Gleyic Stagnic Solonchack (sodic, chloridic). Higher topographic inland levels are reached by the extraordinary tides during he highest tidal cycle. Following the important infiltration and recharge rates during rainy season and floods, local water table reaches maximum altitude over sea level and minimum depth from ground surface. Capillarity processes become relevant from water table, from groundwater of variable dissolved salts concentration. From the month of November and on, a dominant lengthy process of evaporation from soil water takes place, and last for the whole dry season, which makes the salts rise to the surface, forming salt crusts. Only halophytes species highly resistant to saline conditions grow in this portion of the plain, mainly vidrillos species (*Batis maritima*, *Sesuvium portulacastrum*), black mangrove (*Avicenia germinans*) and Chinese mangrove (*Conocarpus erectus*). These are seen as areas of bare white-surface soils with the type Hypersalic Solonchack (sodic, chloridic, sandy).

The third level of flooding occurs during the rainy season in the months from July to October, reaching certain parts of the plain which support black mangrove species and halophytic vegetation (*Acanthocereus occidentalis*, *Cyperus articulatus*, *Annona reticulata*, *Pithecellobium lanceolatum*, *Sesuvium portulacastrum*, *Prosopis juliflora*). In these areas the soil types registered are Salic Fluvisol (oxiaquic, humic, sodic, siltic) + Fluvic Cambisol (humic, sodic, clayic) + Stagnic Mollic Solonchack (sodic, chloridic). Although the soils are subject to seasonal flooding regime, gleying does not show due to good porosity in the soil, maintaining a supply of oxygen into porous media water, thus reducing the manifestation of the reduction processes in the soil.

Finally, the geomorphological region of beach paleoberms and sandy coastal crests along the Pacific coast, corresponds to a landscape of marine accumulation, constructed from continental fluvial sediments, creating a landform of stretched succession of bars and ridges with different altitude (ranging from 0-5 m above mean sea level), which runs parallel to the coast for miles. Small tidal basins were formed along the inter-ridge depressions, depending on the height of the ridge and connectivity with channels outflowing into the ocean. The particular local hydrodynamic of surface and groundwater also determines the development of soils.

The low-lying beach ridges (with altitude ranging from 1 to 2 m) and inter-ridges depressions show features of temporary or permanent flooding, mainly during ordinary and extraordinary high tides. Due to high levels of evaporation and high concentration of salts in soil water, saline crusts are form in the surface. Mangrove and halophytic vegetation grows over soils of the type Hipersalic Gleyic Stagnic Puffic Solonchack, (sodic, chloridic, endoarenic).

The intermediate bars, reaching heights of 2 to 3 m, are flooded during the rain season. Local groundwater-bearing zones are encounter within these landforms, easily recharged through permeable sandy sediments from elevated precipitation rates. The upper parts of the local aquifers normally present freshwater hydrochemical parameters. The type of soil that forms under these conditions is Haplic Arenosol (hiposalic, hyposodic) and develops halophyte vegetation species.

Finally, within the current coast cord system, high ridges have altitudes between 3 to 5 m over mean sea level, and are not flooded in the rainy season. They water table is usually encountered at depths between 90-150 cm below ground surface. The upper parts of the local aquifers normally present freshwater hydro-chemical parameters. The soil type is Haplic Arenosol (hyposodic, eutric). Originally, tropical forests covered these landforms, but currently most of the original vegetation was removed and areas are open to cultivation. The presence of sodium in the soils surface is originated from saline spray by the nearby sea. In proximity to the seashore, coastal dunes are present covered with species such as *Cyperus articulatus*, *Batis maritime*, *Sporobolus splendens*, *Ipomoea pes-caprae*, *Prosopis juliflora*.

Current change processes in soils

The structure and services from the aquatic and wetland ecosystems of the Pacific Coastal Plain in the State of Nayarit (Mexico) is heavily dependant on hydrodynamic in tidal basins and the fluvial watersheds of rivers Acaponeta, San Pedro and Santiago, including the natural flow regimes, floods, and transport processes. Recent anthropogenic works and activities have had a relevant influence as agent of change in the hydrodynamic pattern. Main agent of change were the opening of a large lagoon outlet channel in Cuautla (just over 30 years ago),the construction and operation of Aguamilpa dam on the Santiago River (and a series of upstream reservoirs), flood control works in rivers banks, terraced roads, elevated irrigation channels, large farms and aquaculture facilities and a continuous tobacco, cotton, corn and recently sorghum and beans agriculture for the last hundreds years.

Nowadays, the San Pedro and Acaponeta rivers natural flow regime, includes seasonal floods that covers part of the medium and lower floodplains, and especially their depressions. Based on risk to infrastructure and population in the vicinities of the main river channel, civil protection agencies classified San Pedro river's minor flooding as the one created by flow rates ranging from 800 to 1000 m^3/s, moderate with discharges of 1 500–2 000 m^3/s, and severe with flow rates reaching 2500–3500 m^3/s. Minor floods occur every year, moderate were estimated as having a potential frequency of 2 years, and severe occur with return periods of 3 to 5 years.

An interpretative effort has been done to applied the scarce hydrological data about the San Pedro River natural flow regime, in the context of potential cumulative effects of agents of change on soil salinization and evolution. Data was systematized from the only existing water gauging station, named after the locality where it is installed at Ruiz. Different registries obtained and managed by the Mexican National Water Commission include flow rate data from 1944 to 2009. Also, a large database of different types of satellite images was used to chronologically assess changes in water bodies and soil moisture under diverse conditions. The hydrologic analysis of the San Pedro River natural flow regime, involved assessment of mean monthly maximum and minimum flow rates, seasonal floods during the rainy months and winter wetter periods, the daily flow rates variations, and flooding trends and patterns under singular local controlling processes, including infrastructure construction, dredging and natural channel migrations.

Based on the hydrological assessment results, new flow rates intervals were selected, based on flooding levels and relative water retention times on the floodplains. Minor flooding, registered with peak flow rates reaching 200–300 m^3/s and previous average rates of 150 m3/s within the preceding ten days; minor to moderate whereas peak flows reached approximately 400 m^3/s and previous average rates of 250 m^3/s within the preceding days; moderate flooding when peak flow rates would reach values near 500 m^3/s and previous pulses averaging between 300 to 500 m^3/s; moderate to severe flooding with flow rates over 600 m^3/s and previous average rates between 300 y 500 m^3/s in the preceding ten days, and, severe flooding with flow rates peaks over 1 000 m^3/s and average rates larger than 500 m^3/s during the preceding days.

The inflows towards the low lands from the river watershed, floods and yearly average rainfall rate in the area around 1 200 to 1 400 mm, are the main source of water recharge to regional and perched aquifers under free conditions. Water-table depths are registered from 30 m below the ground surface at the base of the Sierra Madre Occidental mountain range to shallow depth to subsurface position towards the lagoons and the coast. The soils are saturated during the rain season, and residual moisture is retained usually until January or February, to cope with a dry season from March to June. In general, agricultural soils have an ustic regime, in the depressions of the coastal plain and ridges can be udic and even aquic, in the tidal flood plains and low plain depressions.

Moreover, the entry of tidal marine water through the channels and mouths above described, influences three large tidal basins that subsequently controls the evolution of salts-affected soils found at different levels of depressions and beach ridge systems. The main tidal channels outlets are known as Asadero and San Cristóbal mouths (in the Santiago River watershed), mouth of Camichín in the San Pedro area of influence, and Channel of Cuautla and Teacapán mouth within the Acaponeta river area of influence.

Finally, the above mentioned anthropogenic activities in the area are generating a variety of changes in soils, including the loss of carbon stocks, changes in physical and hydrophysical properties and also agrochemical properties, changes still poorly quantified. The alluvial floodplains have been for many centuries a privileged place for agriculture. Since prehispanic times, various settlements were located in this fertile region, as recorded by the Spanish after the conquest (Anguiano, 1992). Even in recent years, the process of land use changes continues and the area devoted to agricultural activities and urban areas is increasing, impacting on the extension of the area covered by the original primary plant communities, mainly forests, mangroves and palm groves. The decrease rate in carbon stocks reached values of around 36% in the high plains, 40% in the medium plain and up to 67% in the low plain (Murray, 2010).

Following a geomorphologic topographic level order, the main current processes of change in soils within the northern coastal plain of Nayarit are: the natural leaching of salts in the higher alluvial floodplains and partly in intermediate floodplains reduction in carbon stocks in almost all agricultural soils of the deltaic floodplains and the beach ridge system, the combine effect of salts leaching by seasonal fluvial floods within the low plain, salt exchange controlled by water table fluctuations and groundwater flow patterns and saltwater intrusion through tide-influenced channels in estuaries. Within the lower the tidal flat areas, marine salinity intrusion is being locally increased by anthropogenic actions (e.g. artificial channels, opening of new hydraulic connections to the ocean, road embankments). Finally, in the ridges adjacent to the ocean coast, a occasional strong marine transgression are associated to cyclonic events and, marine water intrusion is being potentially increased in the lowest part of the Santiago River watershed by the construction and operation of upstream dams.

Vulnerability of soils to climate change in the northern coastal plain of Nayarit

Future variations in the tendencies of the current agents of change and processes in the soils of the coastal plain of Nayarit will be determined by the anthropogenic actions within the fluvial watersheds and tidal basins described for the region and the prospective climate change scenarios. Among new anthropogenic actions that could act as potential agents of change influencing the changes of soil properties in the near future are the modification of the flow regime and flood patterns of Acaponeta and San Pedro rivers as a result of the construction and operation of proposed dams upstream, and the construction of irrigation schemes and drainage systems in the deltaic floodplains. a lack of proper mitigation measurements and adaptative management policies and guidelines based on state of the art environmental and social evaluation of the main actions´ impacts, could also create cumulative changes in soils, derived from the regulation and use of tidal and estuarine water.

The main indicators of climate change that may impact on soil properties of the plain are the increase and concentration of precipitation to the months of August and September, and thus a modified regime of flooding, and leaching of soil salts. Moreover, the average increase of the maximum and minimum temperatures of the order of 1 degree every 30 years will mean greater mineralization of organic matter and thus increases the degradation process of hydro-physical and physical properties of agricultural soils by loss of organic matter.

Finally, a rising sea level trend for the area between 1.9 to 3.3 mm/year (Zavala, 2010), would contribute to a regional process of marine transgression, which could be cumulative enhanced by a concentrated precipitation pattern scenario of shorter rainy times and an increase in frequency and intensity of cyclonic events. Moreover, this combine prospective scenario would potentially have direct impacts on soil salinity in the lower deltaic floodplain and represent a challenge to the adaptative management of water for agricultural irrigation.

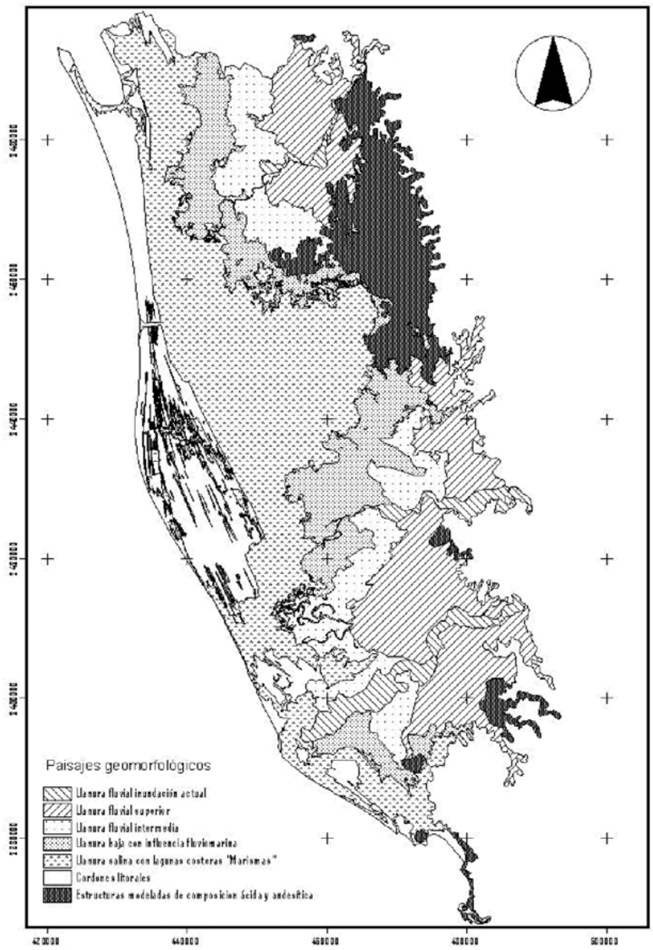

FIGURE 1
Geomorfological landscape of the north coastal plain of Nayarit, Mexico.

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Application of a new seawater intrusion index: SITE method

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One of the main objectives of the Directives 2000/60/EC and 2006/118/EC is to achieve accurate quantitative and chemical status of groundwater bodies by 2015, therefore some work has been focused on selecting and designing methodologies to determine the state of groundwater bodies. In coastal aquifers, seawater intrusion processes lead to a large variation in groundwater quality. Consequently, in most cases only methodologies based on very simple approaches and elemental criteria can provide practical and universal results. In addition, these methods must meet two basic requirements: 1) ease of elaboration from simple and readily available data and 2) ability to provide realistic, discriminatory and understandable information. With these aims the SITE method, designed from the initial bases proposed by Ballesteros (2008), is presented. It allows characterization of the seawater intrusion suffered by a coastal aquifer from four basic parameters obtained quickly and easily: S = Spatial extent, I = Intensity of salinization, T = Temporal variability or seasonality and E = Evolution to medium-long term. Each parameter is determined by specific calculations based exclusively on chloride ion content within the groundwater body. The key output of the method is an index and typological values, which are easy to conceptualize and provide qualitative information and quantitative values for the most representative factors, i.e. extent, intensity and evolution of the intrusive process. This information will help to objectively determine the real condition of coastal groundwater bodies, allowing them to be compared with each other and to improve their management.

Part of the work described is included within an agreement between the Ministry of the Environment and Rural and Marine Affairs of Spain (Directorate General for Water) and the Geological Survey of Spain (IGME). As a result from its application to three Spanish coastal aquifers, the way for the estimation of factors has been redefined and the procedure for obtaining the SITE index has been outlined.

Pilot study of water quality control in the wetland plots of Valencia's Albufera (Spain)

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ABSTRACT

The Albufera of Valencia is one of the most important wetlands in Spain. Its ecological conservation status is preserved by regional and local governments that attempt to reverse, as far as possible, the degradation that it is has suffered.

Historically, the binomial nature-human action has remained a constant balance in the environment, but at the present time, human action and changing environmental conditions (less input of water, poor quality of these, etc.) has produced a rapid degradation of the environment.

This research study, which involves the installation of piezometers in several rice plots, was initiated to investigate the existence of salinization problems and the low yield of rice in some areas of the park. With the intention of finding out why these situations occur, we have temporally and spatially analysed groundwater and surface water.

Keywords: water, Valencia, Albufera, piezometers, quality, salinization.

INTRODUCTION

The Albufera of Valencia is, for its high landscape and environmental value, one of the most important wetlands in the Iberian Peninsula. Located in south of the city of Valencia, has an area of 21 120 ha, of which 14 500 are to rice, 3 000 ha are lagoon and the rest of the area between the sea and the lagoon are beaches, dunes and a forest area. The lagoon is within the Valencia's bounds, although the area of the rice fields includes other municipalities as: Alfafar, Sedaví, Massanassa, Catarroja, Albal, Beniparrell, Silla, Sollana, Sueca, Algemesí, Albalat and Cullera. Its geographical location (in UTM coordinates) is: North: 30S 728 180 4367934; South: 30S 734235 4340633; West: 30S 724462 4346900; East: 30S 739971 4341907 (Figure 1).

Declared a Natural Park in 1986 and included in the list of wetlands of international importance for birds (Ramsar Convention) and the list of Special Protection Areas for Birds (SPAs), has traditionally maintained a delicate balance between the ecosystem and the use that humans have made of it (fishing, hunting, recreation and the most important use: agriculture).

In this sense the water (the main resource in the park), determines its environmental status. Many are the voices of scientists who warned of the high degree of contamination of the lake, and the scarcity of inputs and its poor quality. In several research studies about the lagoon, scientists have encouraged the authorities to establish a plan that can change the current state of degradation (hypertrophic character), to urgent rehabilitation to reverse the accelerating degradation of existing ecosystem.

The principal environmental problem that has the park is the reduction of river inputs (Jucar and Turia), and their poor quality. Today it is known that poor water quality or high ion content can cause the appearance of salts in soils that produce losses in rice production. In addition, we can "intuit" that the problem will be higher in time due to the actual situation of the wetland.

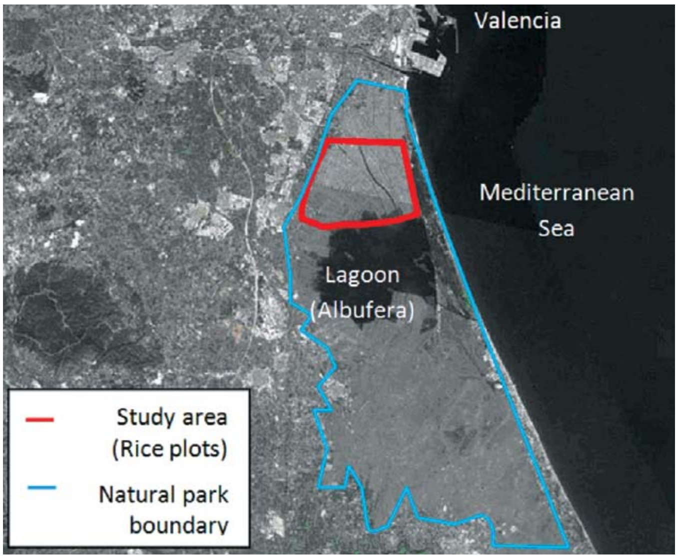

FIGURE 1
Satellite image of the Albufera Natural Park.

Moreover, we do not know what the situation is exactly, or how the binomial natural park/rice plot system, which did not produce any alteration of the environment in the past, may impact not only eutrophication, but also on the salinization process. That is why a careful monitoring, and systematic and periodic water cycle management and quality control of inputs should be the parameters to take into account for the correct management of the park. However, it is difficult to control, because historically there are no data on the quality of inputs, or control of the water entering to the lake or to the marsh, being another problem to be addressed. The variability of inputs—discharges from urban or industrial water, sewage water, natural runoff, "ullals" (natural water springs) and irrigation return flows—with the complexity of the irrigation system—ditches, "escorredors" (narrow ditches), canals, etc.—have hindered such control, although it is a main line of action within the National Hydrological Plan.

Salinization is the process by which the more soluble salts than gypsum are accumulated in the soil profile, causing losses in crop production and degradation of natural environment in the most serious cases. Thus primary salinization involves the salt container by natural processes due to high salt content in soils or groundwater (rich in salts or seawater intrusion). The Albufera of Valencia, being a coastal lagoon may have any of these situations, which have never been studied in advance to agronomic and environmental level. The combination of the anthropic-environmental factor may be the key to a good conservation of Natural Park.

The management of rice is the main anthropic action that occurs in the lake environment. One of the characteristic of him, is the passage of surface water and groundwater from the upper plots to the lower, being the lower plots (near the lagoon), terrain that have been reclaimed to the lagoon by the contribution of soil. These plots reclaimed from the lake are called Tancats and they are hydrological independent units that are characteristics of the Valencia's Albufera. Located at an altitude below the level of the lagoon, are situated in the surrounding ring to it. The status of these parcels and their characteristics makes them areas of high risk of salinization of the soil profile due to the potential rise of the water table with high Electrical Conductivity (EC).

In fact, farmers are having serious problems with the appearance of "circles" of salt, which produce a loss of rice production. These data, together with the current conditions of a few inputs and their bad quality inside the environment of Global

Climate Change, has produced the approach of this research study about the quality of the waters of the lagoon of Valencia and more specifically in the area Tancat de Pipa and Tancat de la Sardina. This area situated in the north of the lake, with a surface of 76 ha (Datum ED50 - 30S 728 731 4360773), have two different management systems: cultivation of rice in the Tancat de la Sardina and green filter and natural lakes in the Tancat de Pipa (Figure 2). The interaction between the free water surface and groundwater in these areas may present a risk of salinization, because the salt efflorescence appear when there is no water on the surface, and the presence of water depends on the human management.

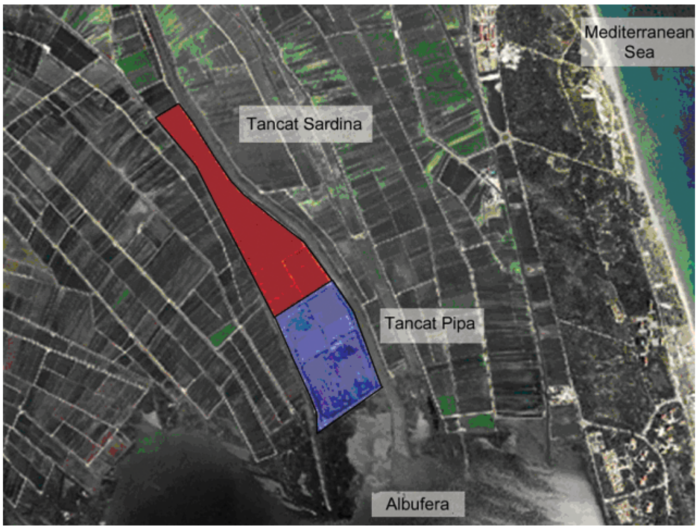

FIGURE 2
Study area with the Tancats.

Based on this premise the objectives of this study the following points:

- Check the quality of surface water and groundwater in the area of Tancats Pipa and Sardina.
- Check the height of the free water surface in the Tancats.
- Characterize surface waters and piezometers waters.
- Check water contributions to the area and its evolution in free surface.
- Capture cartographic space-time evolution of the salinity of waters.
- Establish correlations between water conductivity and physical characteristic of the environment variables (distance to the lagoon, distance from coast, height above sea level, variation of the water table and the free surface).

The methodology used in this study has involved the installation of a network of 21 piezometers sealed PVC, 1.75 m long and 10 cm in diameter, installed in parallel or transverse to the flow of water along the Tancats Pipa and Sardina. For further processing of the data and for mapping, 26 piezometers were installed in 4 adjacent transects to the study area (with a separation of 400 m). In this way, have been installed a network of 46 piezometers for monitoring and control of water quality (Figure 3).

After the installation of piezometers, according to the terrain and the period in which there is no free water on the surface, we designed a campaign to collect and analyse groundwater and surface water. During the year, we take every months one sample, but during the rice campaign (May, June, July, August and September), we take two samples within each month to control the rice influence on the EC.

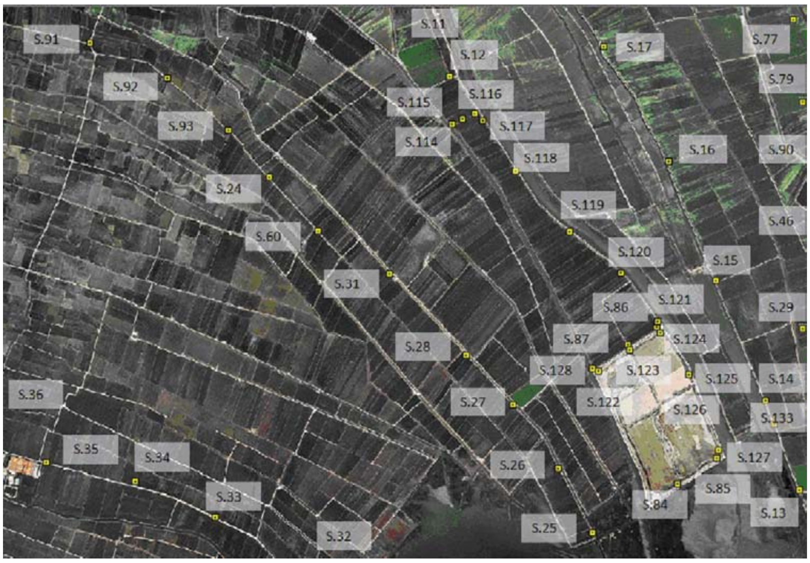

FIGURE 3
Distribution of the piezometer network.

Water samples were taken directly from the piezometers, which are intended to control how the groundwater can affect rice cultivation, while for the control of the free water surface the samples were taken near the piezometer. Besides these samples, regular samples were taken of the canals that provide water to Tancats of the study area. This water supply comes from three sources: "Acequia Real del Jucar" (principal ditch in the west Zone), "Acequia de Favara" (Principal ditch that supplies water to the "Tancats Pipa and Sardina") and "Acequia del Oro" (principal ditch in the east Zone). It is important to know that the "Acequia de Favara" carries water from the Turia River, along with input from the treatment plant "Quart-Benager" and contributions of urban and industrial areas of the Valencia metropolitan area. In other hand, the "Acequia del Oro" irrigates an area with waters that proceed of Pinedo treatment plant; while on the other hand, the water from the "Acequia Real del Jucar" comes from Jucar River.

The parameters analysed in waters were: electrical conductivity (EC), pH, major cations (Na^+, K^+, Ca^{+2}, Mg^{+2}) and anions (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) together with the sodium adsorption ratio (RAS) and total dissolved solids (TDS). The electrical conductivity has been the decisive parameter in this study; it provides an estimate of the ionic charge of the water.

Along with the analysis of groundwater samples and surface water, we controlled, in each shot, the height of the groundwater inside the piezometer and the height of the free water surface in relation to its height in the field. With these data we obtained the physical variables: the height above sea level, the distance to the lake, the distance to the coast, the depth of the water table and the height of free surface above the soil surface. These variables were used to calculate the possible correlations with the EC.

After obtaining the samples analysed in the laboratory, based on the UNE standards and official standards for water analysis (MAPA), we introduced them into Geographical Information System software for further processing, in order to see the space-time evolution of salinity.

The correlations, obtained by the combination of physical parameters and the EC, have been carried out with statistical programs. In these software, we have combined quantifiable parameters (EC, the height above sea level, the distance over the lake, the distance on the coast, and the height of the water table and the free surface on the soil surface), with qualitative parameters (presence or absence of free surface water) to observe the relationships between them.

RESULTS

The waters of the Valencia's Albufera can be classified largely as sodium chloride water according to Piper-Hill diagram, highlighting these anions in the analysis performed (Figure 4).

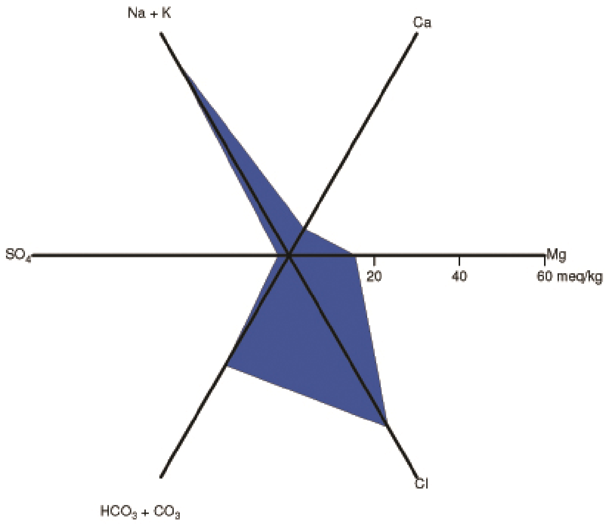

FIGURE 4
Probe no.11 in August.

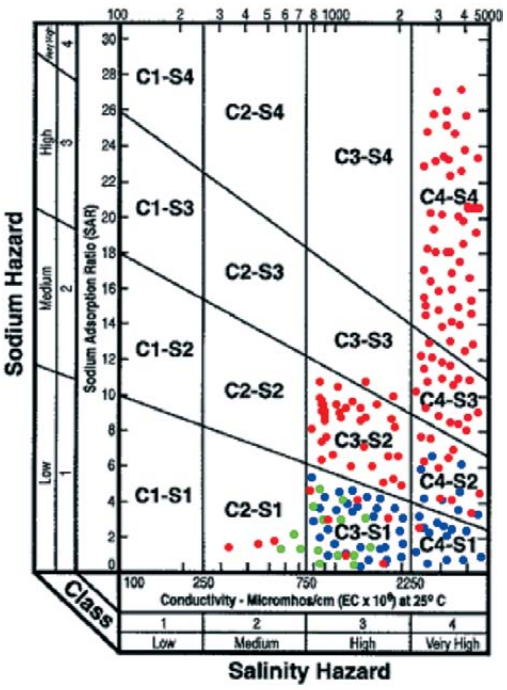

FIGURE 5
Water classification (Riverside).

Regarding the Riverside classification, waters are divided into 7 classes (C2-S1, C3-S1, C4-S1-S2 C3, C4-S2-S3 C4 and C4-S4). We can appreciate their distribution in the Figure 5. Thus we have in green color the normal values of the canals of inputs, while in red color we have the values of groundwater. In blue we have the values of the free water. The most prominent parameter is the electrical conductivity, noting that probes reported minimum values from 0.33 or 0.34 dS/m (S.115 and S.114 respectively) in May 2010 and a maximum value of 41.70 dS/m in the S.127 during August 2008. In the temporal evaluation of water, we can see an increase in groundwater conductivity as the summer progresses (Figure 6):

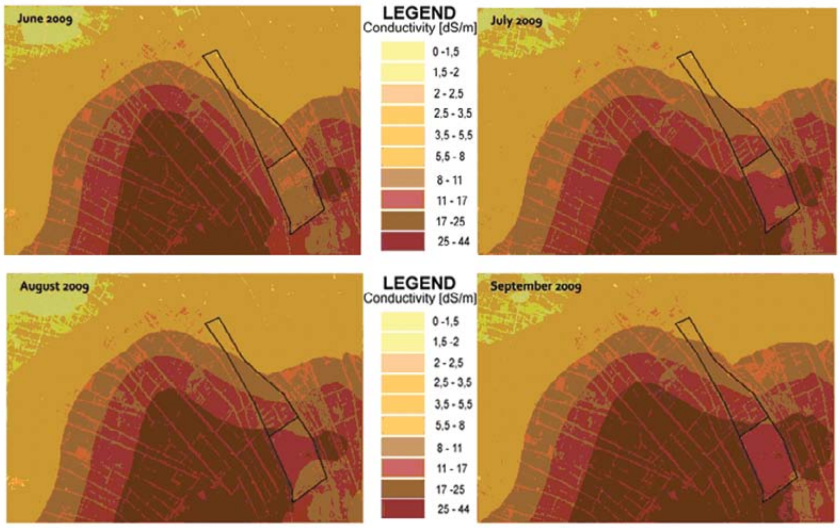

FIGURE 6
Evolution of the EC during the 2009 campaign.

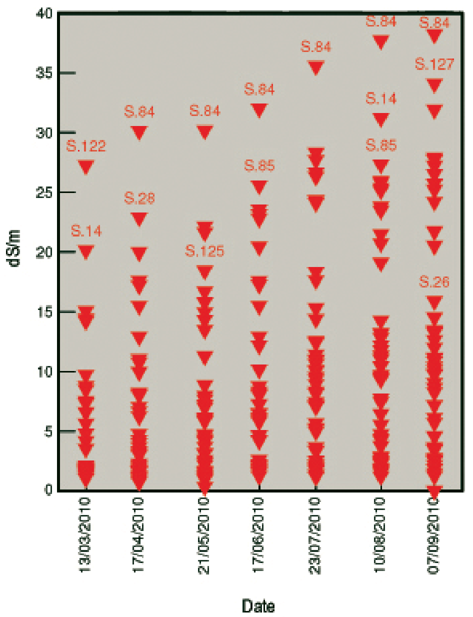

FIGURE 7
Temporal evolution of EC in 2010 (Network of piezometers).

This evolution over the summer period can also be seen in the following graph, which contains all the piezometers, and where we can see that the S.84 (Figure 7) presents the highest conductivity during the 6 months of 2010. (This probe is located in the southern part of the Tancat de la Pipa).

On the other hand, we have also observed differences in the quality of groundwater on the three campaigns analysed, because although the EC values are high, it should be stressed that after hydrological bad years, the existence of water in the swamps of Jucar and Turia rivers shows an improvement in the quality of water (with more contributions of "clean water"). On the other hand, have also observed differences in the quality of groundwater on the three campaigns analysed, because although the EC values are high, it should be stressed that after hydrological bad years, the existence of water in the swamps of Jucar and Turia rivers shows an improvement in the quality of water (with more contributions of "clean water"). This is the case in 2010, where there has been a reduction of EC groundwater values compared to values recorded in 2008 and 2009, in which the lagoon water supplies were much lower (Table 1).

TABLE 1

Evolution of the EC in the sampling campaigns (S. 127, S.14 and S.32)

ELECTRICAL CONDUCTIVITY (dS/m)									
Probe	Aug 08	Jun 09	Jul 09	Aug 09	Sep 09	Jun 10	Jul 10	Aug 10	Sep 10
S.127	41,70	24,80	22,30	24,48	26,18	17,26	24,10	23,80	25,10
S.14	---	34,07	37,89	34,17	40,47	23,15	24,30	31,20	31,90
S.32	---	30,45	30,50	28,97	33,11	8,76	9,55	12,15	13,20

With regard to correlations made to see the relationship between conductivity and physical parameters: distance to the sea, distance to the lake, free water height, the height of groundwater elevation on the ground and the categorical variable (presence or absence of lamina free), the results have been quite mixed. Referring to the correlation between the EC and the distance to the sea, the height of the water surface and the depth of the groundwater table, the results have shown no correlation between these variables. On the other hand, we can observe a fairly strong correlation with

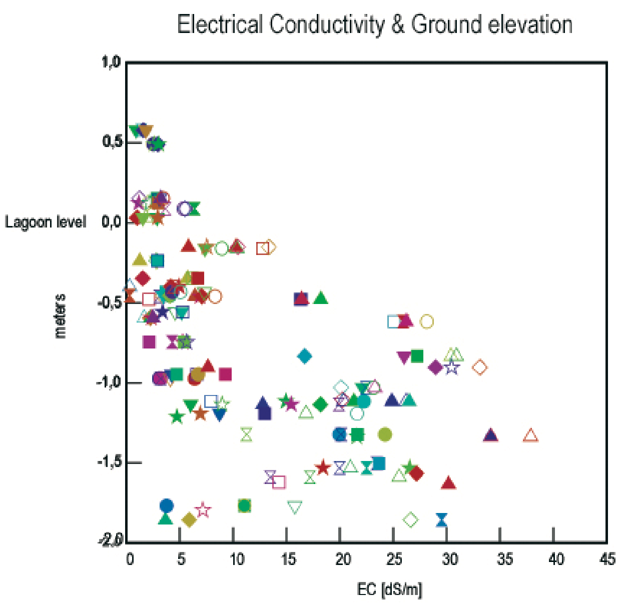

FIGURE 8

EC and ground elevation.

distance to the lake (as shown in Figure 5). The values near the lake present the highest conductivity value in groundwater. Also, there is a strong correlation between the height of the terrain where sample is taken and the EC of the groundwater as shown in Figure 8. We can see that the greater EC values are present in the highest depth points (respect to the lagoon level).

Thus, due to the data collected we can conclude:

- The electrical conductivity is strongly correlated with proximity to the lake and the ground level within Tancats, due to the sample points are below the level of the lake and the proximity of the groundwater level is higher.
- So far, not been able to correlate the EC of the groundwater table with the existence of free water surface on the rice fields. Possibly this is due to the spatial variability of the data and, possibly, require more data for a proper study. In this sense, a priori we cannot conclude that the management of the water layer is the key to prevent salinization of the natural environment. However, we known that farmers have to leave a small layer of water on the surface of the field during periods of without water ("eixugó") to avoid salt efflorescence on the surface.
- The contributions of water in both quantity and quality are paramount to prevent environmental degradation. This has been found in the general decrease in the EC of the groundwater during the three campaigns studied. Given the negative hydrological years 2008 and 2009, with little input and a lot of water recirculation, in 2010, the contribution of water from the Turia and Jucar River, has produced an improvement on the quality of the water.
- The groundwater electrical conductivity increases during the summer campaign. This may be due to the poor quality of water that arrived to the Albufera and the greater extraction in Valencia aquifer to irrigate the vegetables and citrus plots situated in the highest area. It is possible that this behavior of the conductivity in summer also be due to the high rate of water extraction that occurs in wells and can produce an advance of seawater intrusion in the aquifer.
- There are points where the correlation ratios: Cl^-/Na^+ (R=0.84 to 0.86) Ca^{2+}/Mg^{2+} (R=5) and Cl^-/HCO_3^- (R> 200), closely resemble the values obtained for water from the sea, so it is correct to consider the phenomenon of seawater intrusion in the area.
- Since there is no clear correlation between the management and the EC of the water and the data do not follow a systematic behavior, you should thoroughly study the physical characteristics of the soil and more specifically the hydraulic conductivity, because we want to know if the movement and velocity of water in the soil, can be affect the EC values in free water surface.
- Thus, together with the need to explore in depth the soil, you must also continue to monitor the waters to see one or two seasons more natural behavior of these and their status.
- As a final conclusion could say that the Albufera of Valencia has a total dependence on external inputs, and the environment in the Global Climate Change is occurring a decrease in the supply of water resources in general. So we should start to use reliable alternatives to maintain adequate environmental and hydrological status for the wetland.

Opportunities for sustainable utilization of salt-affected lands and poor quality waters for livelihood security and mitigating climate change through agroforestry systems

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ABSTRACT

Vast tracts of arid and semi-arid areas of the world are salt-affected (nearly 1 billion ha) and remain barren due to salinity or water scarcity. From the FAO/UNESCO Soil Map of the World, the total area of saline soils is 397 Mha, while for sodic soils it is 434 Mha. In India about 6.73 Mha land is salt-affected. These lands constrain plant growth owing to the osmotic effects of salt, poor physical conditions leading to poor aeration, nutrition imbalances and toxicities. Besides this large areas in arid and semi-arid regions of the world are underlain by saline groundwater aquifers and fresh water for agricultural use is a scarcity. The requirement of irrigation is more in the inland semi-arid to arid areas and the coastal belts, while the waterlogged areas need more drainage applications in conjunction with limited irrigation facilities.

Meeting the requirements of food and other agricultural commodities for the burgeoning population is a big challenge for the agricultural community. With the increasing demand for good quality land and water for urbanization and development projects, agriculture will be pushed more and more to the marginal lands and use of poor quality water for irrigation is inevitable.

With use of appropriate planting techniques and salt-tolerant species the salt-affected lands can be brought under viable vegetation cover. Further, in most of the arid and semi-arid regions the groundwater aquifers are saline. Cultivation of conventional arable crops with saline irrigation has not been sustainable. Concerted research efforts have shown that by applying appropriate planting and other management techniques (e.g. sub-surface planting and furrow irrigation), the degraded lands (including calcareous) can be put to alternative uses, where salt-tolerant forest and fruit trees, forage grasses, medicinal and aromatic and other high value crops can be equally remunerative.

Keywords: biosaline agriculture, agroforestry systems, biodrainage, waterlogged and saline areas, alternate land uses, auger-hole planting technique, sub-surface planting and furrow irrigation, raised and sunken bed technique, saline vertisols, biological reclamation, carbon sequestration, climate change.

DISCUSSION

Alkali soils have a compact hard sub-surface layer or a caliche (calcite) bed (of nodulated or amorphous $CaCO_3$) in lower depths, which imposes physical impediment to root penetration/ development. Unlike soil reclamation for arable crops, where only plough layer is sought to be improved in the first instance, deep-rooted trees require reclamation of the soil to lower depths. The planting technique should further ensure efficient utilization of rainwater, and leaching of reaction products after interaction of amendments and to root development in the soil profile, soil structural improvement for increased water retention to encourage rapid root penetration in the vertical rather than horizontal direction, and minimize direct sodium toxicity hazards. Keeping this view, attempts were made to develop suitable techniques (pit-auger-hole technique) for planting trees on such lands. In this technique the auger is mounted on a tractor and used for making holes of dimensions 20–25 cm diameter and 1.2–1.8 deep. This technique recognizes that in trees, owing to their deep root systems, management of the root zone by modifying the soil environment to greater soil depths using a limited quantity of amendments has a vital role. With this in mind a number of studies were conducted to establish positive benefits of this planting technique for tree plantations on alkali soils and it was concluded that original soil mixed up with 3–5 kg gypsum (50% of gypsum requirement in the auger-hole) and 8–10 kg farm yard manure (FYM) in each auger-hole is most suitable for alkali soils of high pH. Application of small dose of nitrogen in the auger-hole filling mixture and its regular application every year thereafter (25 g in monsoon and 25 g in winter) proved beneficial in non-leguminous tree species.

A series of long-term experiments were conducted to prove the usefulness of the 'auger hole technique' for raising tree plantations on sodic soils. Based on the evaluation of more than 5 dozen species planted with auger hole technique through series of experimentation on sodic soils), it could be concluded that *Prosopis juliflora* was the best performer for the sodic soils of high pH (>10) followed by *Tamarix articulata* and *Acacia nilotica*. Species such as *Eucalyptus tereticornis, Terminalia arjuna, Salvadora oleoides, Cordia rothii* and fruit trees (with improved management) such as *Carissa carandus, Emblica officinalis* and *Psidium guajava* can be grown with great success on moderate alkali soil (ph <10), preferably at pH around 9.5 or less Where there was problem of prolonged stagnation of water, raised and sunken bed technology was found suitable which also conserved moisture for winter crops. A large proportion of salt-affected lands (particularly in Indian subcontinent) does not belong to individual farmers, but is either government land or in the custody of village *Panchayats*. Reclamation of such lands for crop production is not feasible because of common property rights. Raising suitable trees and grasses would appear to be a promising use of these lands. Highly salt-tolerant and high biomass producing grass species include *Leptochloa fusca, Brachiaria mutica, Chloris gayana,* species of *Sporobolus* and *Panicum.* Mesquite (*P. juliflora*) and *kallar* grass (*L. fusca*) based silvi-pastoral practice has been found most promising for firewood and forage production and also for soil amelioration. This system improved the soil to such an extent that less tolerant but more plantable fodder species such as Persianclover (*Trifolium resupinatum*), Berseem (*T. alexandrinum*), Lucerene (*Medicago sativa*) and Sweet clover (*Melilolus denticulata*) could be grown under mesquite trees after 4–5 years. Many medicinal and aromatic grasses have been identified for these soils. For semi-reclaimed lands *Populus deltoides*-based agroforestry system was found most profitable.

The saline soils suffer from excessive concentration of salts, high water table often leading to waterlogging, and occurrence of poor quality undergroundwaters in many areas. Poor root zone aeration caused by high water table (waterlogging) and excess presence of salts, which operate simultaneously, impair success of plantations on such soils. The planting techniques should be such that salt concentration in the root zone remains at a low level and the plants are able to escape adverse affects of high salinity. Through a series of experiments, techniques of plantations on waterlogged saline soils were developed.

To provide better aeration and avoid excessive salinization planting on high ridges was often considered beneficial for establishing tree plantations on waterlogged saline soils. This method was compared with the sub-surface and furrow planting methods. Long-term field studies were conducted on about three dozen woody perennial species for afforestation of waterlogged saline soils in arid and semi-arid regions of India. The initial electrolytic conductivity of soil (ECe) was 36–40 dS/m in the upper 30 cm and the water table was shallow, fluctuating between 1.5 m depth to the surface in different seasons of the year, and the water was brackish (average EC 30 dS/m). During this study, it was observed that the greater the surface area of the ridges, the more salts accumulated in the surface 1 m root zone of ridge planted trees. In contrast, under the sub-surface planting method, roots were encountering a milder saline transmission zone and were meeting most of their water requirement from the phreatic zone. Difficulty of conserving rainwater on the ridge tops and the presence of salts causing higher susceptibility to soil erosion were the other disadvantages encountered with ridge planting. In the sub-surface planting method the roots encountered a smaller saline transmission zone. Further, the subsurface planting method was modified and furrow planting technique was developed. In this technique, a tractor-driven furrow maker was used to create about 60 cm wide and 20 cm deep furrows. The saplings of a tree species were planted at the base of the furrows. These furrows were subsequently used for irrigating the tree saplings. Establishment of saplings with furrow method was better than sub-surface method of planting. In addition to reducing the water application costs and increasing uniformity in water application, downward and lateral fluxes of water and salts from these furrows helped to create zones of favourable low salinity below their bases, especially when low-salinity irrigation water was used. Creation of such low 'salt-niches' favoured the establishment of young tree seedlings. With the furrow planting technique, salt concentrations were kept lower in the rooting zone of trees, such that the trees were able to escape the adverse effects of high salinity. Moreover, the furrow system seems more viable than the other techniques from a practical point of view for undertaking large-scale plantation of trees.

The data on biomass production after 9 years of plantation established with saline water showed that *P. juliflora* and *Casuarina glauca* was highest (98 and 96 t/ha), followed by *Acacia nilotica* (52–67 t/ha and *A. tortilis* (41 t/ha) when planted with subsurface or furrow technique showing their potential for saline waterlogged soils. Thus, on the basis of performance of trees for 6–9 years after planting in saline waterlogged soils it was found that species like *P. juliflora, Tamarix articulata, T. traupii, Acacia farnesiana*, *Parkinsonia aculeata* and *Salvadora persica* to be most tolerant to waterlogged saline soil and could be raised successfully up to salinity levels of ECe 30–40 dS/m. Species like *A. nilotica, A. tortilis, A. pennatula, Casuarina glauca, C. obesa, C. equisetifolia, Callistemon lanceolatus*, *Eucalyptus camaldulensis, Feronia limonia, Leucaena leucocephala* and *Ziziphus mauritiana* could be grown on sites with ECe 10–20 dS/m. Other species including *Casuarina cunninghamiana, Eucalyptus tereticornis, Terminalia arjuna, Albizzia carbaea, Dalbergia sissoo, Emblica officinalis, Guazuma ulmifolia, Punica granatum, Pongama pinnata, Samanea saman, Acacia catechu, Syzygium cuminii* and *Tamorindus indica* could be grown satisfactorily only at ECe <10 dS/m.

In dry regions, where groundwater is saline, a combination of judicious irrigation with saline water, suitable salt-tolerant plant species, and ideal management options using proper techniques can help in increasing sustained productivity of degraded lands through agroforestry in dry regions. The traditional approach for sustaining the use of saline water is to irrigate more frequently and provide for leaching requirements. Nevertheless, such practices demand for application of additional quantities of saline water and thereby also result in enhancement of salt loads of soils. These approaches were advocated for shallow rooted crop plants in arid environments mainly because the added salts could be pushed beyond the rooting zone. But in deep rooted tree plantations, the additional salts going into the soil through enhanced frequency of irrigations during their establishment may rather aggravate the problem as these are likely to persist within their expanding rooting zones and may subsequently hinder the growth of trees. Therefore, irrigation with saline waters should aim to create favourable niches for the better establishment of saplings and also eliminate the over salinity buildup. This could be achieved by irrigating only the limited area under furrows planted with tree saplings. In this technique furrows (15–20 cm deep and 50–60 cm wide) are created at 3–5 m intervals with a tractor drawn furrow maker. Auger-holes (0.2 m diameter and 1.2 m deep) are dug at the sill of these furrows spaced at 2–3 m intervals. These are re-filled with the mixture of original soil plus 8 kg of farmyard manure, 30 g super-phosphate, 15 g zinc sulfate and 15 g of iron sulfate. Six months old tree saplings are transplanted during rainy season (July-August) at sites where auger-holes are dug. The irrigation with saline water is given in furrows only. The technique is known as subsurface planting and furrow irrigation system (SPFIM). The irrigation may be provided for initial three years (4–6 times in a year) and thereafter, plantations may be irrigated once during the winter only. Salt storage in soil profile may increase during irrigation period but the added salts get distributed in soil profile as a consequence of seasonal concentration of rainfall during monsoons and some episodic events of rainfall during the following years. The inter-spaces may be utilized for growing low-irrigation requiring crops such as barley, toria (*Eruca saliva*), cluster bean, and soya (*Anethun graveolens*) during initial years. Medicinal Isabgol (*Plantago ovata*) was found doing well under partial shade. The soil is enriched with organic carbon (>0.4% in upper 30 cm) under the promising tree species. Thus, rehabilitation of arid soils with the promising tree species using the available saline waters would not only render the abandoned soils to be productive but would also ensure conservation and improvement in environment for long range ecological security on these lands.

A long-term field trial with 31 tree species was conducted over 9 years on a calcareous soil in a semi-arid part (annual rainfall about 350 mm) of north-west India using furrow method of irrigation as described earlier. The saplings were irrigated with saline water (EC 8–10 dS/m) for initial three years (4–6 times in a year) and thereafter plants were irrigated once in a year during winter. Most of the tree species (except *Syzygium cuminii, Bauhinia variegata* and *Crescentia alata*) showed quite high survival rate (71–100%) during first three years. Ranking in order of survival, growth and biomass yield showed that *Tamarix articulata, Acacia nilotica, Prosopis juliflora*, *Eucalyptus tereticornis, Acacia tortilis* and *Cassia siamea* were most successful species. After 7 years of planting, the highest shoot biomass was harvested (Figure 1) from *Tamarix articulata* (71.9 t/ha) followed by *Acacia nilotica* (23.4 t/ha), *P. juliflora* (20.2 t/ha) and *Eucalyptus tereticornis* (14.8 t/ha). Fruit trees like *Feronia limonia, Ziziphus mauritiana, Carissa carandus, Emblica officinalis* and *Aegle marmelos* could be established irrigating with saline water up to EC 10 dS/m and intercrops in wider spaces between rows (5 m) such as cluster bean and barley could be raised with success applying one or two irrigations Table 3). This appears very viable agroforestry system for such soils.

Among forage grasses *Panicum laevifolium* and *P. maximum* were most suitable species producing annually 14–17 t/ha forage. About 25–30% of total forage was also available during lean period of summer when most of the people become nomadic along with their cattle.

In series of experiments the performance of winter annual flowers, aromatic grasses, and some medicinal plant species under saline irrigation was also evaluated on calcareous soils. It could be concluded that ornamental flowers such as *Chrysanthemum, Calendula* and *Matricaria* can successfully be cultivated irrigating with water of EC up to 5 dS/m. These species could yield 13.2, 4.7 and 3.5 t/ha, respectively fresh flowers in a season. If good quality water is available at site, a few irrigations particularly for establishment will increase the yield of flowers. The aromatic grasses such as vetiver, lemongrass and palmarosa, when irrigated with saline water (EC 8.5 dS/m) could produce on an average 90.9, 10.4 and 24.3 t/ha dry biomass, respectively. Different cultivars of vetiver could produce 72.6 to 78.7 t/ha shoot biomass and 1.12 to 1.71 t/ha root biomass. The roots are used to extract aromatic oil.

Among the species tested for medicinal value, the most promising was psyllium (*Plantago ovata*) with average seed yield of 1 050 kg/ha with saline water (EC 8.5 dS/m), which did not show any adverse impact when compared with canal water irrigation. *Aloe barbadensis* was also equally tolerant and could produce 18 t/ha fresh leaves. *Ocimum sanctum* could produce 910 kg/ha dry shoot biomass. In a separate trial dill (*Anethum graveleus*), taramira (*Eruca sativa*) and castor (*Ricinus communis*) could produce 931, 965 and 3535 kg seeds per ha, respectively when provided with three irrigation of saline water (EC 10 dS/m. *Cassia senna* and *Lepidium sativum* can also be cultivated successfully irrigating with saline water up to 8 dS/m. All these high value crops can successfully be grown as inter-crops with forest or fruit trees at least during initial years of establishment. Psyllium did not show any yield reduction with *Acacia* plantation even at later stages showing its suitability for partial shade tolerance.Such uses have additional environmental benefits including carbon sequestration, biological reclamation and mitigating climate change. Agroforestry is not only a necessity for increasing tree cover and hence decreasing pressure on natural forests, but also a most desired land use especially for reclaiming and rehabilitating the degraded lands. In developing countries like India, there seems to be little scope for bringing the fertile lands under forestry cover. It may be emphasized here that we can bring unproductive wastelands and waterlogged areas under forest cover and take agroforestry tree plantation on non-forest community and farmlands. These studies are more relevant in the scenario of climate change. The long-term studies conducted at Central Soil Salinity Research Institute (CSSRI) show that salt-affected and waterlogged areas and saline waters can be utilized satisfactorily in raising forest and fruit tree species with improved techniques, forage grasses, conventional and non-conventional crops, oil yielding crops, aromatic and medicinal plants of high economic value, petro-crops and flower-yielding plants. Opportunities for raising salt-tolerant crops and alternate land uses through biosaline agriculture on salty and waterlogged areas, especially in arid and semi-arid regions have been discussed in this paper.

Agricultural biosaline research and development in Oman

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ABSTRACT

Salinity is an ever-increasing problem in agriculture worldwide, especially in Arabian Gulf Countries. Improved genotypes that are well adapted to saline conditions are needed to enhance and sustain production in these areas. The Sultanate of Oman, the third largest country in the Arabian Peninsula, has about 72 588 ha currently under cultivation, of which fruits occupy as high as 58%, followed by perennial fodder crops (24.5%), vegetables (9.35%) and annual grain crops (8.20%). The Sultanate is categorized as an arid country with low rainfall and high evapo-transpiration (ET). Annual rainfall varies from less than 50 mm in Central Oman to more than 300 mm in the mountains. Groundwater is the main source of water for both domestic and agricultural use. Until the mid-seventies, water demand and supply were relatively well balanced. Subsequently high water demand has led to over pumping and prolonged lack of rains has reduced the extent of recharge. These situations have progressively deteriorated the quality of both water and soil towards salinity. The affected areas are mostly the farms near the coast, which have abundant but saline water.

Plant growth and yields are decreased by salinity, drought and other environmental stress conditions. The combined effects of aridity and soil salinity limit the range of crops that can be grown in Oman. In the Ministry of Agriculture, biosaline agriculture in terms of development and introduction of new crops and salt-tolerant varieties of existing crops has been given priority, along with the water focused solutions. Although the soil salinity problem has been consistently highlighted and emphasized in various surveys and integrated studies conducted in the country, soil and water salinity research has been inadequate in relation to the extent and severity of this threat. Severe deficiencies were observed in the salinity knowledge base. Therefore lack of relevant information and data is felt seriously at present. There is considerable government support for research in salinity tolerance in crop plants. In addition, the present practice of using fresh water to irrigate in Oman is limited and hence, research efforts on the use of brackish and saline water for irrigation required. In view of these facts, the Directorate General of Agricultural and Livestock Research has conducted several projects in the past two decades to select and promote salt-tolerant plants and technologies for using saline water. This paper describes significant findings of research in biosaline agriculture in Oman undertaken over the last 20 years, giving examples of successes in translating techniques from the laboratory to the farming community.

Keywords: Salinity, research, plant/crop species, Oman.

INTRODUCTION

Salinity is an ever-increasing problem in agriculture worldwide, especially in Arabian Gulf Countries, such as Oman). Improved genotypes that are well adapted to saline conditions are needed to enhance and sustain production in these areas. The Sultanate of Oman, the third largest country in the Arabian Peninsula, has about 72588 ha is currently under cultivation of which fruits occupy as high as 58%, followed by perennial fodder crops (24.5%), vegetables (9.35%) and annual grain crops (8.20%) (MoA, 2008). Sultanate is categorized as arid country with low rainfall and high evapo-transpiration (ET). Rainfall varies from less than 50 mm in Central Oman to more than 300 mm in the mountains. Groundwater is the main source of water for both domestic and agriculture use. Until the mid-seventies water demand and supply were relatively well balanced. Subsequently, high water demand has led to over pumping and prolonged lack of rains has reduced the extent of recharge. These situations have progressively deteriorated the quality of both water and soil towards salinity. The affected areas are mostly the farms near the coast, which have abundant but saline water. Plant growth and yields are decreased by salinity, drought and other environmental stress conditions. The combined effects of aridity and soil salinity limit the range of crops that can be grown in Oman. Biosaline agriculture in terms of development and introduction of new crops and salt-tolerant varieties of existing crops should have been given priority along with the water focused solutions. Although soil salinity problem has been consistently highlighted and emphasized in various surveys and integrated studies conducted in the country, soil and water salinity research has been inadequate in relation to the extent and severity of this menace. Severe deficiencies were observed in the salinity knowledge base.Therefore lack of relevant information and data is felt seriously at present. Consequently there is considerable government support for research in salinity tolerance in crop plants. In addition, the present practice of using fresh water to irrigate in Oman is limited and hence, research efforts on the use of brackish and saline water for irrigation are the need of the hour. In view of these facts, Directorate General of Agriculture and Livestock Research has conducted several projects in the past two decades to select and promote salt-tolerant plants and technologies for using saline water. The objective of this paper is to address the current status of using saline irrigation water in biosaline agriculture research activities in Oman. This paper summarizes important findings of these research studies on salinity-tolerance are presented.

Soil, water resources and salinity

Saline groundwaters pose a continuous threat to sustained irrigated agriculture in many arid and semi-arid regions. The efficient substitution of low salinity water for saline water is generally aimed at minimizing yield losses and enhancing flexibility of cropping without much alteration in the farming operations. Strategies available include blending and cyclic use of non-saline/ saline waters, either per irrigation or seasonally.

The pros and cons of such options have been discussed at length by Rhoades (1990) and Minhas and Gupta (1992). Indirect evidence seems to favour cyclic use of multi-salinity waters (Minhas and Gupta, 1992; Naresh *et al.*, 1993) The response may involve a high salinzation risk. Therefore if groundwater extraction is to be increased, the water balance alone may be an insufficient basis for agriculture activities.

Salinity Research at DGALR, Rumais, Oman

Agriculture research activities in Oman were started since early seventies of the last century, but salinity research was initiated in nineties and the period extended. The Directorate General of Agriculture and livestock Research (DGALR) is the central department in the Ministry of Agriculture concerning research activities. It aims at national level to undertake both basic and applied research in agriculture and livestock activities. The results from these research activities at DGALR are summarized below:

- First trial conducted in the field of biosaline agriculture under guidance of Qureshi (1995) were in mid nineties of the last century. Sets of experiments were conducted on various species. The primary results showed species that grew under water salinity conditions ranging from 7.5 to 22.5 dS/m that barley was the most tolerant followed by alfalfa, oats, wheat, and sudan grass.

- Five rangeland species were also tested under water salinity levels of 1, 5, 10, 15, 20, 25, and 35 dS/m. The results showed that exotic Acacia ampliceps was more tolerant to high salinity levels than native A. tortilis, and native Sedr (*Zyzyphus spina-christii*). Native Prosopis cinraria and exotic P. tamarugo did not perform well under high saline water. Five rootstocks of citrus species were tested under four levels of water : 1, 4, 6, 8, and 10 dS/m. It was found that Cleopatra mandarin was the most tolerant rootstock followed by sour orange and acid lime (*Citrus aurantifolia*).
- After this period of these elementary trials, several experiments were conducted over five years (2001-2005) at DGALR and Sultan Qaboos University (SQU) on evaluating different species under salinity conditions and results summarized below:
- Five cultivars of fodder beet (Peramono, Annissa, Petra, Jamon and Winter gold) were tested in the field for irrigation with saline water of EC 2 and 5 dS/m. The cultivars; Peramono, Annissa and Petra produced yield of 131, 119 and 122 t/ha of green matter (foliage and tubers) in 70 days under irrigation with 5 dS/m. The respective yields of these cultivars with irrigation of 2 dS/m water were 97, 88, and 98 t/ha. Thus, the yields with water of EC of 5 dS/m were higher than those recorded with EC of 2 dS/m water irrigation. Jamon and Winter gold yielded 77 and 75 t/ha respectively. All the five cultivars showed good adaptation to Oman saline conditions (Nadaf *et al.*; 2000).
- Screening of thirteen varieties of wheat along with a local cultivar WQS 160 against water salinity (2, 4, 8 and 12 dS/m) was conducted for 2 years. Results revealed a high tolerance of S-24 from Pakistan and Sids-9 from Egypt (Nadaf *et al.*; 2001).
- Selection among local barley cultivars for performance under salinity resulted in identification of one variety- Duraqui (Nadaf *et al.*; 2003).
- Rhodes grass (Chloris gayana) was found to be more salt-tolerant to water salinity (EC: 3, 6, 9, 12, 15 and 18 dS/m) and more productive than indigenous grass species like Coelacbryum Piercii and Cenchrus ciliaris. The performance of Rhodes grass was better in later cuts even up to 25 cuts, particularly in salinity of water below 9 dS/m (Biosalinity News, 2004; Nadaf *et al.*, 2008).
- Hybridization between exotic and local varieties of wheat was done and a number of successful crosses were obtained. The semi-dwarf progeny is being tested against salinity along with rusts and smuts (MoA, 2008).
- Efforts have also been made to collect and maintain germplasm of different crops in collaboration with International Plant Genetic Resources (IPGR), FAO, ICARDA and other organizations. The germplasm pool now has 83 accessions of alfalfa, 100 of wheat, 20 of barley, 20 of chickpea and 68 of pasture species, available at ICARDA.
- Studies of alfalfa showed that the cationic sums in alfalfa petioles were constant when alfalfa was subjected to salinity treatments of 0.0-6.4 dS/m and 8.2-12.2 dS/m. Based on these results they identified the salinity levels that may seriously affect the normal growth and yield of alfalfa.
- Compared to germination studies, relatively little information is available on crop response to salinity stress during seedling emergence. In Sultan qaboos University experiments were conducted by Esechie *et al.*; (2002a) to investigate seedling emergence in two ckickpea (Cicer arietinum) species (ILC 482 and Barka local) in response to varied salinity levels and seeding depths. The salinity treatments were 4.6, 8.4 and 12.2 dS/m, with tap water 0.8 dS/m as control. The interaction between salinity treatment and seedlings was significant. Chickpea cv. ILC 482 obtained from ICARDA in Syria, was found to be more tolerant to salinity at the germination/emergence stage than Barka local, a cultivar planted by most farmers in the Al-Batinah region in Oman.

- To manage salinity problems in irrigated areas properly it is necessary to understand in detail the processes that control the movement of water and salt from the surface to the groundwater table with particular emphasis on the rootzone of irrigated soils. Computer simulation models involving important properties of soil, quality of irrigation water, crop and climate are useful in assessing the leaching and accumulation of salts, a key to the efficient management of irrigated soils (Pal *et al.*; 1990). In Oman, however, little work was done in developing models based on local field saline conditions. The objective of this study was to develop a model to explain the variation between farms in soil water salinity, and thus provide a tool for optimizing management practices to control soil salinization.
- The Directorate General of Agriculture and Livestock Research of the Ministry of Agriculture, has undertaken collaboration activities with ICBA (Dubai) through IFAD and OPEC Project, from 2004 to 2008, whose outcomes have been explained output wise, here under:

PRODUCTION OF SALT-TOLERANT FORAGE GRASSES, LEGUMES AND SHRUBS

Identification of forage grass, legume and shrub species

Different salinity tolerant summer and winter field crop varieties which can be used for forage and highly salinity tolerant perennial grasses and forage shrub and tree species were tested by growing in the farms having different degrees of irrigation water salinity to identify and select the ones having high yielding ability under targeted saline conditions. The highlights of the results obtained are presented below:

Field Crops that can be used for forage–

i. Pearl millet (*Pennisetum species*)

Thirty saline tolerant selected genotypes of pearl millet developed at ICRISAT, India were evaluated consecutively in summer seasons of 2004 and 2005 in the farmer's field at Rumais. During the cropping seasons, in summer 2004, irrigation water salinity ranged from 6.72 to 7.50 dS/m and soil (sandy) EC from 2.84 dS/m (0–15 cm depth) to 5.17 dS/m (15-30 cm depth) while in 2005, irrigation water salinity ranged from 7.50 to 8.25 dS/m and soil EC ranged from 4.84 dS/m (0–15 cm depth) to 15.58 dS/m (15–30 cm depth). Based on their high forage yielding ability in 55 to 70 days during two summer seasons i.e. 2004 and 2005, five genotypes namely IP 6112 (64.75 t/ha), Sudan Pop III (60.17 t/ha), IP 19586 (57.34 t/ha), IP 3616 (57.00 t/ha) and IP 6104 (50.75 t/ha) were selected for their consistent and stable performance and promoted for evaluation in the farmer's field. In the farmer's field of sandy loam soil (EC and pH of 12.2 dS/m and 7.4 and 7.1 dS/m and 7.5, respectively, at 0–15 and 15–30 cm depth) with saline irrigation water of 7.50 dS/m to 8.25 dS/m, IP 3616 recorded the highest green matter yield of 110 t/ha followed by IP 6104 (84.00 t/ha), IP 19586 (80.50 t/ha), Sudan Pop III (75.50 t/ha) and IP 6112 (58.50 t/ha), under higher plant density.

ii. Sorghum (*Sorghum bicolor* Moench)

Thirty saline tolerant selected genotypes of sorghum developed at ICRISAT, India were evaluated consecutively in summer seasons of 2004 and 2005 in the farmers' field at Rumais. During the cropping seasons, in summer 2004, irrigation water salinity ranged from 6.72 to 7.50 dS/m and soil (sandy) EC from 2.84 dS/m (0–15 cm depth) to 5.17 dS/m (15–30 cm depth) while in summer 2005, irrigation water salinity ranged from 7.50 to 8.25 dS/m and soil EC ranged from 4.84 dS/m (0–15 cm depth) to 15.58 dS/m (15–30 cm depth). Sorghum entries were late in flowering and showed moderate performance under both salinity and heat. Based on their high green forage yielding ability in two summer seasons i.e. 2004 and 2005, five genotypes namely ICSV 93046 (27. 84 t/ha), SP 47529 (24.03 t/ha), ICSR 93034 (23.59 t/ha), ICSV 93048 (20.96 t/ha) and ICSV 745 (20.91 t/ha) were selected for their consistent and stable performance and promoted for evaluation in farmer's field. In the farmer's field of sandy loam soil (EC and pH of 12.2 dS/m and 7.4 and 7.1 dS/m and 7.5, respectively, at 0–15 and 15–30 cm depth) with saline irrigation water 7.50 dS/m to 8.25 dS/m, ICSV 93046 recorded the highest green matter yield of 71.20 t/ha followed by ICSV 745 (62.80 t/ha), SP 47529 (48.80 t/ha), ICSV 93048 (46.00 t/ha) and ICSR 93034 (46.00 t/ha), under higher plant density.

iii. Barley (*Hordeum vulgare* L)

Two different sets each consisting of twenty-five saline tolerant selections of barley at ICBA, were evaluated under drips consecutively in winter seasons of 2004–05 and 2005-06 at BARF. In winter 2004-05, under irrigation water salinity of 10.5 to about 14 dS/m dS/m and soil EC of 7.60 dS/m (0–15 cm depth) and 5.40 dS/m (15–30 cm depth), yield levels were low. Eight entries that topped produced highest of 18 t/ha of green fodder in 65 to 70 days. In winter 2005–06, under irrigation water salinity of 14.78 to 16.5 dS/m and soil EC of 15.90 dS/m (0–15 cm depth) to 17.20 dS/m (15–30 cm depth), yield levels were still low. Five genotypes that topped gave higher green matter of 9.00 to 11.53 t/ha. On the other hand, in winter 2005–06, barley genotypes evaluated in a farmer's field of sandy soil with EC of 6.90 dS/m at 0–15 cm depth and 3.00 dS/m at 15–30 cm depth having an irrigation water of 8.50 to 10.50 dS/m, the top five genotypes produced higher green matter of 24.80 to 36.67 t/ha. Of these, 21/2 D produced highest green forage yield of 36.67 t/ha followed by 91/2A (34.80 t/ha), 100/1 B (30.40 t/ha), 113/1 B (25.07 t/ha) and 60/1A (24.80 t/ha). The combined analysis of 2005 and 2006 trials had lead to selection of 91/2A that was found consistently stable and superior yielding mean green matter yield of 23.03 t/ha over two diverse saline water conditions.

In 2006–07 winter, the results of on-farm evaluation trial involving another set of 26 elite barley genotypes at a site of sandy soil (EC and pH of 7.30 dS/m and 7.50 at 0–15 cm depth and of 3.5 dS/m and 7.50 at 15–30 cm depth, respectively) with irrigation water salinity of 10.80 dS/m to 13.50 dS/m at flowering stage, indicated that the genotypes produced green forage yield between 14.70 t/ha and 20.67 t/ha.

iv. Oats (*Avena sativa* L.) and *Triticale*

In 2006-07 winter, on-farm evaluation of two elite forage oat genotypes and a forage triticale genotype was undertaken in the farmer's field under high saline conditions on a site of sandy soil (EC and pH of 7.3 dS/m and 7.50 at 0-15 cm depth) with irrigation water of 10.80 dS/m to 13.80 dS/m. The result indicated that Nagena oats produced the highest green forage yield of 14.68 t/ha in about 53 days followed by Crackerjack triticale (10.63 t/ha in 45 days).

v. Fodder beet (*Beta vulgaris Crassa* group)

Seven fodder beet varieties of first set provided by ICBA were evaluated under drips consecutively in winter seasons of 2005–06 and 2006–07 at BARF and farmer's field located in Rumais. These genotypes were Blaze, Blizzard, Maestro, Adagio, Turbo, Abondo and Dana.

In 2005–06 season, the results of the trial conducted at a site in BARF of sandy soil (EC and pH of 15.90 dS/m and 7.50 at 0–15 cm depth) under saline conditions of higher irrigation water of 14.78 to 16.5 dS/m, indicated that Turbo was found to produce highest total green matter yield of 88.87 t/ha followed by Adagio (80.60 t/ha) and Abondo (80.20 t/ha) whereas the results of the trial conducted at a site in farmer's field of sandy soil (EC and pH of 6.90 dS/m and 7.50 at 0–15 cm depth) indicated that under saline conditions of irrigation water EC ranging from 8.5 to 10.5 dS/m, Abondo was found to produce highest green matter yield of 127.80 t/ha followed by Turbo (125.87 t/ha) and Dana (125.67 t/ha).

In 2006–07 winter season, under saline conditions of higher irrigation water EC to the extent ranging from 20.5 to 23.50 dS/m at BARF, among the seven genotypes, five genotypes were identified to yield numerically higher total green matter (6.74 to 9.64 t/ha) yield than mean performance of all the varieties (mean green matter yield 6.88 t/ha) while under saline conditions of irrigation water EC to the extent ranging from 10.80 to 12.50 dS/m in the farmer's field, among the seven genotypes and two Syrian local genotypes, Blizzard was found to produce numerically highest green matter yield of 95.67 t/ha followed by Adagio (83.00 t/ha), Mestro (79.00), Dana (78.33 t/ha) and Syria-1 (74.00 t/ha). The yield levels of fodder beet genotypes were lower than those in the previous years which could be attributed to significant rise in irrigation water salinity in the cropping season.

Of the seven fodder beet genotypes tested for two years in two different saline conditions, three genotypes namely Turbo (88.87 to 125.87 t/ha), Abondo (80.20 to 127.80 t/ha), and Adagio (80.60 to 83.10 t/ha) were found to be consistent and stable in performance over seasons and diverse locations and have been selected for evaluation for farm trials.

In winter 2006–07, on-farm evaluation of another set of eight-elite fodder beet genotypes supplied by ICBA was undertaken under high saline conditions on a site in BARF. These genotypes were Longshi No.1, Polyfoura, Tintin, Magnum, Asteix, Troya, Nestor and Kyros. The results of the trial indicated that among all the entries tested, Asteix was found to produce numerically highest green matter yield of 17.41 t/ha followed by Longshi No.1 (13.88 t/ha), Kyros (12.91 t/ha), Tintin (12.18 t/ha) and Polyfoura (11.91 t/ha). The yields of fodder beet genotypes were of lower order because exceptionally worse saline irrigation water (20.5 to 23.5 dS/m).

vi. Canola (Brassica campestris L.)

Four canola genotypes provided by ICBA were evaluated during winter 2005–06 at a site of sandy soil (EC and pH of 15.90 dS/m and 7.50 at 0–15 cm depth and of 17.20 dS/m and 7.50 at 15–30 cm depth) at BARF,under saline conditions of higher irrigation water EC ranging from 14.78 to 16.5 dS/m. Canola genotypes showed moderate yielding ability of green matter (20.50 to 30.60 t/ha).Of these, variety, Interval was found to produce numerically highest green matter yield of 30.60 t/ha followed by Hyola 43 (21.43 t/ha), Hyola 60 (20.83 t/ha) and Hobson (20.50 t/ha). In winter 2006–07, on-farm evaluation trial of seven elite canola genotypes of different set was undertaken under high saline conditions on a site of sandy soil with EC and pH of 7.3 dS/m and 7.50 at 0–15 cm depth in a farmer's field under irrigation water of 10.80 dS/m to to 14.20 dS/m. Among all the genotypes tested, Hyola-61 was found to produce numerically highest green matter yield of 32.00 t/ha followed by Hyola-43 (26.75 t/ha) while fodder rape 98-D produced higher green matter yield to the extent of 31.50 t/ha.

Perennial forage grasses

i. Evaluation of ICBA's *Cenchrus ciliaris* accessions:

One-month old seedlings of each of 37 accessions of ICBA's known saline tolerant buffel grass (*Cenchrus ciliaris* L) were transplanted in RCBD with four replications in a site at BARF in May 2005 in 5m long three rows at 2m row to row and 1m plant to plant distance, under drips. These accessions could not grow and develop due to rise in salinity of both soil (40.20 to 60.00 dS/m at 0–15 cm and from 8.93 to 30.60 dS/m at 15–30 cm) and irrigation water (11.5 dS/m in the beginning to 14 dS/m). The experiment was finally annulled.

ii. Evaluation of Omani indigenous *Cenchrus ciliaris* accessions:
One-month old seedlings of each of 10 indigenous accessions of buffel grass (*Cenchrus ciliaris* L) were transplanted in RCBD with four replications in a site at BARF in August 2005 in 3m long three rows at 2m row to row and 1m plant to plant distance, under drips. The land was leached satisfactorily before transplanting. The experiment was conducted by using irrigation water of 12.45 dS/m in the beginning to 13.10 dS/m at the end. All the accessions began to show suddenly the signs of adverse effect of salinity within a week of transplanting with initial leaf burns that gradually extended to entire culms leading to death within a month. The experiment was eventually annulled. Omani indigenous *Cenchrus ciliaris* accessions are known to adopt under non-saline conditions, as they are from the rangelands.

iii. On-farm evaluation trial of seven perennial grasses:
On-farm evaluation trial of seven perennial grasses (i.e. Pensacola Bahia, Kikuyu, Bambatssi, Sabi grass, Queensland Blue Couch and Rhodes grass) was conducted on a new site in Suhail Farm which is located about 3 km far from Rumais Agriculture Research Station during summer 2007. The experimental site had sandy soil with EC and pH ranging from 0.69 dS/m and 8.6 to 8.60 dS/m and 8.0 at 15–30 cm depth. It had abundant quantity of irrigation water that was saline to the extent of 5.2 dS/m recorded just before commencement of trials. The trial was cancelled because of low germination and plant stand in the plots of test grass species while the local check crop, Rhodes grass cultivar, Katambora had 85% germination.

Perennial forage legumes

i. On-farm evaluation trial of six perennial legumes:
On-farm evaluation trial of six perennial legumes (i.e. Burgundy Bean, Commander Chicory, Siran, Alfalfa Eureka, Alfalfa Sceptra and Alfalfa Interior) was conducted on a new site in Suhail Farm which is located about 3 km far from Rumais Agriculture Research Station during summer 2007. The experimental site had sandy soil with EC and pH ranging from 0.69 dS/m and 8.6 to 8.60 dS/m and 8.0 at 15-30 cm depth. It had abundant quantity of irrigation water that was saline to the extent of 5.2 dS/m recorded just before commencement of trials. The trial was cancelled because of low germination% and plant stand in the plots of test grass species while the local check, alfalfa cultivar, Batinah local had 82% germination.

Perennial forb (forage shrub) and small tree species:

Three *Atriplex* species i.e. *A. lentiformis, A. halimus* and *A. nummularia* and one salt-tolerant tree species *Acacia ampliceps* were planted un-replicated in one of the blocks of 40 m x 20 m at BARF during March 2005 under drips. They were irrigated with saline water of about 14 dS/m from the beginning that gradually kept increasing to about 32 dS/m recorded in December 2008. All the three Atriplex species suffered from coupled effect of both soil and water salinity during 2007 while *Acacia ampliceps* were found extremely tolerant as evidenced by their vigorous growth with large canopy. We have estimated the productivity of three *Atriplex* species and *Acacia* species i.e. during the course of their use. It was found that *A. lentiformis* was able to produce highest average green forage yield of 3.81 kg/plant/year from three harvests each year at 4-month interval followed by *A. nummularia* (2.79 kg/ plant/ year) and *A. halimus* (2.18 kg/ha) under very high salinity level of 14 dS/m to 32 dS/m). *Acacia ampliceps* was found more productive with highest green forage yield of 6 to 10 kg/plant/year estimated from two harvests at 4-month interval. These shrubs and tree species were used as mother stock for multiplication and distribution to the farmers.

EVALUATION FOR SALINITY TOLERANCE

Evaluation for salinity tolerance under field conditions

i. Response of selected barley genotypes to different levels of irrigation water salinity under field conditions during winter, 2007–2008:

Four genotypes of barley namely J-51, J-54, J-58 and J-98 and Beecher, selected based on the their superior performance in several year trials of Field Crops Lab. under good irrigation water conditions were subjected for studying their response to six levels of irrigation water salinity i.e. control (1 dS/m), 3 dS/m, 6 dS/m , 9 dS/m , 12 dS/m and 15 dS/m along with international check, Beecher and a variety of ICBA, namely Dictator during winter 2007–08 season (November 2007 to March 2008) under field conditions. Among all the genotypes tested, the salinity tolerance of J-58 was of higher degree and more consistent as it scored high mean values across salinity environments (levels) for all the characters except leaf length, followed by J-51 which scored high mean values across salinity environments (levels) in respect of five characters i.e. plant height, leaf length, leaf width, green matter weight, out of seven characters, studied.

ii. Response of selected saline tolerant sorghum genotypes to different levels of salinity:

Five genotypes of sorghum namely ICSV 93046 (27.84 t/ha), SP 47529 (24.03 t/ha), ICSR 93034 (23.59 t/ha), ICSV 93048 (20.96 t/ha) and ICSV 745 (20.91 t/ha) were selected based on the performance in two summer seasons i.e. 2004 and 2005 from 29 genotypes from ICBA's evaluation trials in farmer's fields under irrigation water salinity ranging from 6 dS/m to 11 dS/m. These selected genotypes were subjected for studying their response to four levels of irrigation water salinity i.e. control (1 dS/m), 3 dS/m, 6 dS/m and 9 dS/m during summer 2008 season (March to June 2008) under field conditions. Among all the genotypes tested, the salinity tolerance of SP 47279 was of higher degree and more consistent as it had high mean values across salinity environments (levels) for three out of six characters at both growth stage of 30 days (plant height, leaf length and leaf width) and 45 days (plant height, No. of leaves and leaf length) whereas for as many as six out of eight characters (plant height, No. of leaves, leaf length and leaf width, leaf chlorophyll content), green and dry matter yields at harvest.

Evaluation for salinity tolerance under hydroponic conditions

Response of selected barley genotypes to different levels of irrigation water salinity under hydroponics system in shade house:

Four genotypes of barley namely J-51, J-54, J-58, J-98, selected based on the their superior performance in several year trials of Field Crops Lab. under good irrigation water conditions were subjected for studying their response to seven levels of irrigation water salinity, i.e. control (1 dS/m), 2 dS/m, 4 dS/m, 6 dS/m, 8 dS/m, 10 dS/m and 12 dS/m, along with international check, Beecher during winter 2007–08 season (March 2008) up to 30 days under hydroponics system developed recently in shade house. Among all the genotypes tested, the salinity tolerance of J-98 and J-58 was of higher degree and more consistent as they scored high mean values across salinity environments (levels), respectively, for three (leaf number, green matter weight and dry matter weight) and two (seedling height and root length) characters out of six characters, studied. J-58 was highly tolerant to salinity based on its low Stress Susceptibility Index (SSI) values for three (seedling height, green matter and dry matter%) characters, followed by J-98 that showed low SSI values for two characters, i.e. leaf number and root length. characters.

Multiplication and propagation of salt-tolerant genotypes

i. Establishment of Nursery of grass species

Nurseries of four salt-tolerant grass species namely *Sporobolus virginicus, Distichlis* *spicata, Leptochloa fusca* and *Paspalum vaginatum* were established in March 2005. in nursery beds of 3.5 m x 10 m. These nurseries were frequently used further in establishing their demonstration plots and/or supplying seedlings to needy farmers.

ii. Establishment of demonstration plots of grass species
Demonstration plots of three salt-tolerant grass species namely *Sporobolus virginicus, Distichlis spicata* and *Leptochloa fusca*, between February 2005 and March 2006 in huge demonstration plots of 25 m x 25 m under sprinklers with irrigation water of 14 to 23 dS/m. These demonstration plots were used not only for estimation of their productivity (green matter yield/ ha) by sampling but also for showing to the farmers, scientists, students and others who visited the BARF to know the activities of the project. It was found that *Leptochloa fusca* was able to produce highest green forage yield of 4.73 kg/sq.m followed by *Distichlis spicata L.* (3.53 kg/sq.m) and *Sporobolus virginicus L* (2.20 kg/ha) under very high salinity level exceeding 19 dS/m .

Selection of promising salt-tolerant forage species

Outstanding high yielding genotypes in different crops have been selected based on the results of trials over two to three years conducted between 2004 and 2007, as follows:

- Barley: 91/2A (23 t/ha)
- Pearl millet: IP 6112 (65 t/ha), Sudan Pop III (60 t/ha), IP 19586 (57 t/ha), IP 3616 (57 t/ha) and IP 6104 (50 t/ha)
- Sorghum: ICSV- 93046 (27 t/ha), SP 47529 (24 t/ha), ICSR 93034 (24 t/ha), ICSV-93048 (21 t/ha) and ICSV-745 (21 t/ha)
- Fodder beet: Turbo (88 to 125 t/ha), Abondo (80 to 127 t/ha) and Adagio (80 to 83 t/ha)

SOIL AND IRRIGATION MANAGEMENT AND MONITORING

In all, eight farms were adopted and developed with required facilities, under the project. Representative soil profiles were analysed for physical and chemical properties. Soil and water samples of were taken in all the farms at the beginning and termination of trials to study the pattern of changes occurring during the course of experimentation and suggest the methods if needed to alleviate increase in soil salinity like irrigation certain quantities of water in the plots before experimentation for allowing leaching of excess salts in the soil.

Assessment of saline water resources (related to forage project)

Assessment of saline water resources was undertaken in six of eight adopted farms during the period of the ICBA projects. Changes in salinity levels of irrigation water of these adopted farms were noted at every three-month interval along with that of at least 7 to 10 neighbouring farms from the beginning of the activity. The neighbouring farms were considered to assess their irrigation water salinity to compare the impact of changes in water salinity as a result of ICBA's activities in the adopted farms in relation to neighbouring farms. In four of the adopted farms namely BARF and Majid Shaikhan farm located at Rumais, Ali Al-Sheedi farm at Suwaiq and Mohammed Al-Jahwary farm at Saham, the activity began in March, 2006 while in Suhail Farm at Rumais and Hilal Al-Faree Farm at Musanna, the activity commenced in October 2007 immediately after their adoption. The results of monitoring have clearly indicated that groundwater salinity has been slowly and steadily rising in almost all the wells, studied.

Management of irrigation water snd soil under saline conditions

Site/soil characterization:
The soil profiles of all eight adopted farms namely Biosaline Agriculture Research Farm

at Rumais, Murthada Al-Lawati Farm at Rumais, Majid Shaikhan Al-Mammari Farm at Rumais, iv. Ali Al-Sheedi Farm at Suwaiq, Mohammed Al-Jahwary Farm at Saham, Suhail Al-Mukhaini Farm at Rumais, Hilal Al-Faree Farm at Musanna and Agriculture Research Station at Rumais, were analysed with respect to both physical and chemical characteristics of the soil from top soil to that up to a depth of 150 cm. In addition, other physical characteristics of soil such as wilting point, field capacity, available water, static hydraulic conductivity and bulk density, were recorded at different depths.

Soil Monitoring for changes in quality (salinity) and management:
Soil quality of five ICBA's adopted farms i.e. Ali Al-Sheedi farm at Suwaiq and Mohammed Al-Jahwary farm at Saham, the activity began in March, 2006 while in Suhail Farm at Rumais and Hilal Al-Faree Farm at Musanna, was monitored during handling of the project activities at quarterly interval from the initiation of the monitoring activity. There was sudden deterioration of quality of soil at three different depths (0–15 cm, 15 –30 cm and 30–45 cm) in these farms during different periods of time as evidenced by increase in Sodium Adsorption Ratio (SAR) from September 2007 to October 2008.

OPTIMIZED PRODUCTION SYSTEMS TRANSFERRED TO NATIONAL PROGRAMS

Establishment/development of demonstration sites and pilot farmers sites for forage production and management

In collaboration with ICBA, six farmers' fields namely Murthada Al-Lawati Farm at Rumais, Majid Shaikhan Al-Mammari Farm at Rumais, iv. Ali Al-Sheedi Farm at Suwaiq, Mohammed Al-Jahwary Farm at Saham, Suhail Al-Mukhaini Farm at Rumais and Hilal Al-Faree Farm at Musanna were adopted for execution of the activities. The sites were divided into 3 to 4 parts of 50 m x 50 m in which modern drip irrigation system was set-up with automatic control panel. Entire irrigation system including 5000-gallons tanks belonged to the farmers after completion of the term-period. In addition about 1 ha of BARF was fully developed with required irrigation systems for different experiments. The site was provided with automatic control panel for irrigation of ten blocks of 40 m x 20 m dimension each, from three 5000-gallons water-tanks. All blocks were provided with underground drainage channels to collect excess water in sump tank provided in one corner. In Agriculture Research Station, Rumais, a site of about 2 ha was adopted and developed facilities for screening various crops/varieties under field conditions using the funds of Ministry during October 2006. Nine 100 lit tanks were provided such that two tanks would supply control irrigation water (0.8 dS/m) and seven tanks can be used for supplying irrigation waters of different levels of salinity to respective specified areas of the crop treatments provided with dripper lines. Besides, shade screening facilities were also developed in the Shade house adapting the same principles used at ICBA.

Transfer of technology to farmers' fields

Almost 90% of the ICBA activities have been carried out in the farmers' fields either in the form of on-farm evaluation, demonstration or pilot trials. Field/farmers' days conducted involving the farmers and Agriculture Extension Officers have directly helped the end users like farmers to learn the technology adopted and material used.

Seed production of annual salt-tolerant forages

Seed production activities of selected varieties of salt-tolerant annual forages such as sorghum (ICSV 93046 and ICSV 745) and pearl millet (IP 6104 and IP 6112) have been under progress during winter 2008 in two Agriculture Research Stations located at Sohar and Jimah, and during summer 2009 at Agriculture, Research Station, al Kamil, for increasing seed quantities to distribute them to farmers.

Seedling multiplication of perennial salt-tolerant forage shrub (forb) species

Seedling multiplication activities of selected forage shrub/tree species, i.e. *Atriplex lentiformis* (500 seedlings) and *Acacia ampliceps* (500 seedlings) through cuttings/ seeds have been under progress since winter 2007–08 at Agriculture Research Center, Rumais for increasing the number of seedlings to distribute them among the farming community.

The salinity research is being continued intensively in the Ministry independently and in joint collaboration with ICBA and ICARDA through their regional projects addressing the transfer of biosaline agriculture technology to the farmers' fields to ensure the effective agriculture extension programs.

CONCLUSIONS

The overall agriculture in the the Sultanate of Oman has been suffering from salinity problem in field, forage and horticultural crops since 1990s gradually until its effect has been worsened during the 2000s when the Ministry of Agriculture resolved to approaches to the solutions independently as well as through collaborative projects of international research centres/institutes like ICARDA and ICBA. The present paper outlines the salient results of the investigations in biosaline agriculture research in Oman. The performance of selected salt-tolerant genotypes and methods of combating soil and water salinity, need to be reconfirmed in large scale demonstration trials to ensure their feasibility of general cultivation.

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Salinity intrusion: Periodical monitoring results in the Sultanate of Oman

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The Sultanate of Oman is situated in the south-eastern part of the Middle East. The northern part of Oman is mostly mountainous, parallel to the coast and separates the fertile plain from the Interior region. The highest peak of this magnificent mountain range is Jabal Shams, whose altitude reaches more than 3 000 m above sea level. The central plateau of Oman is a flat table of carbonates sediments with occasional scattered sand dunes. The extensive sand desert of Rub Al Khali and Rymal AsSharqiyah, and widespread gravel plain covering large areas of the country are extremely arid. A second mountain belt is located in the southern part of the country. The Dhofar Mountains are up to 1 800 m high, and near Salalah they frame a small but important coastal plain.

Oman has an arid and semi-arid climate, generally hot and dry in the summer and mild in the winter, with the exception of Dhofar Governorate, which affected by the monsoon. The Sultanate is characterized by the lowest rate of rainfall and the highest rate of evaporation in the world. Rain is the main source of fresh water in Oman. The average rainfall in the Sultanate is about 100 mm per year and that rate varies between less than 50 mm in the centre of the country to about 300 mm in the mountains. The annual evaporation rate is estimated at between 3 000 mm in interior areas, 2 100 mm in the north and 1 700 mm in the south. There is a high rate of evaporation due to high temperatures and low humidity.

There has been rapid development of the water resources of Oman during the past forty years. The growing economy has brought an increase in urbanization with a demand for high levels of service and quality for water supplies. The challenges faced for water resources in Oman are increased water demand, low agriculture returns compared with the amount of water used and groundwater pollution .

The increase in groundwater use over the last thirty years, mainly as a result of uncontrolled extraction, particularly during the 1970s and 1990s has led to groundwater quality deterioration in some areas and to the inland flow of saline groundwater in coastal areas.

The government has sought to develop management plans and water resources development and these plans rely on a database and available hydrological information. So it established a hydrometric monitoring network covering all regions of the Sultanate. The strategy of water resources monitoring on several axes are to provide data for all water hydrological basins through periodic monitoring and modernize in an integrated database and, in addition, to identify areas that are exposed to a deficiency or pollution in water resources and to find quick solutions to cope with such problems. The hydrometric monitoring network in the Sultanate consists of 4 636 control points (rain, Wadi, Falaj, wells, water salinity, and dams) distributed throughout the Sultanate.

This paper reviews the monitoring activities of groundwater quality in the coastal plains of Oman for the period 1983 to 2010. It is clear that there is an increase in groundwater salinity in most of the coastal areas. This is an indication of aquifer over-exploitation. It is currently monitoring the levels and quality of 1 600 wells. The results of this project and possible solutions to the problem of salinity in Oman are presented.

Effect of climate and land use change to increase salinity impact in North-east Thailand

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Thailand is a country where agriculture has long been important for its socio-economic growth since A.D. 1238. Land area of around 21 Mha is currently under crop, 13 Mha are forests and the remaining 17 Mha comprises urban and public areas, sanitation, swamp land, railroads, highways, real estate and other areas. The climate of Thailand is classified as tropical savannah (the Central Plain, North, North-east and some part of Eastern Thailand), tropical monsoon (west side of Southern and Eastern Thailand) and tropical rainforest (east side of Southern Thailand). The average annual temperature is about 27 °C while the annual rainfall is in the range of 824–5 248 mm. The potential irrigated lands are scattered in every part of the country, with an area of 5 Mha or 23.8% of arable land, of which 46% is located in the Central Plain.

The North-east region of Thailand has a land area of 16.9 Mha or about one-third of the total area of the country. It comprises agricultural land (9.3 Mha), forest (2.5 Mha) and other areas (5.1 Mha). The geomorphological characteristic of this region is a plateau, uplifted from the sea with rolling and undulating topography. An average annual rainfall in this part of the country is below 1 100 mm; it shows irregular distribution, with long drought periods, and is concentrated in summer season, with high potential evapotranspiration rate always exceeding the precipitation, which promotes the upward movement of soil solution and concentration of salts in the surface horizons. Soils are mostly shallow and sandy, with low fertility and deficient in most plant nutrients. Soils in some parts of the region are severely affected by salinization, e.g. in large areas in Khon Kaen and Nakon Ratchasima provinces. The salt-affected areas occur on the lower slope and lowland, where the natural forest has been denuded.

In terms of agriculture, soil and land resources are important factors in agricultural production. However, many land areas in Thailand have changed since 1960 due to the rapidly burgeoning population, land use pattern changes and, in particular, the introduction of modern technologies. The most notable changes were: encroachment on natural forest, using marginal lands and mismanagement of soil and water that resulted in deteriorated soil and water resources, particularly anthropogenic soil salinization.

OBJECTIVES AND METHODS

This paper aims at giving a comprehensive summary of the results and the investigation into the environmental aspects of Thailand. The main objectives of this study were to examine the possible effect of climate and land use change in increasing the salinity impact, to link change and diversity in the effecting areas and to reach an understanding of causes and effects of environmental change and salinization. The study site is in Lam Cheung Krai watershed, Nakon Ratchasima province, North-east region, Thailand.

The investigation on landuse change has been done using visual interpretation techniques. The computer interpretation has been supported by related database, existing soil data, groundwater monitoring, ground truth verification and laboratory investigation.

Aerial photographs, Landsat imagery, soil and water sampling, in-depth interviews, observation of vegetation growth and secondary data were some of the tools used.

RESULTS AND DISCUSSION

In the period from 1961 to 2008, the national forest areas were drastically decreased from 27 362 849 ha or 53% of the total area of the country in 1961 to 12 972 200 ha or 25% in 1998. The forest in the North-east region during 1961 covered an area of 6 409 721 ha or 41% of the total area of the region and declined to the lowest extent in the remaining area of 2 098 400 ha or 13%. Pra Vipak Puwadon (1898) and Montrakun (1964) reported that in the North-east region the population was in a small number. Generally, the forest areas were dense and relatively vigorous but where the soil is lighter and poorer the forest is poor and open. Arable land is used for growing rice, sugar cane and other cash crops.

The meteorological data of the country from 1951 to 2006 showed that the average total annual amounts of rainfall, average temperature and humidity had fluctuated but they were not different when compared among the average amounts of each year. The effect, however, reflected the pristine number of rainy days in the North-east region in the years of 1951, 1961, 1973, 1976, 1982, 1985, 2001 and 2006 in the number of 127.1, 125.5, 109, 123.5, 116.5, 120.3, 121.3, and 112.2 days, respectively, which were gradually reduced. In the Central Plain, the average temperature in November slightly increased in the years of 1956, 1961, 1966, 1971, 1976, 1981, 1986, 1991, 1996, 2001, and 2006 at an average of 25.5, 27.7, 27.2, 24.9, 25.6, 26.4, 26.7, 25.9, 27.1, 25.3 and 28.4 °C, respectively.

A study on "Impact of Climate Change on Salt Patch Distribution" was carried out at Lam Chuengkrai watershed, Nakon Ratchasima province, North-eastern Thailand (Somsak, 2009). Generally, the soil salinization in this study is divided broadly into seven categories:

- the very highly salt-affected area (salt patches on soil surface more than 50%)
- highly salt-affected area (salt patches on soil surface 10–50%)
- moderately salt-affected area (salt patches on soil surface 1–10%)
- slightly salt-affected soil (salt patches on soil surface less than 1% with
- occurrence of saline groundwater)
- slightly salt-affected soil (salt patches on soil surface with normal
- groundwater)
- upland area without salt patches but there are rock salt strata and shale that
- impregnate with salts
- the area with no salinity effect.

The results from the investigation of changing distribution of salt patch areas by the comparison of land characteristics between 2005 and 2009 showed that there was an increase of salt-affected areas in 19 183 ha or 6.45% of the total area of the watershed. Most of these areas, particularly in the lowland, salt patches occurred on the soil surface less than 1% of their areas and has changed with the increasing salt patch areas from 1–10%. Apart from that, on the upland areas where there was no appearance of salt patch, now salt patches appearing on the surface of these areas were found in a range of less than 1%. These areas were normally used for growing field crops in a long period but the salinization occurred after the farmers changed their lands to growing rice. Similarly, when interviewing old farmers, the interesting information regarding soil salinization was given. They said that when they were young there was a dense forest in the North-east region, particularly at the adjacent areas where they used their land for rice cultivation. Later on, when the forest was encroached and used for expanding the community and for agricultural use, eventually, the area became affected by salinization continuously and increasingly (Im-Erb, 2005).

Nevertheless, there was a tendency of some improvement in an area of 16 556 ha or 5.5% of the total area of the watershed. Formerly, salt patches in these areas were found in more than 50% of the whole areas. After five years, the salt patches reduced to 10–50%. Some places with 10–50% of the salt patches reduced to 1–10% and the areas where the salt patches were 1–10% reduced to less than 1%. With an observation and interview with farmers, these areas where the salt appeared had turned to be the better lands. The lands were developed by the owners with integrated techniques, i.e. land levelling and incorporating organic matter to the soil. The remaining areas of about of 247 430 ha or 83% of the watershed were found without change. The statistics revealed that the forest in Nakhon Ratchasima province in 1961 covered an area of 1 137 800 ha or 55% of the province, and it reduced drastically in 1973, 1976, 1978, 1982, 1985 and 2001 to 571 300, 447 700, 365 300, 303 600, 282 600 and 302 651 ha or 27, 21, 17, 14, 13 and 14%, respectively. The average rainfall of the North-east region in 1951, 1961, 1973, 1976, 1982, 1985, 2001 and 2006 showed a slight decline with an amount of 1 536.9, 1 617, 1 179.1, 1 402.6, 1 365, 1 338.1, 1 483.8 and 1 389 mm per year, respectively. The numbers of rainy days of this region in 1951, 1961, 1973, 1976, 1982, 1985, 2001 and 2006 were 127.1, 125.5, 109, 123.5, 116.5, 120.3, 121.3, and 112.2 days, respectively, which gradually reduced. Deforestation would cause the uplift of saline groundwater close to the soil surface while the amount of rainfall and rainy day would directly affect soil moisture content and soil temperature to result in an increasing salt-affected area. It may be concluded that there was a tendency of the above environmental factors that are related and have resulted in such an extent of soil salinization. Similarly, the salinization in other parts of the North-east region was caused by high water table and the movement of the dissolved salts upward by capillary rise, the evaporation process and subsequent accumulation of salt on the soil surface. (Sinanuwong and Takaya, 1974; Arunin, 1985; Im-Erb and Pongwichian, 2003, Im-Erb *et al.*, 2004).

Concurrently, Thaveethavornsawat (2000) reported a study on the relationship between deforestation, landuse change and the distribution of salt patches in Prayun district, Khon Kaen province from 1954 to 1994. The study used aerial photographs with scales 1:15 000 and 1:50 000. The result showed that the land use had changed. The areas of rice field, upland crops, and community had increased while the areas of forest decreased 192 ha per year or at an average of 2.1%. The salinization of the soil surface increased 16.73 ha per year or 3.2%. The study on the relation between forest areas and the areas of salt patches showed that the forest area, the area of salt patches, rice field, upland crops, community area and water bodies were changed in opposite direction. The forest decreased while the areas of salt patches, rice field, upland crops, water bodies and community increased. The salt patch areas increased significantly with the increase of rice field, upland crops, water bodies and community.

The Land Development Department, however, has applied various measures to ameliorate the problems related to global warming and soil salinization. Reforestation in both areas of inland and along the coastal areas by growing mangrove forest and incorporate rice straw to the soils to enhance carbon sequestration is the important measure that is being applied throughout the country. To control and ameliorate soil salinization the integrated soil, water and plant management with low-cost and low risk basis has been implemented. Reforestation by planting fast growing trees and using shallow well has been used for soil salinization mitigation and management. Such measures serve to lower groundwater level both in recharge and discharge areas. In both areas the electrical conductivity of soil decreased, while soil organic matter content increased due to its decomposition (Im-Erb and Pongwichian, 2003; Im-Erb *et al.*, 2004). So far, growing economic salt-tolerant plant varieties, application of organic matter such as rice husk, green manure etc. and appropriate leaching techniques were used to improve salt-affected lands.

CONCLUSIONS

The burgeoning population has triggered the most devastating set of processes leading to land degradation, unsustainable agricultural system etc. The change of land use by encroachment of forest and clearing the land for agriculture, community and other purposes, it affects the integrity of the environment. Reforestation had a positive result in controlling salinization at designated areas. It is imperative to educate people in all society levels to understand the importance of environment, natural resources and its management that will result in proper and sustainable land use. Legislative measures can control the problems that are caused by human activities.

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TOPIC V: ANALYSIS OF THE EFFECTS OF INCREASED SALINIZATION ON FOOD SECURITY AT NATIONAL, REGIONAL AND GLOBAL LEVELS

Facing the food challenge under climate change threats to land resources through increased salinization

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ABSTRACT

Soil salinity and sodicity problems are common in arid and semi-arid regions, where rainfall is insufficient to leach salts and excess sodium ions out of the rhizosphere. Nearly 6% of the total land surface is affected by either salinity or sodicity. These salt-affected soils are distributed throughout the world. More than 80 Mha of such soils are in Africa, 50 Mha in Europe, 357 Mha in Australasia and 147 Mha in Central, North and South America. Similarly, a large bulk of about 320 Mha of land in South and South-east Asia is under the grip of salinity.

Pakistan's agricultural system is predominately irrigated as irrigation water is the major driver of food production. Of the total area of Pakistan (80.0 Mha), 19.3 Mha are available for farming. Of these, irrigated agriculture is practiced on about 16 Mha (about 80%). The irrigated agriculture consumes about 90% of fresh water resources and contributes 80% to national production. Additionally, Pakistan's economy is heavily dependent on the export of agricultural goods and the textile sector depends on the cotton crop. Thanks to the elaborate irrigation network in Pakistan, farmers have obtained quite stable crop productivity. But ironically, soil salinity has emerged as one of the major factors responsible for low crop production after the introduction of canal irrigation system in the Indo-Pak subcontinent. It is an important problem affecting irrigated agriculture of Pakistan. Improper irrigation practices and lack of drainage have generally led to accumulation of salts in the soil, which are harmful to the crops. There is a major imbalance in the amount of salt entering and leaving the soil in Pakistan. This situation is very alarming especially for the Punjab region which is producing a major share of crops for the whole country. Intensive and continuous use of surface irrigation has altered the hydrological balance of the irrigated areas, especially the Indus basin. During the last years, various agricultural regions have significantly lost their productivity potential due to soil salinity. The substantial rise in the water table has caused development of salinity and waterlogging in large areas of Sindh, Punjab, Khyber Pakhtoonkha and Balochistan. Waterlogging is caused by high water table from canal seepage and impeded drainage. Salinity is caused by residual salt accumulation on land surface as a result of evaporation or due to high salt concentration of irrigation water. This paper discusses the possible benefits of using saline agriculture.

Keywords: salinization, climate change, agricultural productivity, salt-affected areas, Pakistan.

DISCUSSION

Salt has always been part of Pakistan's environment. The salt-affected soils are mainly situated in plains. Out of the total geographical area of Pakistan of 80 Mha, the salt-affected area is 6.67 Mha (Khan, 1998) and 80% of this area lies in Punjab. About 6.30 Mha of land are salt-affected of which 1.89 ha is saline, 1.85 Mha is permeable saline-sodic, 1.02 Mha is impermeable saline-sodic and 0.028 Mha is sodic in nature. It is estimated that Punjab has the highest share of saline soils (3.9 Mha) followed by Sindh (0.6 Mha) and Baluchistan (0.2 Mha) (GoP, 2007).

Saline agriculture almost always involves some compromise on yields as even a very salt-tolerant species is bound to suffer some yield losses under the adverse conditions Accumulation of excessive salts at the surface is injurious to plant growth. The salts inhibit germination, lead to poor crop stand, to physiological drought, loss in yield and in severe cases to death of growing plant. The extent of damage to crop yild depends heavily on the stage of crop development and on m ore obvious factors such as duration of waterlogging and temperature. Makhdum and Ashfaq (2008) showed that salinity and waterlogging were negatively associated with wheat production. Waterlogging and salinity have also adverse social (like migration and diseases) and economic (reduction in crop production and increase in poverty) effects on communities in Pakistan, causing poor living standards, poor education, crumbling mud and brick houses, health problems for humans and animals, and bad condition of roads. Many people are forced to migrate to other areas in search of livelihood.

Saline soils may be improved by leaching the salts from the root zone. Leaching is the process in which extra water is added to a field and allowed to soak through the soil and drain away underground. A common method of leaching is to pond the water in basins over the entire field. Sometimes the excess water is removed by pumping from wells. Permissible depths for ground-water tables vary according to the type of soil being irrigated. The amount of leaching water that enters the soil by surface flooding determines how much salt is removed from the soil. When water is leached through the soil, a surface depth of 6 inches of water for every foot of plant root will leach out 50% of the salt. One foot of water for every foot of root zone leaches out 80% of the salt. Two feet of water per foot root zone leaches out 90% of the salt. Besides leaching, many engineering solutions to control salinity have been proposed and used. These include construction of gravity canals for collecting saline water from the waterlogged soils and draining it into main rivers. This approach is cost extensive and has resulted in wastage of land resources without significant improvement of salinity problem. Then, construction of dug wells for lowering the water table was tried with assistance of donor agencies. The project worked well but after the completion of project period, the tube wells were neglected. There was no repair/maintenance of the electric motors and tube well operators were not kept on permanent role of the department.

Over the past few decades, research that has been conducted in Pakistan on a new concept of Biosaline Agriculture. The concept involves growing of salt-tolerant plants in a succession with the highly salt-tolerant plants gradually being replaced by relatively less salt-tolerant plants and ultimately growing of salt resistant crops. The soils with electrical conductivity of less than 4 dS/m are generally considered as salts free, where almost all crops can be grown. As the salt concentration increases, the choice becomes limited and one has to go for tolerant plants suited for specific conditions.

Furthermore, some of these plants are able to lower local water-tables, improving the condition of the land, and acting as 'biological pumps'. If the plant survives the shock at seeding/ transplanting stage, the chances of its subsequent survival and growth are likely to be increased. Several salt-tolerant grain, fruit and fodder species have been identified for practicing saline agriculture in the country. Out of about 5 000 crops that are cultivated throughout the world, a few can survive with water that contained more than 1% salt.

It transpires from the foregoing that biosaline agriculture can be a profitable and practical venture under proper management and by observing suitable precautionary measures. Initial establishment is crucial for subsequent growth and hence stress should be minimized as far as possible at this stage. Biosaline agriculture is an economical and effective approach to use unproductive lands for growing various plant and food crops. This approach, if prudently adapted, can help reduce the imports of agricultural commodities to a great extent.

Climate change is likely to exacerbate the soil degradation through salinization as the process of salinization is dictated by climatic parameters such as temperature, precipitation, wind velocity, water vapor content in the atmosphere. This makes the process highly vulnerable to climate change as changes in temperature and precipitation expected from climate change are likely to affect salt water balance and exacerbate the salinization process. Being located in arid and semi-arid climatic zones, Pakistan experiences high temperatures at the soil surface. The average summer temperature is about 40 °C and the minimum winter temperature remains between 2 °C and 5 °C. The annual rainfall varies between 100 mm and 700 mm throughout the country. The evaporation rate is generally very high and exceeds that of precipitation in most parts of the country. Thus, the insufficient rainfall followed by high evaporative demand and shallow groundwater depth, enhances the movement of salts towards soil surface.

Very little information is available on quantitative assessment of impacts of climate change parameters such as temperature, wind velocity, precipitation, etc. on salinization, on relation between climate change and salt-affected environs, on threats to food security on degraded lands, on most vulnerable communities and areas, and on how to adapt the fragile ecosystems to climate change. As agriculture is not only a provider of food security but of social development, particularly in the developing economies of Asia, so fighting poverty, alleviating hunger and improving the lives of the people is also linked with the solution of the salinization problem. There is a need of time to generate new knowledge and technology in irrigation with saline water as well as to gather, synthesize and disseminate information in this field. Making this information available to poor farmers who must rely on saline water to grow their crops will contribute to increased food and feed productivity on their farms and improve their living conditions. To achieve this end building strong partnerships and linkages with national programs, regional and international research centres, development agencies and private sector companies are pre-requisite. A central feature of these partnerships is the involvement of all parties in problem identification, project planning and implementation. The forum will hopefully provide answers to some of the questions through cross fertilization of ideas, sharing experiences with others and personal interaction among the participating scientists.

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Effects of climate change on salinization in China

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ABSTRACT

The current research hot spot of climate change is focused on global warming. Global warming is the increase in the average temperature of Earth's near-surface air and oceans since the mid-20th century and its projected continuation. According to the 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature increased 0.74 ± 0.18 °C during the 20th century. Most of the observed temperature increase since the mid-20th century was caused by increasing concentrations of greenhouse gases, which results from human activity such as the burning of fossil fuel and deforestation. Global dimming, as a result of increasing concentrations of atmospheric aerosols that block sunlight from reaching the surface, has partially countered the effects of greenhouse gas induced warming.

The IPCC report indicated that the global surface temperature is likely to rise a further 1.1 to 6.4 °C during the 21st century. An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, probably including expansion of subtropical deserts. Warming is expected to be strongest in the Arctic and would be associated with continuing retreat of glaciers, permafrost and sea ice. Other likely effects include changes in the frequency and intensity of extreme weather events, species extinctions, ocean acidification and changes in agricultural yields. Warming and related changes will vary from region to region around the globe, though the nature of these regional variations is uncertain. In China, climate change has caused many different effects. One of the most significant effects on agriculture is the impact on soil salinization in different regions in China.

CLIMATE CHANGE IN CHINA

The temperature in China has been keeping increase for a half century at a rate of 0.18 °C/10a, which is higher than the global average. Regions with high temperature increase rate are mostly in the north of Qinling-Huaihe and in the west of Hengduan Mountain. North-west China, North-east China and Inner Mongolia are regions with high temperature increase rates of 0.2–0.8 °C/10a (Figure 1). South-east China, South-west China and South China are regions with no significant temperature increase.

The climate change in temperature changing leads to rainfall changes, which has caused extreme climate happening frequently in recent years. Number of rain days has been decreasing in China though no significant change in total annual rainfall is observed. North-west China is the region with the highest rainfall increase rate, and Central China is the regions with the highest rainfall decrease rate (Figure 2). As a result, drought and waterlogging and El Niño events occur more often in these regions. For example, in the early 2008 most of provinces in South China encountered a once in a hundred year snow disaster; in early 2010 South-east China encountered a once in a hundred year drought disaster and a once in 50 year rainfall event; and in July, 2010, the Yangtze River encountered a once in 20 year flood.

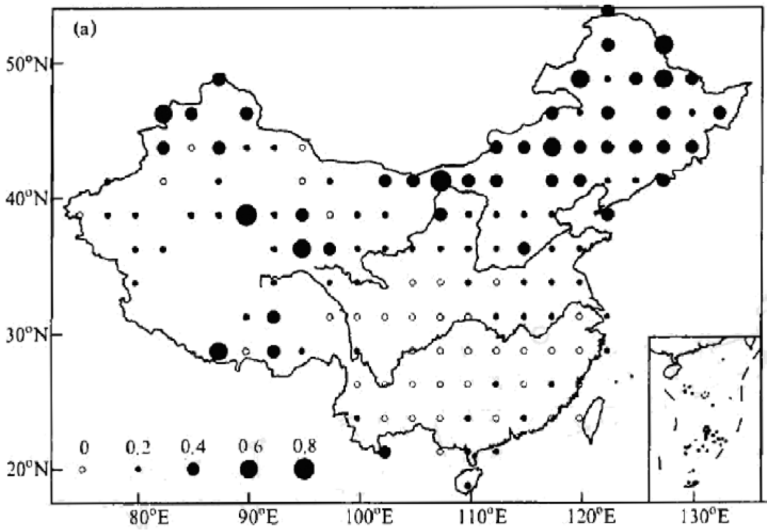

FIGURE 1
Average temperature increase rate (°C/10a) during years 1951–2000 in China.

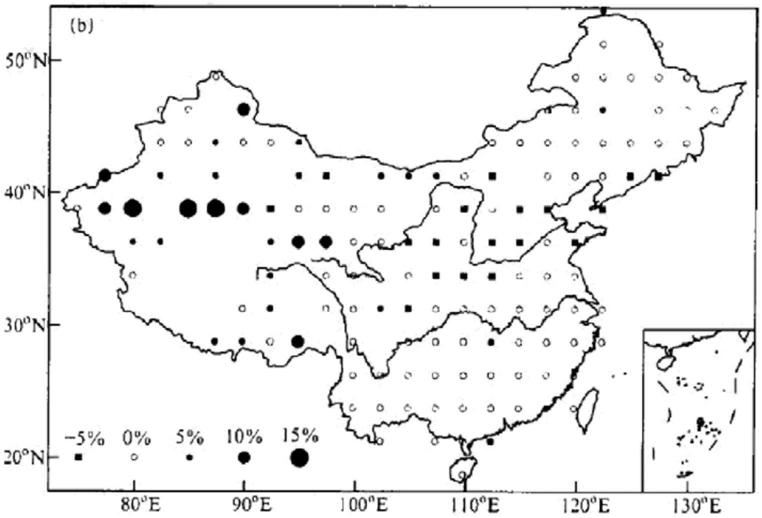

FIGURE 2
Average rainfall increase rate (%/10a) during years 1951–2000 in China.

The climate change in global dimming leads to evaporation changes. Pan evaporation observed in most of regions in China has basically decreased. The average decrease rate in South China and East China is 20 mm/10a, and in North-west China is higher than 40 mm/10a (Figure 3). The decrease of evaporation in spring and summer is more significant.

The climate change in global warming leads to sea level rise. By the year 2009, the average rate of sea level rise reached 2.6 mm annually in the last 30 years, which is higher than the average value of global sea level rise rate, and the rate is the highest in South China Sea. In the next 30 years, the average sea level may increase 80~130 mm in Chinese coast. In Chinese Yangtze River Delta, the sea level may rise 48~78 cm by the year 2050, which is higher than the contemporaneous average value of global sea level rise. Sea level rise and groundwater decline induced by groundwater overdraft are important factors to induce sea water intrusion in the coastal area. Phenomena of sea

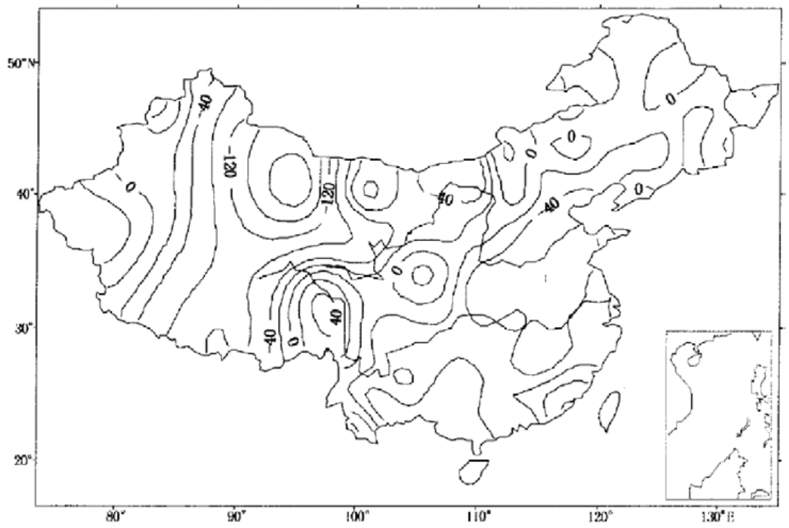

FIGURE 3
Average pan evaporation decrease rate (mm/10a) during years 1956–2000 in China.

water intrusion can be observed in many regions along coast in China, especially in north part of the Country.

SOIL SALINIZATION IN CHINA

Salt-affected soils are extensively distributed in North-west, North, North-east and coastal regions in China (Figure 4), and large areas of arable land are salt-affected as well. The saline-alkaline land area in China is about 3 600 *10^4 hm^2, which is about 4.88% of the total land area in China. The saline-alkaline arable land area in China is about 920.9 *10^4 hm^2, which is about 6.62% of the total arable land area in China. One of the three largest soda saline-alkaline lands is distributed in Songnen Plain in North-east China, soda saline-alkaline land area of which is about 23 329.19 km^2.

FIGURE 4
Saline alkali land distribution in China.

Trend of soil salinization development in China varies from one region to another. Soil salinization becomes stable in some regions, such as the North China Plain, while it becomes more severe in some other regions, such as in the Inner Mongolia and North-east China. Current hot spots of soil salinization evolution almost involve all distribution areas of the salt-affected soils, including North-east China, North-west China, the Inner Mongolia and the coastal region. In general, salinization is still under expansion, such as the Songnen Plain of North-east China, the Great Band region of the Yellow River and the Yellow River delta. For example, the saline alkali land area in Songnen Plain increased in the rate of 1.4–2.5% annually, and in Great Band region of the Yellow River increased in the rate of 1.0–3.0%.

Soil salinization has induced great damage to agriculture and ecological environment in China, and it is a great threat to Chinese and the whole world's food security. And in the future days, the amelioration of soil salinization will face the new challenge of climate change.

IMPACTS OF CLIMATE CHANGE ON SALINIZATION IN CHINA

The driving mechanism of soil salinization development is complicated, and the most important driving factors are climate change and irrigation management. The salt accumulation in surface soil is significantly affected by changing of moisture and thermal regime under the impacts of climate change. Firstly, the soil water and salt movement can be directly affected by changing of atmospheric temperature and ground temperature. Secondly, the climate change can lead to the redistribution of water resource among different regions, which can change the dynamics of surface runoff and underground runoff and water salt movement. Thirdly, the climate change can lead to changing of the structure, composition and biomass of vegetation community, which can affect the microclimate and biological impacts on water salt movement in saline-alkaline regions. Fourthly, the global warming can lead to sea level rise, which can induce sea water intrusion and cause salinization of groundwater and soil.

In China, climate change is considered as a significant driving factor on salinization evolution. Currently climate in North-east China and North China has been turning to a trend of warm and dry process. Such climatic change has promoted the evolution of modern salinization process in the region. In some shallow groundwater table areas of the region, evaporation increase and rainfall decrease induced by climate change can lead to decrease of salt leaching by surface runoff infiltration and aggravation of groundwater and soil salinization. In Songnen Plain in North-east China, climate change has induced temperature increase and rainfall decrease, which has caused decrease of wetland area and development of alkaline desertification.

The climate in North-west China had a trend of warm and dry process from the end of the 19th century to 1987, which caused lake shrinkage and alkaline desertification. Since the mid-1980s, the climate in North-west China has been turning from the trend of warm and dry process to warm and wet process, which caused increase of rainfall and decrease of alkaline desertification land area. On the other hand, the warm and wet process of climate change induced increase of surface runoff, which led to soil salinization in some oasis regions. For example, the saline-alkaline land area increased 142.4% from 1990 to 2000 in Aqsu-Awat-Desert-Oasis in Xinjiang Province.

The extreme climate, such as drought disaster, flood disaster and snow disaster, induced by climate change happened frequently in recent years in China, can easily cause soil salt accumulation upward and waterlogging, which may interrupt existing desalinization and bring new salinization. The impacts are especially significant in South-west China, South-east China and South China.

Climate change can also cause the sea level rise. Salt leaching of soil in coastal region, including the Yellow River and Changjiang River deltas, is therefore subject to a disadvantage owing to blockage of salt outflow and seawater intrusion. Consequently, Desalinization in the region is staved and even local salinization expansion is observed. Synthetically affected by sea level rise and groundwater overdraft, the sea water intrusion is increasing rapidly in the coastal region in China, especially in the north part of coastal region. The groundwater and soil salinization induced by sea water intrusion has been an attentive focus in the coastal region in China. The largest areas of sea water intrusion in China are in Liao-Dong Bay with over 4 000 km^2 and in Lai-Zhou Bay with over 2 500 km^2. The aggravation of sea water intrusion has induced damage to water and soil resources in the coastal region, especially to agriculture by groundwater and soil salinization. For example, the groundwater and soil salinization induced by sea water intrusion has caused quality degradation of 80% high yield land in Lai-Zhou Bay from 1989. And the grain reduction rate in these lands is 7 500 kg/a. On the other hand, from the silts and cultivation in coastal area in China, the coastal land area is increasing annually, especially in Jiangsu Province with an increasing rate of 13.3 km^2/a. And the increased coastal land is important potential land resources for Chinese and the whole world's food security. However, it is being challenged by the sea level rise and sea water intrusion under the impact of climate change.

COUNTERMEASURES OF AMELIORATING SALINIZATION UNDER THE IMPACT OF CLIMATE CHANGE IN CHINA

Countermeasures of slowing down and adapting to climate change have been indicated and carried out in China. The first countermeasure of slowing down climate change is adjusting economic structure and upgrading industrial structure. Policies and regulations have been promulgated and implemented in the principle of reducing consumption of resources and energy and increasing industrial efficiency. The second countermeasure is popularizing energy-saving and emissions-reducing. Policies and regulations have been promulgated and implemented to controlling high energy-consuming industry. The third countermeasure is developing renewable energy resources, such as hydropower, wind power, nuclear power and biomass energy. The fourth countermeasure is reducing greenhouse gas emission, especially in agriculture, by popularizing straw returning and covering, developing bio-gas construction, popularizing household firewood saving stoves, and so on. The fifth countermeasure is increasing the carbon sink function of land by promoting afforestation development. All these countermeasures are based on the developing of science and technology, and comprehensive and precise monitoring of climate change needs to be developed. Besides, national awareness of environment protection needs to be enhanced and international cooperation in the field of climate change research need to be strengthened to face the challenge of climate change.

Concrete to countermeasures of amelioration salinization under the impact of climate change in China, reasonable measures need to be taken to control the sea water intrusion and salinization and waterlogging induced by global warming and sea level rise. Firstly, in order to slow down the sea water intrusion and groundwater and soil salinization, groundwater exploitation in China should be regulated rationally, especially in the coastal region. Secondly, the flood-control and drought-control capacity of different irrigation districts in China need to be enhanced to face the salinization and waterlogging induced by disaster of flood and drought under the impact of climate change. Thirdly, new technology of high efficient utilization of saline water and soil has been put on the schedule in China. Besides popularizing existing amelioration measures of salinization, such as optimal irrigation, straw returning, straw covering and so on, high efficient utilization of saline water and Halophyte Agriculture have been studied and applied. One of the most innovative technologies in saline water utilization is the freezing saline water irrigation in winter on the reclamation of coastal saline soil in China, which has been studied and proved significant effect in China.

Development of Halophyte Agriculture has been paid great attention by Chinese government. High efficient utilization of different kinds of salt tolerance plants has been studied in different kinds of saline-alkaline regions in China. For example, in the coastal saline land in China, some halophytes such as *Salicornia bigelovii* has been studied and planted for use as edible vegetable, bio-fuel, medicinal plant, forage plant, ornamental plant, ecological protective plant, and so on. The efficient utilization of saline-alkaline land can increase the carbon sink function of currently unused land in China.

The impact of climate change on human mobility in West Africa

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Migration is a way of life in West Africa and for centuries people have migrated in response to population pressure, environmental disasters, poor economic conditions, conflicts, and adverse effects of macroeconomic restructuring. These migrants include temporary cross-border workers, seasonal migrants, clandestine workers, refugees and professionals. Cross-border movements involve farm labourers, unskilled workers, female traders and nomads.

The purpose of this research is to briefly explore the nexus between environmental change and human mobility; the implications of environmental change on human mobility; the connection between environmental vulnerability, migration, peace and stability in areas most vulnerable to environmental change, with a focus on human mobility; how climate change could work as a threat-multiplier from a human security point of view, breeding grounds for conflicts over resources and large population movements; the connections between climate change and forced migration; and managing the resulting environmental issues at local level.

INTRODUCTION

The litreature on forced displacement and the migration of people in the West African/ Sahel region emphasises the impact of natural and environment-related disasters on those directly affected, as well as the resulting impact of the migrating population on their host social and ecological environments. But conceptually, there is no consensus among researchers on where to precisely place so-called environmental migration in both the internal-international migration continuum and the voluntary-forced migration continuum (Oucho, 2009).

Over time, people have chosen the option of migration as a means of coping with the effects of environmental changes, particularly those of a sudden and disastrous nature. Usually, affected people seek out environments that would support their survival and their desire for an existence possibly more stable than the one lived before disaster struck. While the occurrence of disastrous environmental events is a significant—and increasingly important—cause of environmentally induced migration, more often migration occurs as a result of less dramatic, gradual deterioration of environments.

It is not sufficient to consider the migration–environment relationship only in terms of migration induced as a response to the occurrence of single, particular environmental events. In recent times, it has become increasingly recognised that major drivers in both forced and voluntary migration are general, on-going environmental degradation, and climate change.

The Sahel region experienced severe droughts and famine in the late twentieth century, resulting mostly from a combination of natural climate variations and human-induced atmospheric changes, the latter related, it would appear, to an increase in greenhouse gases, as well as to other causes. The Geographical Fluid Dynamics Laboratory (GFDL) models project a drier Sahel in the future, due primarily to increasing greenhouse gases.

Droughts are a recurrent environmental problem in the Sahel region. The Sahel received, in general, less than 20 inches of rain a year, and it endured a severe drying trend into the early 1980s, during which annual rainfall amounts dropped by 40%, resulting in large-scale famine. This was followed by partial recovery, but future prospects remain decidedly uncertain (Held *et al.*, 2005). While the frequency of drought in the region is thought to have increased from the end of the nineteenth century, three extremely long droughts have had dramatic environmental and societal effects. Famine followed severe droughts in the 1910s, in the 1940s, and in the 1960s, 1970s and 1980s, although a partial recovery did occur from 1975 to 1980. From the late 1960s to early 1980s, famine killed about 100 000 people, left 750 000 dependent on food aid, and affected most of the Sahel's population. The economies, agriculture, livestock and human populations of much of Mauritania, Mali, Chad, Niger and Burkina Faso were severely impacted.

The period from 1982 to 1984 was particularly destructive to the pastoral Fula people of Senegal, Mali and Niger, and to the Tuareg of northern Mali and Niger. Compounding the sufferings during the 1968 to 1974 drought, many of these people were unable to rebuild herds destroyed a decade earlier. In addition, the shift of political power to settled, rather than nomadic, populations, which came with independence in the 1960s, further undermined the livelihood of these peoples.

ENVIRONMENTALLY INDUCED POPULATION MOVEMENTS

Globally, millions of people have been forcibly displaced from their homes, having been affected either by natural disasters such as famine, drought, floods and earthquakes, or by man-made disasters such as wars, ethnic and religious conflicts, government policies and ill-advised projects. Environmentally induced population movements across the world are caused by the following: environmental stress such as an earthquake, cyclone or other natural disaster; development projects which create a permanent change in the habitat; cumulative changes or slow-onset changes such as deforestation, land degradation or climate warming; industrial accidents; conflict and warfare where environmental degradation is both a cause and effect (UN, 1994; Hugo, 2008).

The key environmental problems in Africa include natural resources degradation such as deforestation, desertification, climate change leading to drought (as in the Sahelian region), and soil erosion, degradation and floods in the coastal regions. Among other problems experienced are natural disasters, dam construction and various levels of conflict. To these must be added water, air and ground pollution, especially in overcrowded cities. These crises often result in population displacements and intensify internal migration, but they may also spark international migration that may become self-perpetuating.

CLIMATE CHANGE, MIGRATION AND HUMAN SECURITY

Climate change can cause land degradation, coastal flooding and drought, all of which threaten human security and can breed conflict over resources–with the victors acquiring territorial superiority and the vanquished escaping by out-migration. It is important to state *ab initio* that, while recognising the fact that environmental change can be an important driver of migration, the multi-causality of factors that prompt emigration make it difficult to establish precisely any undisputed causal relationship between environment change and migration (Hietenen, 2009).

There are other issues such as poverty, poor living conditions, and cultural and religious factors that dispose people to stay or to move, even in the face of disasters. This is one of the key conclusions of the workshop on environmental change and displacement, 'Assessing the Evidence and Developing Norms for Responses', held by the Refugee Studies Centre and the International Migration Institute of Oxford University on 8–9 January 2010. That current knowledge on this relationship is not well-founded should also caution policy-making in this area. Research-based understanding of the relationship is limited and the debate regarding the placing of so-called 'environmental migrants' in the voluntary–forced migration continuum is as yet unresolved. And there is another consideration: for a number of little-explored reasons, most people impacted by environmental degradation do not in fact migrate. As is the case with economically motivated migration, the emphasis of research has been focused on why people *migrate* rather than also, concurrently, why people *do not* migrate. Although there are clusters of emigration-prone localities and regions, only about 3% of the world's population do in fact migrate.

The general belief has been that the drought in the Sahel was caused primarily by the intensive use of natural resources, through overgrazing, deforestation and poor land management. In the late 1990s, however, climate-model studies suggested that large scale climate change were also triggers for the drought. In the early 2000s, it was speculated that the drought was probably caused by global warming, because of air pollution generated in Eurasia and North America.

This pollution has changed the properties of clouds over the Atlantic ocean, disturbing the monsoons and shifting the tropical rains southwards. Further climate-modelling studies in 2005 suggested that this late twentieth century Sahel drought was likely to have been a climatic response to changing patterns of sea surface temperatures. These changes were also attributable to human-induced factors; largely due to an increase in greenhouse gases, and partly due to an increase in atmospheric aerosols (see among others, Hugo, 2008; Gray and Clara, 2007; Brown, 2008; Barrios *et al.*, 2006 and Knivet *et al.*, 2008).

THE CONNECTIONS BETWEEN CLIMATE CHANGE AND FORCED MIGRATION

Climate change in terms of floods, drought, famine has often occasioned forced migration, what El Hinnawi once called 'environmental refugees', but this is a disputed concept since the use of the term 'refugees' is strictly restricted by the UN Convention of 1951 and the OAU Convention of 1969.

Movements of displaced persons by any of the aforementioned reasons are often associated with immediate, concentrated ecological damage, especially when dislocations are sudden, and involve large numbers of people. Principally, on being compelled to move unexpectedly, affected persons are often cut off from the normal systems on which they had depended for basic necessities such as food, shelter, fuel and water. Under such circumstances, wild animals and plants become food, forests are stripped for firewood, and streams become both sources of water and depositories of waste. Distressed displaced persons are forced to live a hand-to-mouth existence, foraging for basic necessities from the natural systems of the places to which they have fled. The stress on the ecosystem of host communities or countries thus becomes significant: as a result of this physical upheaval—and in addition to severe human hardship—such involuntary relocation takes a significant toll on the environment as the mass flights of people profoundly disrupt natural resources and regional ecosystems.

MIGRATION IN AN ECOLOGICAL CONTEXT

In view of the significance of agriculture in the Sahel, population dynamics, especially migration, needs to be considered in an ecological context. Agriculture is the lifeline of the people, and for many decades a delicate balance was maintained between the extensive, longfallow agricultural production system and the fragile environment. But prevailing migration trends now attest to an acute and potentially disastrous imbalance between human and land environmental systems.

There is very limited information available on the relationships between migration and environmental change in the Sahel region. Nevertheless, two important pieces of information do exist: firstly most of the migrations which appear to be environmentally induced occur *within* nations, as internal rather than international migration. Secondly, as the scale and pace of environmental change has accelerated, so has environmentally-influenced migration increased.

POSITING ENVIRONMENTAL CHANGE AND MIGRATION IN AN HISTORICAL CONTEXT

Findley *et al.* (1995) argued that the traditional long-fallow agricultural production system had maintained a balance between man and his environment, but several factors were disrupting this balance. Firstly, during colonisation, land was confiscated for forest reserves, thus reducing the amount available for cultivation and livestock range (and in due course, livestock production became more commercialised for sale in Abidjan and other major cities). Secondly, rapid population growth increased demand for land, for additional cereal production. The resulting intensive land use destroyed the traditional balance: fallow periods were shortened, soil fertility declined and grazing lands deteriorated through overgrazing. Above all, drought accelerated the deterioration process, causing the land to have less potential to support the population.

Sporadic weather patterns and the shifting of the region of adequate rainfall to the south have rendered larger areas in the north Sahel arid and un-arable. Inadequate rainfall reduced the productivity of grazing land and its potential for regeneration after droughts. As I have already explained, the much-publicised 'Sahel drought' was a *series* of historic droughts which affected the Sahel region. The result was famine and dislocation on a massive scale which killed thousands of people in the past and severely impacted the economies, agriculture, livestock and human populations of much of the region.

This population-environment disharmony has had very severe negative impacts on agriculture, food production, nutrition, health of the people and general quality of life. As the quality and quantity of biomass cover deteriorated, nomadic pastoralists in Chad, Mali, Niger and Mauritania–countries with the largest nomadic populations in the Sahel–extended the areas over which they moved their herds. This trend has led to conflicts between the groups over access to water and control over land use. The Sahelian countries2 are mostly land-locked and lack viable resource bases; they are classed among the poorest in the world, and are inhabited mostly by nomads, semi-nomads and sedentary farmers.

CONFLICT OVER LIMITED RESOURCES

It is apparent that this region is facing some of the greatest environmental challenges imaginable in modern times as water resources dwindle rapidly and the population grows at an alarming pace. Many are resorting to guns to settle their grievances with each other as the steady creep of the Sahara desert into more and more of Mali's arable land, and the falling levels of the Niger River force agricultural and pastoral communities into each others' territories, provoking frequent clashes. Runaway population growth, shrinking water resources and deteriorating pastoral and agricultural land are turning neighbours into enemies.

Pastoralists in the north of Mali are, apparently, feeling very marginalised from the development process that is happening in the south of the country. This is another source of tension. Some ethnic Tuaregs in that area have launched a rebellion, demanding political and economic equality for the north. However, the conflict between the Tuareg and the government of Mali reflects, in large part, the underlying conflict between the needs of the traditional nomadic populations and those of the sedentary farmers.

A large majority of the Sahelian populations live on agriculture and livestock production, using wood and hay as their sole sources of energy and also as their only construction materials, thereby contributing to more rapid desertification. In the dry Sahelian region reforestation efforts are hampered by the ubiquitous land tenure system which does not encourage tree planting.

The precarious living conditions have also resulted in strained social relations, and family dislocation, causing, in turn, an increased youth migration to urban areas (Some and Sedgo, 2001).

FAMILY COPING STRATEGIES

There are a variety of mechanisms for coping with the vicissitudes of droughts. One proven measure at the family level is a shift away from cattle to the more drought-resistant goats. Most subsistence farmers on the Senegal River Valley, for example, who experienced severe declines in food and livestock production levels during droughts adopted fall-back coping strategies that substitute alternative food and economic supports for drastically reduced local production. Some families diversified their employment portfolio by ensuring that members worked as causal labourers: hauling and carting, selling firewood, selling beans cultivated along the river basin, doing odd jobs in the towns, and masonry work at construction sites.

International migration also featured among the coping strategies, including migration to Dakar, Abidjan and other Sahelian cities to find work. The strategy also involved expanding the destinations of migrants–within Africa and to France. During periods of droughts, migrants resident in France send money to household members back home, to cover medical and related expenses, as well as for clothing and household utensils (Findley, 1997). Those still within the region, especially in Cote d'Ivoire and Gabon, send remittances in kind in the form of food items to sustain the livelihood of the their drought-affected family members.

Managing environmental concerns: Following the West African Sahel drought of 1968–1973, the United Nations Sahelian Office (UNSO) was created in 1973, to address the problems of drought in the Sahel region. Following the adoption of the United Nations Convention to Combat Desertification in the 1990s, UNSO became the United Nations Development Programme's Office to Combat Desertification and Drought, to reflect its broadened global scope–beyond the focus on Africa. Environmental and ecological degradation and natural disasters require the intervention of specific policy sectors or actors. Thus agencies dealing with environmental issues focus on combating desertification; the humanitarian sector has responsibility for emergency relief operations for victims of natural disaster, and the asylum sector takes care of refugees.

The problem is that the boundaries of these sectors and actors overlap and coordination is often difficult to ensure. Intermediate actors could help improve the resilience and adaptive capacities of the people to the hazards of drought and environmental damages and the dwindling resource base. This should include measures to empower people to plan and manage their own local adaptive mechanisms.

Managing local environmental issues, and the connected emergencies in terms of human mobility, should involve the local people–who best know of their environment, the changes taking place on it, and the forms of rehabilitation or response to emergencies that are most appropriate and desirable.

At the macro level, development policy and assistance programmes can be explicitly targeted towards localities and regions that are sources of environmental emigrants, with the aim of reducing migration 'push' factors: a basket of measures should be pursued to increase production opportunities: promoting irrigation; developing efficient early-warning system that will permit farmers to use drought-resistant crop varieties; emphasising activities that are less droughtsensitive, such us livestock production; and promoting soil and water conservation practices by improved land tenure with appropriate laws regarding soil and water conservation practices; aggressive and genuine reforestation with specifically adapted tree species that are more resilient to tree mortality; increasing the number of small dams and barrages; promoting lower grazing and dry season crop production; as well as any possible income generating activities (Some and Sedgo, 2001). Intervention should also include measures to reduce wood cutting, such as developing and promoting solar powered cooking. On top of all these is the need for creating a good database for rainfall prediction.

These changes will not happen on their own. Land degradation caused by desertification and global warming needs to be countered by educating and training people on sustainable and natural resource management practices, and on the stakes and options related to polluted water use. Promoting environmental education, including health at school and village levels is thus of prime importance. As I have already said, local involvement is an essential part of any hope of success. Deforestation caused by poverty and lack of viable alternatives for survival can be minimised by supporting viable local NGOs to address these issues at the village level. Reducing the cost of alternative technologies, and implementing efficient civic education at the school and community levels are non-negotiables.

With respect to wars and conflicts caused by declining resource base, it is pertinent to develop a good early warning system for conflict prevention as well as strategies that would permit efficient and swift settlement of differences, promote social harmony, democratic principles and popular participation. Finally, of paramount importance is an advocacy for investment in these Sahel countries, which are currently at the bottom of the Human Development Index.

CONCLUSIONS

Although climate change is a global phenomenon, prompted by abuse of the environment by both rich and poor countries, the flash points are not normally distributed, and the ability to cope with its consequences is severely constrained in poor countries that lack the resources, capacity and technology. In the Sahel, in particular, famine, drought, desertification and related environmental challenges have been compounded by rapid population growth, making migration a necessary survival strategy for many households. Such migration, initially in the form of movements to the cities of neighbouring countries, is often translated into international migration to developed countries in search of survival. The limited efforts by local communities, national and international NGOs, and provincial and national authorities to tackle the complex environmental challenges need to be supported by development partners and relevant United Nations agencies. In this context, researchers have a critical role in ensuring conceptual clarity of terms such as ‘environmental refugees’, ‘environmental migrants’, ‘environmentally displaced persons’, ‘involuntary forced migrants’, and so on, in order to promote appropriate and correctly targeted policy-making in the Sahel, as well as elsewhere in Africa.

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Biodiversity, climate change and desertification issues affecting the indigenous communities of Africa: A case study of the Sahel and the Horn

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ABSTRACT

This Sahel environment stretches all the way from Senegal to Somalia cutting across ten African countries bordering the Sahara desert in the north and the Sudan savannah in the south. With an annual rainfall of less than 50 cm per annum, it has good agricultural production as well as large grazing fields for pastoral activities and is a home for many indigenous communities like the Mbororo (Cameroon and Chad), Tuareg (Niger) and the Kanuris (Nigeria, Niger, Chad and Cameroon), who depend on pastoral activities, fishing, irrigation farming and mineral extraction as their main activities of livelihoods.

Desertification is a primary issue faced by these Sahelian communities. Indigenous communities are continuously losing their grazing fields, farmlands, and even villages to the encroaching desert from the north. Indigenous communities in the Sahelian region are currently trying their best in control of the desert encroachment through tree planting campaigns, small or local forestation projects and other programmes using traditional knowledge on their own, but yet the desert keeps expanding invading grazing fields, farms and even villages and towns. Loss of biodiversity, decreases in agricultural output and unemployment are putting food security under threat, leading to hunger, poverty and social insecurity.

FIGURE 1
Map of Africa.

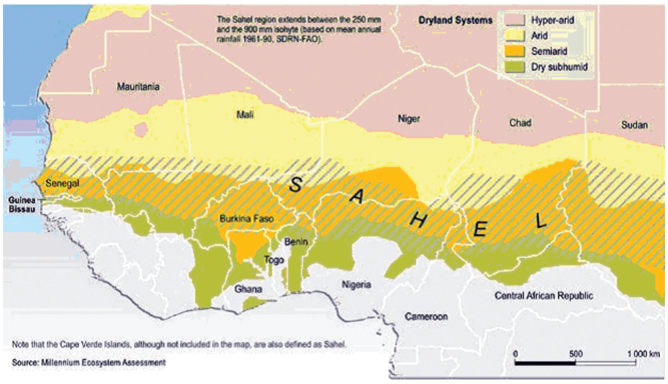

FIGURE 2
Map of the West African Sahel region of Africa.

FIGURE 3
Typical Sahelian environment.

DISCUSSION

Recently conducted research has reported that the desert keeps expanding at the rate of 0.8 km per annum (Abdullah, 2009). It was also reported that the villages of Kaska, Buhari gana and Bukarti in the Sahel part of the North-eastern Nigeria were

FIGURE 4
Arable lands of the Sahel region metamorphosing into an arid land before finally becomes sandy desert.

FIGURE 5
Showing a real Sandy desert in the Sahara with its Sand Dunes.

completely wiped out, or buried under the desert between the years 1987–2005, as well as continuous appearances of new sand dunes in the fertile areas of this Sahel region from time to time and in various areas (Abubakar, 2009).

Abubakar (2009) also reported that some part of the Sahel would be rendered uninhabitable in the next ten years and because the region provides about 40% of the protein requirements of the sub-Saharan African region as a whole in the form of beans, vegetables, beef, lamb, fish, and others if this desertification issue is not brought under control it will lead to continued malnutrition, outbreak of diseases and social conflicts and wars.

Factors leading to the desertification in the Sahel region of Africa include:

- cutting down of trees as a source of fuel for cooking, economic and other socio-cultural activities;
- bush burning, clearing of trees and shrubs by grains farmers;
- overgrazing by nomadic cattle herders;
- lack of strong shelter belts;
- climate change;
- fast growing populations, leading to establishment of new settlements;
- lack of effective attention by relevant international organizations, as well as other stakeholders in fighting the desertification issues.

A second issue is the rapid decline in the volume of the water of Lake Chad because this is main source of water supply, fishing and some other natural resources such as the potassium salt (potassium nitrate), in addition to irrigation and pastoral activities by the indigenous communities living in this part of the Sahel region especially along the shores of the lake.

The drying of the lake is caused by climate change and the damming along the River Shari which supplies over 90% of the volume of water coming in to the Lake in the republic of Cameroon by the Cameroonian government in the quest for generating hydro electric power as well as part of their measures in adapting to climate change through improving and developing irrigational activities along the shores of the major feeder river and its tributaries. This has lead the Lake to drastically reduced to just 10% of its original size of 25 000 km square in just three decades as reported by (Abubakar, 2008). Hence the situation is also leading to massive loss of biodiversity in the Sahel and

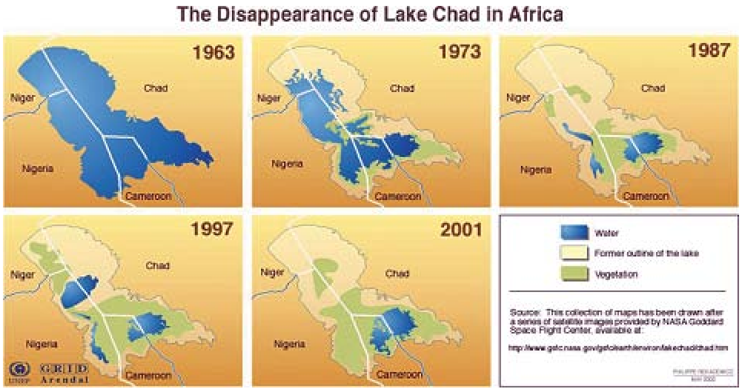

FIGURE 6
Map of the drying Lake Chad at various stages.

increases in the rate of deforestation due to lack of alternative employment opportunities for the people depending on this Lake for their economic activities. Over 40% of the Sahelian indigenous peoples depend on this Lake, so the more the Lake dries, the more the increases in poverty and unemployment which subsequently leading to massive deforestation which brings about desert encroachment and desertification in this region.

Potassium nitrates extracted from Lake Chad are used by the indigenous or local communities of the this region for making many types of traditional medicines, especially in the treatment of stomach pains, diarrhoea, cholera and other related diseases, but over the last two decades there has been an increase in the above mentioned diseases due to the reduction in the saline nature of the waters of the lake which is required for the preparations of such traditional medicines.

Another major issue which is affecting this communities and aids in bringing the loss in biodiversity and desertification is climate change. Climate change may be defined as:

"a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average (for example, greater or fewer extreme weather events). Climate change may be limited to a specific region, or may occur across the whole World" (Wikipedia).

This description of climate change is a very good description of the physical geography of the contemporary Sahel region. The average annual rainfall in many areas of the Sahel has been on the decline and fluctuations over the last 40 years. The annual average is now below 500 mm per annum.

In addition there is a significant physical increases in the harsh winds, sandstorms plus increases of the temperature from between 3 and 5 °C over the last 40 years. In view of the above there are increases cases in climate change associated disasters in this region such as flooding, famine, hunger, diseases and many others. For example in September 2009 many lives and propertises were destroyed by the flooding; In total, around 430 000 people in Burkina Faso, Senegal, Ghana, Mali, Mauritania and Ivory Coast have seen damage to their homes or are facing health risks linked to the lack of fresh water, deteriorating hygiene or other problems (Reuters–AlertNet)

RECOMMENDATION

I call on Sahelian governments via the African Union and UN development agencies such as CBD,UNDP, UNESCO, UNEP, FAO, and IFAD, to ensure the participation of the indigenous communities of the Sahel and the Horn in all decision-making related to desertification, climate change, land and territory in Africa.

Indigenous issues should be mainstreamed into the UN Convention on Control of Desertification (UNCCD) and related desertification conventions. Indigenous peoples should be recognized as a 'major group' for the CCD Conference of Parties.

Recognition by African governments to communal lands and stopping to give lands and territories to bio-fuels.

Constructions of dams along all feeder rivers of the Lake Chad should be stopped. Just like Nigeria, all the other countries bordering Lake Chad should establish Lake Chad Development Authorities in their respective countries in order to promote irrigation and pastoral farmings in the Sahelian environment.

Cooperation with UNFCCC, UNESCO, CCD and CBD on traditional knowledge of biodiversity and sustainable development of arid areas in the Sahelian region; indigenous peoples must be involved in decision-making processes.

Relevant international conferences, workshops, seminars and other relevant or related events should increase the participation of the people coming for their programmes from this part of the word (the Sahel region) in order to participate and share knowledge for the development of all on the issues related to desertification.

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POSTER PRESENTATIONS. SESSION 1

Climate change, evapotranspiration and salinization: A case study from Iran

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ABSTRACT

This research investigates the potential effect of vegetation cover evapotranspiration on the concentration or dilution of soil water and therefore, acceleration or alleviation of soil salinity for the next three decades in a region with shallow saline groundwater. The reference, potential and actual evapotranspiration (ET) were simulated for the time period 2010–2039 by integration of the surface energy balance algorithm for land (SEBAL), remotely sensed satellite images and General Circulation Model (GCM) derived data. This research indicates that the role of vegetative surfaces in a global changing climate would be paramount in alleviation of soil salinity. In other words, acceleration of soil salinization rate would be probable under low vegetation cover conditions, especially when the groundwater is saline and shallow.

Keywords: climate change, evapotranspiration, SEBAL, HadCM3, salinization, Iran.

INTRODUCTION

Evapotranspiration (ET) is a combined process of transpiration from surfaces of plant leaves and evaporation from the soil in which it is growing. It counts the total volume of water lost through transpiration and evaporation processes and express in cubic meter or mm in a specified time period. Three main types of ET can be defined; actual, potential and reference ET. Actual evapotranspiration (ET_a) is a process in which crop demand for water mainly controls through crop leaves and stomata status, climatic conditions, environmental stresses, soil features and management practices. In contrast, potential ET (ET_p) is an indicator of crop required water for healthy growth and productivity in a non-stressed, disease free and water abundance conditions. Reference ET (ET_o) also demonstrates evaporative demands of the atmosphere and fully depends on climatic conditions. In fact ET_o is known as a crop independent term of ET. Among these different ET terminologies, ET_a seems to be paramount in illustration of wasted water through plant evapotranspiration, especially when the area is being under stress. Also it is a good indicator for illustration of CO_2 impact on stomatal conductance and photosynthesis and therefore, crop productivity and water use efficiency (Le Houerou, 1996). In areas with shallow saline water table, actual ET, caused primarily by deep-rooted phreatophytes, is a significant factor for capillary rise and consequently salinity build-up hazard in the region. In contrast, when the soil is bare and also availability of water is limited to shallow groundwater, reference ET can demonstrate the power of ET for acceleration of capillary rise and movement of salts to the surface. Therefore, to investigate the effect of ET on salinization hazard in areas with shallow saline water table, two conditions of bare soil and vegetated surfaces should be considered together with the help of ET_o and ET_a, respectively. Since ET controls by different climatic factors (e.g. temperature, sunshine, wind and humidity) it would be possible to simply monitor the impact of climate change on this phenomenon as well as the impact on soil salinization in areas with shallow saline groundwater.

At present there are different approaches for determination of actual ET. Examples of techniques used to estimate ET include water balance, lysimeters, micro-meteorological techniques such as Bowen Ratio and Eddy Covariance, and water table fluctuations (Scanlon *et al.*, 2005). Information on ET in Iran is generally limited to meteorological station data used to estimate potential ET in different parts of the country. But none of these measurements provide estimates of actual ET. New procedures such as remotely sensed (RS) energy balance algorithms are other beneficial techniques for estimation of ET. Advantage of these techniques refers to a good illustration of actual ET in the region both spatially and temporally. These techniques are now available in Iran in addition to the availability of high, moderate or low resolution satellite images, relatively. In this study Surface Energy Balance Algorithm for Land (SEBAL) was used for determination of actual ET in the satellite overpass times. Since data of General Circulation Model (GCM) derived are also available, a linkage between RS techniques and GCM data would help for proper assessment of climate change impacts on actual ET in the future decades. Main objective of this study is to assess the impact of climate change on potential and actual evapotranspiration of bare lands and vegetated surfaces and consequently, their impacts on changes of soil salinity status in Azadegan plain, west of Iran; a region with severe salinity and waterlogging problems as main important hazards for its resources.

MATERIALS AND METHODS

Study area

The study area is Azadegan plain or Dasht-e-Azadegan (DA), one of the plains located at lower part of Karkheh River Basin (KRB) in Khuzestan province, west of Iran. It lies between 31° 05' to 31° 51' N and 47° 43' to 48° 39' E. The total area of DA is 334 000 ha, of which about 250 000 ha have been cultivated and used for agricultural purposes. The annual long term precipitation in DA varies between 150 and 250 mm in different parts of the region, while annual evaporation is between 3 500 and 3 700 mm.

Methodology

Figure 1 show the methodology used for estimation of actual, potential and reference ET in the future period of time and consequently, impacts on soil salinization in two soil surface conditions of bare and green vegetated surfaces. As shown, in this study two main sources of data were used: Historical and simulated data. Historical data include

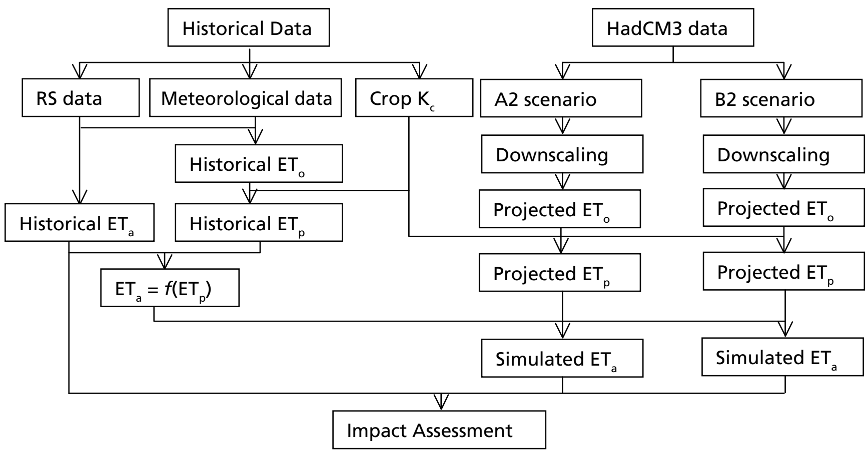

FIGURE 1
Flow chart of the methodology used for impact assessment of climate change on evapotranspiration and soil salinization in Azadegan plain, western Iran.

T_{min}, T_{max}, sunshine, humidity and wind speed of Bostan meteorological station from 1960 to 1989. Also a time series of satellite images were acquired and used as historical RS data. GCM data include monthly data of HadCM3 model for projected period of 2010 to 2039 that were resulted from GCM-runs for the Third Assessment Report (TAR) based on the IPCC-SRES scenario of A2 and B2, respectively. HadCM3 is a well-known GCM model that uses worldwide (Bates *et al.*, 2008). Key assumptions in A2 scenario are a very heterogeneous world, strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development. B2 emission scenario represents a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions (IPCC, 2010). In fact A2 and B2 are the most frequently used emission scenarios in the world.

For determination of actual ET a time series of remotely sensed images and also ancillary climatic data were prepared. RS data were included 18 cloud free images that were acquired from Terra (MODIS) satellite during the wheat cropping season. Surface Energy Balance Algorithm for Land (SEBAL) was used for determination of ET_a. This algorithm is a relatively new procedure for estimation of actual ET at different scales e.g. farm, catchments and basin levels and is now used widely around the world and also in Iran for computation of crop water requirement under standard and non-standard conditions, as well. In general, SEBAL uses digital images acquired by satellites that record thermal infrared radiation in addition to visible and near infrared radiation and computes ET on a pixel by pixel basis for the instantaneous time of the satellite overpass. This algorithm predicts ET from the residual amount of energy in the form of latent heat flux (LE) and is equal to Rn-G-H of which, Rn is above ground surface net radiation, H is sensible heat flux and G is the ground heat flux. Details about the SEBAL procedure and steps for running the algorithm are presented in Bastiaanssen *et al.* (1998a, 1998b), Bastiaanssen (2000) and Tasumi *et al.* (2000). Also reference ET was calculated through Hargerives-Samani procedure (Alizadeh, 2004). Thereafter, potential ET of winter wheat, as dominant vegetation cover, was calculated with considering its coefficient (Kc), which was varied during the growth season (0.3 to 1.15). Afterwards, relationships between ET_p and ET_a were investigated to develop the best fitted model for determination of actual ET via potential ET. This model then was used for projection of actual wheat ET in the future period of time. For this reason, General Circulation Model (GCM) derived data were linked to the Hargerives equation, first for projection of reference and potential ET and then, insertion into the developed model for simulation of actual wheat ET in upcoming three decades. This procedure was accomplished for 2010–2039 projection period using HadCM3-A2 and HadCM3-B2 data, respectively. Since data of HadCM3 were available in a low spatial resolution (2.5 in 3.75 degree), a stochastically approach was used for downscaling of HadCM3 data (both A2 and B2) in the projected period of 2010 to 2039 (Massah Bavani, 2005).

RESULTS AND DISCUSSION

Figure 2 shows the best fitted quadratic model between historical data of ET_a versus ET_p. As was mentioned before potential ET has been estimated through Hargerives equation with considering winter wheat coefficient (K_c). Fair correlations could be found in the fitted model (R^2=0.72). This model then was employed for simulation of wheat actual ET during the 2010–2039 time interval. As shown in this figure, for ET_p of less than 6 mm per day, higher value for ET_a would be resulted for higher ET_ps through this model. After this point, the ET_a values would have a descending trend. It is noticeable that ET_p of more than 6 mm per day is an explanatory of shifting the climate

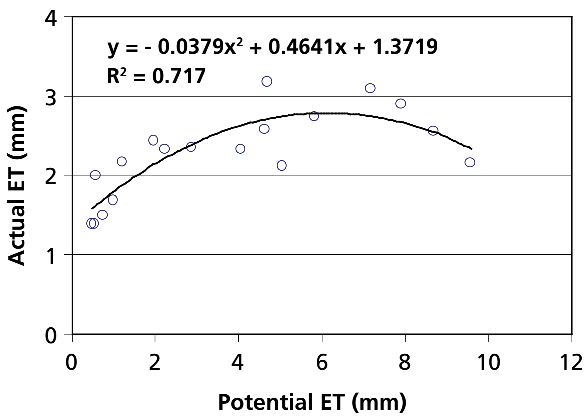

FIGURE 2
Best fitted quadratic model for simulation of wheat actual ET using potential ET in Azadegan plain, west of Iran.

to some drier conditions, lack of water for evapotranspiration and consequently decrease of ET_a, as shown in the model outputs. Therefore, it is anticipated that the lower ET_a would be projected in the future compared with the historical period of time, when the climate shift to higher ET_p values.

Figure 3 shows averages of observed and simulated reference ET (ET_o), potential ET (ET_p) and actual ET (ET_a) in historical and projection period of times, based on A2 and B2 scenario data, respectively. As was mentioned before, ET_a, terminologically belongs to green vegetated surfaces and reflects the crop response to water availability, while ET_o illustrates the evaporative demands of the atmosphere and depends fully on climatic conditions of the region. ET_o therefore, can represent the evaporation rate in a bare soil and consequently, an explanatory of moving salts to the surface.

As shown in this figure, both simulated ET_o and ET_p tend to higher values compared with observed values. In contrast, differences between observed and simulated values of ET_a for 2010–2039 seem to be negligible, both for A2 and B2 scenarios. It means that evaporative demand of the atmosphere would increase in upcoming three decades, but green vegetated surfaces would prevent from wasting of water to the atmosphere. In other hand, salinity of soil in vegetated surfaces tends to be constant, but salinity build-up hazard is expected for bare surfaces. In fact, the role of vegetation cover seems to be significant in prevention of salinization hazard in upcoming three decades at the studied region.

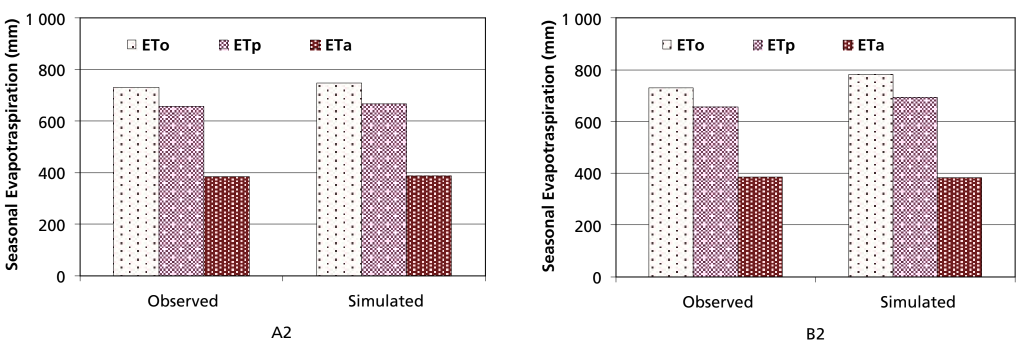

FIGURE 3
Observed and simulated seasonal evapotranspiration for 2010–2039 using different scenario data.

CONCLUSIONS

In this study a hypothesis was tested and evaluated: evapotranspiration of vegetation cover in dry saline water-logged areas have a negative impact on salinization of soil resources due to pumping of saline undergroundwater to the surface. But the results disproved this hypothesis; ET comparisons between green vegetated surfaces and bare abandoned lands represented the positive role of surface vegetation in alleviation of soil salinity in the studied conditions. Key deterministic factors in salinization of soil resources in the studied condition were included climate, vegetation cover, salt stores, geological and topographical features of the region. Also the roles of these factors in contributing to salinization were interrelated. Among these factors, fluctuations of climate and vegetation cover were found more probable as results of climate and land use changes, respectively. However, in a global changing climate the role of vegetative surfaces seems to be paramount in alleviation of salinity in a long term period. It means that acceleration of salinization is probable in a lack of vegetation cover condition. In this way, tactics and strategies to mitigate climate change impacts via a proper land use and sustainable environment programmesmust be implemented and supported by decision makers, social, political and other related sectors.

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Old landfills as emergent vulnerable ecosystems to salinization: Soil characteristics and response of the plant species to increasing Na and anion contents

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ABSTRACT

The anion contents of soil samples taken from the discharge and slope areas of landfills are considerably elevated with respect to soils collected from ecosystems surrounding these landfills. In this study, greatest concentrations were observed for the more soluble ions Cl^-, NO_3^- and SO_4^{2-} and lowest concentrations for F^- and PO_4^{3-}.

Species such as *Bromus tectorum*, *Desmazeria rigida*, *Trifolium tomentosum*, *Anacyclus clavatus*, *Carduus tenuiflorus*, and *Diplotaxis virgata* showed a preference for soils containing appreciable amounts of chlorides, sulfates, and sodium, and high electrical conductivities (EC). Of the species listed in the four ecological profile tables provided, *Hordeum murinum*, *Bromus rubens*, *B. tectorum*, *Hirschfeldia incana* and *Polygonum aviculare*, also showed a preference for soils with high values of these four factors and were followed by *B. hordeaceus*, *Juncus bufonius*, *Spergularia rubra, Trifolium cernuum, Medicago polymorpha*, *Crepis vesicaria*, *Plantago coronopus* and *Reseda lutea*.

Trifolium tomentosum and *Crepis capillaris* predominantly grew in soils with "certain levels" of chlorides and sodium. *Carduus tenuiflorus* was most often found in high sodium soils with high conductivity. *Diplotaxis virgata* preferred soils with high contents of sulfates and sodium. Finally, *Desmazeria rigida* only grew in soils with a high EC.

The species listed comprise the plants that are currently revegetating the steep slopes, "saline" soils and discharge zones of many landfills. These species are helping to reduce the pollutant leachates that eventually reach nearby streams, marshes and pastures.

Keywords: chlorides, sulfates, Na, electrical conductivity, plant autoecology, ecological profiles, semi-arid environments.

INTRODUCTION

Many ecosystems are in weak equilibrium and vulnerable to human interference generating problems such as reduced availability of nutrients, with the consequence of diminished soil productivity, and soil pollution. In many disturbed ecosystems, the balance of mobile anions controls the entire ion equilibrium. Anion cycles are also very fragile and are constantly perturbed by abiotic, biotic and, above all, human factors. Hence, any study of mineral cycles should commence with experiments designed to determine the proportions of soluble anions transported by water in disturbed and natural ecosystems.

The chemical pollutants of landfills close to a river are likely to be released into the fluvial network. Pollutants are then likely to affect aquatic life and will be a health hazard for the public at large. Through leaching, pollutants become dispersed in a stream, but some may also be adsorbed by soils and sediments. The contamination of surface water, underlying groundwater and bioaccumulation of pollutants in the surrounding biota are possible routes for these landfill leachates to affect the environment and its human or animal inhabitants.

The composition of landfill leachates has been examined by many authors. Robinson and Maris (1983) determined the chemical composition of the soil and surface waters adjacent to a landfill, and Murray *et al.* (1981) assessed the extent to which landfill leachates pollute groundwater. In addition, Cyr *et al.* (1987) have provided physicochemical data on such leachates and their inorganic contents, particularly heavy metals. Following the exploitation and sealing of the landfills examined in these studies, no preventive measures were taken to avoid leachates reaching the areas outside the landfills.

Among the landfill pollutants identified, inorganic soluble anions have attracted most attention since they control the entire ionic balance of an ecosystem. Several authors have noted that some inorganic contaminants, such as anions, continue leaching for decades. These anions, including chlorides, sulfates, nitrates, phosphates and fluorides, deserve greater attention because their effects on health are not well understood. Some are key elements for plant growth (nitrates, phosphates and sulfates), some are important soil organism nutrients and others such as fluorides can be harmful or toxic for animals and plants.

The present study was conducted within the framework of our effort to address the ecology of representative native species able to grow in landfill covers or discharge areas. These plants may serve to initiate the recovery of these environments, as well as minimize serious erosion problems. In previous studies, we dealt with some aspects related to this question (Pastor *et al.*, 1993). Herein, we focus on the botanical composition of landfill soils and those of other more or less degraded systems surrounding the landfills. We also analyse the main soil characteristics of the rooting soil in an effort to correlate specific plant compositions to several soil variables.

In Central Spain (Madrid Automous Community, 6 400 000 inhabitants) there are many large old landfills that contain mixed urban and industrial residues. When sealed, these landfills were simply covered with soils from the surrounding areas and today they are found close to large towns in the Madrid region such as Móstoles, Villaviciosa de Odón and Navalcarnero.

To minimize the negative impacts of these landfills on the soils of the area such as erosion, degradation, salinization, and pollution with heavy metals and organic compounds, along with effects on the natural flora and wild animals, the effects of the contaminants generated on the natural environment need to be examined in detail. In this study, we determined soluble chlorides and sulfates, exchangeable sodium, electrical conductivity and pH in cover soil samples taken from the slope and discharge areas of three old landfills in the towns mentioned above.

MATERIAL AND METHODS

Description of the landfills

The three landfills examined were mixed domestic and industrial waste landfills in the west of the Madrid province overlying an arkosic substrate. UTM coordinates for the landfills are: Navalcarnero 414.8; 4462.6, Móstoles 423.7; 4465.5 and Villaviciosa de Odón 421.8; 4466.8.

Many landfills of solid urban and industrial waste are found on slopes, terraces and depressions, with steep gradients. Navalcarnero is the result of the infilling of a depression. Móstoles is situated over a depression and has a significant slope over a stream and Villaviciosa de Odón is situated on the terrace of a stream. The cover soil at these sites is affected both by erosion and pollution derived from leachates. The three landfills store urban and industrial waste and have an ondulating profile with slopes reaching heights of 15 to 60 m.

Their pedological and geological features are quite uniform, and they consist of arkosic soils. These are oligotrophic and have a neutral or acid pH and low nutrient contents. In the past, they were poor grasslands used for cattle grazing and hunting. Soil texture varies from sandy loam to clay. Their waste contents generally occur at a depth of about 30 cm although depths range from less than 10 cm to as much as 80 cm. Most of the leachates are scattered on the soil surface and affect the streams near the landfills.

Mediterranean semi-arid climate

In Mediterranean climates in which intense storms frequently occur in spring and summer, the vegetation cover of a soil-sealed landfill plays an essential role. This cover can attenuate interactive processes of erosion and pollution, especially in its surface layers or slopes. When water percolates through solid waste in a landfill, it dissolves inorganic and organic components arising from degradation processes. This event generates polluted leachates determining a high environmental risk for both the landfill cover soils and surrounding ecosystems. The factors that condition effects on soil include leachate composition and volume, regional climate, hydro-geopedological characteristics such as substratum porosity, permeability and composition, annual rainfall, refuse quantity and quality, exploitation characteristics and age of the landfill site.

Study samples

Control samples were taken from the topsoil layer of surrounding lands (fallow pasture lands, broom shrublands and oak forests of the secondary succession process). These systems represent a "gradient" of reference ecosystems for the landfills, given the predominance of therophytic herbaceous species, many of which are those that spontaneously grew before the land was abandoned. This large sampling effort focused on different biotopes. The strata were selected by stratified sampling, based on soil and land use. In total, 147 phytoecological surveys were performed on the top 15 cm of soil, at randomly selected points corresponding to three landfills in the south of Madrid in several of the reference ecosystems.

Analytical determinations

Soil extracts were obtained by shaking 10 g of air-dried soil (<2 mm) with 25 ml of deionised water in sealed glass tubes for 24 h in a cold room, according to the extraction methods described by Hernández and Pastor (1989). The resulting suspension was centrifuged for 20 min at 7 000 rpm and immediately filtered, preserving the supernatant. The extracts were kept refrigerated until analysis. The anion concentrations of soil extracts and leachates were determined by ion chromatography. The equipment used was a Dionex Chromatographe 4500i with PED detector, an AG4A precolumn, and AS4A-SC Dionex IonPack separator column.

RESULTS AND DISCUSSION

Ecological profiles in the study of the ecological relationships of the plant species with the EC, chlorides, sulfates and sodium contents of the soils

To identify possible associations between frequencies/abundances and the physico-chemical characteristics as anions or Na of the soils, the "ecological profiles method" (Guillerm, 1971; Daget, 1977a, b; Daget and Godron, 1982; Loudy *et al.,* 1995; Mesli *et al.,* 2008) was used. Frequency data were converted to corrected frequencies (Gauthier *et al.*, 1977).

This method is based on the frequency distribution of a species in the different classes of a factor "the ecological profile of a species for this factor" and the "mutual

TABLE 1

Soil pH, Na, Cl^-, SO_4, F^-, $PO_4H_2^-$, NO_3^- (mg/kg.) and E.C. (μS/cm) in the studied ecosystems

Ecosystems		pH	Na^+	Cl^-	SO_4	F^-	$PO_4H_2^-$	NO_3^-	EC
Landfills									
Navalcarnero (discharge area)	M	7.1	282.0	50.0	27.4	n.d	n.d	9.38	1 900
n=5	sd	0.3	48.7	7.0	34.9			3.51	1 440
Navalcarnero (slope)	M	7.1	11.5	33.0	77.5	1.16	0.38	1.29	323.7
n=6	sd	0.4	12.0	26.7	127.6	0.75	0.17	0.24	205.9
Villaviciosa (discharge area)	M	7.0	65.0	25.2	11.5	n.d.	n.d.	15.0	1 500
n=4	sd	0.4	76.8	7.0	9.5			8.9	910
Villaviciosa (slope)	M	7.3	5.8	15.2	20.0	1.77	0.39	3.61	234.3
n=11	sd	0.2	5.2	18.0	7.6	0.69		6.25	69.0
Móstoles (discharge area)	M	5.8	132.5	31.3	34.7	n.d.	n.d.	4.5	5960
n=22	sd	1.4	246.7	9.2	53.9			4.4	15 780
Móstoles (slope)	M	6.9	3.4	21.1	33.3	1.30	0.36	2.1	246.6
n=8	sd	0.3	1.6	19.6	21.7	0.31	0.25	1.6	96.9
Anthropomorphic ecosystems (weed communities, fallow plots)	M	6.0	2.0	10.8	10.6	0.85	1.48	6.0	135.6
n=35	sd	0.6	1.5	4.2	6.2	0.74	3.14	6.1	52.7
Grazed grasslands	M	6.0	1.3	4.3	12.0	0.82	1.23	2.6	97.5
n=49	sd	0.5	0.4	1.2	37.8	0.52	1.71	2.7	62.6
Reference ecosystems (brooms & oak thickets)	M	6.0	0.9	1.6	7.3	0.52	1.45	1.6	60.2
n=7	sd	0.5	0.3	0.4	7.2	0.37	0.6	1.3	9.1

n.d.: non-detected; sd: standard deviation.

information between the species and the factor", which is the amount of information involved in the presence or absence of this species for that factor (Lepart and Debussche, 1980). The method enables the determination of the effective factors and the "ecological indication" of the different species. It is based on the calculation of entropy and mutual information. This calculation is used to define the ecological groups. Both the input and the processing of files was carried out following the functions established by Gautier *et al.* (1977) and Legrand (1984). This frequency distribution reflects the behavior of each species with respect to the different classes of variable studied.

Profile indices (Gauthier *et al.*, 1977) are also shown in the tables. The bottom rows of the profiles indicate the corrected frequencies only in cases where the class value is significant at the 95, 99 and 99.9% (positive or negative) level, depending on the number of soils sampled in this class. The values of the profiles, clearly higher than 100, indicate the preference of the plants for same soils.

Extent and type of salinization

Table 1 summarizes the results of our study of the soluble anion contents of the soils of the different landfills expressed as average concentrations in mg/kg. The table indicates that the lowest concentrations detected were those of F^- and PO_4^{3-}. Both these anions are strongly adsorbed on soil particle surfaces and are thus not really soluble. In contrast, the more soluble ions NO_3^- and SO_4^{2-} were detected in greater amounts.

Observed impacts on ecosystems and natural resources

Table 2 provides a list of the 45 species or genera most commonly found in the discharge areas of the studied landfills.

The high Cl^- and SO_4^{2-} contents detected in the soil covers of landfills have also been reported by Pastor *et al.* (1994) and Hernández *et al.* (1998). The higher nitrate contents observed in several of the samples may be attributed to constant grazing by sheep and rabbits.

TABLE 2

List of the species (ordered by frequency) best represented in the discharge areas of the landfills

Hordeum murinum L.	Convolvulus arvensis L.	Cichorium intybus L.	Malva neglecta Wallr.
Bromus hordeaceus L.	Trifolium tomentosum L.	Aegilops geniculata Roth	Eryngium campestre L.
Lolium rigidum Gaudin	*Spergularia rubra* (L.) J et C Presl.	Aegilops triuncialis L.	Crepis capillaris L.
Trifolium campestre Schreber	Andryala integrifolia L.	Melica ciliata L.	Scolymus hispanicus L.
Cynodon dactylon (L.) Pers.	Carex sp.	Marrubium vulgare L.	*Elymus pungens* (Pers.) Melderis
Plantago lagopus L.	Geranium molle L.	Onopordum sp.	Phalaris minor Retz.
Anacyclus clavatus (Desf.) Pers.	Medicago polymorpha L.	Daucus carota L.	Trifolium cernuum Brot.
Bromus madritensis L.	Plantago coronopus L.	Picnomon acarna (L.) Cass.	Rumex crispus L.
Echium vulgare L.	Bromus diandrus Roth	Brassica sp.	Carlina corymbosa L.
Senecio vulgaris L.	Trisetum paniceum (Lam.) Pers.	Carduus tenuiflorus Curtis	Gaudinia fragilis (L) Beauv
Hirchsfeldia incana (L.) Lagréze - Fossat	Juncus capitatus Weigel	*Avena barbata* Pott ex Link	Centaurea melitensis L.
Bellardia trixago (L.) All.	Juncus bufonius L.	Avena sterilis L.	Vulpia ciliata Dumort
Bromus rubens L.	Medicago rigidula (L.) All.	Bromus tectorum L.	Trifolium repens L.
Rumex sp.	Taeniatherum caput-medusae (L.) Nevski	Medicago minima (L.) Bartal.	

When the soil samples were ordered from more to less affected by landfill leachates on slopes or the foot of the landfills, of particular note were the high levels of sodium and chlorides and high EC detected in the discharge areas. In the landfills of Villaviciosa de Odon and Móstoles, these areas occur on the banks of a stream. In all cases, soil fluoride and phosphate levels were low or undetectable.

Tables 3, 4, 5 and 6 show the ecological behaviour of the species that were found to preferably grow in soils with high chloride, sulfate and sodium contents as well as high EC.

TABLE 3
Ecological profiles (corrected frequencies and indices) of the species growing in soils with high soluble chloride contents

Family Species	Frequency	Entropy species	Mutual Information species-factor	Chlorides (mg/kg)					
				3.0–7.5	7.6–12.5	12.6–20	20.1–30	30.1–50	50.1–171
				No. of relevés					
	N			(32)	(33)	(34)	(21)	(21)	(10)
Gramineae									
Bromus rubens	44	0.87	0.13	96	41 –	90	49	261 +++	102
Bromus hordeaceus	91	0.97	0.08	57 – –	95	102	118	134 +	132
Gaudinia fragilis	12	0.40	0.06	0	38	111	299 +	131	251
Hordeum murinum	30	0.72	0.06	94	61 –	59	71	167	302 ++
Bromus tectorum	69	0.99	0.05	61 –	86	102	114	135	153
Vulpia ciliata	44	0.87	0.05	53 –	83	90	114	196 ++	102
Leguminosae									
Trifolium tomentosum	58	0.96	0.08	40 – –	134	104	111	148 +	156
Lathyrus angulatus	22	0.60	0.04	64	83	100	163	112	274 +
Compositae									
Crepis capillaris	45	0.88	0.04	94	61	78	111	175 +	134
Other species									
Hirschfeldia incana	41	0.84	0.11	69	33 –	86	105	192 +	257 ++
Polygonum aviculare	9	0.33	0.06	52	50	0	159	159	503 +
Reseda lutea	8	0.30	0.05	0	57	111	45	359 +	188
Juncus bufonius	8	0.30	0.05	58	0	111	0	359 +	188
Plantago coronopus	33	0.76	0.04	42 –	124	94	65	152	183
Spergularia rubra	52	0.93	0.05	54 –	96	93	96	165 +	145

The data in Table 3 indicate that the grasses *Bromus rubens*, *B. hordeaceus*, *Gaudinia fragilis*, *Hordeum murinum* and *B. tectorum* show a clear preference for the soils of the landfill slopes. The profile obtained for *Vulpia ciliata* reveals a less clear preference for soils with high chloride contents.

Within the family *Leguminosae*, *Lathyrus angulatus* appeared to prefer soils with high Cl levels, while the clover species *Trifolium tomentosum* showed a more ambiguous behaviour.

Of the *Compositae*, only *Crepis capillaris* preferred soils with high chloride contents, yet tolerated soils with intermediate (12.6 to 30.0 mg/kg of chlorides) or low (< 12.5 mg/kg) chloride levels. Among the other family species: *Hirschfeldia incana*, *Polygonum aviculare*, *Reseda lutea*, *Juncus bufonius*, *Spergularia rubra* and *Plantago coronopus* thrived in soils with high chloride contents.

The data in Table 4 indicate the clear preference for high soil soluble sulfate levels of *Hordeum murinum* and *Bromus rubens*, followed by *Vulpia ciliata* and *Bromus tectorum*. The preference of *Bromus hordaceus* for sulfates was unclear. Among the *Leguminosae*, *Medicago polymorpha and Trifolium cernuum* preferred soils with high sulfate contents.

TABLE 4

Ecological profiles (corrected frequencies and indices) of the species growing in soils with high soluble sulfate contents

Family Species	Frequency	Entropy species	Mutual Information species-factor	Chlorides (mg/kg)					
				8–12.5	12.6–20	21–30	31–45	46–66	66–845
				No. of relevés					
	N			(31)	(41)	(26)	(20)	(16)	(15)
Gramineae									
Hordeum murinum	30	0.72	0.11	45	85	66	75	157	335
									+++
Bromus rubens	44	0.87	0.06	93	58	65	120	150	205
					–				+
Vulpia ciliata	44	0.87	0.04	51	83	105	102	171	160
				–					
Bromus tectorum	69	0.99	0.04	72	96	84	109	123	160
									+
Bromus hordeaceus	91	0.97	0.04	85	84	121	116	116	132
Leguminosae									
Trifolium cernuum	20	0.56	0.09	68	36	29	151	377	100
					–			+++	
Medicago polymorfa	7	0.27	0.05	130	0	0	107	269	287
Compositae									
Centaurea melitensis	18	0.53	0.06	50	40	64	83	262	279
								+	+
Other species									
Hirschfeldia incana	41	0.84	0.13	44	53	70	128	184	270
				–	–			+	+++
Polygonum aviculare	9	0.33	0.08	0	0	64	251	209	335
									+
Spergularia rubra	52	0.93	0.07	52	84	89	116	199	135
				–				++	
Juncus bufonius	8	0.30	0.06	0	92	0	94	235	377
									+
Diplotaxis virgata	34	0.77	0.04	80	54	85	155	166	148
					–				

Of the Compositae, *Centaurea melitensis* showed a clear preference for high soil sulfate contents. Among the species in other families, *Hirschfeldia incana* and *Polygonum aviculare* especially, and *Spergularia rubra, Juncus bufonius* and *Diplotaxis virgata* also preferred high soil sulfate contents.

The ecological profiles of the grass species that grew in soils with appreciable levels of exchangeable sodium indicated a clear preference for this nutrient of *Hordeum murinum*, *Vulpia myuros* and *Bromus tectorum*. The behaviour of *Bromus hordeaceus* and *Bromus madritensis* regarding the exchangeable sodium contents of the soils was unclear.

In the family *Leguminosae*, *Trifolium cernuum* preferred the higher Na soil contents, while *Trifolium tomentosum* was more indifferent. Corrected frequency profiles and profile indices identified as preferred soils were those with levels of exchangeable sodium between 29.1 and 45.0 mg/kg.

The ecological profiles of the three *Compositae* shown in Table 5: *Crepis capillaris*, *Anacyclus clavatus Carduus tenuiflorus* indicated their slight preference for soils with high sodium contents.

Among the species of other families, *Hirschfeldia incana* and *Polygonum aviculare* clearly stood out followed by *Spergularia rubra*, *Plantago coronopus* and *Diplotaxis virgata* prefer relatively high sodium content in soils.

TABLE 5
Ecological profiles (corrected frequencies and indices) of the species growing in soils with high exchangeable Na contents

Family Species	Frequency	Entropy Species	Mutual Information species-factor	Sodium (mg/kg)				
				5–11	11–17	17–29	29–45	45–350
				No. of relevés				
	N			(63)	(22)	(31)	(17)	(18)
Gramineae								
Hordeum murinum	30	0.72	0.11	63 –	45	48	177	307 +++
Vulpia myuros	44	0.87	0.08	49	109	99	181	190
Bromus rubens	44	0.87	0.07	81	93	44 –	201 +	171 +
Bromus tectorum	69	0.99	0.06	100	89	80 –	167 +	121
Bromus hordeaceus	91	0.97	0.04	92	98	80	136 +	129
Bromus madritensis	45	0.88	0.03	74	122	108	98	167
Leguminosae								
Trifolium cernuum	20	0.56	0.06	23 – –	102	121	222	209
Trifolium tomentosum	58	0.96	0.03	90	82	83	168 +	117
Compositae								
Crepis capillaris	45	0.83	0.08	69 –	30 –	173 ++	118	149
Carduus tenuiflorus	28	0.69	0.05	77	73	52	158	239
Anacyclus clavatus	83	0.99	0.04	103	90	79 –	128	131
Other species								
Hirschfeldia incana	41	0.84	0.18	52 – –	50	59	238 ++	265 +++
Polygonum aviculare	9	0.33	0.06	0 –	152	127	296	186
Spergularia rubra	58	0.93	0.04	73	79	112	136	161
Diplotaxis virgata	34	0.77	0.03	91	60	71	130	197 +
Plantago coronopus	33	0.76	0.03	76	101	72	196	183

The information provided in Table 6 reveals that Hordeum murinum, Bromus rubens, Bromus tectorum, Desmazeria rigida, Medicago polymorpha, Carduus tenuiflorus, Chondrilla juncea, Hirschfeldia incana, Polygonum aviculare, Juncus bufonius and Reseda lutea, were all capable of growing in the landfill soils showing high electrical conductivity values.

The values shown in Table 6 are those commonly found in landfills. Thus, the species listed could be in the process of revegetating the slopes (often steep slopes), saline zones and discharge zones of many landfills, and may therefore be mitigating the effects of pollutant leachates reaching nearby streams, wetlands and pastures.

TABLE 5

Ecological profiles (corrected frequencies and indices) of the species growing in soils of high electrical conductivity

Family Species	Frequency N	Entropy species	Mutual Information species-factor	Chlorides (mg/kg) 8–12.5	12.6–20	21–30	31–45	46–66	66–845
				No. of relevés (31)	(41)	(26)	(20)	(16)	(15)
Gramineae									
Hordeum murinum	30	0.72	0.17	40	0	74	110	154	377
					– –				+++
Bromus rubens	44	0.87	0.07	54	59	63	117	184	142
								++	
Bromus tectorum	69	0.99	0.07	105	98	67	123	115	164
						– –			++
Desmazeria rigida	10	0.35	0.04	0	104	93	55	235	116
								+	
Leguminosae									
Medicago polymorpha	9	0.33	0.05	86	74	0	134	112	539
									+
Compositae									
Carduus tenuiflorus	28	0.69	0.05	86	37	79	84	165	224
									+
Chondrilla juncea	16	0.49	0.04	75	97	139	147	101	157
Other species									
Hirschfeldia incana	41	0.84	0.20	14	12	68	126	212	245
				– –	– – –			+++	++
Polygonum aviculare	9	0.33	0.07	0	0	124	104	138	559
									++
Juncus bufonius	8	0.30	0.04	0	65	0	176	217	157
Reseda lutea	8	0.30	0.04	0	195	104	117	145	157

Description of efforts to prevent further salinization or efforts to rehabilitate salt-affected areas

We are presently engaged in further research into the ecophysiology of the mineral nutrition of species growing in soils with high levels of anions. Owing to the lack of space, we cannot provide the results obtained so far for many species. This study will be soon completed with data for a large number of additional species.

This ongoing study will serve to increase existing knowledge of the role of the different species to act as "green filters" capable of minimizing or preventing pollutants that leach from old landfills reaching streams or adjacent ecosystems.

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Centrifugation affects salt content and ionic composition in the 1:5 water extracts of calcareous soils

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The 1:5 soil water extracts are frequently used for salinity appraisal because they are easier to obtain than saturation extracts. The experimental conditions for obtaining the 1:5 extracts should guarantee that the equilibrium status of the solution regarding calcite, gypsum and CO_2 has been attained and preserved in order to use them instead of saturation extracts for salinity diagnosis and also model validation.

A laboratory experiment was conducted in order to determine the time that calcareous soil samples need for attaining equilibrium with calcite, gypsum and CO_2 in 1:5 soil to water suspensions. Once this time was known, the effect of the centrifugation extraction on the thermodynamic parameters of the 1:5 extracts was studied. This was done comparing the ionic activity products of calcium carbonate of 1:5 extracts obtained by centrifugation with those not obtained by centrifugation. According to the results the centrifugation affects the ionic composition of the extracts and also the equilibrium parameters. However, for some measured parameters it was not possible to identify significant differences between centrifuged and non-centrifuged extracts. The study of the equilibrium parameters of 1:5 extracts obtained from soils with calcite and gypsum should continue before they can be reliably used instead of saturation extracts.

Rain effect on salts dynamic in the semi-arid region of Bou Hajla (Central Tunisia): Characterisation and long-term simulation

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Rainy events are rare and a characteristic of semi-arid regions. They play a regulatory role on the leaching of salts from topsoil to deeper layers which increase the risk of aquifers salinization. For this purpose, parcel in the region of Bou Hajla (Central Tunisia) was selected. Samples of soil were collected at 4 m depth from 26/12/2006 until 22/07/2008. Water and salt profiles highlight the role of a silty clay layer in the infiltration of water and salt transfer. This layer reduces salt's training but do not stop it which increases the risk of the aquifer salinization. The simulation was carried out by Hydrus-1d. The hydrodynamic parameters were determined by inverse modelling. The simulation allowed the analysis of two scenarios; the first being the effect of a very rainy event (> 50 mm/d) on the dynamics of salts. This type of event allows leaching of the accumulated salts in the topsoil which promotes their burial in depth. The second scenario is the long-term evolution of the saline profile in 25 years, which showed the cyclical nature of salts leaching in the topsoil and a continuous leaching in the deeper layers, increasing groundwater contamination.

Keywords: salinity, rain, soil, aquifer, Hydrus-1d, Bou Hajla.

Ecosystem's fragility under continuous methods of irrigation (learning from modern experiences)

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A long-term investigation of subsoil irrigated and drop irrigated soils in South Russia has been carried out over the last 6 years. Under the subsoil and drop methods of water delivery a non-uniform watering pattern is achieved, e.g. subsoil 0.5–1.0 m (the distance between subsoil outlets), drop 0.2–0.6 m (distance between droppers). The inefficiency of subsoil and drop watering is reflected by superfluous continuous watering and consequent local waterlogging of the soil and loss of irrigation water to groundwaters. A defect of the present-day irrigation concept is its imitating approach—a technical reproduction of a natural mode of water inflow into the ground from above or from below by means of a gravitation field or capillary forces. Development of a discrete artificial mode of applying water to a soil is required in order to achieve even watering.

Keywords: Chernozem, chestnut soil, irrigation, salinization, modern experiences.

The method of intrasoil discrete plant watering (introducing new technologies)

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The method of intrasoil pulse discrete watering of plants is proposed. It includes water delivery on an irrigation site and its distribution. It provides water delivery inside the ground by means of injector element in consecutive step-by-step pulse injection under pressure in discrete portions, immersing the bottom end of an injector element into ground at a depth of 0.05–0.15 m, step-by-step along a direction of movement of the chassis through 0.1–0.15 m. With the method of watering proposed there is no longer the necessity to protect the landscape from irrigation. The amount of water consumption for irrigation is 2–3 times less than with standard irrigation methods. This method minimises the use of fresh water resources, which are under threat globally due to climate change.

The management of soils with salinization risk from experimental field Lacu Sarat, Braila

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ABSTRACT

The management of saline soils requires a combination of agricultural practices depending of the careful investigations of soil characteristics, water quality and local conditions including climate, crops, economical, social, political, and cultural conditions, as well as the existing farm systems.

The research was carried out in the eastern part of the Romanian Plain (Braila Plain) in a depressionary area, on a slightly to moderately salinized Chernozem. Taking into account the natural conditions of the experimental field, an improvement scheme on an eight ha area was established, with multiple variants of ameliorative treatment.

The results presented in this paper were obtained between 1998 and 2004 at the Lacu Sarat trial plot in natural conditions in the frame of the ameliorative field scheme and also the crops structure. The results presented here are compared with the benchmark variant = 100, identified as the variant with the minimum ameliorative practices, due to the lack of a real benchmark variant.

Keywords: management, salinization, Braila Plain.

DISCUSSION

In all countries, there are concerns for improving saline soils and those with risk of salinization, to increase agricultural production, to reduce content of soil soluble salts, therefore to increase the range of crops suitable for these lands, to obtain technical elements to improve breeding technologies, environmental protection and economic efficiency of improvement technologies, and to increase standards of living in areas with saline and alkaline soils.

First information reported in Romania on salinized lands or saline soils (*saraturi*), were made by Maior (1912) and Saidel (1912, 1917). Research on these soils increased after 1950, when new terms, such as Solonetz and Solonchack were adopted from Russian litreature in the new studies, those becoming international terms (Crişan, 1954; Florea, 1956, 1958 a, b, 1961 a, b; Marcu, 1956; Manuca, 1958; Maianu şi colab., 1958a, b), and are still continuing until now.

In Romania, saline soils have been identified in 29 of the 41 counties. Total area of these soils is 614 000 ha. Generally, saline soils are located on low lands, in depressionary areas, with low natural drainage, and, sometimes, on hilly regions (saline soils on slope). On irrigated soils, as a result of increased groundwater level, the risk of salinization occurs mainly in soils with shallow groundwater and in drought conditions.

The soils of the Braila Plain present a sound importance for the agriculture of this region. In this area, some of the most fertile soils from Romania could be found, as well asthe most various and important crops. However, often, the soils with a good fertility are interspersed with areas of saline soils or soils with salinization risk and low productivity.

The Lacu Sarat micro-depressionary area is located in the eastern part of Romanian Plain (Braila Plain or Northern Baragan), (Posea, 1989) in a microdepressionary area (crov), on a total area of about 300 ha which accumulates groundwaters from neighbouring higher areas, this phenomenon also being the cause of soil degradation processes by salinization and recurrent waterlogging. This microdepressionary area is a representative area for microdepressionary areas from Northern Baragan affected by salinization. Surface deposits are made of loess and the texture varies from loamy-sandy to loamy-clayey. On the bottom of the valley, where the trial plot is located, groundwater table reaches levels of less than 2 m and, in some parts, less than 1 m depth. Groundwaters are moderat and strong mineralized (mineral residue of 1–4.5 g/l) in periferic areas and low–moderately mineralized (4.5–11 g/l) in central areas of microdepressionary area. The trial plot was located on slightly–moderately salinized Chernozem (SRTS, 2003), sited in the dry steppe (Bogdan, 1999), characterized by hot and dry summers, with an average multiannual temperature of 10.9 °C, precipitations of 452 mm annually, potential evapotranspiration of 705 mm and a climatic water deficit of 345 mm (Braila Weather Station).

The natural conditions of the trial plot (with an area of 8 ha) were the basis to design the layout for several treatments, each of them composed from several ameliorative works, as follows: horizontal drainage, deep loosening, ameliorative irrigation, organic fertilization, chemical fertilization, soil tillage with soil material inverting, soil tillage without soil material inverting, mulching and amendment.

The horizontal drainage was done through a buried drainage setup with ceramic pipes of 70 mm in diameter, positioned at the depth of 1 m, with a rubble filter in three situations of intensity:

- high intensity: drain lines positioned at a 20 m distance;
- moderate intensity: drain lines positioned at a 40 m distance;
- low intensity: no drainage.

The deep loosening tillage was done using MAS-60 machine, at a depth of 50–52 cm and the distance between crossings of 1.5 m. Before this work, due to the fact that the land was unused for a long period of time, a fallowing work has been done. After the deep loosening tillage, to level the land, a disc harrowing tillage has been applied, with the GDG 4.2 hard disk on two perpendicular directions.

Ameliorative irrigation was not applied during the growing season of 1999, because weather conditions did not require this work and in 2000 was not applied due to the unoperatibility of irrigation system. In agricultural year 1998–1999 the crop received a total contribution of water of 563 mm, with 218 mm during summer and exceeding the mean annual rainfall of 152 mm. The agricultural year 1999–2000 was deficient in the spring-summer seasons, when the inputs in the soil water budget were with 103 mm lower than the multi-annually value. The next agricultural year studied was 2002–2003, characterized as an overall average year, with a water intake of 473 mm, with a low summer rainfall providing 97 mm, with 152 mm lower than the multi-annually value. For agricultural year 2003–2004, the rainfall summarized 664 mm (annual average being only 452 mm), the summer season was particularly rich in precipitation, summarizing 327 mm (the multi-annually average being 152 mm), and July and August being three times bigger than the multi-annually value.

Organic fertilization with manure was performed at a dose of 120 t/ha wet manure (60 t/ha dry manure), and scattered using a MIG-5 machine.

Chemical fertilization was applied in spring 1999 at the establishment of crops, at different doses: for maize, 600 kg/ha ammonium sulfate ($(NH4)_2SO_4$) was applied to provide 120 kg N/ha for variants V_2–V_{8a} and 300 kg/ha ammonium sulfate to provide 60 kg N/ha for V_1 variant, where manure (60 t/ha of dry manure) was applied for the seedbed preparation; for sunflower 400 kg/ha ammonium sulfate was applied to provide 80 kg N/ha for variant V_2–V_{8a} and 100 kg/ha ammonium sulfate to provide

20 kg N/ha for V_1 variant, with the same quantity of manure (60 t/ha of dry manure) applied for the seedbed preparation.

The tillage with soil material inverting was done in autumn each year, together with ploughing improvement methods that has been done with the paraplaw plough (without soil material inverting) in order not to bring salts to the surface from depth.

Mulching, as the ameliorative treatment, was achieved by administration of barley straw on the surface layer of 8–10 cm soil in V_6 variant.

The soil amendment had a preventive character having regard to the low percentage of exchangeable sodium and received phosphogypsum dose of 6 t/ha.

The yield for the studied crops in the trial plot for the agricultural years 1998–1999, 1999–2000, 2002–2003, 2003–2004 are presented both as absolute and relative values compared to the benchmark treatment=100, which in the trial context can be considered the V_{8a} variant (*No drainage + chemical fertilization + soil tillage with soil material inverting + amendment*) which undergone the least improvements, an actual benchmark (with no improvement) treatment missing.

The interpretation of yield data was performed in two ways, to highlight the influence of a single improvement, and the influence of the whole system works compared to the benchmark treatment.

The first method consist in a comparison that have been made on pairs of variants related in terms of work, but differring by a specific improvement work (the first of them being considered the comparison variant), as follows (Coteţ, 2008):

- for intense drainage V_2 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment) were compared with V_8 variant (No drainage + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- for moderate drainage V_7 variant (Drainage with 40 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment) were compared with V_8 variant (No drainage + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- for without drainage V_8 variant (No drainage + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment) were compared with V_2 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- when no ameliorative measures are applied V_{8a} variant (No drainage + Chemical fertilization + Soil tillage with soil material inverting + Amendment) were compared with V_8 variant (No drainage + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- for deep loosening V_2 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment) were compared with V_4 variant (Drainage with 20 m between the drains + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- for ameliorative irrigation V_2 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment) were compared with V_5 variant (Drainage with 20 m between the drains + Deep loosening + Chemical fertilization + Paraplaw + Amendment);
- for the influence of organic fertilizers V_1 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Organic fertilization + Chemical fertilization + Paraplaw + Amendment) were compared with V_2 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);
- for soil tillage with soil material inverting V_3 variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Soil tillage with soil material inverting + Amendment) were compared with V_2

variant (Drainage with 20 m between the drains + Deep loosening + Ameliorative irrigation + Chemical fertilization + Paraplaw + Amendment);

- for mulching V_6 variant (Drainage with 20 m between the drains + Deep loosening + Chemical fertilization + Paraplaw + Mulching + Amendment) were compared with V_5 variant (Drainage with 20 m between the drains + Deep loosening + Chemical fertilization + Paraplaw + Amendment).

Intense drainage (D=20 m) determined significant yield enhancements, reaching 25–114%, the highest being for maize green matter and sunflower.

Moderate drainage (D=40 m) lead to important yield enhancements, between 6 and 36% in all crops, the highest being recorded for sunflower, 15–36%.

Without drainage (D=0 m), but with the application of different ameliorative measures, low yields were obtained, even 50% lower than the reference treatment, with decreases of 20–53% for all crops.

When no ameliorative measures are applied (except for chemical fertilization and amendment), the yield decrease is obvious, but 4–24% lower than the previous case.

The use of deep loosening tillage as ameliorative treatment led to small improved increases for maize, sorghum, and sunflower, between 0 and 11%, with the exception of Sudan herb and maize green matter, which obtained increases of 11 to 18%.

Ameliorative irrigation resulted, in agricultural year 1998–1999, to lower yields for all crops, namely between 4 and 6% for maize, sorghum, and 13% for Sudan grass, unlike the next years, when anyield increase for all cultures have been obtained, between 3–26%. This is explained by the fact that the first year was a wet year, leading to a less favorable aerohydric regime.

Under organic fertilization, yield increases could be noticed for all crops and for all years as follows: 18–50% for maize, 2–5% for sunflower, 7–35% for sorghum and 2–79% for Sudan herb.

It could be noticed that the highest yields were obtained in the agricultural year 1998–1999, an agriculturally favourable year, with precipitations of 563 mm, compared to the multiannual average of 452 mm and an annual mean temperature of 11.1°C compared to the multiannual average of 10.9°C, another explanation being the fallowing of the meadow before setting up the trial plot.

In the third variant V_3 where ploughing with soil material inverting has been applied, relative yields increases are between 22 and 104%, mentioning that the largest relative increases occur for sunflower crop, where relative yields are 198 to 208%.

In the second variant V_2, increases of the relative yields are between 43 and 157% (the average being 72 to 119%), excepting the sorghum and wheat, where relative increases are 19 to 54%. The sunflower yields relative values are similar and between 205 and 241%, differentiated from the V_1 with approx. 10 to 12%, differences that may be caused by the application of organic fertilizers.

The application of tillage with soil material inverting, as an improvement methods, in the first two years led to yield decreases quite large, between 10 and 30%, excepting sorghum and sunflower, where yields are similar to the compared variant. In the further years, the decrease of yields is still present, but at lower values of 3 to 5%.

Mulching with straw gave no production increase, but instead they were lower by 1–5%, except agricultural year 1999–2000 when the yield decline was 2–28%. The smallest decrease recorded sunflower yield between 2 and 5%.

The second method of interpretation, in order to highlight the whole effect of applied ameliorative measures in the various technological variants from the experimental fields, consists of a discussion of absolute and relative values of yields (% from the benckmark variant=V_{8a}), (Coteț, 2008).

For the first variant (V_1) with the most ameliorative works, the increase yields are very larger, from 115–208%, excepting the sorghum, the wheat and the maize green matter, where the increases are only 50–56%. Sunflower had a relatively constant yield in the 4 studied years between 215–253%.

In the second variant (V_2), quite similar to the foregoing variant, but without organic fertilization, there are yields increases between 43–157%, excepting the sorghum and the wheat where the increases are 19–54%. Another notice is the fact that the sunflower yields are closely, being in a range of 205–241%, different to V1 with about 10–12%, the differences that could be determinated by the application of the organic fertilizers.

For the third variant (V_3), where soil tillage uses paraplaw (without soil material inverting), the increase yields are between 18–111%, noting that the largest increases appear to sunflower, with yields between 198–208%.

In the fourth variant (V_4), without organic fertilizers and deep loosening, the increase yields are between 53–132%, excepting the sorghum, wheat and maize green matter in one year, with yields increases of only 18–47%.

In the fifth variant (V_5), due to the lack of ameliorative irrigation, the yields increases are between 39–141%, except the sorghum and the wheat where the increases are only 26–46%. The sunflower yields are between 185–214%.

For the sixth variant (V_6), the yields vary between 72–107%, excepting the sorghum, the wheat and the maize green matter in a year with increase yields of 16–25%. The sunflower yields are between 175–207%.

In the seventh variant (V_7), the moderat drainage leads to yields increases of 15–80%, for the sunflower the yields varying between 135–180%, and for the maize between 139–163%.

For the eighth variant (V_8) (without drainage + deep loosening + ameliorative irrigation + chemical fertilization + soil tillage with soil material inverting + amendment), the increase yields are smaller, between 2–55%, but for the sunflower the yields are larger, between 105–155%, while for the maize the yields being between 124–132%.

Drainage triggered significant yield increases, the value being double in the case of intense drainage (D=20 m).

The lack of drainage strongly affects the development of crop plants, due to the unfavourable air-water regime related to the presence of groundwater close to the surface.

The use of deep loosening tillage in the complex of measures leaded to low increases of crop yields, excepting the Sudan herb, with yield increases between 11 and 18%.

Application of ameliorative irrigation has led to slight ameliorative production increases between 3 and 26%.

The application of manure together with the other improvements had favourable effects, especially in maize, sorghum, and Sudan herb. The application of manure in doses of 60 t/ha leads to the improvement of permeability and structuring degree, the reactivation of microbiological activity etc., with positive effects together with other agropedoameliorative measures.

The tillage with soil material inverting has low or nonconclusive effects due to medium texture and relatively good soil characteristics. Favourable effect, although relatively moderate, had also the tillage without soil material inverting (paraplaw). Soil tillage at shallow depth and without soil material inverting is recommended, and in order to reduce subplough layer compaction, annually changes of ploughing depth are recommended.

Soil mulching has inconclusive effects in experimental conditions, causing slight decreases of yields.

After the ameliorative measures applied in complex, the conclusions could be:

- the yields continuously increase with the intensification of the drainage from weak (without drainage D=0 m) to moderat (D=40 m) and intensively (D=20 m);

- the yields are also influenced by ameliorative irrigation, with pozitive effects especially for sunflower, Sudan herb and maize green matter; but with no significant effects for sorghum and wheat;
- on the other hand, the lack of deep loosening, the paraplaw plough and mulcing, lead to small yields increases (insignificant);
- the variant with organic fertilization has the larger increase of yields for all studied crops and for all studied years.

The most important conclusion is that even slightly–moderately salinized Chernozem soils could have yields close to those obtained on unsalinized soils.

Water quality and irrigation system affects salt accumulation and distribution in the soil profile of citrus orchards: A case study in Almenara (Valencia, Spain)

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The citrus crops cultivated in the Mediterranean area of Almenara (Spain) are threatened by soil salinization. Three citrus orchards representative in the area were sampled at monthly intervals at 10, 30, and 60 cm depth during the irrigation period and analysed for soil salinity parameters in the saturation extract: electrical conductivity, pH, alkalinity and major ions. One of the plots was drip-fertirrigated with water of low salinity and the two others were surface-irrigated with more saline water.

Samples grouped by plot and depth were statistically treated by Discriminant Analysis (DA) in order to disentangle the soil salinity parameters discriminating among the groups. A function explaining 51% of variance separated the plots by the quality of irrigation water, with chloride and sodium in the soil saturation extract as the main variables separating plots. Another function explaining 33% of variance separated shallow from deep soil layers, with nitrites and potassium as the main variables discriminating among depths. Samples at 30 and 60 cm depth in the surface-irrigated plots had similar salt composition. In the drip-fertirrigated plot, nutrients decreased beyond 30 cm depth. This suggests an efficient use of water and nutrients by plants that decrease salt accumulation in the profile, compared to the accumulation of salts in the root zone and beyond it in the surface-irrigated plots. Drip irrigation systems should be used in a new scenario of climate change, given the future lack of good quality water resources and the increase of water demand by the crops due to higher temperatures.

Water re-use projects as a solution of salinity problems in scarcity areas

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Recurrent droughts in recent decades have shown that water supply is not always balanced with demand. More than 70% of Europe's population face water stress problems with semi-arid coastal and highly urbanized areas being the most affected. Salinization is a problem that has been known for a long time, which particularly affects the soil in areas where precipitation is scarce. In addition, global climate change will worsen this situation, especially in southern European countries where greater susceptibility to drought can cause serious environmental, social and economic problems.

In this context, wastewater regeneration and re-use is emerging as an important future alternative because it enables water resources to be increased, lessening the pressure on conventional natural resources. It may also help to reduce salinization as the wastewater regeneration process for agricultural purposes includes filtration systems that significantly reduce salt concentrations. In many cases reclaimed water has lower content of salt than water from natural sources. In recent decades significant technological progress has been made in the field of wastewater regeneration and project feasibility is now mainly subject to economic considerations. However, thed economic aspect is perhaps the least studied in the research on wastewater regeneration and re-use. This is because while internal impacts can be easily translated into monetary units, the external effects, such as environmental benefits, are not considered by the market and, therefore are relegated to a series of statements about the advantages of water re-use but without economic valuation. As a result, the true benefits and costs of many projects are not properly evaluated.

With the aim to integrate the economy in the design and implementation of water re-use projects, this work shows a methodology to assess the economic feasibility where not only internal but also external impacts are considered. Using the concepts of distance functions and shadow prices for undesirable outputs, we calculate the value of avoided environmental damage or a proxy to the environmental benefit derived from the water re-use. This is a very important issue especially for the areas affected by salinity problems.

In order to show the usefulness of the proposed methodology, an empirical application has been made with a sample of Spanish wastewater treatment plants that re-use effluent for environmental purposes. In this case study, to obtain an economic viability indicator, the monetary values of internal and environmental benefits have been quantified. Results show that when water re-use projects are analysed taking into account just the internal benefit, some projects are not economically feasible. However, if environmental benefits are incorporated to the analysis, the economic feasible evaluation provides positive results for all of them.

This work shows the importance of the valuation of the environmental benefits derived from water re-use and justifies the use of this kind of projects to solve the salinity problems in certain areas.

Keywords: economic feasibility, environmental benefits, shadow prices, water re-use, wastewater treatment.

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Compost application: Effect on soil salinity

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Composting organic residue is an interesting alternative to recycling waste as the compost obtained may be used as organic fertilizer. Nevertheless, the application of compost on soil could affect the quality of soils and plants. The objective of this study were determine the effects of applying different doses of compost, elaborated with rice straw and sewage sludge, on soil salinity and plant development in pot experiments. Sandy (psamment) and clayey (xeralf) soils were amended with different doses (0.0%, 0.2%, 0.8%, 1.5%, 3.0%, 6.0% and 100% for clayey soil, and 0%, 1%, 2%, 4%, 6%, 10%, 20% and 100% for sandy soil) of mature compost and covered with with barley straw in pot experiments, under laboratory conditions. To assess the effects of compost-amended soil on *Hordeum vulgare* L. plants, the root/shoot (R/S) ratio index was determined.

The results showed that doses over 2% in sandy soil and 0.8% in clayey soil considerably increased EC values. It is well known that EC (1:5 w/v soil extracts) values over 0.4 dS/m lead to salinity problems in soils. The variability of the R/S relationship in terms of the compost doses applied to soil indicated that the lowest R/S ratio values were 0.37 for barley grown in sandy soil with doses of 4 and 6%, and 0.45 for barley grown in clayey soil with a dose of 0.8%. These facts, along with the effect of the compost on soils, undoubtedly confirmed that the optimum dose to obtain the best effect on the soil–plant system were 34 Mg/ha for sandy soil and 11 Mg/ha for clayey soil. Under there conditions, the only limiting factor of agronomic compost utilisation was the increased soil salinity. The authors wish to thanks the Generalitat Valenciana (project GV-CAPA00-03), and the Ministry of the Environment (project MMA 4.3-141/2005/3-B) for the financial support.

Problem soils and their amelioration, with emphasis on saline soils

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ABSTRACT

Thailand has abundant and diverse natural resources. The socio-economic growth of the country is mainly through the agricultural sector, in terms of gross domestic product (GDP), employment and provision of food security. The total land area of the country is approximately 51.4 Mha, comprising of 38% farmland, 25% forests, and the remaining 37% is public area, i.e. sanitary districts, swamp land, railroads, highways, real estate and others.

The climate of Thailand is classified as tropical savannah (the Central Plain, North, North-east and some parts of eastern Thailand), tropical monsoon (west side of the southern and eastern parts) and tropical rainforest (east side of the southern part). The average temperature is about 27 °C, while the annual rainfall is in the range of 824–5 248 mm. The potentially irrigated lands are dispersed over an area of approximately 5 Mha or 23.8% of the country's arable land, of which 46% is allocated in the Central Plain (Center for Agricultural Information, 2005).

In the last decade, land resources have been extensively used to increase agricultural production to provide for the burgeoning population—from 8 million in 1911 to 63 million at present. This has resulted in a constant expansion of land use for agriculture, even into marginal lands and encroachment on national forest reserves. Moreover, many areas are being cultivated with inappropriate methods causing deterioration of the land. This has accelerated degradation, which in turn causes poor production and loss of cultivated land.

The Land Development Department (LDD) is an executive agency responsible for planning, implementation, assessment, monitoring, improvement and rehabilitation of degraded soils for increasing yield and sustainable use of land resources.

PROBLEM SOILS AND THEIR AMELIORATION

Generally, the degraded soils are caused by both natural phenomenon and anthropogenic processes, but mainly from human activities. From soil survey and classification, land resources of the country showed that the degraded soils are classified into six major categories which are acid sulfate soils, peat soils, sandy soils, soil erosion, soils after mining and saline soils, and the extent ameliorated.

Acid sulfate soils

Acid sulfate soils in Thailand extend in areas of about 1.5 Mha, occurring in the Central Plain and along the coastal areas. These soils are formed from marine deposit. The limiting factors effecting suitability of soils for plant growth are strong acidity, potential Fe, Al and Mn toxicity and unavailability of some nutrients. These areas are mostly used for rice cultivation but with very low productivity of about 937–1 250 kg/ha.

The use of liming materials (i.e. lime, marl, burned-shell lime, ground limeste, etc.) is considered to ameliorate the soil by raising soil pH. In the Central Plain where acid sulfate soils exist, the LDD has studied remedial treatments to accelerate crop yields. Results showed that marl is capable to remedy acid sulfate soils, thus producing high economic return. The deficient elements are improved by adding organic and inorganic fertilizers. Aside from that, soil, water and crop management are also needed. However, the application of lime, the residual effect can remain for 10 years depending on application rate and other environmental factors (Muensung *et al.*, 1992).

Although, lime is very important to ameliorate acid sulfate soils, the farmers have limited budget to purchase this material. Since 1975 marl was used for improving acid sulfate soils. A project started, using marl as soil amendment, which is distributed free of charge to the farmers to improve their lands such as a big demonstration farm. This is the only way to improve acid sulfate soils and increase crop yield in these areas. On the other hand, the acid sulfate soils along the coastal areas in the southern part of the country use ground limeste. This has been introduced and also being distributed to farmers to improve their farms, free of charge.

Peat soils

Generally, peat soils are perennially wet at the surface and are mostly under reeds and native swamp trees. It approximately covers an area of 0 .08 Mha on the fringe of the swamps where the squatters had the land cleared. Rice is the dominant crop that can be grown in this type of soil, including wild sago palms which scatter throughout the areas. Soils in this area are extremely acidic and have inadequate nutrients for growing economic crops. The thickness of peat layer is a limiting factor on its utilization, particularly on holding and penetration of rooting system in the soils. In classification, soils contain 20% organic matter at the surface layer but the minimum depth must be at least 40 cm thick.

Remedy of these soils requires an appropriate management e.g. regulating the drainage, liming and application of chemical fertilizers.

Sandy soils

These cover an area of approximately 9.28 Mha (Srithongchim, Chaturongkakul and Tanbhiban, 1992) and found in every part of the country, with the largest area is in the North-east region. They are coarse textured and derived from sandste, with a low moisture retention capacity, low organic matter content and low cation exchange capacity.

These soils can be improved by using soil mulching, soil amendments, and split fertilizer application. Water management is also important to retain water in soils for plant growth, which applied with various methods such as the use of subsurface irrigation and drip irrigation. For subsurface irrigation, use of porous earththenware as a moisture emitter at the root zone has been practiced.

Soil Erosion

As the number of population rapidly increased in recent years (3–4 decades) demand for land cultivation has constantly increased, that led to the use of marginal land and unsuitable land, such as steep slope for production. However, the hectarage of agricultural lands has increased to 10, 18, 20 and 21 Mha in 1963, 1973, 1986 and 1995, respectively. Results from land use changes led to increasing the rate of soil erosion in many areas particularly in highlands where the farmers grow upland crops without any conservative measures.

About one-third of the total land area of the country is mountainous with slopes higher than 35%. They are scattered in the North, North-east and Southern parts of the country, covering an area of 17 Mha. The soil loss occurred at the rate of 50–93 t/ha/year (Chantawat and Anechsamphant, 1992).

Soil and water conservation in Thailand has been conducted more than hundred years. The irrigation terraces for rice cultivation still remain as an evidence in the North,

North-east and in the Southern part of the country (Chantawat, 1991). The responsibility on soil and water conservation was transferred to the Land Development Department (LDD) in 1963. The technology transfer has been conducted including demonstration, training, general meeting and media. Soil and water conservation comprises of mechanical and biological measures. The mechanical measures are terracing, diversion terrace, bench terrace, hillside ditch, individual basin and farm pond while biological measures are contour cultivation, strip cropping, reforestation, mulching and cropping system.

In 1991, His Majesty the King initiated the use of vetiver grass for soil and water conservation. This grass has been used nationwide–a good response from various experiments and information dissemination campaign. Vetiver seedlings are currently distributed free of charge in every part of the country as requested by the farmers.

Soils after mining

Mining in Thailand has long been operated, extending in an area of about 0.032 Mha (Srithongchim, Chaturongkakul and Tanbhiban, 1992). Tin mining is mostly done in the Southern Region. After mining, land was being abandoned because soils become a waste product from separation mineral contents to the soil like tin or other minerals. It comprises gravel, sand and slime with a very low fertility and low pH.

The utilization of these areas can be done in 3 purposes namely: 1) reforestation by using fast growing trees, i.e. eucalyptus and acacia etc.; 2) growing cover crop or forage for soil improvement and environment in the surrounding areas; and 3) use economical upland crops for cultivation, i.e. baby corn, pineapple and water melon etc. Since it is an adverse soil with lots of problems, requirement of a good management regarding soil, plant and water are needed for utilization.

Saline soils

The extent of salt-affected soils in Thailand is approximately 3.5 Mha, which are in the North-eastern part, the Central Plain and along the coastal belt of the country. Although the salt-affected lands comprise of only 16% of the cultivated lands, it is a major soil problem affecting the agricultural land use for production. They are divided broadly into two groups, inland saline soils and coastal saline soils.

Inland saline soils occur in an area of 3.0 Mha, covering two parts of the country, 1) In the North-east region it covers an area of 2.84 Mha in 17 provinces. It is recognized as seasonal dry land area that occurs during dry season due to irregular distribution of rainfall. Besides that, this region is constrained by shallow soil and sandy soil with low fertility and nutrient deficiency for most plants. 2) In the Northern region: Salt-affected soils are found in provinces, i.e., Nan, Uttaradit and Pitsanulok, covering in an area of 0.0026 Mha. 3) In the Central Plain, these soils occurred in three provinces, i.e. Nakhon Pathom, Ang Thong and Suphan Buri, covering an area of 0.16 Mha.

Coastal saline soils extend along 2 600 km of the coastal belt area, covering 24 provinces on both sides of the Gulf of Thailand and also the Andaman Sea, with a total area of 0.58 Mha.

MAJOR CAUSES AND PROCESSES OF SOIL SALINIZATION IN THE COUNTRY

Soil salinization is caused by both natural and anthropogenic processes. Saline soils are usually formed through a natural process, and presently human activities in farming system too. The causes and processes of formation of salt-affected soils are described below.

Natural process

The inland saline soils occur in the North-east and the Central Plain. The North-east is a plateau with rolling or undulating topography as its area has been uplifted from the sea millions of years ago. Distribution of salt-affected soils in this area is found on low-lying areas which salinity level of the soils is higher than other areas. Salts are derived from rock salt strata, weathering of sandste and shale impregnated with salts, and also from shallow saline groundwater (Sinanuwong and Takaya, 1974; Arunin, 1985; Im-Erb and Pongwichian, 2003).

For the Central Plain saline soils, most salts in these areas have been derived from underlain old marine sediments. The salts in the soils are chloride, sulfate and carbonate of Na, Ca and Mg. From the soil survey, this part of the country was under the influence of tidal flat condition since 4,000 to 8,000 years ago. Due to the expansion of agricultural areas to cope with the increased need of food, this has caused the inappropriate use of land and water resources in this region. The excavation of land, over-irrigation, shallow saline groundwater and the use of saline groundwater for agriculture, and particularly most of the areas lack drainage, have resulted in the increase in soil salinization.

In the coastal zone, the land is under the influence of seawater. Most of these soils are derived from marine deposits. The salt in these areas is dominated by high contents of sodium chloride, with smaller amounts of sodium sulfate and calcium, magnesium and potassium chlorides and sulfates.

Anthropogenic causes

Human activities have been responsible for anthropogenic salinization. Deforestation and the growing of shallow-rooted crops cause the consumptive use of rainwater by the vegetation to be much less, allowing excess water to percolate down to the water table. The change of ground hydrology has resulted in the movement of the groundwater and its salinity level. This caused high water table and the movement of the dissolved salts upward by capillary rise and the evaporation processes and subsequent accumulation of salts on the soil surface.

Salt making has usually been found in the very strongly saline soil areas of the North-eastern region. The process is that the producers pump the shallow concentrated saline groundwater to get evaporated on the earth pans to obtain salt afterward. This results in the seepage of saline water to adjacent area. The occurrence of saline soil due to the construction of reservoirs is usually related to its proximity to the sources of salt or in the area where saline groundwater is shallow. In that case water in the reservoirs will attain high salinity level within a few years.

Shrimp farming is a big problem that causes anthropogenic soil salinization. In the process shrimp farmers transfer concentrated brine (and occasionally applied with salt granules) to the ponds and dilute it with freshwater to a salinity level of 3–10 ppt which is suitable for shrimps before releasing them to the pond. The intensive use of chemicals and antibiotics has severely affected the environment. Discharge of sludge, excess feeds and saline water into nearby irrigation canals, including seepage of saline water to adjacent agricultural areas and undergroundwater has led to a significant build-up of toxicity and salinity. In some severe cases large rice fields have gone out of production.

MAIN SOLUTION, TECHNOLOGIES APPLIED IN THE COUNTRY TO COMBAT SALINIZED LAND

The Development Department has been involved in the soil salinity programmessince 1963. It conducts agronomic research, soil salinity classification, and demonstration of some correction measures.

Prevention

The prevention and control measures of soil salinization can be either engineering or biological. Engineering measures include open ditch drain, surface field drain and sub drain, etc. to regulate water table to be at a depth that the capillary rise can be controlled. This is relatively costly. Biological control measure, which is less expensive, includes screening of suitable salt-tolerant plant varieties with a deeper-rooted system and high consumptive use of water. These plants have been grown in recharge areas to reduce the amount of excess water that goes down to the water table. This lowers the water table to the depth that will not cause a capillary rise of the salty groundwater. Salt-tolerant plants such as *Acacia ampliceps* and *Casuarina glauca* have been effectively grown; they can tolerate the condition of the North-east region and are shown to lower the saline groundwater in any discharge area (Dissataporn *et al.*, 1995). Reforestation minimized salt-affected area in the project site by a proportion of 5:1 (Im-Erb and Yamclee, 1996).

As for the coastal areas they are usually subjected to tidal movement and occasional flood, and engineering control measures are normally needed. Dikes or polders being used on the coastal belt of the country are constructed high enough to prevent high tides from inundating the lands. To regulate the brine and freshwater flow, sluice gates are installed.

Improvement and reclamation

As saline infertile soils in the North-east region caused a major production constraint, a government policy was initiated in 1982 through the National Economic and Social Development Plan (NESDP). This policy aimed to increase yields in the area of slightly and moderately saline soils which are used mostly for rice production. Low-cost technology packages from research findings have been disseminated to the farmers in the target areas through training and demonstration. Results from demonstration plots showed that the application of green manure *(Sesbania rostrata* at the seed weigh rate of 43.75 kg/ha), compost (12.5 t/ha), farm yard manure (12.5 t/ha) and rice hull (12.5 t/ha) gave rice yields of 2.74, 2.99, 2.98, 2.63 and 2.31 t/ha, respectively, which are all higher than the control (LDD, 1997). Reclamation of soils that have been subjected to seawater or brackish water inundation is necessary in some areas because the salinity level of soils is high, making the lands unsuitable for cultivation. Actually, the coastal saline soils are mostly fertile, but not productive due to high salinity, acidity and texture. Reclaiming saline soils requires the removal of the exchangeable sodium from the root zone. Reclamation then requires calcium such as gypsum for replacing exchangeable sodium. Various experiences on desalinization of soils in the polder system showed that at a depth of 0–100 cm, the average EC was reduced by 40%. Desalinization by basin irrigation showed the highest desalinization at a depth of 20–40 cm (Tandatemeya and Im-Erb, 1978). However, farmers in the coastal areas use the indigenous technologies to reclaim their lands. The lands are improved by ridging to grow coconut or other salt-tolerant crops. Reclamation process usually takes time and farmers have to wait for many years before they can grow high-value crops. Continued leaching, use of salt-tolerant crops and soil amendments such as gypsum and/or organic matter is recommended to assist in this process.

Legislative measures

Although the degraded soils, particularly salt-affected soils, can be solved by present technologies, land deterioration has continued to be a problem. Salt production and shrimp culture, which have caused salinity problem in large areas, have also continued to grow. Legislation can be also a better measure so that the government can impose policies to protect arable land from various harmful activities. All legislative issues have been concerned with the effective use of natural resources, conservation of land resources, rehabilitation and development of degraded lands and pollution prevention and alleviation. In 1989, the government banned illegal salt production in the North-east region and in 1998 banned shrimp farming in freshwater areas of the Central Plain.

CONCLUSIONS

In the last five decades, land use in Thailand has changed due to rapidly growing population, land use pattern change and introduction of modern technologies in particular. These changes brought encroachment of natural forest, use of marginal lands and mismanagement of soil and water which resulted in deteriorated soil and water resources, manifested particularly in term of land degradation.

Among these marginal lands, saline soils are the oldest and one of the most important environmental problems of mankind. They cover a total area of 3.5 Mha. It is a form of degraded land that has become causative factor for low agricultural productivity in the Northern region, North-eastern region, the Central Plain and along the coastal areas of the country.

The problem of soil and water deterioration that has become a significant national issue. The highlight outputs of its studies have been used to conduct and disseminate to the stakeholders in the degraded lands including to increase awareness of decision-makers, which would be a better chance for having sustainable use of marginal lands, particularly to enhance good agricultural production to meet the fast increasing demand.

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Saline water effect on three tomato cultivars under subsurface drip irrigation with three regimes in Tunisia: Yield and fruit quality

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ABSTRACT

In the investigation of crop salinity tolerance and management, an experiment was carried out on three tomato cultivars (*Solanum lycopersicum*, cv. Río Tinto, Río Grande and Nemador) treated by drip irrigation (DI) and subsurface drip irrigation (SDI). This experiment was done in a silty clay soil using saline water (6.57 dS/m) and applying three irrigation regimes: 100%, 85% and 70% of the tomato plants' water requirement.

In the case of a deficit regime with DI, the results show an increase of soil ECe and a decrease in flower and fruit numbers and yield for all three cultivars. We also observed an increase of titratable acidity (TA) and total soluble solid content (TSS), while there was a decrease in fruit juice pH.

Keywords: Soil salinity, tomato, deficit irrigation, subsurface drip irrigation, salinity tolerance.

INTRODUCTION

Soil salinity is a major limiting factor that affects about 20% of the irrigated area in the World (FAO, 2005) and about 30% of Tunisian irrigated areas (Hachicha, 2007). In the arid context, salt stress inhibits crops growth and yields. Tomato studies show that the increase of irrigation water salinity induces a decrease on the fresh fruits weight (Li *et al.*, 2001; Magan *et al.*, 2008).

In other respects, localized irrigation systems can also reduce evaporation and accumulation of salts in the root zone (Al Omran *et al.*, 2005). Among these systems, drip irrigation (DI) permits an uniform and frequent application of water (Oron *et al.*, 2002) and direct feeding to the plant at the root zone level, inducing an increase of yield and save of water (Sezen *et al.*, 2008). However, this system can create an accumulation of salts in the soil surface (Oron *et al.*, 2002; Hachicha *et al.*, 2006). As an alternative to reduce these negative aspects and improve water use efficiency, subsurface drip irrigation (SDI) has been developed (Oron *et al.*, 2002; Al Omran *et al.*, 2005). The aim of this study was to investigate the response of three tomato cultivars to subsurface drip irrigation and drip irrigation in relation to three irrigation regimes by studying its responses on growth, yield and fruit quality under saline water conditions (6.57 dS/m).

MATERIALS AND METHODS

Plant material

Three tomato cultivars (*Solanum lycopersicum*) were used: Río Grande, Río Tinto and Nemador.

Experimental design

The experiment was carried out during summer 2007 (from May to August) at the Cherfech Agricultural Experimental Station, 25 km north of Tunis in the Low Valley of Mejerda River. Climate of the region is Mediterranean with 470 mm as annual rainfall and 1370 mm (Penman method) as annual evapotranspiration. The experiment was set using emitters with filters in DI and pipelines buried at 30 cm depth in SDI.

The irrigation water came from a well with ECw=6.57 dS/m and SAR=14.2.

Crop measures and analyses

Measurements were made to determine components of yield (flowers, fruits numbers, fruit yield) and fruit quality (titratable acidity, total soluble solid content, pH).

Soil analyses

Soil salinity was determined before installation and at the end of the crop cycle at the roots level and every 20 cm up to 40 cm depth.

Data analyses

Statistical processing was achieved by the software STATISTICA, Version 5 (Statsoft France, 1997). A factorial analysis of variance and means comparison were carried out as needed by the LSD test at a significance level of 0.05.

RESULTS

Effect on soil

An increase of ECe in the case of the regime 70% of tomato water requirement.
An increase of ECe for the three tomato cultivars in the case of DI.
The increase of ECe was more important in the layer 0–20 cm that 20–40 cm.

Effect on the flower numbers

A significant decrease of the flowers number for the three tomato cultivars with the deficit regime.
The evolution of flowers number was significant between SDI and DI.

Effect on fruit numbers

A significant decrease on Río Grande cultivar for the regime 70% of tomato water requirement.
A highly significant increase of fruits number in SDI in comparison to DI for Río Grande and Nemador.

Effect on yield

A significant decrease of fruit yield on Río Tinto and Nemador cultivars for the regime 70% of tomato water requirement
A significant increased of fruit yield in the case of SDI compared to DI for the three tomato cultivars.

Effect on fruit quality

An increase of TA and TSS for the three tomato cultivars with the regime 70% of tomato water requirement and in SDI.

A reduction of pH for the three tomato cultivars for the regime 70% of tomato water requirement and no significant variation of juice pH between SDI and DI on the two cultivars Río Tinto and Nemador.

DISCUSSION

Irrigation by saline water increased soil salinity (ECe) and it was more pronounced with the more deficit (70%) irrigation regime, in DI than SDI and at the surface layer (0–20 cm). Some similar results have been obtained by Oron *et al.* (2002) and Hachicha *et al.* (2006).

The study of salinity effect in interaction with the irrigation systems (SDI and DI) and the three irrigation regimes (100, 85 and 70% of crop water requirement) shows a decrease of the fruit number for the three tomato cultivars. These results are in agreement with those of Showemimo *et al.* (2007).

Results markedly exhibited a decrease in mean fruit weights in the three tomato cultivars, essentially for the more deficit regime. They agree with those obtained by Della Costa and Granquinto (2002) for pepper. Therefore, the decrease of this parameter leads to the consequence of yield decrease. The response of Río Grande cultivars was more adaptive to the deficit regime. Iqbal *et al.* (2008) obtained similar results for two cultivars of Sunflower. However, the increase of yield is statistically significant for SDI. These results are in agreement with those found in onion (Enciso *et al.*, 2007) and squash (Al-Omran *et al.*, 2005). Besides, the use of saline water (6.57 dS/m) induces an increase of fruit quality; notably percentage of titratable acidity, total soluble solid content (TSS) and a decrease of pH is marked on the three tomato cultivars in the case of the deficit regime (70% of crop water requirement). The present study is also in agreement with those found on eggplants by Savvas and Lenz (1996) and on tomato by Magan *et al.* (2008). Regarding the use of irrigation systems, the increase of these two parameters of the fruit (titratable acidity and TSS) was observed in the three cultivars with DI treatment.

CONCLUSIONS

The deficit irrigation induced a decrease of fruit yield in the three tomato cultivars, particularly Río Tinto and Nemador. Concerning the irrigation system, Río Grande variety had the best yield with SDI. In opposition to its negative aspect, the use of saline water with water deficit (70% of crop water requirement) and DI system improved fruits quality; notably TA, TSS and caused a decrease of the juice pH.

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Improving management of saline water irrigation at farm scale: A case from the south of Tunisia

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In this study we followed several agricultures in terms of irrigation management with high salinity level of the irrigation water in three locations in the south of Tunisia. We calculated the crop water requirements of the cultivated crops (especially fodder) using the method described in the FAO56 guideline for computing crop water requirements.

Comparing the calculated crop water requirement with what is actually given by the farmers revealed bad irrigation management by the farmers, mainly in terms of the quantity of water supplied and because the concept of water quality was not included in the irrigation management system.

Effect of proline exogenous application on two tomato varieties irrigated with saline water by subsurface drip system

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An experiment was carried out using saline water (6.57 dS/m) and subsurface drip irrigation (SDI) on two tomato varieties (*Solanum lycopersicum*, cv. Rio Grande and Heinz$_{-2274}$) in a silty clay soil. Exogenous application of proline was done by foliar spray at two concentrations: 10 and 20 mg/l, with a control situation (saline water without proline), during the flowering stage.

The results show an increase in plant growth (leaf area), fruit yield and mineral composition (K and Ca) in the leaves of both varieties accompanied by a significant decrease of Na^+ and blossom-end rot (BER), particularly at the lower concentration used (10 mg/l).

Keywords: *Solanum lycopersicum*, salt stress, proline, SDI, Tunisia.

INTRODUCTION

Water scarcity and salinity are the most important limiting factors for agriculture in arid and semi-arid Mediterranean regions (Hachicha, 2007). This salinity provokes salt stress which is the most important abiotic stress seriously affecting crop growth and productivity.

Under a saline environment, plants develop different adaptative mechanisms (Sairam *et al.*, 2006). One adaptative plant response to salt stress is the synthesis and accumulation of proline (Fidalgo *et al.*, 2004). It can be associated with several stresses such as temperature, drought and starvation (Ashraf and Foolad, 2007). Therefore, the exogenous application of proline promises an alternative/additional way to genetic engineering to improve the yield under environmental stress (Heuer, 2003; Demiral and Turkan, 2006).

MATERIALS AND METHODS

Plant material

The experiment was carried out during the summer 2008 and 2009 (from 2/05 to 27/08). Two tomato cultivars (*Solanum lycopersicum*) have been used: a tolerant variety to salts, Rio Grande (Maggio *et al.*, 2004) and sensitive variety to salts, Heinz$_{-2274}$ (Kahlaoui *et al.*, 2010).

Experimental design

The experiment was carried out at the Cherfech Agricultural Experimental Station located 25 km north of Tunis in the Low Valley of Mejerda River. Climate of the region is Mediterranean with an annual rainfall close to 470 mm and an average yearly evapotranspiration of 1370 mm (PET Penman). The experiment was set using emitters with filters and buried at 30 cm depth in subsurface drip irrigation (SDI). Three conditions were used: two exogenous applications of proline at 10 and 20 mg/l and a control (without proline application).

Irrigation water

The irrigation water used comes from a well with ECw=6.57 dS/m and SAR=12.81. The water chemical characteristics are described in table 1. The total water quantity used was 272 mm.

RESULTS

Growth parameters

- An increase of leaf area on Rio Grande and $\text{Heinz}_{\text{-}2274}$ with the lower proline concentration (10 mg/l).
- Fruit yield and blossom-end rot (BER).
- A significant increase of fruit yield for both tomato varieties with lower and higher concentration of proline particularly for $\text{Heinz}_{\text{-}2274}$.
- A greater increase of BER in the sensitive variety ($\text{Heinz}_{\text{-}2274}$) that in the tolerant one (Rio Grande) with saline water.
- A significant reduction of BER in the $\text{Heinz}_{\text{-}2274}$ variety by foliar pulverization of proline at 10 mg/l.

Mineral nutrition and ion quantification

- A significant reduction of Na^+ content in leaves of both varieties by foliar spray of proline.
- A significant increase of K^+ content at the leaves in both varieties treated with the lower proline concentration.
- An increase of Ca^{2+}content by the lower proline concentration in leaves on both tomato varieties.
- An increase of Ca^{2+}content in the Rio Grande and a reduction in $\text{Heinz}_{\text{-}2274}$ at 20 mg/l of proline.

DISCUSSION

The exogenous application of 10 mg/l of proline led to a significant increase of leaf area. Indeed, the exogenous application of proline can play an important role in enhancing plant stress tolerance. In various plant species growing under saline conditions, this exogenous application of proline provided osmoprotection and facilitated growth (Ashraf and Foolad, 2007), by providing a stress-preventing or recovering effect.

Salinity led to a significant decrease in fruit yield, in the tolerant variety (Rio Grande) than in the sensitive variety ($\text{Heinz}_{\text{-}2274}$). Exogenous application of proline by foliar pulverization caused a significant increase in both tomato varieties studied, particularly in the $\text{Heinz}_{\text{-}2274}$ at the lower proline concentration. These results are in agreement with Kaya *et al.* (2007) on melon. The reduction observed with the higher proline concentration was due to an increase of the blossom-end rot (BER), which seems to have been induced by the exogenous application of the higher proline concentration in both tomato varieties, principally the $\text{Heinz}_{\text{-}2274}$. This increase was also observed in $\text{Heinz}_{\text{-}2274}$ irrigated only with saline water that caused a deficiency of Ca^{2+}.

In our experiment, salinity stimulates the accumulation of Na^+ in leaves of both tomato varieties. However, this accumulation was dramatically reduced in these plant organs in the presence of 10 mg/l of proline used for foliar application, suggesting its interference in the process of osmotic adjustment. As a consequence, this decreased accumulation led to an increase of K^+. This can be attributed primarily to the ability of roots to exclude the salt from the xylem sap flowing to the shoot, which would immediately imply better plant growth (Heuer, 2003). In the present study, there was a significant decrease of Ca^{2+} in leaves on both tomato varieties without exogenous proline application. This effect no longer is deleterious by the proline exogenous application treatments, which was better detected in the tomato tolerant variety Rio Grande.

CONCLUSIONS

The experiment carried out in the field with saline water put in evidence the positive effects of foliar spray of proline and of subsurface drip irrigation on plant productivity. Indeed, the exogenous application of 10 mg/l proline led to an improvement of the growth parameters (leaf area , fruit yield and mineral composition (K, Ca) in leaves of both tomato varieties studied accompanied by a significant decrease of Na^+, BER, particularly in the sensitive variety (Heinz$_{-2274}$).

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A key role for ABA-GE and atypical LEA protein expression in an American halophyte treated with different sodium salts

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ABSTRACT

The plant hormone abscisic acid (ABA) plays a major role in plant responses to stress. Although rapid production of ABA in response to salt stress is essential to define ABA as a stress hormone, an equally rapid catabolism of ABA when such stresses are relieved is also essential in that role. Since ABA mediates so many stress responses, the initial perception of dehydration and the subsequent changes in gene expression that lead to rapid ABA biosynthesis constitute the most important stress signal transduction pathway among all the plant responses to stresses. In glycophytes, stress tolerance is increased with high concentrations of ABA, whereas in halophytes the ABA role in not yet known. Thus, endogenous ABA levels in leaves and roots of salinized plants of the halophyte *P. strombulifera* were determined. ABA levels differed with the type of salt, the concentration, the analysed organ and the plant age. A remarkably higher ABA content was found in leaves in comparison with roots, maybe due to its protective role, and a rapid biosynthesis and distribution from roots, where the highest levels were detected at the beginning of the treatments. Leaves from sulfate treated plants showed the highest ABA levels, in coincidence with toxicity symptoms showing up. Dynamics of ABA levels from 6 to 24 h in all treatments would indicate that ABA would act like a triggering signal for adaptive biochemical and molecular mechanisms for plant survival to salinity.

With respect to ABA metabolism, our results showed that both roots and leaves of *P. strombulifera* seedlings accumulated mainly ABA-GE (Glucose conjugated) in relation to PA and DPA which levels were very low. This pattern was especially marked in plants treated with the highest Na_2SO_4 concentration. The greater ABA-GE accumulation recorded in roots under high salt concentrations (Ψo: -2.6 MPa) could be related to ABA transport to the leaves where the highest levels of free ABA were detected. It is noteworthy that in the presence of Na_2SO_4, both roots and leaves showed the highest ABA-GE concentration of as well as free ABA, which correlates with the severe stressful condition imposed by this salt. Northern analysis in *P. strombulifera* revealed the expression of an atypical LEA protein in control roots showing constitutive expression; its over-expression in roots of sulfate-treated plants at Ψo: -1.8 MPa correlates with the beginning of ABA and ABA-GE accumulation.

Keywords: Halophyte, abscisic acid, salt-induced gene expression.

ABA METABOLISM AND SALT-INDUCED GENE EXPRESSION IN *PROSOPIS STROMBULIFERA*

Abscisic acid (ABA) is a phytohormone with many functions in plants, including roles in seed development, dormancy and germination, root and shoot growth, maintenance of water relations and stress tolerance (Zhang *et al.*, 2006). The level of ABA in plant cells is controlled through a homeostatic mechanism involving biosynthesis, catabolism and redistribution. These processes combine to result in elevated levels of ABA in key cells and tissues at specific developmental time-points and in response and tolerance to stress (Finkelstein and Rock, 2002; Priest *et al.*, 2005). This phytohormone in response to environmental abiotic stress has been well-studied in glycophytic plants, but such information is much more limited for halophytic plants.

Prosopis strombulifera (Lam) Benth is a halophyte shrub distributed from the Arizona desert (U.S.A) to Patagonia (Argentina) and is especially abundant in the salinized areas of central Argentina. This species showed a halophytic response to NaCl surviving up to 1M NaCl in *in vitro* experiments, but a strong growth inhibition at lower Na_2SO_4 concentrations. These differential responses to the most abundant salts present in most salinized soils make this species an excellent model to study salt-tolerance mechanisms in halophytic plants.

Endogenous levels of ABA and its metabolites in leaves and roots of salinized plants of the halophyte *P. strombulifera* were analysed. The results obtained showed that ABA levels were different depending on the salt type and concentration, the organ analysed and the age of the organ. Moreover, regardless of treatments, it is important to note that the highest ABA concentration was recorded in leaves compared to roots. The synthesis of this hormone can occur in both roots and leaves, however, in this species leaves seem to be the main ABA source or alternatively, ABA could accumulate mainly in these organs regardless of the site of biosynthesis. These results are consistent with studies by Maggio *et al.* (2007) in tomato plants in which ABA concentration was higher in the shoot suggesting that ABA accumulation in the shoot could involve the release of stored conjugated forms and/or *de novo* ABA synthesis.

This large ABA accumulation recorded in our experiments may be related to its protective role through stomatal opening regulation and compatible solutes synthesis (Wilkinson and Davies, 2002). The endogenous levels recorded since the beginning of the experiments show that ABA synthesis and transport are rapid responses observed in all treatments including controls, mainly in roots (Sosa, 2005; Llanes, 2010).

The decrease in ABA levels at Ψo: -1.8 MPa NaCl (500 mM) in roots suggests that this treatment may not be sensed as stressful by this species, taking into account that growth was stimulated up to this concentration showing a true halophytic response (Sosa, 2005; Reinoso *et al.*, 2004; Reginato, 2009). In the presence of sulfate, instead, leaves had higher ABA content especially at the lowest osmotic potential. Therefore, ABA would act as a trigger signal of biochemical mechanisms for the osmotic adjustment necessary for plant survival from the beginning of the stressful situation, mainly under sulfate treatment. These results coincide with the proposal that low ABA concentrations would be essential for vegetative growth in various organs (Cheng *et al.*, 2002), but large quantities produced under stress would have a role in inhibiting processes such as stomatal opening, leaf expansion and stem growth. Recently it has been suggested that low levels of ABA contribute to the best adaptive response to salt stress (Zhang *et al.*, 2006). This would explain the low levels of ABA and its metabolites found in this work in NaCl and salt mixture-treated plants, in which only soft stress symptoms were observed at the highest salt concentration.

The content of biologically active ABA and its metabolites in plant tissues is the result of a combination of transport processes, biosynthesis and metabolism. While it is clear that the biosynthesis of ABA responds to environmental stress conditions, in recent years it has become evident that the catabolism is also required to control the ABA levels in response to an environmental condition. Rapid ABA accumulation elicits many biochemical and molecular responses that help the plant to survive in the stressful situation; to perform this function efficiently, ABA accumulation must meet two requirements: its production must be initiated rapidly after an environmental signal to avoid any inhibition of life processes and plant growth under such condition. The second is that it is quickly degraded or deactivated when the stress is relieved, to restore the normal processes and growth rate.

In relation to ABA metabolism, both roots and leaves of *P. strombulifera* seedlings accumulated high ABA-GE levels in comparison to PA and DPA, the former being the major ABA metabolite determined in this species, mainly in plants salinized with the highest sulfate concentration (stressed plants).

Sauter *et al.* (2002) suggested that ABA conjugates are formed in the cytosol of root cortical cells and are transported to other cells via parenchymatic symplast (because of its highly hydrophilic property cannot cross the endodermal barrier) and then dumps the wood vessels. The salt stress tripled the flow of ABA-GE in the xylem of several plants. Little is known about this mechanism, but evidence obtained in Arabidopsis suggests the existence of a specific carrier to flow ABA-GE into the xylem, similar to the ABC-transporters across membranes observed in other conjugated hormone, the indole-acetyl-aspartate (Sauter and Hartung, 2000).

In *P. strombulifera* the greater accumulation of ABA-GE recorded in roots under high salt concentrations (Ψo: -2.6 MPa) could be related to the transport of ABA to the leaves, where the highest levels of free ABA were recorded. In the presence of sulfate, both roots and leaves showed the highest concentration of ABA-GE as well as free ABA.

Analysis of ABA-glucosidase enzyme activity revealed that sulfate-treated seedlings showed greater enzymatic activity in leaves (0.093 Enzyme Units /ml of extract) than in roots (0.0073 Enzyme Units /ml of extract) indicating that in this species ABA-GE would be an ABA-transport form from the roots towards the leaves where increased levels of free ABA were observed. This results constitute the first report of conjugated ABA role in a halophytic plant.

Low levels of DPA were generally determined and in most cases PA was not detected, demonstrating that is rapidly metabolized. The relatively high DPA content registered in sulfate-treated leaves, mainly at Ψo: -2.6 MPa, would be an indicator of metabolic control of endogenous ABA level by stimulation of hydroxylase activity for ABA degradation.

On the other hand, a gene encoding an atypical LEA protein from *P. strombulifera* was isolated and characterized. Atypical LEA proteins are those containing a significantly high proportion of hydrophobic residues. Given their physicochemical properties, atypical LEA proteins are not soluble after boiling, suggesting that they adopt a globular conformation (Cuming, 1999). Expression analysis of plant proteins of this group, as well as information available from transcriptomic projects, shows that they accumulate in mature seeds in response to dehydration, salinity, or low temperatures (Romo *et al.*, 2001). Some members also respond to hypoxia (Siddiqui *et al.*, 1998) or to high-excitation pressure imposed by high light (Dong *et al.*, 2002).

Northern analysis for LEA proteins in *P. strombulifera* roots showed a constitutive expression of a LEA gene which is inhibited by mild salt treatment (Ψo: -1 MPa) and is induced by Na_2SO_4 treatment at -1.8 MPa and lower. This last result is consistent with the beginning of ABA and ABA-GE acumulation in plants and suggests a role for ABA in the regulation of this gene which expression pattern might reflect the stress level sensed by the root system; considering that *P. strombulifera* is a halophyte, the constitutive expression in non-treated roots maybe related to that the absence of salt could also be sensed as stressful by this species, in coincidence with the high ABA levels detected in control plants.

However, a different expression pattern for this gene was observed in leaves, where no constitutive expression was observed. Instead, a NaCl induction with both concentration tested (Ψo: -1 and -1.88 MPa) was also observed in these organs. Furthermore, its expression at Ψo: -1.8 MPa in leaves of NaCl-treated plants showing optimal growth, reveals a protective role for increased stress tolerance by protecting biomolecules from dehydration, ion sequestration, among others.

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Soil Doctor: Its significance to the land development programmes in Thailand

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ABSTRACT

Thailand has abundant and diverse natural resources. As an agrarian country, its economy is dominated by the agricultural sector in terms of gross domestic product (GDP), employment and provision of food security. It is estimated that the agricultural sector accounted for 38% of the population in 2005. The total land area of the country is approximately 51.4 Mha, comprising 38% farmland, 25% forests, with the remaining 37% occupied by public area, sanitary district areas, swamp land, railroads, highways, real estate and othes (Center for Agricultural Information, 2005).

The use to which the land is put has always been dynamic, depending on various factors, such as rapid increase of population, change of cropping pattern and emergence of new technologies. Prior to the mid-1950s the agriculture system was characterized by mono cropping, with rice cultivation as the major crop. In 1960 rice cultivation covered almost 60% of total cultivated land, compared to 12% for upland crops and 16% for tree crops. The upland crops increased substantially in the period 1960–1984 from 12–23%, reaching almost 25% by 1993, while forested areas decreased sharply from 54% in 1960 to 26% in 1993 (Charrupat, 1998).

Soil resources are being used to increase agricultural production to provide for the increasing population, growing from 8 million in 1911 (Office of National Statistics, 1958) to 63 million in 2008. This has resulted in constant expansion of land use for agriculture, even into marginal lands and encroachment on national forest. Moreover, many areas are usually cultivated without proper use of chemical inputs, due to lack of basic knowledge and inappropriate land use. This situation led to the accelerated degradation of land resources, causing fertility decline of soils. This is a major cause of poor production and loss of cultivated land.

Degradation of soils and mismanagement of land and water resources are the major causes that limit agricultural productivity. This problem has increased while the number of officials in the Land Development Department (LDD) has declined. To solve the problems, the LDD has planned several programmes including Soil Doctor Programme. The Soil Doctor Programme was initiated to be a part of non-governmental support. This paper covers the achievement of Soil Doctor volunteers and their activities.

MATERIALS AND METHODS

Since 1961 the government policies on land use have been formulated in national economic and social development plan. The plan attempts to address these issues in accordance to maintain agricultural productivity, increasing the farmers' income and standard of living including promotion of sustainable development and use of natural resources.

The mandate of Land Development Department is to conduct soil survey and classification and for analyzing land suitability, soil fertility research and management, soil analysis, land reclamation and improvement and soil and water conservation. As the problem on land degradation has increased, the number of official in the LDD has declined. The government did not increase the number of official even the problem continues. To address the problem, the LDD has initiated the Soil Doctor Programme in 1992. Soil doctors are the farmers who volunteer to assist the officials in transferring land development techniques to farmers in their own villages through out the country. The technologies are soil and water conservation, land rehabilitation and improvement and modern agricultural production including organic farming, etc. which were simplified by the extension workers and transfered by soil doctors to the farmers. The total Soil Doctors in the country is now 73 832, scattering in every village.

Land Development programmes in 2007 were selected to study the achievement of soil doctors. The programmes are: 1) rural development to eliminate poverty, and 2) reengineering of agricultural system. The objectives of the programme were to develop land resources in a total area of 288 000 ha of 1.5 million households through out the country through the improvement of crop yields and the sustainable use of soil and water resources.

RESULTS AND DISCUSSION

The results showed that the developed areas by using various techniques have been covered arable land in an area of 288 000 ha of 1.5 million households. Several soil and water conservation methods have been screened and tested methods which are proved that suitable to area condition. In fiscal year 2007, the knowledge and techniques regarding soil sciences and land development have simplified and transferred to Soil Doctors. The purpose is to conserve soil and water resources including sustainable use of natural resources. For instance, introduction of land development techniques, organic farming and using biotechnologies techniques including soil rehabilitation and improvement have been transferred. On highlands where a slope of 12–35%, bench terraces and hillside ditch are recommended in conjunction with vegetative control measures. Hedgerows consisting of multipurpose which are leguminous trees and crops pigeon peas or grass strip such as vetiver have been recommended. Moderately sloping lands with a slope of 5–12%, diversion, diversion, absorption and other graded terraces have been recommended. Diversion terraces are constructed on the steeper slopes and absorption terraces or level terraces have been recommended for soils with a high infiltration capacity. In lowlands, the method on controlling water level or regulating water is to evacuate the proper ditch in farm areas. Water conservation and water harvesting are also introduced in the same time which a construction of farm ponds, moisture ponds and sediment ponds, incorporated with graded terraces and absorption terraces.

Water deficit also became a severe problem, even though the country is located in the tropical monsoon region. The occurrence of water shortage for irrigation derived from low amount of rainfall with irregular distribution and long drought periods. The Land Development Department has developed rainfed areas by providing irrigation through the construction of many small ponds with the cost-sharing programme that the farmers have to pay around 15% of the total cost. The consequences of water impounding for irrigation in the developing areas showed that the farms had increased the average farmer's net annual income 27% (Planning Division, 2008). Moreover, introduction of land development techniques, organic farming and using biotechnologies techniques including soil rehabilitation and improvement has been done.

As the Land Development Department initiated Soil Doctor Programme in 1992 with 190 soil doctors of (Attaviroj, 1996) and succeeded increasing to 73 832 at present. The capability of them is gradually developed with training and actual field practices. The soil doctors have worked with Land Development Department Officials side by side and have particularly played an important role on Land Development to eliminate pauperization and rural development and reengineering of agricultural system including sustainable use of soil resources as well. The major achievements of soil doctors in the Land Development Programmes in 2007 were:

- Rehabilitation and prevention on soil erosion conducted in an area of 166 516 ha.
- Land degradation improvement (such as saline soils, acid sulfate soils and sandy soils) has conducted in an area of 24 119 ha.
- Advocate agricultural career in the southern province by improving abandoned paddy fields, improvement of soil and water conservation system and improvement of abandoned areas for growing oil palm trees have conducted in an area of 1 460 ha.
- Mobile Agricultural Laboratory: the activities have been conducted on soil and water analysis including recommendation to farmers in the number of 670 107.
- Establishment of a study centre, following the King's initiative project on self sufficiency theory completed in 800 centres in every district thoughout the country.
- Construction of 20 840 small farm ponds ponds, with the farmer paying about a 15% share per unit.
- Enhance the use of organic substances to replace chemical substances including establishment of organic farmer groups, organic farming in school and refrain burning rice straw and incorporate to the soil has done in an area of 2.8 Mha.
- Prevention of global warming effects by construction of soil and water conservation systems, growing trees, encouragement of incorporation of rice straw in the soil.

CONCLUSIONS

Soil Doctors have played an important role on soil resource management in the new era of modern agriculture. The advanced technologies and essential information recommended by Land Development Department have been disseminated through this channel for farmers and villagers. The programmes are 1) eliminate pauperization and rural development and 2) re-engineering of agricultural system. The participation of soil doctors on efficient use of Soil and water conservation and management technologies were successful to ensure farmers in cultivation of their land with conserved soils and water and sustainable use of land including a high productivity. The study confirmed that the soil doctor programme have been used to assist the officials to remedy the rapid deterioration of soil resources. The water impounding in rainfed areas is increased the farmer net annual income 27%.

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Response of photosynthesis, water relations and root growth of two tomato varieties (Lycopersion esculentum Mill.) to irrigation water salinity under arid conditions

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In several arid and semi-arid regions vegetable production is attractive option but dependent upon the availability of large amounts of irrigation water. The Arava Valley in southern Israel is a typical area where vegetable production has increased steadily in recent years. Unfortunately, water resources in the Arava and other arid regions are limited and the salinity of available irrigation water tends to be high. Furthermore, high solar radiation and low air humidity are additional stress factors for plant growth. Tomatoes have been defined as moderately sensitive to soil water salinity.

The effects of salinity and water quantity were investigated for two tomato varieties (5656 and Daniela) in lysimeter and field experiments. Irrigation water was applied by a drip irrigation system. Salinity levels increased from 1 to 11 mS/cm. The irrigation amounts varied between 210 litres (30%) and 760 litres (130%) per plant and growing season. Pre-dawn leaf water potential was measured with a Scholander pressure probe. Maximum stomata opening were measured with a portable porometer CO_2/H_2O system. Diurnal CO_2 gas exchange was determined parallel with the transpiration. Chlorophyll fluorescence was used to determine the effects of salinity and temperature stress on the photosynthesis systems. Increasing salinity effects stomata opening and limits CO_2 uptake and photosynthesis by 40%. Irrigation amounts affecting the leaf gas exchange only at extreme drought stress at 30% relative irrigation. Stomata opening is regulated by the water uptake and therefore a relation between pre-dawn water and leaf conductance could be found. Furthermore, root growth was effected by soil salinity.

Evaluation of soil phytodesalinization capacity of *Sesuvium portulacastrum* L. by a test-culture

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ABSTRACT

Progressive worldwide salinization is a major environmental threat for crop production, which forces the scientific community to look for suitable solutions for reclaiming degraded lands and to explore new farming systems for the exploitation of saline soils.

The presented work aimed to evaluate the potential use of the obligate halophyte *Sesuvium portulacastrum* for remediation of an experimentally-salinized soil to allow the subsequent growth of a glycophyte test plant. A 189-day period of cultivation of *S. portulacastrum* was effective in reducing EC, SAR and soluble Na^+ content in the upper soil layer, and to increase them in the lower horizon, probably owing to root-assisted solubilization of soil-absorbed ions.

Phytodesalinization by *S. portulacastrum* cultivation ameliorated the percentage of barley germination and allowed a partial recovery of shoot and root growth, accompanied by a decrease of Na^+ and an increase of K^+ concentration in the shoots. It is therefore evident that *S. portulacastrum* cultivation is a promising and effective strategy for phytoreclamation of salt-affected lands.

INTRODUCTION

As more than 40% of the earth is arid or semi-arid and most of the planet's water is saline, there is a growing necessity to exploit new practices and technology to prevent further soil salinization and to recover the land for cash crop cultivation. Among the most pressing environmental problems of mankind is the shortage of freshwater. Freshwater is the main environmental resource for inland agriculture and forestry, its presence is the first condition for making a land surface arable.

Sodic and saline sodic soils are characterized by poor physical properties and fertility problems which adversely affect growth and yield of most crops. The worldwide occurrence of such soils emphasizes the need for efficient, inexpensive and environmentally acceptable management.

Excess sodium (Na^+) replacement from the cation exchange sites by calcium (Ca^{2+}), followed by Na^+ leaching, may contribute to soil amelioration. Many sodic and saline sodic soils contain a source of Ca^{2+}, i.e. calcite ($CaCO_3$) at varying depths, but, owing to its extremely low solubility, this Ca^{2+} source does not contribute significantly to soil improvement (Qadir *et al.*, 2002). Amelioration of saline sodic and sodic soils with chemical amendments (among which addition of $CaCO_3$) is an established technology. However, chemical strategies have become costly, making it absolutely need to find alternative solutions to cultivate salinized soils.

In Tunisia salinized area represent more than 10% of territory. These zones enlarge progressively and they comprises poor cultivated fields or lands supporting non-exploited halophytic vegetation. Precondition for an applicable plant candidate for soil desalination are at least a high salt resistance, a high biomass production, a considerable shoot sodium content and a high degree of economic utilization. Halophytes are plants able to achieve their life cycle in extreme conditions of saline habitats and have therefore a major role in future agriculture and in rehabilitation or restoration of degraded lands. The use of such plants can be potentially viewed as an alternative method for soil desalinization since soil degradation resulting from salinity is a major impediment to optimal utilization of land resources. Halophytes have economic interest as they can be used in agro-food applications as dietary or functional foods, oils and fodders. Abdelly and cooworkers (1995) found that in saline ecosystems like the sabkha of Enfidha, annual glycophytes (*Medicago* ssp.) grow much better inside than outside the tufts of perennial halophytes.

The aim of our work was to investigate the capacity of phytodesalinization of soil by *Sesuvium portulacastrum* L. allowing a successful growth to a glycophytic test culture *Hordeum vulgare* L.

MATERIALS AND METHODS

The soil substrate was a loamy sand (11% clay, 8% silt, 49% fine sand, 32% coarse sand) taken from a farm in Soliman (N-E Tunisia). After drying and grounding soil was transferred into non-perforated pots (12 kg soil each) and pots were assigned to three treatments with ten replicates each:

- non-salinized (N), irrigated with tap water during all the experiment period.
- salinized (S), irrigated with tap water in the first week of treatment, salinized during the second and the third weeks using salinized tap water (30 g NaCl per pot), and then irrigated with non-saline tap water again until the end of the treatment period.
- phytodesalinized (P), five seedlings of the halophyte *Sesuvium portulacastrum* L., taken from mother-plants grown under moderate saline conditions at the Biotechnology Centre of Borj Cedria, were transplanted on soil and after one week, soil was salinized as previously described.

The experiment was carried out in greenhouse under sunlight conditions and after 189 days, *S. portulacastrum* plants were harvested. Soil and plant samples were immediately analysed. Soil from the three different treatments was used as the substratum for a one-month test culture of *Hordeum vulgare* L. (var. Manel). Six seeds per pot were sown and irrigated with tap water until their harvest.

At the end of the phytodesalination culture, the soil column (20 cm of height) of each pot was divided into two portions (upper horizon: 0–10 cm depth and lower horizon: 10–20 cm depth). ECe, SAR, and soluble sodium concentration were determined in the saturated paste extract. The extraction was performed under vacuum. Electrical conductivity (ECe) and the concentrations of Na^+, Ca^{2+}, and Mg^{2+} were measured in the extracts.

Plant samples were oven-dried and extracted with a three-day incubation with 0.5% HNO_3. Mineral composition of soil saturated paste extracts and plant HNO_3 extracts was determined by a Corning spectrophotometer (for Na^+ and K^+ measurements) and a VARIAN 220FS Atomic Absorption (for Ca^{2+} and Mg^{2+} analysis).

Sodium adsorption ratio (SAR) was calculated from Na^+, Mg^{2+}, and Ca^{2+} concentrations in the soil saturated paste extract according to Qadir *et al.* (2001) and water content was calculated as follows: water content=(FW - DW)/DW.

A one-way ANOVA test of SPSS 11.0 for Windows was used in data statistical analysis and means were compared according to Duncan's test at 5% (3 replicates for soil and 8 replicate for plant analyses, respectively).

RESULTS AND DISCUSSION

Non-salinized soil showed the same ECe in the upper and lower soil horizons (2.8 dS/m). SAR ranged from 4 to 12 (mmol $l^{-1})^{1/2}$ and Na^+ concentration from 0.15 to 0.30 mg g^{-1} soil, in the lower and upper layers, respectively. The experimental addition of NaCl led to an increase in the three parameters in both horizons. In particular, a 4-fold and a 1.5-fold increase of ECe were measured in the upper and lower soil layer, respectively (Table 1). Similarly, SAR and Na^+ concentration underwent a significant increase of about 4- and 5-fold (SAR) and about 3.5- and 3-fold (Na^+), in the upper and lower soil horizon (Table 1). Following salt addition, EC, SAR and soluble Na^+ content differed between the upper and the lower layers of the S soils, being higher in the upper one. This distribution reflects the difficulty of Na leaching due to its absorption on the colloids and its retention in the soil micropores.

Sesuvium portulacastrum L. culture under non-leaching conditions induced in EC a decrease (-37%) or an increase (+33%) in the upper or the lower soil horizon, respectively, in comparison with S soil. SAR and soluble sodium concentration reflected the trend exhibited by EC. The phytodesalinization culture led to a significant decrease in these two parameters (-34% for SAR and -36% for soluble Na concentration, respectively) in the upper horizon, whereas both SAR (+75%) and Na concentration (+50%) were found to increase in the lower 10 cm soil (Table 1). However, the values of these parameters did not differ between the two soil layers.

TABLE 1
Percentage of variation of electrical conductivity of the soil saturated paste extract (ECe), sodium adsorption ratio (SAR) and soluble Na^+ concentration (Na^+) of soil samples taken from the upper and lower 10 cm of non-perforated pots, compared to non-salinized soil

	Upper		Lower	
	S	P	S	P
ECe	+410%	+258%	+146%	+229%
SAR	+392%	+225%	+500%	+950%
Na^+	+367%	+200%	+300%	+500%

S: salinized soil (soil added with 2.5 g NaCl kg^{-1} soil), P: phytodesalinized soil (soil salinized by NaCl addition and desalinized by a culture of S. portulacastrum over 189 days).

The decrease observed in EC, SAR and soluble Na concentration in the upper horizon by *S. Portulacastrum* culture confirms the Na-hyperaccumulating ability owned by this halophyte. The detection of increased values of these parameters in the lower soil horizon may be the consequence of root-mediated Na^+ substitution by Ca^{2+} and increased sodium leaching as a probable consequence of root expansion, in turn affecting soil physical properties. Root respiration induces in fact an increase in CO_2 partial pressure in soil atmosphere, followed by CO_2 dissolution in water to produce H_2CO_3, which dissociates in H^+ and HCO_3. Finally, H^+ reacts with soil $CaCO_3$ to produce Ca^{2+}, which replaces Na^+ at the soil's cation exchange sites (Qadir *et al.*, 2002).

Our results showed that *S. Portulacastrum* absorbed elevated amounts of Na^+ and accumulated it mainly in the above-ground biomass. Leaf Na^+ concentration was in fact about 71% and 300% higher that of stem and roots, respectively. Cultivation of *S. Portulacastrum* was able to remove about 37% of the sodium quantity added to soil at the beginning of the experiment. Such a sodium removal corresponds to a phytodesalinization capacity of about 1 t Na^+/ha. Moreover, while almost the same quantity of Na^+ added to the pots at the beginning of the experiment was recovered in salinized soil, the sum of plant and soil Na^+ of phytodesalinized treatment exceeded the initial one. This effect derives from *S. Portulacastrum* mediated mobilization of a certain amount of sodium ions already present in the initial soil before experimental salinization. Therefore, the desalinization ability of *S. Portulacastrum* is not limited to its capacity to absorb soluble Na^+ but also to the root-assisted solubilization of soil-absorbed ions.

Although the phytodesalinization process was not complete, it allowed a successful germination and growth of the moderate salt-resistant glycophyte *Hordeum vulgare* L. In fact, despite seeds sown on both salinized and desalinized soils displayed a 3-days delay in coleoptile emergence in comparison to seeds sown on non-salinized soils, after 18 days the percentage of germination on phytodesalinized soils increased over that of salinized ones (percentage of germination about 43%, 73% and 100% in S, P and N pots, respectively).

Barley plants cultivated on N soil showed a biomass production of about 1 g and 0.26 g DW $plant^{-1}$ for shoot and roots, respectively. Soil salinization induced a dramatic growth inhibition in comparison to plants grown on non-saline soil, as indicated by the decrease in shoot (-92%) and root (-77%) dry weight, accompanied by a significant water loss (-35% and -56% in shoots and roots, respectively, Table 2). Soil phytodesalinization by *S. Portulacastrum* allowed a partial recovery of barley growth capacity, the dry weight of shoots and roots being about 3 and 2.6 fold higher, respectively, than in salinized treatment. Water content of barley plants grown on P soils was statistically similar to control plants as far as shoots are concerned, while in the roots it partially recovered (-31%, in comparison to non-saline condition, Table 2). It is therefore evident that salinity remediation by *S. Portulacastrum* culture is a promising strategy to allow the restoration of non-productive soils for successful cultivation of moderate salt-resistant species. Similar results have been reported by Abdelly *et al.* (1995), who studied associations between glycophytes and halophytes, Kushiev *et al.* (2005), who employed liquorice for saline soil remediation, and Graifenberg *et al.* (2003), who cultivated tomato plants in a saline environment with desalinization plants.

The ability of *S. Portulacastrum* culture to reclaim saline soils was confirmed by the results concerning barley Na^+ and K^+ concentration. Shoot and root barley cultivated on N soil exhibited a Na^+ concentration of 32.6 and 26.1 mg g^{-1} DW, respectively, while K^+ concentration was 53.5 and 25.8 1 mg g^{-1} DW, in shoot and roots respectively. Cultivation on S soil led to enhanced Na^+ accumulation in the shoots (+40%) and induced a decrease in K^+ concentration in both shoot (-54%) and roots (-55%, Table 2). When barley was cultivated on phytodesalinized soil, shoot Na^+ concentration decreased back to control (N soil) values. Although plants grown on both saline and desalinized soil displayed similar and significantly lower root K^+ concentration than control plants, a partial recovery of shoot K^+ content was observed (+37% in comparison to saline treatment, Table 2) in phytodesalinized treatment.

TABLE 2

Percentage of variation of shoot and root dry weight (DW), water content (H_2O), Na^+ and K^+ concentration in barley plants grown over one month in non-perforated pots containing salinized soil. (S; soil added with 2.5 g NaCl kg_1 soil) or phytodesalinized soil (P, soil salinized by NaCl addition and desalinized by a culture of *S. portulacastrum* over 189 days)

	Shoot		Root	
	S	P	S	P
DW	-92%	-68%	-77%	-17%
H_2O	-35%	-17%	-56%	-31%
Na^+	+40%	+2%	+13%	+3%
K^+	-54%	-37%	-55%	-59%

In conclusion, our data reinforce the belief that *S. Portulacastrum* has the potential to desalinize soils and to allow the subsequent cultivation of glycophytes, due to its capacity of Na^+ uptake and accumulation and its ability to promote the release of a certain Na^+ amount adsorbed on the cation exchange sites.

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Aspects of sustainable vineyard management in La Mancha (Central Spain): Potential impact of soil salinity increase in drip irrigated vineyards

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Vineyard irrigation management in La Mancha (Central Spain) has significantly changed over the past two decades. Efficient water management in the vineyards of this region has resulted in the application of lower water quantities, resulting in nearly 100% efficiency of irrigation.

Global warming is a scientific reality which is having an impact, whether good or bad, on vineyard management. The current drought conditions in the region make irrigation a neccessary practice. In recent years the salinity of irrigation water has been high, and an excess of salt may have been added to the soil. The question now is whether this is a long-term sustainable system considering the environmental conditions that will result from global warming.

Many vineyards in the region are now drip irrigation, or they are in process of being converted to drip systems. The potential problem is the presence of salts in soil under drip irrigation and their accumulation due to low water application rate of drip irrigation systems.

In some areas subsurface drip systems are now being tested, which show some interesting results in relation to root zone salinity. In the presented work a study was made to determine the degree of salt accumulation with drip irrigation in some vineyards in La Mancha. Several conclusions can be drawn: 1) Vineyards that were drip irrigated between four and ten years showed no dangerous level of soil salinity in the root zone; 2) It is necessary to adapt the management of water and soil to individual cases depending on environmental factors; and 3) An understanding of the processes of soil salinity and various management options to address these problems is a good basis on which to make recommendations for wine-producing areas in the region.

Detoxication of *Capsicum annuum* L. with zeolites

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ABSTRACT

The widespread occurrence of pollution is the reason for continuous examination of heavy metals and their impact on physiological processes in plants, diversity and ecology. For that purpose, the world's most developed investigating centres often use methods such as immobilization and phytoremediation. Zeolites are the most often used immobilization minerals, which neutralise heavy metals and change their oxidation structure.

This study examines the changes in the level of pollution in soil when zeolites are added to soil in which pepper plants (*Capsicum annuum* L.) are cultivated. The soil was treated with different concentrations of cadmium (0.1, 0.2, 0.4, 0.8 mg/kg soil), copper (0.5, 1.0, 10.0, 20.0 mg/kg soil) and zinc (1.0, 5.0, 10.0, 20.0 mg/kg soil). Parallel to the physiological metabolism, anatomic changes have been studied. The results confirm the positive effects of zeolites in the process of soil-phytoremediation. In every case studied the zeolite significantly reduced the uptake of cadmium, copper and zinc ions by the pepper plants.

Keywords: pollution, heavy metals, zeolites, cadmium, copper, zinc, soil-phytoremediation.

INTRODUCTION

Great amounts of contaminants are present almost in every soil examined and it seems to be impossible to immobilize all the pollutants. According to Ouzonidou (1995) metals accumulate in the roots more than the other parts of the plant and their toxicity comes from the fractions included in cell metabolism. Reducing the negative effects of toxicants can be a helpful method for further ecological progress. Phytoremediation can be defined as the combined use of plants, soil amendments and agronomic practices to remove pollutants from the environment or to decrease their toxicity (Salt *et al.*, 1998). Phytoremediation refers to the utilization of plants to clean contaminated environments (Pletsch, 2004). Immobilization is presented as a reliable method for preventing the metal uptake by the plants or their reaching to the groundwater (Barbu *et al.*, 2002). This kind of detoxication includes different alkali materials-zeolites (Czupyrna *et al.*, 1989; Cworek, 1992; Edwards *et al.*, 1999) as well as Fe-oxides (Chlopecka and Adriano, 1997). Zeolites are three dimensional crystalline microporous alumino-silicate materials. The term "zeolite" comes from the Greek words for boil and ste. Zeolites are natural minerals that are used as alumino-silicates to bind the ions of heavy metals. There are many types of zeolites generated in two groups: natural and synthetic. Natural zeolites are nutrition supply, oil absorbents (petrol absorbents) as well as gas absorbents. Synthetic zeolites are used as immobilization reagents because of the capability of accumulating enormous amounts of toxic materials and neutralizing effects they have. Zeoilites are known to have the ability to increase the biomass of bacteria cultures that are thermally stabile and resistant to radiation.

Great number of natural zeolites has been used in order to remove the heavy metal ions in soil and aqueous solutions. Clipnoptilolite, has been utilized for the removal of lead in aqueous solutions (Bektas and Kara, 2004) which has also been used for the continuous elimination of metal and non-metal ions (Calvo *et al.*, 2009). Natural zeolites have many uses in removing cobalt, copper, zinc and manganese from wastewater (Erdem *et al.*, 2004). Although latest research reports that natural zeolite are not effective adsorbents for anions and organic compounds (Wang and Peng, 2010) they still have major utilization contributing the immobilization issues. The use of synthetic zeolites for arsenate removal was reported to be very effective (Shevade and Ford, 2004; Xu *et al.*, 2002). Synthetic zeolites were also used as backfill for radioactive waste (Ibrahim *et al.*, 2008). It is now widely accepted that zeolites having porous structure is an effective heavy metaladsorbent. Nevertheless, nano scale zeolite has been less developed (Cox and Cundy, 2003)

Many studies underline the utilization of zeolites in immobilization processes and present various ways of synthetically produced minerals that have strong ability to remove great part of the accumulated heavy metals in different types of soils. Figueiredo *et al.* (2009) reported a study in which they clarify the synthesis and immobilization characteristics of a new heterogeneous catalytic material (zeolite CrNAY) used in oxidation reactions of heavy metals in wastewater.

DESCRIPTION OF PRACTICE

Pepper plants (*Capsicum annuum* L.) have been cultivated in experimental conditions at the Institute of Biology, Faculty of Natural Sciences and Mathematics, Skopje. The retention capacity of the soil where plants have been cultivated was maintained from 55 to 65% and the relative humidity where the material was developed was 70–80%. Plants were treated with three different concentrations of heavy metals (cadmium, copper and zinc): 0.1, 0.2, 0.4, 0.8 mg/kg Cd; 0.5, 1.0, 10.0, 20.0 mg/kg Cu; and 1.0, 5.0, 10.0, 20.0 mg/kg Zn. The results of the treated material were compared to the results provided from the control group of plants. The aim of our study was to examine the zeolite effects of immobilization with $CdSO_4$, $CuSO_4$ and $ZnSO_4$ solutes Temperature can alter the zeolite structure as well as the induction period and crystal growth kinetics. During the procedure we examined the influence of the following experimental parameters: temperature of 303 K, time period of 10, 15 and 20 minutes of zeolite application.

The present study has the following objectives: (i) to clarify the negative effects that heavy metals cause on the anatomic construction of the pepper plants (*Capsicum annuum* L.), (ii) to compare the effects of the selected zeolite (NaA) on accumulation of heavy metals (Cd, Cu and Zn) by the pepper plant and (iii) to increase the knowledge of the effects of the current zeolite on the quantity of mobile forms of Cd, Zn and Cu. The main objective of this research was to investigate the efficiency of zeolite's accumulation of cadmium, copper and zinc, according to the concentration they appear in soil.

The concentration of Cd, Cu and Zn in plant material (*Capsicum annuum* L.) was quantified by atomic absorption spectrometry (AAS). The results confirmed our expectation in the positive role of zeolites as immobilization minerals. In order to follow the changes in the anatomic level, we also collected material during the continuous phases of the vegetation period, as well as different material for the vegetative part of the plant. The anatomic analyses gave a precise morphological and morphometric hystological structure of the examined material.

RESULTS

Heavy metals decrease the dimensions of some parts of the stem cortex, including the epidermal layer. We concluded that Cu and Zn have similar effects comparing to the effects of Cd in which the cortex gets thinner as well as the epidermis, which, depending on the concentration applied, replaces with peridermal layer. The negative effects of heavy metals are significant in the xylem parts. Copper treatments resulted with 5-times thicker xylem than the one in the control group of plants, 2-times when plants are treated with Cd and we noticed a small difference between the plants treated with Zn and the control material. Significant reduction of the number of xylem vessels is noticed in the plants treated with zinc, whereas the vessels and libriform fibres are numerous than the structures of the mechanical tissue.

The detoxication effect seemed to be very effective when higher doses of Cd were applied (0.8 mg/kg soil). The results showed that the amount of Cd ions in plant material of pepper (*Capsicum annuum* L.) before the application of zeolite was 0.048–0.077 mg/l compared with the metal concentration in plant samples when zeolite has been used (0.017–0.028 mg/l). The zeolite used (6 g NaA) absorbed 0.017–0.058 mg/l Cd according to the concentration of the metal applied as treatments. Zeolite accumulated from 0.101–0.164 mg/l copper so that 0.009–0.035 mg/l Cu remain in the plant although copper was added in relatively high concentrations (1–10 mg/kg soil). Zn appeared as a metal for which the zeolite we have been using during the experiment has the highest accumulation power (0.386–1.425 mg/l). The pepper plants treated with Zn accumulated 0.4–1.439 mg/l from this metal before the application of zeolite and 0.014–0.069 mg/l after the zeolite usage.

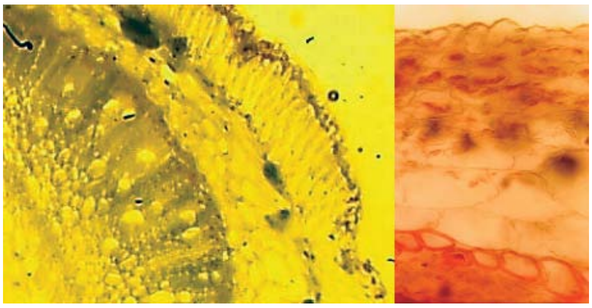

FIGURE 1
Lateral cut from stem (a) and cortex (b) in control plants from *Capsicum annuum* L.

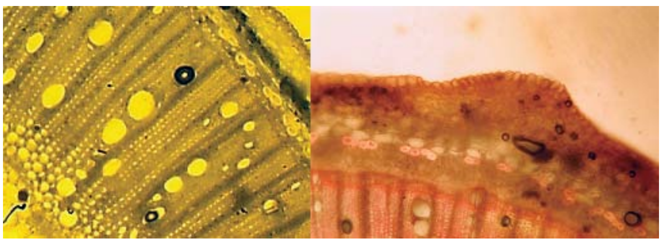

FIGURE 2
Lateral cut from stem of *Capsicum annuum* L. treated with fourth concentration of Cd.

In the vacuoles in all treatments we noticed accumulation of oxalate crystals (Ca crystals). The leaves of treated plants have increased number of sclerenchyma fibres.

CONCLUSIONS

According to the results presented we concluded that when these three metals are applied in higher doses the effectiveness of zeolite immobilization is stronger. Zeolite's are low costs material with wide range of uses, due to its potential as an exchanger of ions, its capacity for reversible adsorption (the process through which a solid is used to eliminate a water soluble substance) and its function as a natural molecular sieve. These materials can be used to clean up aggressive toxic substances (lead, nickel, iron, cobalt) (Grogg, 2010). This fact is to be recommended when high polluted areas are the target zones for soil phytoremediation and immobilization.

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POSTER PRESENTATIONS. SESSION 2

Physiological and morpho-anatomic anomalies in pepper after treatment with cobalt chloride

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ABSTRACT

The study was carried out at the glasshouse of the Faculty of Natural Sciences and Mathematics, Institute of Biology in Skopje, Republic of Macedonia. The aim of this study was to determinate how cobalt affects growth and metabolism of plants, by treatmenting with four levels of cobalt chloride ($CoCl_2$): 0.25, 1.5, 3.0, 5.0 mg/kg soil. We investigated phytotoxicity and bioavailability of cobalt to the pepper plant by determining the concentration of secondary biomolecules (total and soluble sugars and phenols), biopigment concentration (chloroplast pigments) and the effectiveness of some antioxidants, such as vitamin C and antocyanins, as well as the anatomic-morphological changes by the cytotoxic and phytotoxic activities of cobalt.

The results indicated the activation of plant defense metabolism after intoxication, by increasing the concentration of polyphenols, inhibiting the synthesis of antocyanins and vitamin C as major group of antioxidants as well as inhibiting the differentiation of starch grain. We also concluded that cobalt alters the structure and increases the number of chloroplasts per unit area of leaf. The third and fourth concentrations (3.0 mg/kg and 5.0 mg/kg soil) are the most toxic, causing extreme visible changes in leaf anatomy. The epidermal layer of plants treated with third and fourth concentration is thin and oxalate crystals appear under the palisade row of cells, particularly in plants treated with 3.0 mg/kg soil. All plants treated with higher concentrations have undisintegrated cores and a large number of sclerenchyme fibres.

Keywords: anatomic changes, antioxidants, phytotoxicity, secondary biomolecules.

INTRODUCTION

The plant reaction to the toxic concentrations of heavy metals is usually expressed by changing the activities of different physiological and biochemical processes and leads to the appearance of major disturbances. Accumulation of a certain quantity of any toxic element causes visible morphological changes in plants, as well as disorder in the nutritive chain, plant metabolism and plant productivity. Cobalt (Co) is an element that naturally occurs in many different chemical forms in the environment (Co II and Co III). Although usually described as beneficial for plants Co is not an essential element. Cobalt is a trace element which is commonly constituted in plant mass (0.002–0.4 ppm). The distribution of cobalt in plants is species-dependent. The uptake is mostly through roots and it is provide by an active transport. Its translocation is usually faster compared to the one of similar heavy metals (Cu and Cr) (Chatterjee and Chatterjee, 2000). Cobalt is an essential component of several enzymes and co-enzymes; it is component of vitamin B_{12} and cobamide coenzymes (Dekker and Barker, 1967). In the form Co^{2+} it provides the fixation of molecular nitrogen in root nodules of leguminous plants and promotes growth of plants, especially by elongation of stem, usually better that Ni, Mn and Fe (Thimann, 1956). Toxic effects of cobalt on morphology include inhibition of greening and discolored veins, premature leaf closure and leaf fall.

The exogenous application of cobalt induces the differentiation of membrane complexes of the endoplasmic reticulum that are later dilated and destroyed (Herick and Bobák, 1975). This is probably the reason of disturbances in cell division. Cobalt delays the processes of karyokinesis and cytokinesis. Application of high concentrations of cobalt hampers RNA synthesis and decreases the amounts of the DNA and RNA by modifying the activity of large number of endo- and exonucleases (Palit *et al.*, 1994). One of the main differences between Co and the other heavy metals (microelements) is that only Co stimulates the uptake of S and its transport to the plant shoots (Liu *et al.*, 2001). Cobalt interacts with other elements to form complexes. The interaction of cobalt with other metals depends on the concentration of the metals used. The beneficial effects of cobalt include retardation of senescence of leaf, increase in drought resistance in seeds, regulation of alkaloid accumulation in medicinal plants and inhibition of ethylene biosynthesis (Palit *et al.*, 1994).

DESCRIPTION OF PRACTICE

The investigation was carried out in the period 2006–2007. Pepper plants (*Capsicum annuum L.*) were cultivated in Mitscherlich plates under controlled conditions in glasshouse. Seedlings were treated with water solutes of four different concentrations of $CoCl_2$ of 0.25, 1.5, 3.0, 5.0 mg/kg soil. Treated plants were compared with a group of control plants. Materials for analysis were vegetative organs (root, stem and leaves) as well as generative organs (fruit) from mature plants collected at the end of vegetation period. They were dried at 60–70 °C. The concentration of chloroplast pigments and vitamin C is measured on raw material. To determine the concentration of chloroplast pigments (chlorophyll a, chlorophyll b and carotenoids) was used acete extract measured on Perkin-Elmer spectrophotometer on three wave lengths. The content of total and soluble sugars was measured according to the method of Dubois *et al.* (1962). The concentration of antocyanins was measured spectrophotometric (510 nm) as well as the concentration of phenols (765 nm). Vitamin C was determinated using 2,6-dichlorophenolindophenol (*DCPIP*) as an indicator. Detailed anatomic analysis were made on stem and leaf lamina. Fixated material was used for the preparation of water and glycerin microscope slides. In aspiration to express the toxic effect of cobalt we used no coloring for the anatomic investigations.

RESULTS

The results showed the inhibitory effect of Co on the synthesis of vitamin C. The first two applied concentrations (0.25 and 1.5 mg/kg soil) have simulative influence which is not a conclusion for the highest concentration of $CoCl_2$ (5.0 mg/kg soil).This reveals to the fact that inhibiting the synthesis of vitamin C plants lowers their antioxidative answer. The third concentration of Co is the major stress factor for pepper plants that indicates the negative correlation between the applied element and vitamin C. Low concentrations of Co^{2+} in medium stimulate growth on plants. Relatively higher concentrations have strong toxic effects.The results of our study refer to pepper anatomy showed that plants treated with first and second concentration of $CoCl_2$ have thickened epidermal layer and disintegrated core as changes characteristic for stem and leaves. The third and fourth concentrations seemed to have most toxic effects that cause extreme visible changes in leaf anatomy. Epidermal layer of plants treated with third and fourth concentration is thin; the upper palisade layer is rich with chloroplasts. Oxalate crystals seemed to appear in the idioblasts under the palisade row of cells particularly in plants treated with 3.0 mg/kg soil. These plants have undisintegrated core and a great number of sclerenchyme fibres.

Our goal was to determine the toxic effects of cobalt on plant metabolism through organic productivity of pepper, its antioxidative answer and anatomical changes in peppers stem and leaf lamina. Cobalt concentrations seemed to affect strong antioxidative changes, especially at the highest concentrations of applied $CoCl_2$. Vitamin C is known to be an antioxidant, which helps plants deal with stresses from drought to ozone and UV radiation and it is confirmed that plants could not grow without it.

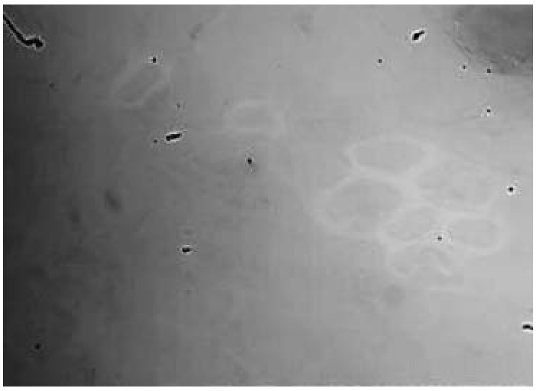

FIGURE 5
Sclerenchyme fibres in control plants.

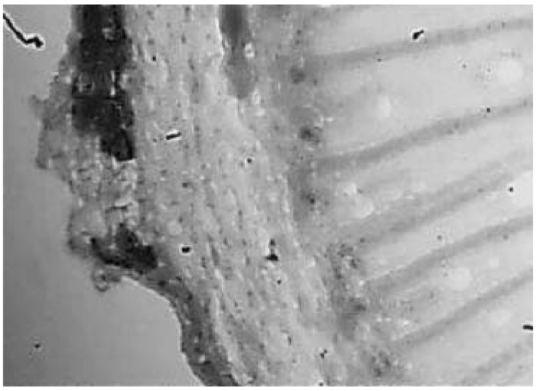

FIGURE 6a
Lateral cut from stem cortex of pepper (*Capsicum annuum* L.).

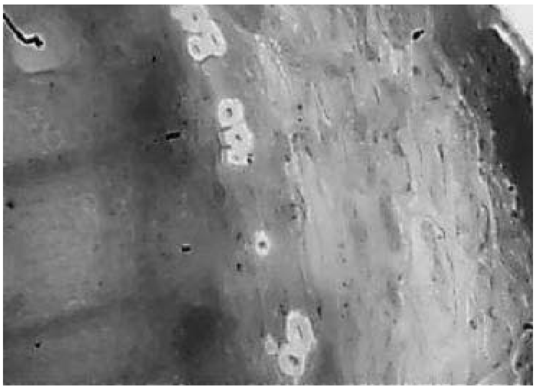

FIGURE 6b
Lateral cut of pepper stem cortex treated with $CoCl_2$ (5.0 mg/kg soil).

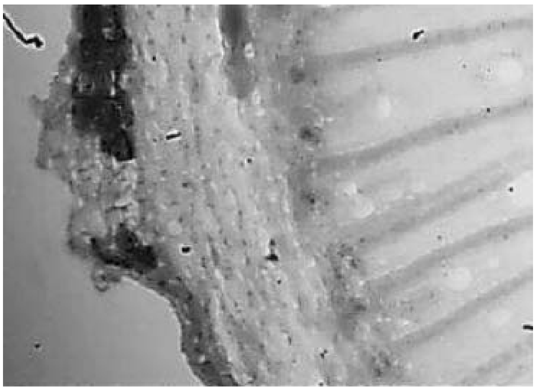

FIGURE 7
Lateral cut from stem of pepper plants treated with lowest concentration of $CoCl_2$ (0.25 mg/kg soil).

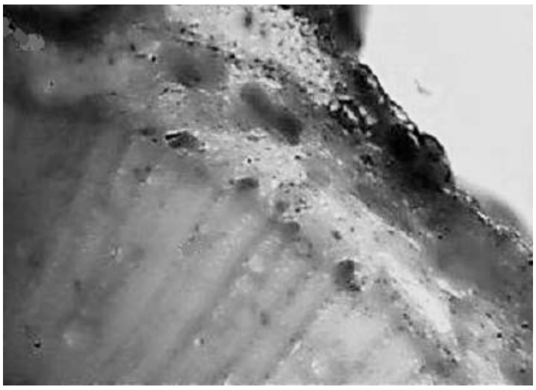

FIGURE 8
Lateral cut from stem of pepper plants treated with fourth concentration of $CoCl_2$ (5.0 mg/kg soil).

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Possible correlation between soil salinity and proline accumulation in halophytes

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Despite advances in our knowledge on the biology of salt-tolerant plants, mostly derived from experiments performed under controlled laboratory and greenhouse conditions, there are still relatively few data regarding the physiological and biochemical responses of halophytes in their natural stressful environments. Our study focuses on the accumulation of proline in several halophytes (*Sarcocornia fruticosa, Arthrocnemum macrostachyum, Juncus acutus, Juncus maritimus, Inula crithmoides, Limonium sp.*) collected in a coastal salt marsh in the province of Alicante (South-east Spain), from four selected experimental plots with different degrees of soil salinity.

The aim of our work is to establish whether proline biosynthesis could be used as a reliable stress marker in halophytes subjected to salt stress in their natural habitats. Generally speaking, in those species which use proline as the major osmolyte, a positive correlation has been found between the level of salinity in the soil and the content of proline in the plants. However, it is difficult to assert if soil salinity *per se* induces proline biosynthesis in all investigated taxa; at least in some species, the accumulation of this osmolyte could represent a constitutive rather than an inducible mechanism of response to salt. In addition, halophytes in nature are normally subjected simultaneously to different stressful environmental conditions, apart from salt stress, e.g. drought, high or low temperatures, high irradiation, which could also induce osmolyte accumulation. Therefore, the possible use of proline concentration in halophytes as an indicator of soil salinity level must be carefully checked. Further investigations will help to elucidate if, and how, proline biosynthesis in salt-tolerant taxa differs under natural and artificial conditions, and the relative contributions of different abiotic stresses to proline accumulation in the plants.

ACKNOWLEDGEMENTS

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Can malondialdehyde (MDA) be used as a marker of abiotic stress in halophytes growing in their natural habitats?

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Different abiotic stress conditions, including high soil salinity, cause secondary oxidative stress in plants, by generation of 'reactive oxygen species' (ROS), which in turn leads to membrane lipid peroxidation, among other deleterious effects. Maintenance of cell membrane integrity under salt stress should therefore contribute to salt tolerance, and this could be assessed by determining the levels of malondialdehyade (MDA), the major peroxidation product of polyunsaturated fatty acids in membrane lipids. To our knowledge, all available data on correlations between MDA contents and salt stress responses have been obtained in experiments carried out under artificial greenhouse conditions. The aim of this work was to establish whether MDA could also be used as a reliable biochemical marker of salt stress—and of abiotic stress, in general—in the natural habitats of the plants.

Three 100 m² plots have been selected in a salt marsh (*mallada*) in the Natural Park 'La Albufera', 15 km south of the city of Valencia (SE Spain). The plots have different levels of salinity, according to their vegetation and soil electric conductivity. Plant material was collected from 11 different species, in three successive seasons (summer and autumn 2009, spring 2010), and MDA contents were determined as described by Hodges *et al.* (1999). Preliminary results indicate a negative correlation between MDA accumulation and the degree of salt tolerance of different species; for example, *Helianthemum syriacum*, a relatively salt-sensitive plant (present only in the zone of lower soil salinity), has significantly higher MDA levels than several halophytes growing in the same plot. However, no significant differences were found when comparing samples of individual species, collected either from different plots or in different seasons. These data suggest that chemical and enzymatic antioxidant systems efficiently protect the cells from membrane lipid peroxidation, despite temporal or spatial changes in the degree of soil salinity; higher salt concentrations, not found in the natural habitats of the investigated halophytes, will probably be required to overcome these antioxidant systems and affect cellular membranes. Therefore, MDA content does not appear to be a useful biochemical marker of salt stress for halophytes growing in their natural habitats.

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Synergic effect of salinity and CO_2 enrichment on growth and photosynthetic responses of the cordgrass *Spartina maritima*

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Spartina maritima is a C_4 halophytic species that has proved to be an important pioneer and ecosystem engineer in salt marshes on the Atlantic coast of southern Europe. A glasshouse experiment was designed to investigate the synergic effect of 380 and 700 ppm CO_2 for 0, 171 and 510 mM NaCl on the growth and the photosynthetic apparatus of *S. maritima* by measuring chlorophyll fluorescence parameters, gas exchange and photosynthetic pigment concentrations. We also determined total ash, sodium, potassium, calcium and nitrogen concentrations.

Elevated CO_2 stimulated growth of *S. maritima* at all external salinity after 30 days of treatment. This growth enhancement was associated with a greater net photosynthetic rate (A) and improved leaf water relations. Despite the fact that stomatal conductance decreased in response to 700 ppm CO_2, A was not affected.

On the whole, plant nutrient concentrations declined under elevated CO_2, which can be ascribed to the dilution effect caused by an increase in biomass and the higher water content found at 700 ppm CO_2. Finally, CO_2 and salinity had a marked overall effect on the photochemical (PSII) apparatus and the synthesis of photosynthetic pigments.

Potential impacts of climate change on primary soil salinization at Iran's national scale

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ABSTRACT

Long term meteorological data and the 1:1 000 000 soil salinity map of Iran were used (after excluding agricultural areas and miscellaneous lands) to develop correlations between soil salinity and climatic factors,. Mean soil salinity showed fair correlations with different climatic variables developed as simple and multiple linear regression models (R^2 of 0.56 to 0.72). Since predictors of these regression-based models consisted of different climatic variables, General Circulation Model (GCM) derived data were found suitable to link to the models for projection of salinities in upcoming decades. Data of HadCM3 model that were resulted from IPCC-SRES scenarios of A2 and B2 were used for projection of monthly T_{min}, T_{max}, annual P and ET for the nine next decades. Predicted variables were inserted in the developed regressions to project future status of soil salinity. At a country wide scale results showed that for the upcoming 90 years, mean soil salinity may increase from 1.5 to 4.7 dS/m, in different scenarios and time intervals

Keywords: soil salinization, climate, HadCM3, A2 and B2 scenarios, Iran.

INTRODUCTION

Iran is located between 25–40° N and 44–65° E with total area of 165 Mha. Climatic conditions of Iran are mostly typical of arid and semi-arid regions. Soil salinity which threatens agricultural production in the arid regions of the world including Iran, is a dynamic property of soil which changes rapidly in response to the action of salinization agents. Due to geological, climatic, and hydrological conditions of Iran, many factors may take part in the development of saline soils. Siadat, *et al.* (1997) put these factors in two groups: Natural (primary) factors and human-induced (secondary or anthropogenic) factors. The natural causes of soil salinity in Iran are geological conditions, climatic factors (evaporation, rainfall, and wind), salt transport by water, and intrusion of saline bodies of water into the coastal aquifers. While secondary salinization stems from overdraft of groundwater and poor on farm water and field management.

Climatic conditions play the most important role among natural (primary) salinization factors. The trace of climatic factors on soil properties is not only obvious in the evidences of ancient times (Taghizadeh *et al.*, 2009) but also it can be monitored in the conditions of present day time. However it cannot be expected to find a straightforward relationship between climatic factors and salt accumulation in the soil at the national scale (Nell, 2010). On the other hand the relationship between salinization or desertification processes and climatic indices such as P/ET or ET and temperature is well defined (Masoudi *et al.*, 2006; Nell, 2010; Ahmadi *et al.*, 2001).

As mentioned by FAO/UNESCO (1973) saline soils mostly occur in regions with a pronounced hot and dry climate, hence all conditions and factors which increase the evaporation of groundwater which having little drainage will facilitate salinization. In addition to evaporation and rainfall which directly affect on water balance and salt balance, other climatic variables such as temperature and humidity can also alter the rate of evaporation and salinization especially with shallow/saline groundwater tables (FAO/UNESCO, 1973). Other natural (primary) salinization factors such as geological and land form conditions may also have an important role in developing saline bodies such as marshes, salt flats, salt plugs and etc., but such regions could be excluded when the relation between salinization and climate is to be evaluated. The same conclusion is correct to exclude cultivated area in order to remove secondary salinization process.

Considering the spatial variability in climatic conditions and salinity on the national scale, correlations could be derived between these factors with a feasible distribution in the range (Nell, 2010). To develop these correlations two types of information is needed; numerical status of salinity and long term meteorological data. These data sources are the minimum requirements which are simply available in the developing countries and can be used to create regression equations between salinity and climatic variables. The best fitted model, if available, could be used for prediction of soil salinity using one or more climatic parameters like temperature, precipitation, evaporation and etc. Also a linkage between this climatic related model and General Circulation Model (GCM) data could be accomplished for projection of soil salinity in upcoming decades. Main objective of this study is to assess the impact of climate change on primary salinization of land resources and also to simulate average soil salinity for next nine decades with the help of HadCM3 model data, as a well-known GCM model in the world. Most frequently used data of A2 and B2 scenarios also were employed in this way (Bates *et al.*, 2008; Milly *et al.*, 2005).

MATERIALS AND METHODS

Data sources used for development of correlations were climatic and numerical soil salinity data. Long term climatic records of synoptic stations (Figure 1) are available in the official websites which were used after processing. Soil salinity data were also extracted from 1:1 000 000 soil map of the country (in digital format) which was prepared using data surveyed during the period of 1953 to 1995. Figure 2 shows the distribution of saline soils in different parts of the country (After Moameni *et al.*,

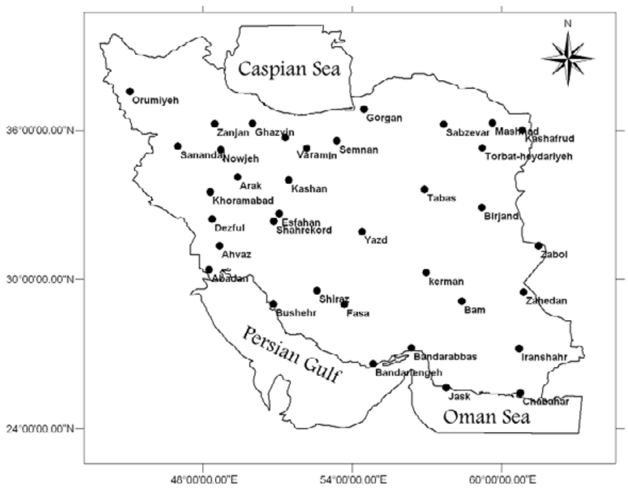


FIGURE 1

Distribution of synoptic meteorological stations throughout the country.

1999). This map includes both primary and secondary saline soils. To focus on natural (primary) salinization the cultivated area was excluded using the land use map. Also the vast area in the country is occupied by miscellaneous land resources such as sand dunes, playa, salt plugs, marshes and etc, which may be saline or non-saline but the exact amount of their salinity is not known. To achieve a map in which soil salinity is affected mainly by climate, these parts were excluded too. After purification of soil salinity map, each synoptic station was surrounded by a polygon or map unit which shows the class of soil salinity. In cases where the station was located in the excluded area, the nearest or the more abundant map unit was selected for that station. This procedure was followed at the national scale of Iran.

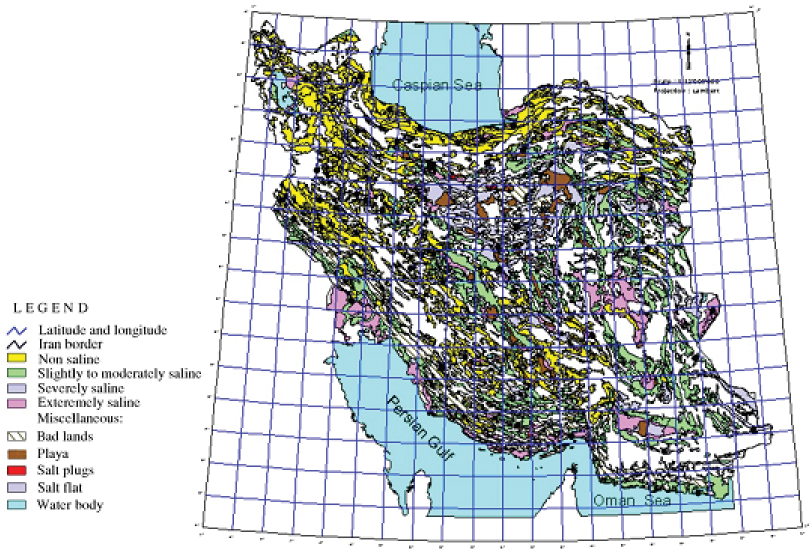


FIGURE 2
Distribution of saline soils in Iran (Moameni *et al*., 1999).

Correlations between climatic factors and average soil salinity were then looked for, using simple linear regression and backward multiple regression methods. The best models which can predict soil salinity with the highest regression coefficients were selected in advance. Table 1 describes the methods used in 4 selected best fits, their predictors and number of observations.

TABLE 1
Description of the best fit models used for prediction of salinity from climatic factors

Method No.	Predictors	No. of observations	Analysis approach
1	T_{max}, T_{min}, P, ET	33	Multiple Regression
2	T_{max}, P, ET	30	Multiple Regression
3	T_{max}	30	Simple Regression
4	P	33	Simple Regression

Predictors of the models were maximum temperature (T_{max}), minimum temperature (T_{min}), annual precipitation (P) and reference evapotranspiration (ET). These models showed their highest correlations when used for the regions have not more than 400 mm annual precipitation.

The variety of these salinity related models allowed application of at least one of them with considering data availability and also desired accuracy. Since predictors of these regression-based models were consisted of different climatic variables, so General Circulation Model (GCM) derived data were found suitable to link to the models for projection of soil salinities in upcoming decades. For this purpose, data of HadCM3 model that were resulted from IPCC-SRES scenarios of A2 and B2 were acquired and used for projection of monthly T_{min}, T_{max}, annual P and ET for the nine next decades of 2010–2039, 2040–2069 and 2070–2099. Thereafter, predicted variables were inserted in the developed regressions to project future status of soil salinity in the mentioned time intervals.

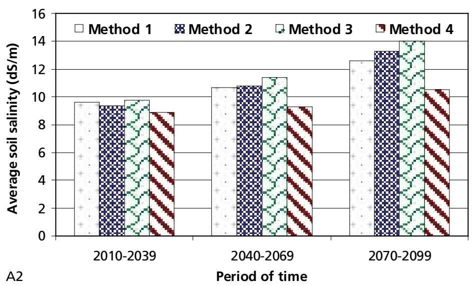
RESULTS AND DISCUSSION

Table 2 shows the equations and regression coefficients for correlations between salinity and climatic variables. The accuracy to determine soil salinity from climatic variables on the countrywide scale is surprising at least for the Central Plateau (P<400mm).

TABLE 2
Best fitted equations for prediction of mean soil salinity using different climatic variables

Method No.	Equation	R^2	Description
1	$S = 2.18T_{max} - 0.043P - 1.169T_{min} - 0.015ET - 8.87$	0.64	P<400 mm
2	$S = 1.094T_{max} - 0.027P - 0.006ET - 7.272$	0.72	P<400 mm
3	$S = 1.1716T_{max} - 21.181$	0.63	P<400 mm
4	$S = -0.0523P + 18.149$	0.56	P<400 mm

After linking General Circulation Model (GCM) derived data to the regression coefficients average soil salinity projected with the data of HadCM3 model for the national scale as shown in Figure 3. For the first 30 years interval there is no significant difference between the four regression equations. The difference becomes more pronounced for the last 30 year interval (2070–2099) in both scenarios. This finding is hopeful that at least for the next 30 years all regression equations yielded to the same prediction of salinity status at the national scale, which permits application of equations which require minimum input data such as methods number 3 and 4.



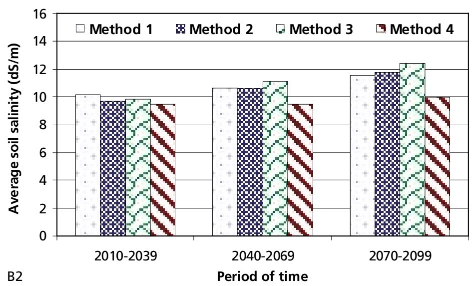


FIGURE 3
Results of different methods for simulation of soil salinities in the future periods of time under A2 and B2 scenarios, respectively.

Predicted salinity averaged on four regression equations in different parts of the country is shown in Figure 4. This Figure shows that for the first 30-year interval, mean soil salinity will increase 1.5 and 1.9 dS/m, based on A2 and B2 scenario results, respectively. While projected salinities for the second interval were 2.7 and 2.6 dS/m and for the third interval were 4.7 and 3.5 dS/m, resulted from A2 and B2 scenarios, respectively. Similar to the previous discussion the most significant difference between two scenarios is occurred in the last 30 years intervals. In this case there is no difference between A2 and B2 scenarios results in the next 60 years. This provides opportunity for equal application of each of scenarios to predict mean soil salinity in the next 60 years. For the last 30 years interval on the other hand there is significant difference between predicted salinities based on two scenarios. The increasing trend of salinity in the next 90 years is also illustrated in Figure 4. This finding shows that long term changes in climatic variables will ultimately pronounce the primary salinization problem. This phenomenon is estimated to be the result of decreased precipitation and increased evaporation as can be found from regression equations (Table 2). Primary salinization could be important in the case of rain fed agriculture and for policy makers in the national programmesto combat desertification. The methods introduced in this paper could be a useful tool for them to project the hazards which threatens sustainability of their system as a result of climate change.

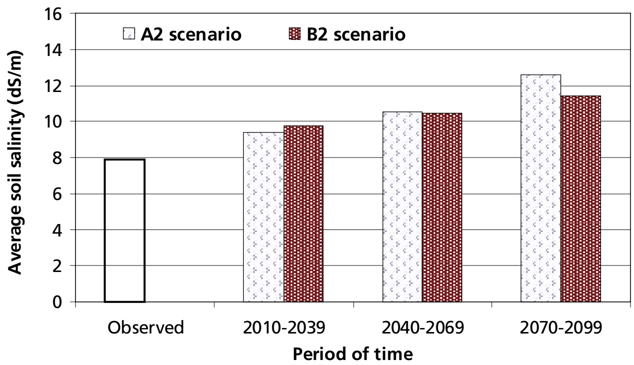


FIGURE 4
Average of observed soil salinity in addition to the projected salinities based on different scenarios.

CONCLUSIONS

There are significant relationships between climatic factors and natural (primary) salinity of soils on the national scale. These relationships help us to predict the future status of salinity based on the available scenarios of climate change. Two scenarios tested in this paper had no significant difference in projection of soil salinity in the upcoming 60 years. The additional trend of salinity was observed using each of scenarios which may be related to decreased precipitation and increased evaporation in this century as expected. It should be considered that the effect of climatic factors on primary soil salinization is not so straight because other factors such as geologic, topographic features and ancient climatic conditions may also take part in accumulation of solutes in the soil profile. Considering some uncertainties that arise in such similar studies, the method described here can be simply adapted for large scale salinity projection. In combination with other information layers such as water quality and national scenarios for future irrigation management and productivity, the results could be used for prediction of secondary salinization too.

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A soil salinization study in a coastal plain of Mexico

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Previous studies (Bojórquez *et al.,* 2006, 2008 and Gonzáles *et al.*, 2009) have shown the susceptibility to salinization in the Holocene coastal plain of Nayarit, Mexico. A large area of about 230 000 ha is undergoing this process. With the aim of knowing the dynamics of soil salinity, a study is taking place in a transect of 24 km at 36 stations in the lowlands.

This study pretends to establish salt movement in the soil profile monitoring in two seasons evaluating variables of depth to the water table, EC, pH and texture. The first monitoring indicated salinity variability in the dry season of 0.22–94.8 dS/m, pH 6–8.8 and textures of sand-loam. The lowest EC was observed higher altitudes with sandy texture and were highest towards lower altitudes with loamy texture. In the soil profile higher EC was found towards the surface and near to the water table.

Remote sensing detection in land use change and salinization

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A multi-temporal analysis was made on the land use changes in the marsh of Pego-Oliva (Valencia, Spain). The earliest information of land use was obtained from the ortophotomosaic interpretation (American flight from 1956), which has been georeferenced to projection UTM, Datum ED-50 and from information contained in the topographic sheet 796 (DGIGC and SGE, 1950). The actual parcel boundaries of land use have been consulted in Visor SIG-PAC (2008).

The major changes observed were urban proliferation, mainly in the sand barrier area and an estimated reduction of 41.4% of the wetland by land filling for agriculture. Possible influence of these changes has been analysed in the two saline intrusion wedges identified by Ballesteros *et al.* (2009) in the sandy superficial section of the Pliocuaternary aquifer of Pego-Oliva. By superimposition of EC isolines and the amended cartography it was possible to prove that both wedges coincide with two highly modified zones: 1) Urbanization zone with a golf course—the saline intrusion wedge is attributed to an overexploitation of the aquifer and it retrieves in the wet season with the rise of the piezometry; 2) SE land filled zone—the saline intrusion wedge is attributed to the automatic pumping to lower level, out of range of the plant roots. In the wet season intense pumping provokes an increase in salinization due to a phenomenon of "up-coning" in the superficial aquifer with a drawing effect on the saltier waters from the surrounding calcareous aquifer (Ballesteros *et al.,* 2009).

In order to know the IR radiation reflected by the crops, the Landsat 5 TM (432) from 1988 has been analysed. Citrus crops on land filled zones appear in purple, in contrast with the intense red color indicating strong photosynthetic activity shown by the surrounding citrus crops fields.

Finally, a field test of the health of citrus crops was made in areas affected by salt degradation, using GPS to locate them, finding correspondence with that observed in satellite images.

Climate change and temporal trend of climatic parameters influencing the evapotranspiration: Case of Chatt-Meriem region

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ABSTRACT

This study concerned the effect of climate change impact on temporal trends of the climatic parameters influencing the evapotranspiration and the crop water requirement, using the Penman-Montheith methodology described in the FAO Irrigation and Drainage Paper No. 56.

Temporal trends of the climatic parameters and the reference evapotranspiration over a period of 33 years have been analysed using the Mann-Kedall trend test. The sensitivity of ETo has been studied in terms of changes of the most significant climatic parameters. The results show that maximum and minimum temperatures do not evolve similarly. A significant temperature trend was detected during the spring and summer period (hot season), especially for maximum temperature. A highly significant trend for the air vapour deficit was detected, which appears especially from May to June. The wind speed shows a significant decrease trend during the year. The sensitivity analysis test showed that the most influential parameters on ETo are net shortwave radiation, actual vapor pressure, long wave radiation and maximum temperature. This temporal trend analysis of the climatic parameters will be used to develop future regional scenario of evapotranspiration and crop water requirement under climate change conditions.

INTRODUCTION

Climate change constitutes a real environmental problem concerning the whole world. All around the world rapid changes in the weather are already happening. According to IPCC, 2007, the warming of the climate system is unequivocal and evident. The consequences of such climate change are multiple and the degree of impacts depends on which part of the world we are looking at.

In North Africa, and especially in Tunisia, people's lives are very bound closely with climate and its fluctuations. Arid to semi-arid climates represent 75% of the total area, making agriculture and the water sector the most vulnerable to the predicted climate change. Apart from climate change, Tunisia already suffers from weather variability like most Mediterranean countries,. Climatic variations, periodic droughts and sporadic rainfall, often jeopardize harvests. The pattern of spatial and temporal changes in climatic variables due to global warming is a matter of much debate, and studies are increasing worldwide (Chattopadhya and Hulme, 1977; Georgiadi *et al.*, 1991; Muhs and Maat, 1993; Iglesias *et al.*, 1994; McNulty *et al.*, 1997 and Feddema, 1999 and others quoted by R.K.Goyal, 2004).

Many studies cited by Gao (2007), have shown a decrease in the evapotranspiration trend overt the past decades in many places of the world. Others has reported the opposite phenomenon an increase in the evapotranspiration trend (Gao, 2007; Chang-Yu, 2006). The studies of Xu *et al.* (2006a, 2006b) and Ohumara and Wild (2002) indicate that the evapotrtanspiration trend is not determined by temperature alone. In this context we tried to study trend of the evapotranspiration and the climatic parameters involved, in the aim of developing future regional scenarios of evapotranspiration and crop water requirement under climate change condition.

METHODOLOGY

Study region and data

The study has concerned the region of Chott-Meriem (35° 55’ N, 10° 34’ E, 15m altitude) situated at the coastal centre of Tunisia, given the availability of the climatic data. Daily long-term meteorological parameters, (temperature, humidity, wind speed and sunshine hours) of 33 years (1973–2005) have been used.

Evapotranspiration calculation method

The Penman-Monteith equation (1) (Allen *et al.*, 1998) recommended as the standard and the most used method of crop water requirement calculation. This method was used in our study for calculating reference evapotranspiration and crop water requirement:

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \dfrac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \qquad (1)$$

where:

ETo: is the reference evapotranspiration (mm day^{-1}), defined as the evaporation of an extension surface of green grass of uniform height (height of 0.12 m) which is actively growing and adequately watered having the surface resistance of 70 sm^{-1} and albedo of 0.23;

Rn: net radiation at the crop surface ($MJm^{-2}day^{-1}$);

G: soil heat flux density (MJm^{-2} day^{-1});

T: mean daily temperature at 2 m height [°C];

u2: wind speed at 2 m height [ms^{-1}];

es: saturation vapor pressure[kPa]

ea: actual vapor pressure [kPa];

es–ea: saturation vapor pressure deficit [kPa];

Δ:slope of vapor pressure curve [kPa $°C^{-1}$];

γ: psychrometric constant [kPa $°C^{-1}$]=0.665×10^{-3} ***P***

Trend analysis

The Mann-Kendall trend test, which is highly recommended for general use by the World Meteorological Organization (Mitchell *et al.*, 1966), was used to determine the trends for the reference evapotranspiration as well as involved climatic parameters.

We used for this trend analysis the Excel template MAKESENS (Mann-Kendall test for trend and Sen’s slope estimates) developed by Salmi *et al.*(2002), for detecting and estimating trend in time series of annual values and monthly values. The Mann Kendall test is applied in case when data values xi of a time series can be assumed to obey the model:

$$x_i = f(t_i) + e_I \qquad (3)$$

where:
f(t) is a continuous monotic increasing or decreasing function of time
e_I : a residual that can be assumed to be from the same distribution with zero mean. It is there fore assumed that the variance of the distribution is constant in time.

Sensitivity analysis

In order to study which climatic variables most affect the reference evapotranspiration (ETo), a sensitivity analysis of the reference evapotranspiration to meteorological variables was performed using the Palisade precision tree (vers1.0) tools for Microsoft excel. The mean of the 33 years daily values of the climatic parameters was used with the [-20% to +20%] variation ranges.

RESULTS

Trend Analyses

Temperature

The Kendall trend test for the monthly maximum temperature revealed a height significant increasing trend from April to June. According to this analysis we ca highlight that autumn and summer period are becoming hotter; on the other hand there is no trend for the winter period. The minimum temperature presents the same trend as maximum temperature but not as the same level of signification. The maximum temperature increasing is more important, especially during the hot period. In the opposite an absence of temperature trend (maximum neither minimum) during coldest months have been noticed.

Vapour pressure deficit and net radiation

For the two parameters that influence the flux of the water through the crop, known as VPD (vapour pressure deficit) and Rn (net radiation), we noticed a height significance increasing trend of the vapour pressure deficit, from May to June period and two opposite trend period for the Rn (increasing trend from January to may and decreasing trend from September to October).

Wind speed

For the wind speed parameter the increase trend is generalized during the hole year, and this trend is highly significant (a=0.001) from March to October (Table 6 Annexe).

Even if similar trend was sited by Chang-Yu *et al.* (2006), when studying the climatic parameters trend, for the Yangtze River catchment, but relating this decreasing trend of the wind speed to climate change phenomenon must be considered with more delicacy. Because such change in wend speed can be also result of environment changes around the measure station, as building rising and or trees growth.

Rainfall

The rainfall parameters didn't present any temporal trend at annual scale but at monthly scale we detected significant increasing trend (α=0.05) during the month of September.

Sensitivity analysis

The results show that the most influential climatic data on the reference evapotranspiration (ETo) are the solar net radiation (short wave radiation) followed by the actual vapour pressure (VPD), the net long wave radiation and the maximum temperature. If we use only the measured meteorological parameters needed as input in the ETo calculation in Panman Montheith method, we noticed that respectively the relative humidity (HR), maximum temperature (Tmax) and the wind speed U_2 present the most important parameters.

CONCLUSIONS

- The maximum temperature and minimum temperature do not increase similarly and the maximum temperature trend is more important and staggered.
- The hottest months become hotter but the colder months did not present any significant trend.
- The trend of decreasing wind speed must be considered with much precaution, because such a change may be the result of physical changes around the measuring station, such as raised buildings and/or tree growth.
- We also noticed a significant trend of decreasing relative humidity (HR) with an increase in the actual vapor pressure (ea). As a result, there is a significant trend for higher vapor deficit (VPD) occuring essentially from May to June. As the region already suffers from water deficit this increasing VPD will also increase crop stress.
- According to sensitivity analysis, the most important climatic parameters that affect the reference evapotranspiration and the crop water requirement are the net shortwave radiation, the actual vapor pressure, the long wave radiation and the maximum temperature.

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Ecological discharge of the aquifer of Oropesa-Torreblanca (Castellon, Spain) for recovering the seawater/fresh water equilibrium

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Seawater intrusion is normally associated to over exploitation of groundwater. When fresh water discharge is drastically reduced the hydrodynamic equilibrium between fresh and seawater is altered, provoking saltwater intrusion. In order to recover or preserve the natural equilibrium in the coastal aquifers an ecological approach to the discharge should be considered. Is not easy to estimate how large this discharge has to be, but if a consistent conceptual model is reached the implementation of mathematical models can be a good tool to achieve this objective.

The Oropesa-Torreblanca aquifer (Castellon, Spain) is being over exploitated and the seawater intrusion process is affecting it severely. Increasing the ecological discharge of fresh water appears to be the only way to recover the natural water quality.

Both the drastic reduction of the groundwater abstractions and the application of artificial recharge using wastewater are being considered in a mathematical model implemented using the MODFLOW code. The results show that a progressive reduction of the pumping by up to 40% could re-establish the original equilibrium.

Regional flows contributing to the groundwater salinization of coastal aquifer of Castellon, Spain

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The general hydrogeochemical features in the coastal aquifer of Castellon Plain are very complex due to the overlapping of several processes, both natural and anthropogenic. Seawater intrusion and agricultural and industrial pollution lead to the existence of five well differentiated water-types. Water salinization is very intense in the southern part of the aquifer where overexploitation has been recorded since the 1970s.

The major process accompanying seawater/fresh water mixing is inverse ionic exchange (Ca against Na) which does not involve magnesium, even though the saline water is clearly enriched in this ion. Sulfate contents are also larger than expected. If a sulfated member is considered in the fresh water, the ionic excess of sulfate and magnessium is fully justified. The sulfate water-type has around 16 meq/l of SO_4^{2-} and 7 meq/l of Mg^{2+}.

Significant amounts of boron, lithium and strontium are also involved in this regional flow.

Determining agronomic crop tolerance to salinity: Citrus as a case study

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For the last 50 years, the world has been continuously drifting into a water crisis. Currently about 20% of the world's irrigated areas have become salinazed. As a result, determining a crop's tolerance to salinity is a key factor in evaluating its economic potential.

Citrus is an important crop worldwide that is known for its sensitivity to salinity. Its salt tolerance has been studied for more than 60 years. As a result, citrus salinity research can be used as a case study for evaluation of crop tolerance to salinity. Initially, the citrus salinity research was focused on the osmotic effects of salinity, and the effect of the soil-water electric conductivity on yield reduction was determined. Then the toxicity aspects of salinity (mainly chloride toxicity) were taken into account. The research focused on the mechanism behind chloride uptake, as well as on the effects of the rootstock on chloride uptake (including ranking rootstocks for their tolerance to chloride). Yet, after all these years, the data is relatively inconsistent and we still have difficulties with estimating the effects of salinity on citrus yield reduction. For example, the rootstock of Sour Orange appears in some papers as salt-tolerant while in others as salt-sensitive.

The effects of experimental design, measuring methods, and scion characteristics on citrus tolerance to salinity will be discussed. Furthermore, a new citrus salt-tolerance model that considers both the osmotic effects and toxicity effects of salinity will be described.

Improving the calculation of crops' virtual water content in a context of climate change and salinization risk

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Increased water scarcity and increasing intersectoral competition for water are important reasons to look at the way water is managed on our planet. The water requirements for food are by far the largest and this is why the concept of virtual water is so important when discussing food production and consumption. One of the fundamentals of management is the ability to measure fluxes and volumes. For that we need standardized measurement tools and methodologies, since improved information on virtual water is going to be pertinent for the water management debate. In this regard, recent assessment approaches, such as water footprint calculations (Hoeckstra**,** Chapagain *et al.*, 2009. *Water footprint manual, state of the art.*) are an important step forward, but some shortcomings and methodological problems need to be properly addressed. Three additional dimensions in particular that should be included when estimating virtual water contents and total water availability are highlighted:

1) The water generated from salinization plants (*witty water*), which is an increasingly important water source in arid and semi-arid regions, in addition to the "green" and "blue" water usually considered in virtual water calculations.

2) The quality of "blue" (irrigation) water matters and therefore the use of water of poor quality for irrigation purposes *(salty water*). In many semi-arid regions the available water is of low quality and the irrigation practices should avoid the development of adverse soil conditions due to the appearance of soil salinity that decreases crop yield through osmotic and toxicity stress effect on plants.

3) Last but not least, it is essential to refine the calculations of water crop requirements, by means of taking into account the differences in soil composition and the complexity of soil processes. Recent papers (Aldaya and Llamas 2008), (Chapagain and Orr 2008), although very valuable, assume an oversimplification of the transient soil water processes (runoff, infiltration, storage) that can lead to a significant bias in the calculations.

Keywords: virtual water, salinization, evapotranspiration, *witty water*, *salty water*, soil water processes.

Effects of long-term saline irrigation on soil properties and vegetable crops

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Salinity is one of the major environmental constraints that limit crop productivity and quality. The United Nations Food and Agriculture Organization (FAO) has estimated that approximately 20% of irrigated lands are affected by increasing salinity. The competition for fresh water in agricultural, domestic and industrial uses, mostly due to the growing population and climate change, is exacerbating the spread of salinization. Arid and semi-arid regions are more exposed to this phenomenon since in these climatic zones high evapotranspiration rates, irrigation and reduced rainfall all contribute to salt accumulation in the uppermost soil layers, where root development mostly occurs. Salinization does not pertain only to extreme environments and/or southern regions of the world. In Europe, 26 countries have reported cases of salinization with a higher frequency in Mediterranean coastal areas. Although soil salinization could be delayed through proper irrigation management, it cannot be avoided. Consequently the progression of salinization is increasingly jeopardizing productions of irrigated lands, the most active agricultural areas of the world.

In Mediterranean areas, the diversity of agricultural systems underlies the existence of different salinities, whose effects on crop yield and quality should be analysed in an agronomic context. The Department of Agricultural Engineering and Agronomy at the University of Naples Federico II has been engaged since 1988 in a long-term research activity aimed at elucidating the complexity of crop-salinity interactions in specific agricultural contexts. During the dry season (Spring–Summer), the effects of drip irrigation with saline water were studied on growth, yield and market quality of some vegetable crops (broad bean, broccoli, carrot, cauliflower, endive, fennel, lettuce, pea) and on soil properties. The treatments consisted of 5 levels of water salinity (0%, 0.125%, 0.25%, 0.5% and 1%) obtained by adding commercial sea salt to good quality canal water (0% treatment). Electrical conductivities at 25 °C (EC_w) of the 5 irrigation waters were 0.5, 2.3, 4.4, 8.5 and 15.7 dS/m, respectively. Furthermore, a non-irrigated control was also included. After equilibrium levels of soil salinity were reached, the effects of the variably lower soil salinities were studied on plant growth, yield and market quality of fall-winter vegetable crops (cabbage, celery, pepper, eggplant, snap bean, tomato for processing) under a rainfed regime. Sustained irrigation in summer time with saline waters induces salt accumulation and increase of sodium in soil with constraints resulting in reduced crop yields even during the fall-winter season. Soil physical and chemical conditions have been altered by long-term irrigation with saline water: the soil of 1% treatment assumed typical characteristics of alkaline-saline soil with decreased structure index and water infiltration rate, higher water content, surface crusting, pH ≥8.0 and consequently poor aeration in the root zone. Exchangeable sodium percentage (ESP) was much higher in salinized soil. The soil water infiltration rate varied between 12 mmh^{-1} (treatment 0%) and less than 1 mmh^{-1} (treatment 1%), which may be caused by the sodium dominance on the adsorption complex that would determine deflocculation or puddling of the clay particles. The index of stability of the aggregates in water (IS) was reduced from >50% to 12% with irrigation at 1% NaCl. In this paper we summarize some of the results achieved and highlight future research needs.

Use of an aboveground electromagnetic induction meter for detecting salinity gradients and indurated soil layers in a volcanic landscape

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In some volcanic landscapes salts accumulation can appear in the bottom parts of the relief as a consequence of the downward transport of the solutes resulting from rock alteration. Such geochemical process can originate the appearance of mineral-zonation belts according to their relative solubility.

Electromagnetic induction (EM) is a non-invasive technique that can help in quick surveying of landscapes, producing a primary magnetic field than induces a secondary magnetic field if some conductors are present into the soil. The measurement integrates the induced secondary magnetic field from a volume of soil that depends of the sensor geometry. Using the Geonics EM38 sensor, the effective depth of measurement extends to 2 m that is appropriate for soil survey and agriculture applications. The instrument allows two geometry configurations, vertical and horizontal mode that integrate soil and geologic materials response from different depths.

In a conceptual model, the EM signal response can be described as a complex function of geologic materials conductance, soil solution conductivity, soil volumetric moisture, temperature, texture and type of clay, among other factors, each layer contributing unevenly to total signal response.

An andesitic hill in Central Mexico is surrounded by rings of entisols, calcids, salids and argids arranged in the downhill sense. A bottom-top longitudinal survey has been performed measuring with a Geonics EM38 meter, both in vertical and horizontal model, as well as surface temperature with an infrared thermometer, at 95 points along a distance of 762 m, positioning each measurement with a WAAS enabled GPS (HDOP <3 m). Several soil samples were taken to relate the bulk EM ECa with ECe of the saturated paste.

Three distinct zones were clearly discriminated through the analysis of the EM38 raw signals and soil surface temperature: a first area of saline-alkaline soils with halophytes and cactacea; a second area of non-saline soils with petrocalcic horizon where halophytes are absent; and a third area of shallow, less-developed soils with moderate slope at the bottom part of the hill. The measurements provided data for the bulk soil conductivity at every point, showing salinity gradients, area heterogeneity, detecting the appeareance of petrocalcic horizon and computing if salinity is in the topsoil or the bottom soil.

Assessing the relationship between soil salinity and plant distribution using electromagnetic induction

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Salinity distribution in natural or managed ecosystems can follow a complex pattern due to differences in soil texture, permeability, drainage, topographic position, microclimate and vegetation activity, among other factors. Direct sampling of soil profile and water, and subsequent laboratory analysis of ion concentrations and minerals present, is the most informative study approach at point scale, providing detailed data for soil salinity type and magnitude, but is time and effort consuming, only point representative and difficult to perform several times to keep track of landscape time-changing conditions.

Electromagnetic induction (EM) is a useful, low cost technique for quick measurement of bulk soil electrical conductivity, being non-invasive, non-disturbing and can provide very useful information about soil conditions (salts concentration, soil moisture and texture). The measurement integrates the induced secondary magnetic field from a volume of soil.

In a conceptual model, the EM signal response can be described as a complex function of soil solution conductivity, soil moisture, temperature and amount and type of clay, among other factors, each soil depth contributing unevenly to total signal response. The EM apparent soil electrical conductivity (ECa) signal response can be related to ECe of the soil saturation paste extract at particular depths, through statistical calibration.

This study focuses on the relations between topography/soil salinity/vegetation in a low-energy coastal environment at the Western Mediterranean Sea (Valencia, Spain). A seashore–inland longitudinal survey along seashore (origin), sand dunes, salt-affected depressions, sand barriers with trees and bushes and a salt marsh, has been performed measuring bulk ECa with a Geonics EM38 meter, both in vertical and horizontal mode, at 5 m interval, along a distance of 420 m, positioning each measurement with WAAS enabled GPS (HDOP <3 m) and a topofil meter. Each measurement was triplicated and the values averaged.

Signal analysis allowed discrimination of 4 sub-environments, provided data of the actual bulk soil conductivity at every point measured, showed slight salinity gradients, computed if salinity is concentrated in topsoil or in the bottom soil and was useful to relate vegetation present to soil salinity conditions.

Keywords: salinity, electromagnetic induction, 3D mapping.