Part 2
Abstracts according to programme

INAUGURAL SESSION

Welcome

The Inaugural Session took place at the Headquarters of the International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates (UAE). Mr. Shawki Barghouti, Director General, Mr. Fawzi Al-Sultan, Chairman, and Dr. Faisal Taha, Director Technical Programme, ICBA, talked about the mandate and on-going activities of ICBA as a scientific research institution focusing on development and promoting systems that facilitate crop production in areas characterized by saline water or soils.

Mr. Mohammed Toure, Islamic Development Bank (IDB), and Dr. Anwar Nasim, OIC Standing Committee on Scientific and Technological Cooperation (COMSTECH), addressed the Consultation with a brief presentation of the role, funding programmes, activities and achievements of their institutions.

Mr. Kayan Jaff, FAO Representative in the UAE, described FAO's mandate and the work carried out in the region to improve agricultural production and presented FAO's work on issues related to soil degradation, including salt-affected soils and related subjects within the framework for combating global land degradation. He also highlighted FAO's collaboration with several institutions.

Dr. Amin Mashali, on behalf of Dr. Clemencia Licona Manzur, Soil Reclamation and Development Officer (FAO), emphasized FAO's role in providing advice on preventing soil degradation and managing problem soils. He also discussed the reactivation and expansion of the SPUSH Network to cover aspects of prevention of salinization as well as the management of salt-affected soils.

Introduction to the SPUSH Network

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Soil salinization has been identified as a major process of land degradation. As the nature of the problem is dynamic, the cost of measurement is high and there is a lack of data required to classify a soil as salt-affected. To date there is incomplete information on the extent, distribution and degree of salinity development for all countries affected.

According to various estimates, the extent of salt-affected soils in the world differs considerably. This is due to the lack of systematic surveys, the continuous change in the extent of salinization due to secondary salinization/sodication or seawater intrusion and differences between countries' approaches for detecting and classifying salt-affected soils.

Many experts have tried to map salt-affected soils. However, figures and available maps are questionable and need to be updated, since they may be based on data and maps collected more than 30 years ago. There are differences between the countries in the diagnosis, classification and criteria they use to identify salt-affected soils, e.g. saline soils can overlap with sodic soils, acid sulphate soils, mangrove soils.

Therefore, practical methodologies for monitoring and mapping of salt-affected soils is a requisite for determining the extent and magnitude of salt-affected soils; for assessing the causes and sources of the problem as well as the effectiveness and appropriateness of irrigation and drainage practices; and for the effective management strategies.

To avoid the fragmentation of technical research and development efforts, FAO has recognized the need to reactivate and expand the Global Network on Salinization Prevention and Productive Use of Salt-affected Habitats (SPUSH).

This paper provides a brief overview of the causes of salinity and mapping efforts of salt-affected soils, as well as the previous work of the SPUSH Network.

SESSION 1: ASSESSMENT AND MONITORING OF SALT-AFFECTED SOILS AT FIELD, LANDSCAPE AND IRRIGATION DISTRICT LEVELS

Assessing and monitoring the risk of salinization in a Sicilian vineyard using the Geonics EM38

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In many arid and semi-arid countries, as well as in Sicily, the increasing scarcity of good quality waters, coupled with the intensive use of soil under semi-arid to arid climatic conditions, results in irrigation with saline waters, leading to secondary salinization.

Salinization is closely associated with the process of desertification. Salinity may have direct negative effects on crop yields by reducing the ability of plant roots to take up water. The reduced availability of water to the plant is due to soluble ions and molecules causing an osmotic pressure effect. Threshold relationships between the soil electrical conductivity (EC) and crop yield have been empirically determined for several crops and can be used to evaluate the influence of saline irrigation water on agricultural production.

The salinity of irrigation water is defined as the total sum of dissolved inorganic ions and molecules. Soil salinity can be measured in the soil by determining the EC of the soil solution. The EC measured in the saturated extract (ECe) is used as an expression of salinity. The USSL (1954) developed the saturation extract technique, a way to estimate soil salinity that uses a reference water content. However, methods suitable for a rapid assessment of soil salinity are necessary for surveying large areas susceptible to degradation and for prevention of desertification.

Application of an electromagnetic induction sensor (EM38) makes possible, after calibration, rapid surveys of large areas for identification of the places with the greatest risk of salinization, where detailed investigation is necessary to develop countermeasures and strategies suitable to control desertification. Application of this technique provides a measurement of the EC of the "bulk soil" (ECa). Since ECa is influenced not only by the chemical and physical properties of the soil solution, but also by those of the solid phase (soil texture, mineralogical composition of the soil), a preliminary calibration is necessary in order to convert the field measured ECa into the saturated electrical conductivity (ECe).

A number of international and national projects have been developed in Sicily since 1998, with the objective of developing integrated approaches for sustainable management of irrigation. This investigation is part of the "Evolution of cropping systems as affected by climate change" (CLIMESCO) project (2007–2009), and was carried out within the framework of a bilateral agreement for scientific cooperation between the University of Palermo and Arizona State University.

The objective of this paper was to show the results of using the Geonics EM38 probe (Geonics Limited, Mississauga, Ontario, Canada) for monitoring salinization in Sicily, where irrigation with saline water is increasingly practised and a risk of salinization and desertification is envisaged. Maps showing the spatial and temporal variability of salinity determined by two different irrigation treatments are analysed and the effect of using two irrigation waters of different salinity are discussed.

Use of an aboveground electromagnetic induction meter for assessing salinity changes in natural landscapes and agricultural fields

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Salinity can be considered as a property that changes quickly in time, influenced by lateral water movement through a landscape and vertical water fluxes in soils, due to infiltration and evapotranspiration. An irrigation event or the rainfall associated with an intense storm can change the amount and distribution of salts in a soil profile. For large areas, soil conditions can differ from one site to another, imposing local differences in management practices.

The nature of soil salinity/alkalinity is best studied through soil sampling and analysis of the saturated paste extracts and other soil properties. Within a framework of modern land management, some decisions are more rationally based if some soil geostatistical information is available. The collection of numerous field samples and subsequent analysis in the laboratory is a costly activity for assessing/monitoring soil salinity. On the other hand, the decision about the necessary number of samples to provide a uniform area cover, providing statistical information, as well as the decision about the sample location, poses a difficult question that should be answered after a previous salinity screening of the field. The ratio of the desired number of samples to the associated cost of sampling can be optimised through an adequate sampling design.

Electromagnetic induction (EM) is a useful non-invasive technique for taking quick measurements. It can provide raw information about soil components (salts concentration, soil moisture and texture). The EM signal response can be related to the apparent soil electrical conductivity (ECa) at particular depths, through statistical calibration. 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 two examples presented show the way to derive soil salinity information from above-ground electromagnetic induction measurements. The first example is a multitemporal monitoring of salinity in a small agricultural field with uniform texture and topography, with sodium chloride-type salinity, using a regular-grid surveying scheme. Two sensor geometries are used and, based on the signal treatment, quasi three-dimensional multitemporal maps of bulk soil salinity can be drawn and trends of soil salinity recognized.

The second example is an automated longitudinal survey along a landscape, designed for discovering differences in salinity type, soil texture and total moisture content. Soil sampling sites are selected from the profiling and statistical treatment of response signal.

Keywords: electromagnetic induction, soil salinity, salts zonation.

Primary soil salinity, sodicity and alkalinity status of different water management areas in South Africa: The quest for baseline data

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The objective of this paper was to describe and quantify the primary salinity, sodicity and alkalinity status of soils in terms of the 19 water management areas of South Africa by using data from more than 26 520 soil samples. South Africa's salt-affected soils, derived from complex geological formations and soil forming processes, comprise almost 32 percent of the country's surface area.

The data were derived from soil survey reports for irrigation and environmental planning and the South African Land Type Survey of the ARC-Institute for Soil, Climate and Water. The minimum requirements for inclusion in the data set were: (a) the profiles should have comprehensive chemical and physical analyses, and the preference was given to data sets where soil analyses followed the methods of the *Non-Affiliated Soil Analyses Working Group* (1990) and where the analyses were done in the ARC-ISCW laboratory; (b) accurate profile location information should be available; (c) only primarily data could be used – no human-induced salinization or sodication; (d) soil profile description should have been done according to *Soil Classification: A Binomial System for South Africa* (1977) or *Soil Classification: a Taxonomic System for S.A.* (1991). Although data verification was carried out on most samples previously, much effort was devoted to data cleaning. From the original data (in excess of 40 000 data points), only 26 520 data points were used due to the stringent cleaning protocol.

After a countrywide process of public consultation, 19 water management areas covering the entire country were established. The boundaries of the water management areas lie mostly along the divides between surface water catchments and do not coincide with the administrative boundaries that define the areas of jurisdiction of provincial and local government authorities. The water quality data that were used in the assessment of fitness for use of South Africa's surface water resources for domestic and irrigated agricultural use were collected as part of the National Chemical Monitoring Programme. This programme has been in operation since the early 1970s and samples are collected regularly at approximately 1 600 monitoring stations at a frequency that varies from weekly to monthly sampling. The data collected is stored on the Department of Water Affairs and Forestry's database and information management system, namely the Water Management System. For this study, a suitable water quality sample site was considered to be one with an adequate level of sampling (not too infrequent or sparse) over the study period.

The problems of primary soil salinity, soil sodicity and soil alkalinity are most widespread in the arid and semi-arid water management areas of South Africa, but salt-affected soils also occur extensively in sub-humid and humid water management areas, particularly in the coastal areas where the intrusion of seawater through estuaries, rivers and groundwater causes problems. In South Africa, where the rainfall is approximately five to ten times less than the potential evaporation, salts derived from rock weathering, bio-cycling and atmospheric deposition may accumulate to relatively high levels in the soil.

Currently, the secondary salinity and sodicity of South African waters and soils are on the increase due to mining, urban, industrial and agricultural developments and the re-use of water resources. Irrigated agriculture is not only at the receiving end of water quality deterioration, but it is itself a major contributor to the observed water quality deterioration in many rivers. The use of such water poses a future threat for soils in areas of South Africa where leaching is limited.

In South Africa, many water bodies are naturally high in dissolved salts, especially where rivers flow over marine sediments. Irrigation farmers are often accused of causing much of the salinization, sodication and alkalization of water in South Africa, because they are the biggest users of water. Leaching of primarily mineral salt from the surrounding geology after rainfall, as well as pollution from industrial and mining activities are, incorrectly, not considered as also being important. Soil salinity seems to be largely under control in South Africa at present, but this situation could change dramatically as a result of industrial, municipal and mining effluents used on agricultural land. Primary soil sodicity and alkalinity are a bigger problem than primary salinity in South Africa.

Using satellite imagery and electromagnetic induction to assess soil salinity, drainage problems and crop yield in the *Río Fuerte* Irrigation District

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The survey of soil salinity and drainage deficient areas, as well as the estimation of yields in the *Río Fuerte* Irrigation District, northwest Mexico, were carried out by applying satellite imagery, a portable electromagnetic-type sensor and a GPS unit. Soil and plant samples were obtained in selected salt-affected fields grown with wheat (*Triticum aestivium*), cotton (*Gossipium hirsutum*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*), which were considered as the reference crops, since all together covered most of the cropped area of the irrigation district. Spectral values (TM2, TM3 and TM4 bands) were extracted from Landsat TM images. The images were obtained during the flowering stage of each crop. Salinity and spectral data were analyzed and multiple regression models were obtained to estimate the salinity status of the cropped areas, together with its correspondent crop yield. Salinity and yield maps for each crop were digitized and classified on the Landsat image using the regression models. The non-referenced area of the district (fields planted with any other crops, non-cropped, fallowed, or abandoned) was mapped *in-situ* using an EM38 electromagnetic sensor, along with a GPS unit to locate the geographic coordinates of each of the sites. Both Landsat- and EM38-based salinity maps were joined and a final map covering all the Irrigation District area was obtained. The total mapped area was 319 976 ha and it was estimated a salt-affected area of 138 345 ha (43 percent, EC >4 dS m^{-1}). Poorly drained areas were also obtained based on water table monitoring for the most critical period of the year. This information was also added to the salinity map previously obtained, so salt-affected areas with shallow water table were determined for reclamation and planning purposes. Yield maps were also combined with the salinity map to analyze the effect of the various existing salinity levels on crop yield. The economical analysis performed showed this method is highly cost and time effective, compared to the traditional one (extensive soil sampling and laboratory analysis).

Keywords: satellite imagery, salinity, drainage, yield, regression model, electromagnetic sensor.

SESSION 2: ASSESSMENT AND MONITORING OF SALT-AFFECTED SOILS AT NATIONAL AND REGIONAL LEVELS

Soil salinity monitoring and assessment in irrigated Arab agriculture

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In the Arab world, irrigated agriculture contributes about 70 percent of the total crop production commodities. Irrigated agriculture in the Arab world is about 10.7 Mha. The irrigation systems used for irrigating such land are flood, sprinklers and localized. About 87.6 percent for the irrigated areas is irrigated with different flood irrigation practices, 11 percent with sprinkler and 1.4 percent localized. The efficiencies of the irrigation systems used are not more than 50 percent. These low efficiencies of irrigation systems lead to increase in soil salinity and waterlogging. In addition, due to the shortage of good quality water, several Arab countries hav large reservoirs of low quality (3–11 dS m^{-1}) underground or agricultural drainage water, as well as sewage drainage water. Use of such water is possible if it is properly managed. The use of low quality water must be used with extensive planning and proper infrastructure of drainage networks.

Good agriculture practices will minimize salinity build-up in the soil profile. These agricultural practices are: good irrigation scheduling; addition of organic manures; deep ploughing; and no tillage practices. Addition of soil inorganic and organic amendment has been used to prevent soil alkalization. Low quality water has been used by the Arab Center for the Studies of Arid Zones and Drylands (ACSAD) in different Arab states for irrigating winter crops such as barely, wheat and potato. This supplementary irrigation practice improved the income of poor farmers without degrading their fields by salinity. This finding was determined by salinity monitoring for seven years in more than 80 farmers' fields and in ACSAD experimental stations over fourteen years. The salts in these fields are leached out as far as 3.5 m below the soil surface in sandy and sandy loam soils. Measurement of salts in the soil profile indicated that salts moved down to drainage systems in clay, clay loam and silt clay.

Different methods were used by ACSAD for monitoring and assessment of soil salinity. These included field methods, such as EM38, salinity sensors and traditional methods of collecting soil samples and determining the salinity.

Each method has its limitations and some of them gave wrong the interpretation and correlation with yield increase or decrease if not carried out correctly. It was found that the method that correlated most closely with yield increase or decrease was when the soil solutions were collected by ceramic cups.

The salt balance for irrigated Mediterranean coastal soils shows most salts, which accumulate in summer crops, were leached out by rain in winter, when the soil profiles were more liable to leaching.

Advances in the assessment of salt-affected soils for mapping, monitoring and management strategies in India

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Salt-affected soils in India have variable distribution patterns and occur mostly in belts or patches that make them difficult to map and monitor. The first mapping of salt-affected soils in India began in 1902, when Leather delineated several *Usar* (alkali) patches enriched with sodium carbonates in the fields of the Etah district in Uttar Pradesh. After independence in 1947, several workers across the country conducted traditional soil surveys including field traversing, profile studies and analysis of soils and water samples to produce reports and maps on salt-affected soils falling under various projects and irrigation schemes. Such surveys produced fragmented and localized results. They differed in methodology and criteria; hence the information produced could not be extrapolated to other areas. The Committee on Natural Resources of Planning Commission, in 1966, estimated 6 Mha of salt-affected soils and depicted its distribution in a map, based on standard surveys using aerial photo interpretation. The map showed occurrence of salt-affected soils in compact areas of the Indo-Gangetic Plain and in scattered blocks in other parts. After its establishment in 1969 at Karnal, the Central Soil Salinity Research Institute (CSSRI) carried out a countrywide assessment of the problem and made a first estimation about the nature and extent of salt-affected soils. By focusing on soil characteristics and the feasibility of reclamation, two main classes of salt-affected soils, namely alkali and saline, were recognized. Abrol and Bhumbla upgraded the estimate to 7 Mha in 1971 and Bhumbla, in 1975, depicted six categories of salt-affected soils on a map, i.e. alkali soils, saline soils, potentially saline soils, coastal saline soils, deltaic saline soils and acid sulphate soils. In 1980, Murthy compiled and synthesized benchmark profiles of salt-affected soils from all over India and classified them into associations of major groups. The mapping legend consisted of 12 associations. The absence of systematic surveys and a reconnaissance map showing the distribution and extent of salt-affected soils prompted the individuals to report on their extent. The calculated figures, as expected, ranged from 3.3 to 26.1 Mha. The wide variations in the figures reflect the degree of concern and perception authors had for the problem.

The recent mapping methodology includes visual (manual) and digital (computer) interpretation of satellite data supported by field and laboratory investigations. The first systematic mapping of salt-affected soils of the entire country was made in 1996 by the National Remote Sensing Agency (NRSA) in Hyderabad, in association with other national and state level organizations including the CSSRI and the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP of ICAR). A total of 125 false colour composite prints of the Landsat TM satellite images were used in mapping salt-affected soils at a 1:250 000 scale. The methodology consisted of development of a nationwide mapping legend, interpretation of satellite data, ground truth collection, analysis of soil samples, post field interpretation and reconciliation and area estimation. In order to accommodate salt-affected soils occurring in different parts of the country, a common legend was evolved after extensive discussions with the collaborating partners engaged in either conventional soil survey or those working with remote sensing techniques. The 125 map sheets showed a 6.73 Mha salt-affected area in the country. However, it did not differentiate between saline and sodic soils, the two major classes for which distinct sets of reclamation techniques are evolved under Indian conditions.

By abstracting information from the mapping legend – kind of soils, clay minerals, climatic conditions and physiographic setting of various regions – the area of 6.73 Mha of salt-affected soils was divided into two major classes (saline and sodic). Moderate and highly saline soils were easily identified due to the presence of white salts on the surface. A combination of red and infra red bands helped in separating saline and sodic soils. Integration of thermal band interpretation with false colour composite helped in resolving the problem of spectral similarity between saline soils and sand dunes.

The use of GPS in surveys of salt-affected soils has improved the quality of comparable studies like improvement in soil properties in the post reclamation phase, precise detection of hot spots of salinity emergence, expansion, identification and establishment of benchmark sites of salt-affected soils. Furthermore, the CSSRI has developed sustainable and cost-effective technologies for the reclamation and management of salt-affected soils.

The state-wide distribution and extent of saline and sodic soils is presented in the paper. A brief account of these technologies and their impact in terms of productivity gains, socio-economic dimensions and environment is also discussed.

Salt-affected soils in Thailand: Assessment and monitoring of salinization

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Agriculture has long been important for the socio-economic growth of Thailand. About 21 Mha of the land area is currently under cultivation, 13 Mha are forests and the remaining 17 Mha are composed of urban development, public areas, sanitation, swamp land, railroads, highways, real estate and others. In terms of agricultural production, land has been used to provide for the rapidly increasing food demand, which increased along with the population growth. This has led to diverse use of the land for many purposes, eventually resulting in degradation of land, particularly anthropogenic soil salinization of arable land.

Salinity is the oldest and one of the most important environmental problems. The problem of salinization is the presence of excessive salts on the top layer of the soil, resulting in the deterioration of its chemical and physical properties. It is a form of land degradation that has become a major cause of low agricultural productivity in the Northeastern region, the Central Plain and along the coastal belt of the country.

Salt-affected soils cover approximately 3.5 Mha. These soils are classified broadly into two groups, i.e. inland saline soils and coastal saline soils. These two broad categories of saline soils cover approximately 3.0 and 0.58 Mha, respectively. These naturally occurring saline soils normally expand to cover wider areas with time. Anthropogenic soil salinization has also become an important part of the rapid increase in soil salinization.

The assessment and monitoring of salinization for managing salt-affected land in Thailand has been greatly facilitated by various methods. The goal of this process is to assess the influence of salinity, preventing distribution of salinity on arable land and to manage the improvement and sustainable utilization of land resources. The criteria in defining salt-affected areas are based on an electrical conductivity (EC) value of 2 dS m^{-1}, while water has an EC value of 0.75 dS m^{-1}. Methods were developed to complement the soil salinity classification system, to evaluate and predict the existing salt-affected areas and to develop appropriate soil management guidelines. The conventional method was used in 1963 to assess and monitor soil salinity. This new method applies integrated technologies that have been assessed in terms of measurement of EC and laboratory analysis of soil and water samples, including determination of vegetation and plant growth.

Since 1989, advanced technologies for the assessment and monitoring of soil salinity have been used to provide spatial coverage faster than conventional methods. Image analysis of remote sensing data (Landsat) using visual and digital methods is carried out and verified by ground truth data and laboratory investigations. False colour composite bands 5, 3, 1 (blue, green and red) showed promising data for visual interpretation. Ground based surveys, using electromagnetic induction (EM34 and EM38), were conducted to measure bulk soil conductivity to a depth of approximately 7, 15 and 30 m, while EM38 measured conductivity over a depth of approximately 1.5 m. Piezometer installation on the salt-affected area was also used to observe and monitor water quality, depth of water table and flow.

The Land Development Department has been implementing the assessment and monitoring of salinization using the above-mentioned methods in different areas for several decades. The prototype of soil survey and monitoring, remote sensing and some computer models, were applied to generate maps of salt-affected areas and to obtain manuals and reports on appropriate prevention of soil salinization and improvement of technologies and approaches, database of soil resources and salinity management guidelines (including assessment and prediction of soil salinization and distribution). Outputs have been used to support stakeholders in the salt-affected areas, e.g. maps of salt-affected areas in the Northeastern region and the Central Plain provinces, a map of reforestation areas for soil salinity control, a report on the impact of the tsunami in the West Coast area, the impact of shrimp farming on arable land and monitoring of reforestation to prevent soil salinization.

An overview of the salinity problem in Iran: Assessment and monitoring technology

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Agriculture plays a vital role in the national economy of Iran. It accounts for 27 percent of the GNP and 23 percent of the labour force of the country. Scarcity of water is the major constraint for agricultural development in the country and based on projections for 2025, Iran will be in a water scarcity situation. Considering the growing demand for water from other sectors and the fact that 93 percent of renewable water resources are already allocated to the agricultural sector, allocation of more water to the sector is not foreseeable in the future. Under these circumstances, increasing water productivity in agriculture holds the greatest potential for improving food security and preventing environmental degradation.

The exact extent of salt-affected soils in Iran is not known. Based on a recent estimate, 34 Mha or nearly 20 percent of the surface area of the country is salt-affected. This includes 25.5 Mha of slightly to moderately and 8.5 Mha of severely salt-affected soils. Salt-affected soils are mainly distributed in the central plateau, southern coastal plain, Khuzestan plain and inter-mountain valleys. The salinization of land and water resources has been the consequence of both naturally-occurring phenomena and anthropogenic activities. Secondary salinization has been the main cause of the spread of salinity and, as a result, the waterlogged area has increased from 160 000 ha in 1977 to 0.7 Mha today, only in areas under the command of new dams.

In spite of the extent of soil salinity in the country, there are few studies which have been carried out to assess and monitor soil salinity. A number of these studies have been concerned with the evaluation of soil salinity in irrigated fields as a means of evaluating the appropriateness of on-going management practices. In these studies, soil salinity has been assessed in terms of laboratory measurement of electrical conductivity. The results from one such study in the south-west of the country show that wheat fields irrigated with saline water of electrical conductivity ranging from 8–12 dS m^{-1} produced a relatively good yield of 4–6.5 tonnes ha^{-1}. Monitoring of root zone salinity throughout the growing season for three years showed that mean root salinity in almost all the fields was nearly equal to the electrical conductivity of irrigation water, suggesting a high leaching fraction as a result of poor on-farm water management.

The use of advanced technology for assessment and monitoring of soil salinity based on bulk soil electrical conductivity is still in its early stages. Although instrumentation such as EM38, four electrode probe and time-domain-reflectometry (TDR) are now available, their actual field use has been very limited. In a case study an EM38 device was used for soil salinity survey in a pistachio orchard in central part of the country. Results indicated that the device could be conveniently used as a rapid measurement tool for soil salinity appraisal both in surface and depth.

On the other hand, remotely sensed data, especially satellite images, have been used more often for assessing and monitoring soil salinity in different parts of the country. Most of these studies utilized images obtained by Landsat TM and ETM sensors combined with other auxiliary data such as field measurements, DEM, slope and aspect maps. Methodologies used included visual interpretation of FCC map, image classification (both supervised and unsupervised) and selection of effective band(s) or indices.

Advances in the assessment and monitoring of soil salinization for managing salt-affected habitats in Egypt

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Agricultural development in Egypt is facing human-induced degradation, mainly due to salinity and waterlogging. The causes include seepage from irrigation canals, inadequate drainage systems, poor irrigation practices, use of slightly saline (drainage or mixed) water for irrigation without proper management and inappropriate agronomic practices. The presence of excess salts in the soil directly or indirectly affects plant growth. Salinity can affect the survival of normal field crops leading to completely barren soils which need to be reclaimed. As a result, soil salinity has become one of the most frequently used parameters to characterize field variability for application to sustainable agriculture.

The value of spatial measurements of soil electrical conductivity (EC) to sustainable agriculture is widely acknowledged, but soil EC is still often misunderstood and misinterpreted. The following areas are discussed with particular emphasis on spatial EC measurements: a brief introduction to soil degradation, soil salinity (worldwide) and the extent and causes of salt-affected soils in Egypt. This paper also presents an overview of advances in technology used for assessing and monitoring soil salinity such as remote sensing (RS), geographic information systems (GIS), mobile instrumental systems and computer assisted expert systems. These advances in technology can contribute to the planning and implementation of measures to combat salinization. Selecting the method of detection depends on several factors such as the accuracy required, cost of the project, available funds and the area to be surveyed. The future of sustainable agriculture rests on the reliability, reproducibility and understanding of these technologies.

Recent evolution of soil salinization and its driving processes in China

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Salt-affected soils are spread extensively in China, covering a wide area from tropical to temperate zones, from the coast to the inland and from the semi-arid to desert regions. Currently the total area of salt-affected soils is about 36 Mha, which occupies 4.88 percent of usable land in the whole country. About 9 Mha of arable land is salt-affected, accounting for 6.62 percent of the total land in the country.

Salt-affected soils are mainly distributed in Northwest China, North China, Northeast China and coastal regions. All these areas have hot spots of soil salinization. In the Songnen Plain and the Great Bend region of the Yellow River, the extent and degree of salinization are increasing. The area of salt-affected soils reaches 3.5 Mha in the Songnen plain, with an annual rate of salinization increase as high as 1–1.4 percent. About 45 percent of salt-affected land in this area has been degraded to severe saline land and abandoned. Salinity in the Great Bend region of Inner Mongolia has increased 1–3 percent annually in the last three decades due to inappropriate irrigation. Similarly, secondary salinization has occurred in the West Corridor of Gansu.

Irrigation with brackish water has been an important cause of salinization in the north part of China. According to monitoring data from Guyuan region in Ninxia, soil salt content increased to 2.3 g kg^{-1} after 5 years of brackish water irrigation and up to 8.3 g kg^{-1} after 14 years. Shallow ground in most river irrigation districts of Ninxia, Inner Mongolia and Xinjiang has been observed and salinization occurred as a result. The salt-water regime has changed under drip irrigation practices in some regions of Xinjiang, causing sat accumulation. Approximately 35 percent of irrigated land in Gansu, Xinjiang and Ninxia and 50 percent irrigated land in Inner Mongolia, are currently risking salinization. There are also imbalances in salt-water movement in coastal regions, such as the Yellow River delta.

The main driving factors of evolution of salinization in China are inappropriate water resource and land management as well as climate change. Inefficient water use is the dominant cause of soil salinization in irrigation districts, due to large seepage of irrigation canals, low irrigation efficiency, unnecessary high irrigation norms, poor drainage systems, blockage of drainage ditches and the rise of groundwater table from the construction of plain reservoirs. Micro irrigation practices such as drip irrigation in arid regions can potentially change the salt-water regime and therefore may cause salt accumulation. Local salinization has already been found in some areas with drip irrigation and such phenomena tend to expand.

Inappropriate land management in semi-arid and arid regions is also a driving factor in accelerating salinization, worsening soil physical and chemical properties (due to poor fertility management), increasing the evaporation surface and impairing soil drainage by removing vegetation cover from over-grazing, deforestation.

Climate change is considered as another significant driving factor on salinization. Currently climate in North China and Northeast China has been warming and precipitation has decreased. Such changes have promoted the evolution of salinization in the region. Climate change may also cause sea level rise. Salt leaching from soils in coastal regions, including the Yellow River and Changjiang River deltas, is therefore subject to a disadvantage owing to blockage of salt outflow and seawater intrusion. Consequently, local salinization expansion is observed.

Assessment and management of salt-affected soils in Sudan

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Sudan, the largest country in Africa, has an area of approximately 2.5 million km^2. Its climate is diverse, ranging from tropical humid in the south to desert in the north. This paper highlights the changes in climatic conditions and the properties of salt-affected soils in relation to salinity and sodicity. The distribution and area covered in every region is shown. The system adopted in Sudan for the assessment of a soil as being salt-affected is derived from the USDA system with amendments to fit the Sudan conditions (based primarily on the results of research trials). The research activity in reclamation of salt-affected soils is also covered and some of the results of the trials are shown.

The studies on climatic changes showed that there has been a considerable decrease in the annual rainfall. It reaches 19 percent in the arid climatic zone and 1 percent in the semi-arid climatic zone compared to the averages for 1941–1970 and 1971–1999. This, combined with human misuse of natural resources, water scarcity and removal of vegetation cover, necessarily implies a deterioration in soil properties. The increase in population and the limited extent of good agricultural lands in the Khartoum area and along the river banks in the northern regions have led to expansion into the marginal lands of the higher terraces of the Nile, where soils are affected by varying degrees of salinity and/or sodicity.

In many areas of the world the presence of salts (including sodium) in arid and semi-arid zones is a widespread phenomenon and Sudan is no exception. The salinity or sodicity may result as a consequence of physical weathering under low rainfall conditions coupled with low humidity and high temperatures by evaporation or by capillarity. All these conditions exist or have previously existed in Sudan. The reclamation of salt-affected soils was very limited until the 1970s, and was confined to some experiments in the Gezira, Soba and Hudeiba research stations. In the 1970s, Sudan witnessed some environmental, political, scientific and demographic changes that accelerated the need for reclamation of salt-affected soils, including:

- the decrease in good agricultural lands due to desertification, sand encroachment and river bank erosion that led to thinking about expansion into new lands to cover the food gap and support exports;
- the adoption of a local government system, so the different states tried to develop and exploit their resources, e.g. the northern states – as wheat-producing areas – expanded their areas into the high terrace salt-affected soils;
- the foundation of the Land and Water Research Centre, to classify, evaluate and reclaim salt-affected soils.

Salt-affected soils in Sudan fall under three soil orders: Vertisols, Aridisols and Entisols. They extend along vast areas at latitudes 14–22° N, including the White Nile, North Gezira, Khartoum state, along the river Nile, crossing the river Nile and the northern states. The land suitability classification system adopted in Sudan by the Land and Water Research Centre is derived from the FAO system, but some amendments were made to fit the Sudan conditions, e.g. exchangeable sodium percentage (ESP) values of up to 35 in the topsoil and 50 in the subsoil were incorporated as acceptable limits for the potential rating of the soil as marginally suitable in Gezira. These values were generalized over other soils in Sudan. Very good efforts were made for reclamation by researchers from agricultural research stations in Gezira, Hudeiba and Soba and the farm of the University of Khartoum. The Land and Water Research Centre and other experts reported that about 268 636 ha were found to be affected by salinity and/or sodicity.

From research results on the reclamation of salt-affected soils in Sudan, it was concluded that gypsum is a good amendment for leaching salts from the topsoil, while organic amendments like farmyard manure, chicken manure and dry sewage increased crop yields. The strategy for research should focus on a well-defined soil series, for ease of transferring the technology to other similar soils. Encouraging breeding programmes for salt and heat tolerance is of paramount importance, as is the promotion of extension programmes to transfer the technological packages to farmers. Finally, the Land and Water Research Centre of the Agricultural Research Corporation is carrying out a very important programme to have a soil database of all the soils in Sudan with special reference to salt-affected soils. We now have an up-to-date geo-referenced soil information database with digital maps.

SESSION 3: MODELLING FOR SALINITY/SODICITY DEVELOPMENT

Overview of salinity modelling approaches at different spatial-temporal scales

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Salinity is a natural property of many natural environments, arising from the geomorphic and geochemical processes creating landforms and coastal areas. During recent decades, the environmental role of natural salt-affected ecosystems has been recognized and the conservation and restoration of such habitats has become a priority policy worldwide. On the other hand, salinization is a progressive, human-driven, soil and water degradation process and an increasing environmental concern that affects the most productive agro-ecosystems under irrigated agriculture in arid and semi-arid regions.

Modelling is a valuable mathematical tool for studying salinization, dealing with simplified representations of systems; revealing complex interrelations of properties of the system under study; and creating scenarios for investigating "what if?" questions. Modelling of natural saline environments, as well as agricultural environments subject to salinization, has been addressed in several ways, from deterministic soil-plant-water-atmosphere approaches to systems dynamics model development, including social, economic or cultural factors, among others.

Each modelling exercise tries to provide an answer to a particular question formulated; hence the input information required to run the models ranges in complexity, as do the data acquisition requirements. Some models are used only by researchers whereas others are affordable by farmers. Many models are dynamic in concept, while others reflect a steady-state condition. The scale of application, geometry of the system, biological, chemical and physical processes represented, as well as the capability of representing an evolving system, are the main differences between models.

Some aspects that are important under normal agricultural practices are not well reproduced by some codes nowadays. Management practices, geometry of irrigation and evaporation, sinks of solutes (plant uptake) and interaction of fertilizers with soil components are incorporated in an uneven way in the available codes, and should be developed further.

Although it is desirable that the models become more and more deterministic and mechanistic, this requires a very intensive effort in research and computing. There are uncertainties associated with the values of the input parameters, with the computation procedure or with the inaccurate description of the system. The parameter estimation, analysis of sensitivity and validation procedures are refinements applicable to most models.

This paper gives an overview of different modelling approaches; compares the most used models based on their implementation, advantages and limitations; and discusses the possibilities of nested approaches and the advantage of clearly establishing an exit strategy in the management plans.

Keywords: Soil salinity, salinity modelling.

SMSS: a soil-plant model describing the impact of irrigation on soil and runoff water salinity

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In arid and semi-arid regions, water is the main limiting factor for agricultural production. In fact, both the quantity and the quality of irrigation water fundamentally affect soil quality and crop production. The presence of salts in irrigation water and the evaporation potential in the irrigated areas usually lead to the salinization and alkalinization of soils, particularly in arid and semi-arid zones. The monitoring of both soil and water qualities in irrigated areas is necessary to measure the sustainability of the production system. Thus, modelling the movements of salts in irrigated soils is a means to predict their evolution. For this purpose, two models (SMSS2 and SMSS3) were developed in order to predict the impact of irrigation on soil and water qualities.

The first model (SMSS2), based on the Laudelout model (1994), is used to analyze the movements of salts in saturated conditions with perfect drainage. It is a simple model essentially allowing the prediction of salinity/sodicity of soil after a long period of irrigation. It is controlled by two types of parameters: the exchange selectivity coefficients and the volume and quality of irrigation water.

The second model (SMSS3), improved from LEACHM (Hutson *et al.*, 1992) and UNSATCHEM (Šimůnek *et al.*, 1993) models, is used to simulate water and solutes transport in partially saturated soil profiles. Over a short period of time it allows the follow-up of the soil salinity and sodicity, which are controlled by different parameters such as: (i) simulation period, (ii) the conditions at the boundaries, (iii) soil physical properties, (iv) soil chemical properties (exchange selectivity and ionic activity products), (v) the crop, (vi) the temporal distribution of applied chemicals, tillage, rain and irrigation water and (vii) weekly distribution of the crop coefficients and potential evapotranspiration.

The validation of the SMSS2 model with the data of the lower Euphrates valley in Syria showed that the simulated data agreed with those measured in the field. The mean differences found between the simulated and the measured data in the field varied between 0.5 and 1 dS m^{-1}.

The validity of SMSS3 model, applied to the Doukkala region in Morocco, allowed predicting with acceptable precision the evolution of soil salinity and sodicity in the studied area. The obtained mean differences between the measured data in the field and those simulated vary between -0.25 and 0.13 dS m^{-1}. A sensitivity study of this model showed that the use of ionic activity products (IAP) of soluble minerals is preferable to their solubility products. For example, the use of the IAP of calcite produced a gain of approximately 18 percent in precision of the electrical conductivity in comparison with the result obtained using its solubility product.

Keywords: salinity, alkalinity, irrigation, modelling, Euphrates, Syria, Doukkala, Morocco.

SESSION 4: MAPPING AND INTERPRETATION OF SPATIAL DATA

Emerging challenges addressing the characterization and mapping of salt-induced land degradation

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Salt-induced soil degradation is an inherent and natural feature of the arid and semi-arid regions. Over the last few decades, it has increased steadily in several major irrigation schemes throughout the world. This has triggered imbalances between the goods and services supplied by the natural resources (land and water) and the demands of societies. Since soil degradation occurs both 'on-site' and 'off-site', it affects the livelihoods within and outside the farming communities. Therefore, salt-affected soils are usually considered as a major environmental and agricultural productivity constraint. However, these soils are a valuable resource that cannot be neglected, especially in areas where significant investments have already been made in irrigation infrastructure. From the perspective of managing salt-affected soils for economically feasible productivity enhancement, it is imperative to characterize different types of salt-affected soils for suitable technical interventions. Several efforts have already been done in the past to characterize salt-affected soils through different approaches. Owing to the complexity of different processes leading to the development of salt-affected soils and the use of a variety of assessment criteria, there is no single system that fits well with the characterization and classification of these soils.

Understanding the processes that lead to natural or anthropogenic soil salinization is as important as the characterization of salt-affected soils. From an agroecological perspective a distinction needs to be made between primary and secondary salinization. Primary salinization refers to the build-up of salts as a result of lithological inheritance or topographical position and is a natural process in arid zones. Secondary salinization is not linked to natural factors, but involves anthropogenic activities related to inappropriate irrigation management using both freshwater and saline water without drainage provision, groundwater depletion, and/or seawater intrusion.

The current status of salinity assessment in the dry areas is unsatisfactory. There is a lack of good information on the actual location, extent and severity of the salinity problems in most countries. This has severe implications on the ability of the respective governments to formulate appropriate policies and target investment towards control or reclamation projects. Although soil salinity is easy to detect, most soil maps, particularly at small scales, show primary salinity because of its association with geological or geomorphological features, which are easy to map at these scales. The mapping of secondary salinization is more complicated because of high spatial and temporal variability. Therefore, reliable figures are however hard to obtain. Secondary salinity is spotty both in horizontal and vertical distribution and can affect any soil type, which makes it difficult to obtain representative sampling points from which to extrapolate its true extent. Secondary salinity responds more rapidly to management practices than primary salinity and is therefore more difficult to capture in classical soil surveys, which provide one-time shots of a highly dynamic picture.

Mapping salinity is expensive and in order to achieve a rapid and effective assessment of its extent and severity, a multi-scale strategy is essential. The key principle is to build up an understanding of the spatial variability at different scales using indicators appropriate for each scale. These indicators can include spectral signatures from different remote sensing platforms, secondary data such as existing thematic maps, direct field measurements using appropriate sampling schemes and interpolation methods and participatory assessments with farmers along transects. Used in a practical and complementary manner, these approaches will help to zoom rapidly into the salinity hotspots at different resolutions and be far less costly than the classical field surveys, even where assisted by geostatistical tools.

Given the highly dynamic nature of salinity, assessments of extent and intensity need to be undertaken at regular intervals for trend monitoring and require an institutional setting. The most effective way might be by adapting the mission and mandates of the national institutions with the capacity of undertaking soil surveys and land resource studies to the new information requirements of development projects and environmental monitoring agencies. The United Nations Convention for Combating Desertification (UNCCD) could be a useful framework for capacity building in long-term salinity monitoring.

Monitoring, predicting and quantifying soil salinity, sodicity and alkalinity in Hungary at different scales: Past experiences, current achievements and outlook with special regard to European Union initiatives

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Approximately 13 percent of Hungary is considered to be salt-affected and with this large extent it is unique in Europe. There are large areas of naturally saline and sodic soils, but secondary salinization is also known to occur.

Due to the geological and hydrological conditions, the country demonstrates the most characteristic features of natural continental (not marine) salinization, sodification and alkalinization. Since the most important direct source of soil salinization is the shallow groundwater level below the lowland surface, there is a chance of irrigation-related salinization in two dominant situations: when the abundant use of river waters causes waterlogging and rise of saline groundwater (salinization from below); and when typically saline tubewell-waters are used for irrigation (salinization from above).

The spatial assessment of salt-affected areas began with the systematic mapping of salt-affected areas. There is a series of ten maps describing different aspects (salt-affected soil types, vegetation types, salt-efflorescences) of the salinity-status nationwide from 1897 onward, with the latest survey finished in 2006.

Besides the national scale of 1:500 000, soil salinity is also mapped at the scale of 1:100 000 on the AGROTOPO map sheets and 1:25 000 in the Kreybig Soil Information System (spatial vector data for maps and database for profiles and test boring). In spite of the two systems being digitally available, the information collected at the scale of 1:10 000 is available only for two-thirds of the country and is not digitised.

Very early maps at field scale, later at regional scale showed numerical salinity/ sodicity values. At present field scale numerical maps are analysed in order to optimise salinity mapping in space and time.

Systematic monitoring of soil salinization in irrigated areas dates back to 1989 in the irrigation district of Tiszafüred in the county of Jász-Nagykun-Szolnok. A nationwide Soil Information and Monitoring System was initiated from 1991. In this system, from the 1 236 soil profiles, 69 profiles classified as salt-affected are sampled and analysed yearly for the indicators of salinity and alkalinity.

When the large-scale irrigation projects were planned in the second half of the last century, prediction of soil salinization was based on the concept of the critical depth of saline groundwater. As an alternative, a numerical rule-based algorithm was developed for the prediction of the risk of soil salinization in irrigated fields. Numerical process-based modelling with LEACHM and UNSATCHEM simulation programs was tested, but with limited success so far for Hungarian areas.

Based on environmental correlation, there is a long history of predicting the occurrences of salt-affected areas. A unique physical modelling system using compensation lysimeters are used for testing the effect of saline groundwater at different depths and with drainage management in a dominantly sodic area.

Reclamation, including installation drainage and afforestation of salt-affected soils, has lost its momentum in the country due to a decrease in financial profitability. On the other hand, over the last few years a clear picture has been drawn of how efficient the different reclamation techniques are and how afforestation changes the salt distribution of soils and underlying strata.

Hungarian soil scientists play a leading role in the development of good practice for the management of salt-affected areas in Europe. Based on the initiatives of the Soil Framework Directive of the European Community, salinization is considered as a serious “soil threat” to agriculture. There is a well-developed concept of salinization and a set of common criteria for delineating areas threatened by salinization, are agreed on. A currently running EU-financed research project (ENVASSO) focuses on the assessment methodologies for quantifying soil threats. Another project (RAMSOIL) catalogues and evaluates the available risk assessment methodologies of each EU member country. To facilitate the spatial assessment of soil salinity/sodicity/alkalinity according to the EU-wide legal framework, the EU provides grants for promising research proposals to establish sensor-based digital field soil mapping methodologies. Such projects are based on the rich history of salinity sensing with field devices, such as the *Geophilus Electricus* system for multiple depth assessment of salinity.

Salinization and sodification of irrigated soils in Eastern Kenya

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The Hola irrigation scheme covers 1 700 ha of land of which 872 ha are under irrigation. The scheme is in agro-climatic zone VI where the ratio of rainfall to evaporation is 15–25 percent. This zone covers 12.4 Mha of land in the country of which 2.3 Mha have soils that are slightly saline, 1.4 Mha are moderately saline and 1.9 Mha are severely saline. The major land uses in the research zone are semi-nomadism and nomadism. The soils in the study area are classified as Mollic and Haplic Solonetz, sodic or salic phase; Gleyic, Vertic and Calcaric Cambisols, sodic or salic-sodic phase and are developed on marine sediments of Pleistocene to Recent age and old alluvial deposits. Irrigation in the area started more than fifty years ago but increased salinization and sodification of the soils has led to the abandonment of irrigated farming in many fields since the mid-1980s.

The objective of this study was to assess irrigation induced changes in soil characteristics in the period 1987–2002 with a view to giving recommendations on possible management remedial measures in addition to assessing the possible impacts on the soil characteristics by the introduced shrub *Prosopis juliflora* in the study area.

Though the quality of irrigation water had been assessed to be satisfactory, sodicity and salinity of the soils have been increasing, while porosity has been decreasing in the topsoils, during the fifteen years of monitoring. Mean electrical conductivity (EC) values initially increased from 1.4 dS m^{-1} to 2.1 dS m^{-1} in the first nine years, but it has decreased to 1.1 dS m^{-1} during the last six years. This may be an indication of increased leaching after the introduction of the shrub *Prosopis juliflora*, which has improved soil physical characteristics and thus enhanced flushing of the dissolved salts. Mean exchangeable sodium percentage (ESP) values have more than doubled from 10 percent to 24 percent, while porosity has reduced from 53 percent to 48 percent. Increase in EC and ESP indicate that processes of salinization and sodification have been taking place possibly due to inefficient use of irrigation water. A decrease in porosity indicates deteriorating soil physical characteristics.

Nature and distribution of salts in the Upper Wami-Ruvu Plains, Morogoro, Tanzania: Implications for land management methods

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Tanzania has about 7 Mha of potential irrigated agricultural land, which is located in 9 major river basins. The area under irrigated agriculture almost doubled to reach 3 percent of the total potential irrigated land over the past 10 years. While the government of Tanzania has ambitious plans to rapidly expand the area under irrigation as one of the strategies to address the Millennium Development Goals, there is evidence of decline in crop yield in farms that have been under irrigation for some time. The decline is associated with salinization, which is attributed to poor land management. Salinization is considered one of the key factors accounting for low returns in small-scale irrigation schemes in Tanzania. This study was conducted within the upper part of the Wami-Ruvu river basin in Tanzania in order characterize and map salt-affected soils for the purpose of developing an appropriate land management strategy suitable for small-scale irrigated and rainfed rice production.

A 250 ha area of farmland located along the Ngerengere River (located between 6° 49’ 00” S and 37° 35’ 10” E) representative of the upper part of the Wami-Ruvu basin was chosen for the study. Soil auger observations were carried out at 50 m grid points to the depth of 100 cm in order to characterize the distribution of soils in the area. Soil samples from representative soil profiles were analysed for selected chemical, physical and mineralogical characteristics. The soils were classified according to FAO system. Rock, soil and surface and groundwater samples were collected and analysed in the laboratory so as to determine the source of salinity in the studied area. Supplementary 10 m grid soil observations were carried at a depth of 0–50 cm in a 2 ha area. The area had patches that showed clear features of salt accumulation at the soil surface coupled with pockets in which the paddy rice crop performed poorly or the soil surface was bare. Soil samples from these points were analysed in the laboratory for pH and electrical conductivity (EC). Salinity and alkalinity classes were developed using established criteria. The performance of paddy rice crop was evaluated at the vegetative stage prior to flowering on the basis of crop vigour.

Three salt-affected and four taxonomic types of soils exist in the study: saline soil (Stagnic Solonchak – Chloridic, Clayic), normal soil (Stagnic Cutamic Luvisol – Hypereutric, Profondic, Clayic), sodic soil (Luvic Stagnosol – Eutric, Clayic) and Stagnic, Salic Solonetz (Abruptic, Clayic). Both the Solonchak and Stagnosol contained swelling type of clays. Basic gneiss, amphibolite and hornblendite were among the dominant rocks in the study area. All of them were rich in bases, which can be considered to be an important source of salinity. The EC of the water in the Ngerengere River remained low throughout the year while the content of sodium increased from 0.3–0.4 mg l^{-1} during the rainy season to 29.9 mg l^{-1} by the end of the dry season. Its use for irrigation is limited due to its sodicity. Most of the groundwater samples showed high EC and, as with the surface waters, chlorides, carbonates and bicarbonates of sodium were dominant. These are taken to be the direct source of salinity and possibly alkalinity in the studied soils.

Drastic spatial variations in EC and pH occurred over short distance in the saline-sodic soil. They had a pattern similar to that of the performance of paddy rice during the late vegetative growth stage. The mean values for EC in the root zone were 0.5, 4.0 and 20.2 dS m^{-1} in the patches with healthy, wilted and withered crop or bare ground surface, while the corresponding mean pH values were 7.0, 8.1 and 8.9, respectively.

On the basis of the linkage between the performance of the paddy rice crop and the corresponding pH and EC values, the studied soils could be put into three broad salinity-alkalinity categories: very slightly acid to moderately alkaline and none saline to slightly saline soils, moderately alkaline to very strongly alkaline and moderately saline to strongly alkaline soils. These could serve as the basis for land management in the area. It is recommended that knowledge of the salt patch distribution, their characteristics and the chemistry of both ground and surface waters over the entire growing season should be investigated prior to any attempt to solve the problem of salinity and alkalinity in the study area. In view of the inconveniences that small-scale farmers are likely to face while linking with specialized laboratories to have soil and water samples analysed for EC and pH, efforts should be made to facilitate field-based characterisation and interpretation.

Salt-affected soils in Romania

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This paper presents information related to: (A) the assessment of salt-affected soil based on specific indicators and on (B) diagnostic criteria for their classification; (C) a distribution of salt-affected soils in Romania including (D) a map of salt-affected soils and vulnerable or susceptible soils to salinization; (E) a simple example in pilot area; and (F) the research concerning reclamation and management practices applied in Romania for salt-affected soils.

The assessment of the quality of salt-affected soils has been carried out using classical indicators of soil salinity. Soil sodicity is characterized by total salt content (TSC) in mg 10^{-2} g soil, exchangeable sodium percentage (ESP) in percentage of cation exchange capacity (%CEC), sodium adsorption ratio (SAR), in mg me l^{-1} and pH (soil:water = 1:2.5). Saline soils are characterized by their electrical conductivity (EC), measured in mMho cm^{-1}. From the taxonomical point of view salt-affected soils are assessed using the main specific diagnostic horizons: Salic Horizon (sa), Hyposalic Horizon (sc), Natric Horizon (na), Solonetzic Horizon (Btna), Hyponatric horizon (ac), Sulphuric Horizon. According to these criteria, the main soil types affected by salts in Romania are Solonchaks, Solonetz and Salinez soils, a category of non-saline soils with high risk or potential for salinity under certain conditions.

The areas affected – Romanian Plain (200 600 ha), Western Plain (175 000 ha), Moldavia (114 000 ha), Transylvania (20 400 ha) and Dobrogea (104 000 ha) – total 614 000 ha. To this area we can add the surface area at risk of salinity, which is 1.221 Mha. The Map of Salt-affected Soils and Susceptible Soils to be Affected by Salt in Romania shows the distribution and degree to which soils are affected by, or susceptible to, salts, as well as classes and sub-classes of soils and the dominant salinization type. Other details include relief units and groundwater depth and salinity.

Research concerning the reclamation and management practices for salt-affected soils has had a long tradition in Romania. Various institutions have been investigated techniques for management of reclaimed land affected by salinization, such as the National Research and Development Institute for Soil Science, Agricultural Chemistry and Environment (ICPA), Bucharest and the Research and Development Station for Improvement of Salt-affected Soils, Braila. They have tested traditional agricultural management methods. According to the National Soil Quality Monitoring System, these soils have been a particular problem since 1977. The amount of land cultivated for rice, one of the most profitable farming systems, doubled between 1980 and 1990 in the Maxineni-Corbu area, from 20 000 ha to 49 000 ha. However, from 1990 onwards, this area decreased dramatically. Other solutions for controlling soil salinization and improving soil status and crop yields, which were tested in experimental fields, involve drainage, land levelling and modelling, leaching, gypsum amendment, chiselling, soil improvement fertilization, halotolerant crops and crop rotation.

This paper presents a simple example of a study concerning salt-affected soils in a pilot area in the west of Romania.

SESSION 7: SUSTAINABLE BIOSALINE AGRICULTURAL SYSTEMS

Biosaline agriculture: Prospects and potential within global and regional context

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During the last few decades, net agricultural production has suffered a significant drop, although productivity per unit area has increased. Among the many reasons, salinity and associated factors, like waterlogging and/or drought, have contributed significantly. The increase in saline areas has been directly attributed to both water and soil salinity problems. An increase in groundwater pumping has resulted in the intrusion of seawater, in both coastal and inland areas. Furthermore, fresh water aquifers have been exhausted and, hence overlying saline water layers mix with fresh water, resulting in the increase of salinity in the groundwater. The most common reasons for the increase in salt-affected lands are the mis-management of irrigated areas. Inadequate or absence of drainage systems and high rates of irrigation water application have resulted in the movement of salts in the soil profile, especially in the dry areas, where these salts are brought to the surface as a result of high evapo-transpiration rates.

A number of approaches have been evaluated and implemented to combat the salinity problems, based on specific types of site, regional and global problems. These include soil reclamation, water management and plant-based approaches. The first approach of soil reclamation in large areas requires not only high financial investment, but also continuous maintenance to make it technically feasible. The other two approaches are management strategies using appropriate irrigation and drainage systems and selection of appropriate agriculture production systems, suitable for specific edaphic and climatic conditions. These approaches, when applied in an integrated form, constitute the backbone of biosaline agriculture.

Plant-based approaches to using salt-affected lands in an economically and environmentally safe manner are based on the salinity ranges of soil, water (including groundwater) and other associated factors. The selected production system(s) not only helps in halting further deterioration of marginal lands, but also has direct commercial uses such as food, forage/fodder, livestock industry, medicinal uses, wood, etc. In addition, the use of these marginal resources also provides many secondary and indirect products, including bio-fuel and bio-energy, carbon sequestration, phyto-remediation, etc.

Strategies for plant-based solutions to the use of salt-affected areas include the production of new genotypic material through conventional breeding or biotechnological methods (for glycophytes) or selection and adaptation of existing salt-tolerant germplasms (both glycophytes and halophytes). Both strategies are equally important and feasible based on the nature of the salinity conditions.

This paper will cover the latter approach of identifying, evaluating, screening and optimizing the productivity of existing salt-tolerant germplasms. Different management strategies to increase productivity will also be discussed. Case studies will be presented from different regions of the world (especially from third world countries) to use marginal and saline resources in different types of agricultural production systems. The paper will also describe the economic and environmental benefits of the case studies.

Greywater use for irrigation of home gardens in peri-urban areas of Jordan

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Marginal water includes saline water, waste water and runoff water. These water sources differ in location with regard to the application site, quality, quantity and stability of supply. Marginal water is usually deficient in one or more qualities that make it fit for open irrigation or other beneficial uses.

In a water-scarce region like the Middle East, it is not surprising that marginal water is considered to be an important water resource. Reclaimed waste water is mainly used in agriculture and its proportion in comparison to ground and surface water will be on the rise as the volume of municipal water flow increases and the respective collection and treatment systems are expanded and enhanced.

Projects implemented in Jordan show that implementation of greywater re-use systems could lead to an increased efficiency in the use of water, as well as a decrease in water demand by 15 percent and water bills by 27 percent on average. This provides an opportunity that should not be missed for improving the life quality of urban poor people as well as rural households. Greywater re-use for urban agriculture is especially relevant given that, by 2015, it is expected that 85 percent of Jordan's population will be living in urban areas.

The Inter-Islamic Network on Water Resources Development and Management (INWRDAM), Amman, Jordan, has implemented more than 1 200 greywater use installations since 2000 in different parts of Jordan. Experience has shown that the potential of greywater use at household level is not fully utilized and that there are no social or religious barriers to greywater use for irrigation of home garden crops under restricted irrigation practices.

This paper will address technical and socio-economic issues of greywater use at household level in peri-urban areas of Jordan and how greywater use is gaining increasing popularity in nearby countries such as in Lebanon, Yemen, the West Bank and Gaza and other countries in the region. The paper will address issues related to greywater treatment options and quality that it is possible to achieve by low-cost treatment methods, types of crops to grow, environmental impacts of greywater on soil and plants, benefit-cost analysis of re-use, acceptance by the local community and recommended re-use guidelines that it is possible to apply to regulate greywater re-use. The paper will also discuss and recommend policy options for increased use of greywater as an untapped marginal water resource.

Saline agriculture: Pakistan scenario

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Pakistan, having a land area of 800 000 km^2, is highly dependent on irrigated agriculture to feed over 155 million people. Irrigation has been one of the most important causes of salinization in the cultivated areas. Of the approximately 6.3 Mha of salt-affected land, about half is situated within the canal commands, thus having serious social and economic consequences for Pakistan.

These salt-affected soils vary not only in terms of physical and chemical characteristics, depth of water table, availability of water for leaching of salts as well as crop cultivation, but also their distribution pattern is highly variable. Therefore, there are different options to reclaim these lands and for their profitable agricultural use. Various types of salt-affected lands in Pakistan have been defined.

A summary of the wealth of knowledge accumulated through detailed experimentation involving screening programs for salt tolerance of crop species, studies in laboratory and agronomic studies in field have been described in this paper. Some indicators of economic returns of saline agriculture have also been discussed. The history of saline agriculture in Pakistan and the success story of the studies carried out in different parts of the country are included in the paper.

Extent of salt-affected land in Central Asia: Biosaline agriculture and the utilization of salt-affected resources

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The economy of Central Asia countries (Uzbekistan, Kazakhstan, Turkmenistan, Tajikistan and Kyrgyzstan) is based primarily on agriculture and agricultural processing, with cotton and wheat being the major export crops. This dependence of the economy on agrarian-based activities is unlikely to change in the foreseeable future as most of the countries mentioned have embarked on a staged process of market liberalization. With the collapse of the former Soviet Union, economies in several of these countries have contracted with associated socio-economic, environmental and food security issues attaining greater prominence.

The large expansion of the irrigated area in the Aral Sea Basin has exacted a substantial toll on land and water resources in the Basin. Elevated water tables associated with poor irrigation management and non-functional drainage infrastructure, due to the lack of financial resources, have resulted in significant salinization of crop lands that invariably results in abandonment of land due to declining wheat and cotton yields. Approximately 600 000 ha of irrigated cropland in Central Asia have become derelict over the last decade due to waterlogging and salinization. It is estimated that approximately 20 000 ha of irrigated land of the Mirzachuli Steppe (marginal transboundary areas of Uzbekistan, northern Tajikistan and the southern part of Kazakhstan) are lost to salinity and invariably abandoned every year. The proportion of irrigated land that is salinized to some extent has risen from 48 percent in 1990 to approximately 64 percent in 2003. In some downstream provinces of Uzbekistan (Navoiy, Bukhara, Surkhandarya, Khorezm and Karakalpakstan), Turkmenistan (Dashauz) and around the Syrdarya delta from the Kazakh side, 86–96 percent of irrigated lands are salinized. Saline areas are generally found in poorer areas of the region with per capita incomes 30 percent lower than the national average and where unemployment levels are 40 percent higher. Soil salinity and waterlogging are a heavy burden for resource-poor farmers who are located in arid/hyper-arid degraded zones. This phenomenon has had a major impact on the livelihoods of rural communities who are dependent on land and water resources for goods and services. The conventional approach to rehabilitating these salinized areas requires major technical expertise and investments that are beyond the means of national budgets, as well as farmers' investment capacity, in these emerging/

transition economies.

Degradation of natural desert pastures, throughout all the Central Asia states has reached an alarming degree, requiring prompt action for the fragile ecosystems. The average annual rainfall here varies from 80 to 120 mm. Soils are sandy loam to loamy in texture, with poor vegetation cover that is highly saline with a low fertility. *Artemisia*-ephemeral and psammophytic rangelands available for grazing of animals have been replaced by halophytic plant communities with less palatable fodder plants. In addition, these *Artemisia* pastures tend to disappear under excessive and permanent grazing and also because they are currently being heavily uprooted for fuel. The anthropogenic transformation of pasture vegetation is evident near wells or watering places, saline lakes, settlements, sheep folds and along roads.

The poor natural drainage system of marginal cropping irrigated lands and sandy deserts has also caused an increase in the salt contents of surface soils and groundwater, which has induced secondary salinization. This has resulted in the migration of the local population (mostly Kazakh and Uzbeks) to neighbouring cities or countries. A consequence of pasture degradation is a big decline in the livestock system and the livelihoods of the communities in the region.

Nowadays, a unique source for development of agropastoral livestock-feed systems in the remote desert/semi-desert zones of all Central Asia countries is the reclamation of saline pastures (currently occupying 3.2 Mha), where halophytes that have the ability to grow adequately under prevailing edaphic conditions play a valuable role as feed for livestock and for medicinal purposes. Until recently, no serious research efforts have been made on the cultivation of wild halophytes, so they have had no market value as yet.

The role of plants in the remediation of saline and sodic soils is an emerging low-cost approach in the reclamation of abandoned irrigated lands. In this respect, the creation of highly productive fodder systems through the establishment of palatable halophytes has been shown to remediate saline/sodic soils as well as providing an income to resource-poor farmers. These genetic resources play a very important role in (i) the rehabilitation of degraded lands; (ii) controlling high water tables; (iii) utilization of non-conventional water resources; and (iv) landscaping. An innovative programme and experimental fields on domestication and utilization of *Glychyrryza glabra, Hippophae ramnoides, Elaeagnus angustifolia, Artemisia diffusa* and *Alhagi pseudoalhagi* with suitable modern agro-technologies were initiated in 2006 in the Central Kyzylkum Desert. Incorporation of these plants into a biosaline farming system represents the only source of income for many poor rural families, who live far away from markets. These plants, due to their ability to be propagated by both reproductive (seeds) and vegetative (suckers) means, are the target fodder species for rehabilitation of degraded pastures; sand-fixing; water-table and soil erosion control; haymaking and silage; better stock feeds (feed blocks) for animals in the late autumn/winter; bee-keeping and honey production; and the volatile oil of *Artemisia* for traditional medicine. The fruit of *Hippophae* and *Elaeagnus,* as they are rich in sugar, falconoids and various vitamins, can be used by local people for jam and wine production and dyes. Glychyrric acid extracted from *Glychyrryza glabra* roots is used as flavouring in food, as well as in tobacco, alcohol, candies and cosmetics.

Options for improving the livelihoods of the rural population in some Central Asia regions by using artesian thermal and groundwater are evident. The artesian waters could be used for development of arid fodder production systems, as well as for recreation, vegetable production, and other purposes through appropriate management practices. The establishment of highly-productive fodder systems will ensure the safety of the natural habitat and increase the income levels of the poor farmers. However, since the whole issue involves using the saline artesian water for long-term sustainable production, care needs to be taken of management and environmental issues.

Transferring new technology or methodology of the International Centre for Biosaline Agriculture (ICBA) in the planting of both perennial and annual valuable halophytes (based on worldwide dataset from similar sites and conditions) is an alternative approach that is already being tested in some Central Asia regions. Preliminary results are very encouraging and demonstrate the potential of salt-tolerant plants and halophytes for food, animal feed, fuel wood, bioenergy and other products. These species offer an alternative to the traditional cotton growing systems, the yield of which has been significantly reduced due to an increase in salt-affected areas.

Many farmers who had abandoned their cotton farms have returned to the production system and are gaining economic returns. Sorghum and pearl millet, among conventional forage, and *Atriplex* spp. and *Acacia ampliceps*, among the non-conventional forage crops, have gained a good deal of interest in the region. Such integrated research is both novel and timely for bringing these countries into the modern world.

Extent and utilization of salt-affected lands: Biosaline agriculture and marginal resources in Tajikistan

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The agricultural sector is an important part of the national economy due to its contribution to the GDP, employment and exports. Considering that three-quarters of the population lives in rural areas, the agriculture sector will play a crucial role in poverty alleviation. While arable land is scarce, experience in recent years, based on the ongoing restructuring of the large state-owned cooperative farms, has shown that the transition to private farms can raise yields substantially.

Food security is a big issue for Tajikistan. It is a landlocked country, and the Government has emphasized that self-sufficiency in wheat production is a national priority, flour being the single staple food. Agricultural land in Tajikistan, especially arable land, is a very scarce resource. Total agricultural land is 4.57 Mha, of which arable land counts for 0.7 Mha, or 0.11 ha per capita, including pasture lands. The major problem is the access of peasants to land and its fair distribution. Efficient use of, and fair access to, land and water resources is one of the sector's priorities in fighting poverty. A key issue for agricultural development in irrigated zones of Tajikistan are the pumping and maintenance costs of groundwater and irrigation facilities. High expenditure is required every year to keep them in working condition. With the transition of the country to a market system, a fee on water consumption was introduced, starting in 1996. However, farmers are only able to afford a small part of the maintenance costs. The main concern still remaining is the state of pumping stations covering almost 300 000 ha, or 40 percent of irrigated land. A rural population of about 2 million resides and earns a living in this area.

Low efficiency of water consumption in agriculture is another big problem. Lack of inputs and technical resources and destruction of their distribution systems, destruction of irrigation system infrastructures, among others, has caused soil degradation by salinization and waterlogging. This has resulted in decreasing productivity of crops by as much as 50–60 percent, poor crop quality and more energy for pumping water. As a result, at present, Tajikistan has more than 116 000 hectares of saline and 30 000 hectares of waterlogged land. The irrigation and drainage water in valleys has raised the groundwater level (1–2 m to soil surface) in the lower-lying lands and territories. Many of the cotton-producing areas of the country are now suffering from marked salinity.

Development of irrigation in the republic has been accompanied by an increase in water use. For 80 years, it was 5.5 km^3 $year^{-1}$. Currently it is 11.2 km^3 $year^{-1}$ with water consumption above 20 000 m^3 ha^{-1} $year^{-1}$. As a result, 30 000 hectares of irrigated land are experiencing secondary salinization and waterlogging.

Biosaline agriculture provides a big opportunity to use these marginal resources in wastelands and turn these into production systems. The use of physical, chemical and biological management practices could help in flushing the salts down in the soil profile. As a result of plant succession using different salt-tolerant plant species, economic returns can be achieved and thus help to alleviate poverty.

The salinity problem in the Sultanate of Oman: Past, present and future perspectives

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The Sultanate of Oman is one of the countries located in dryland areas. Its average annual rainfall is less than 100 mm. In the previous three decades the salinity problem has increased dramatically. The main reason besides lower rainfall was the over pumping of fresh water. The Ministry of Agriculture and Fisheries (currently the Ministry of Agriculture) recently became aware the problem. Through a field survey it was found that at least 50 percent of groundwater in the agricultural coastal region of Batinah was saline. Some control measures were taken, including legislation preventing the digging of new wells. Detailed surveys were conducted to study the soil and water salinity problem and attempts were made to use the saline water. Programmes were established and still being conducted to select salt-tolerant crops. Several experiments were conducted on field crops, forest trees, shrubs and vegetables. A scheme of transferring plants that consume high quantities of water away from the salinity affected areas is the current focus. The ministry cooperated with international institutes, such as the International Center of Biosaline Agriculture (ICBA) and the Food and Agriculture Organization of the United Nations (FAO), as well as local agencies like the University of Sultan Qaboos and the Ministry of Regional Municipalities and Water Resources.

A programme for the development of salt-tolerant cultivars and varieties was started by ICBA in 2003. Under this programme, different lines of varieties of pearl millet, sorghum, barley and canola (*Brassica sp*) were studied under moderately and highly saline irrigation water. Shrub species *Atriplex lentiformis, Atriplex halimus* and *Atriplex nummularia* and tree species *Acacia ampliceps* were experimented at higher water salinity levels. In addition, demonstration plots of grass species *Leptochloa fusca*, *paspalum vaginatum, Distichlis spicata, Sporobolus virginicus* and a nursery of grass species *Leptochloa fusca*, *Paspalum vaginatum, Distichlis spicata, Sporobolus virginicus* were also established at higher water salinity level. The most tolerant lines of the tested varieties were then replanted to select the most suitable to distribute to farmers.

Moreover, the Ministry recently got involved in a programme with the University of Sultan Qaboos. This programme has the following objectives: monitoring and preparation of salinity maps; identification of management practices to tackle soil and water salinity; cultivation of salt-tolerant fodders/grasses; selection of sowing techniques; fish culture with saline water; and socio-economic analysis.

To identify the quantity and quality of the brackish water in whole of the Sultanate, the Ministry of Municipalities, Water Resources and Environment conducted a field survey. In this survey remote sensing tools were used. Areas of aquifers were identified and results were presented in tables, graphs and maps. An area of about 107.8 km^2 of brackish groundwater was found in the inland areas of Oman. Options were suggested for using brackish water, including using the water directly, economic model projects, allocation to large-scale farming, small aquaculture farms and desalinization with reverse osmosis to produce potable water.

The salinity problem in the sultanate could be solved through continuing to apply the legislation of minimizing groundwater pumping; developing new salt-tolerant plants through screening and breeding techniques; and developing planting and irrigation techniques which suit saline agriculture.

Water shortage in western US and saline recycled water use for urban irrigation

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Critical water shortages are occurring throughout the western U.S. due to population pressures resulting from urban influx and prolonged drought due to climate change. Land and water used for irrigation is rapidly shifting from agriculture to urban use and most (50–70 percent) of urban water use is for landscape irrigation. Rapid urban development along coastlines has resulted in salt water intrusion due to over-pumping, causing salinizing of fresh water aquifers. For these reasons, governmental policies have been adopted in western states requiring use of recycled sewage water, brackish groundwater and other secondary, saline water sources for urban landscape irrigation.

Landscape managers face unique challenges due to high traffic and the inability to cultivate soil, exacerbating sodicity issues due to compaction pressures. Special management is often required, such as irrigation scheduling, irrigation acid injection, modified root zones and subsurface drainage, in addition to the use of salt-tolerant species and cultivars. Relative salinity tolerance and associated physiological responses of turf grasses for urban landscapes were investigated.

Tolerance ranged from salt-sensitive to halophytic. Species were ranked for salt tolerance, and recommendations made. Salinity tolerance was associated with increased root/shoot ratios, shoot saline ion exclusion, minimal shoot osmotic adjustment, salt gland activity and compatible solute accumulation.