



# Sustainable Management of Saline Waters and Salt-Affected Soils for Agriculture

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Proceedings of the Second Bridging Workshop

15-18 November 2009, Aleppo, Syria

Bridging Workshop

## Editors

M. Qadir, D. Wichelns, J. Oster, S.-E. Jacobsen,  
S.M.A. Basra and R. Choukr-Allah



## About ICARDA and IWMI



Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is one of 15 centers supported by the CGIAR. ICARDA's mission is to contribute to the improvement of livelihoods of the resource-poor in dry areas by enhancing food security and alleviating poverty through research and partnerships to achieve sustainable increases in agricultural productivity and income, while ensuring the efficient and more equitable use and conservation of natural resources. ICARDA has a global mandate for the improvement of barley, lentil, and faba bean, and serves the non-tropical dry areas for the improvement of on-farm water use efficiency, rangeland and small-ruminant production. In the Central and West Asia and North Africa (CWA-NA) region, ICARDA contributes to the improvement of bread and durum wheats, kabuli chickpea, pasture and forage legumes, and associated farming systems. It also works on improved land management, diversification of production systems, and value-added crop and livestock products. Social, economic and policy research is an integral component of ICARDA's research to better target poverty and to enhance the uptake and maximize impact of research outputs.



The International Water Management Institute (IWMI) is one of 15 international centers, supported by the CGIAR. With the vision 'Water for a food-secure world', IWMI's research agenda focuses on water and land management challenges that affect the livelihoods, nutrition and health of poor communities, as well as the integrity of ecosystem services on which they depend. Its mission is to improve the management of water and land resources for food, livelihoods and the environment. The goal is to generate and disseminate freely available public goods that benefit poor people in developing countries and improve their food and livelihood security. IWMI's research projects in more than 20 countries are implemented by over 75 scientists representing both the North and South. The institute is well placed to make cross-comparisons of results and learn from the knowledge and experience generated in different hydro-ecological and socio-cultural environments. IWMI works with a broad range of international organizations, NGOs, national research institutions, and advanced research organizations. This provides IWMI access to state-of-the art scientific knowledge and also to indigenous knowledge well matched to a range of conditions.

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International Center  
for Agricultural Research  
in the Dry Areas



International Water  
Management Institute

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## Foreword

### The context

Irrigation plays an important role in crop production and agricultural development in arid and semi-arid regions. The area of irrigated land in these regions has expanded substantially, particularly in the second half of the twentieth century. However, further expansion will have to occur within the limits of annual renewable freshwater resources, which, in many places, have largely been allocated already to various water-use sectors. Competition among domestic, industrial, environmental, and agricultural sectors already exists and will inevitably increase. This will lead to a gradual decrease in freshwater allocation to agriculture. This phenomenon is expected to continue and to intensify in arid regions in less developed countries that already have high population growth rates and significant environmental degradation.

As an alternative to freshwater, water resources of marginal quality – such as saline water generated by agricultural drainage systems or pumped from saline aquifers – can be used to reduce the gap between demand and supply. Although saline water is already used in agriculture, its use without suitable soil-crop-irrigation management poses high risks of land degradation through the development of salinity, sodicity, ion-specific toxicity, and nutrient imbalance in soils. These conditions reduce crop productivity and limit crop choice.

Use of saline water for agriculture is likely to increase with increasing water scarcity. It will be important to modify current soil, irrigation, and crop management practices to cope with the inevitable increases in soil salinity and sodicity. It will also be important to assess the future sustainability of using saline water, in regard to maintaining soil physical properties and crop productivity. Clearly, there is need to rethink the ways in which saline water is used for irrigation; and to develop appropriate technical and policy options for productive use of saline water in water-scarce countries.

### 'Bridging' Workshops

In partnership with key national and regional institutions, ICARDA and IWMI are working together to develop management practices that can significantly increase agricultural productivity and income generation among communities that rely on marginal-quality water resources such as saline water. In order to bridge the knowledge gap between advanced research institutions and young developing-country researchers, ICARDA and IWMI have launched 'Bridging Workshops' on different aspects of water resources management. These workshops aim to guide young researchers towards state-of-the-art, multi-disciplinary research, applying an open-space and

open-mind environment where participants are mentored by experienced scientists, and encouraged to ask questions they would not usually ask in conventional workshops. This initiative will involve lead international scientists and young and mid-career scientists from agricultural research institutions developing countries.

This publication summarizes the proceedings of the second Bridging Workshop held during 15-18 November 2009 at ICARDA headquarters in Aleppo, Syria. The workshop included three modules:

- Stimulating sessions on pre-defined topics, led by resource persons
- Country sessions where developing-country participants presented case studies.
- A final session summarizing research challenges and gaps identified during the workshop.

Based on extensive discussions during the workshop, the participants prioritized a range of research issues and best practices relating to the assessment, implications, and overall management of saline water and salt-affected soils. The two most important topics were:

- Provision of drainage systems and reuse of drainage water to manage salts in irrigated soils.
- Use of modern irrigation systems to optimize irrigation needs and leaching requirements under saline water irrigation.

Two other topics were considered almost equally important: use of salt-tolerant crop cultivars and trees for salt-affected areas; and implementation of policies to create an enabling environment for salinity management at different scales.

Financial support from the United States Agency for International Development (USAID) for organizing the workshop and publication of the proceedings is gratefully acknowledged. Further bridging workshops on water resources management are expected to be held every alternate year.

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# Stimulating Sessions



## Stimulating Sessions

### Stimulating Session 1

### Geographical information systems and remote sensing for mapping and monitoring salinization and distribution of salt-affected soils at different scales

Resource Person

Eddy De-Pauw  
ICARDA, Aleppo, Syria

This session aimed to provide an overview of geographical information systems (GIS) and remote sensing (RS) for mapping and monitoring salinization and distribution of salt-affected soils at different scales. The use of GIS and RS techniques is becoming increasingly important because salinity assessment in dry areas is not satisfactory, for two reasons. There is uncertainty about the true extent of salinity, particularly in irrigated areas. And conventional approaches used in salinity assessment are time consuming and expensive.

The session began with a presentation, which generated considerable interest, and discussion, on GIS and RS methodologies. The presentation highlighted the lack of good information on the actual location, extent and severity of salinity problems in most countries. This severely limits the ability of governments to formulate appropriate policies and target investment towards salinity 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 geomorphologic 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. 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 snapshots of a highly dynamic picture.

The methodology for regional-scale salinity assessment must be based on: (i) compilation of secondary data, (ii) remote sensing, (iii) multi-scale assessment, (iv) multi-temporal analysis, and (v) field work.

Salinity mapping is expensive. In order to rapidly and effectively assess 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 spec-

tral signatures from different RS 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 will be far cheaper than classical field surveys, even where assisted by geo-statistical tools.

Given the highly dynamic nature of salinity, assessments of extent and intensity must be undertaken at regular intervals for trend monitoring, and require an institutional setting to be effective. The most effective way might be to work through national institutions with the capacity of undertaking soil surveys and land resource studies; and adapt their mandate to the new information requirements of development projects and environmental monitoring agencies.

In summary, the session highlighted the need for an updated inventory of salt-affected soils at global, regional, national and local scales. This is particularly applicable to those areas where new irrigation schemes and/or land reclamation projects have been launched since the 1960s and 1970s (the peak period of soil surveys). Given the rapid evolution of irrigation systems, with more emphasis on water conserving technologies, it is likely that the status of salt-affected soils worldwide has changed considerably. There is a need for cost-effective and situation-specific methods, based on multi-scale approaches that combine salinity indicators (based on remote sensing), field measurements along landscape-based or production system-specific transects, farmer participation, and out-scaling through spatial interpolation methods.

## Stimulating Session 2      Salt balance and leaching requirements for salinity control; steady-state and transient models addressing salinity management

Resource Person

Peter Vaughan  
San Joaquin Valley Agricultural Sciences  
Center, California, USA

This session provided an overview of the role of modeling for addressing soil salinity problems in agriculture. It also reviewed basic information on soil salinity – processes and principles, salinity effects on crops, modeling and soil salinity dynamics. The presentation included how-to material to help participants handle some practical issues that arise in soil salinity management.

Soil salinity has been affecting agriculture for thousands of years, but only in the past 100 years has significant research been conducted. One important finding is that salinization can be studied by considering only a limited set of cations and anions. Two measures of the chemical status of soils are the electrical conductivity of the saturation paste extract ( $EC_e$ ) and the sodium adsorption ratio (SAR). These measurements provide the information required to categorize soils as sodic, saline or saline-sodic, and thus to determine what management strategies are appropriate for a particular soil. Research has also focused on the effect of soil salinity on crop plants. The Maas-Hoffman (M-H) model provides a simple rationalization based on the concept of a threshold value of soil salinity above which crop yields decline linearly with increasing mean  $EC_e$  in the root zone. The parameters of M-H threshold and slope have been experimentally determined for many crops. Other factors that may need to be considered include specific-ion toxicity and the varying effects of soil salinity at different stages of plant growth.

Computational models of subsurface solute transport and effects of salinity on crop yield face a practical problem: the need to specify parameter values for the osmotic stress model. A model such as SWAP (Soil-Water-Air-Plant) works directly with the M-H coefficients but other models such as Hydrus and SaltMed represent the salinity effect as a sigmoidal curve. The presentation discussed how to convert M-H coefficients into the hPhi50 (osmotic head at 50% yield reduction) and p (an exponent) required in these other models. A non-linear least-squares analysis was described and programmed in a spreadsheet that accepted the M-H threshold and slope while returning hPhi50 and p. This spreadsheet was distributed to the participants on a CD along with other materials including the SaltMed program.

The modeling segment of the presentation focused on the importance of developing specific goals in the initial stages of modeling studies. By refining the goals in detail, the modeller can construct criteria to determine what

kind of model will be most appropriate to the problem. With this in mind, models of soil salinity effects and treatments can be selected from a range of models having varying degrees of complexity, from simple formulas to full-blown transient numerical models of multi-component solute transport. Factors that are important in refining goals are the desired accuracy, availability of required data, time-frame for delivery of results, appropriate model output, testing of model results, and the capabilities of the personnel who may be assigned. The modeling may be best handled by choosing several models of varying degrees of complexity which can provide results of various degrees of accuracy and suitability.

The presentation covered transient numerical models in some detail as these models are widely available and implement easy to implement compared to models 10-20 years ago. Examples of such models are SaltMed, SWAP and Hydrus. These are coupled models – meaning that several different processes are operating simultaneously – and they are transient, i.e. the model simulates the variable behavior of a system over time. Such models can be easily misused due to either their complexity or because the problem being addressed may have critical factors that are not represented by the model. The water flow calculations of these models require measurement or estimation of the hydraulic properties of soils including saturated hydraulic conductivity and water retention capacity. The Rosetta program can estimate such properties from simple measurements of bulk density and soil texture. Rosetta was also included on the CD.

Some specific problems of salinity dynamics were presented. The models can be used to estimate leaching requirement or the excess irrigation water needed to maintain a stable salinity profile in the root zone. A simple model, WatSuit, was designed for this purpose and was included on the CD. Transient models can also predict leaching requirement. Salinity of the irrigation water can be increased in successive model runs to determine the irrigation water EC for which mean root zone salinity exceeds a criterion established through the M-H relationship for a specific crop.

The dynamics of root zone salinity are strongly influenced by the concentrating effect of root water uptake and the resulting induced osmotic stress. Competing mathematical representations of the effects of osmotic and matric head include the additive representation used in the Enviro-Gro model and the product model used in Hydrus and SWAP. The equations describing these different models were presented. The self-regulating effect of reduced root water uptake causing increased leaching was also mentioned.

Another example of an application associated with soil salinity dynamics is the reclamation of salt-affected soils. A saline soil can be reclaimed by leaching; so a transient model of single-component solute transport such as SWAP can provide data to be used in constructing a leaching program. The

leaching program would apply to a particular soil and irrigation water salinity. Sodic soils present a more complex reclamation problem because soil amendments such as gypsum or green manure must be applied to reduce the soil sodicity. Modeling these kinds of reclamation programs requires multi-component transient codes such as Hydrus that can represent cation exchange reactions.

In summary, the presentation provided an overview of how to apply various models to address soil salinization problems. Models range from simple formulas to complex numerical codes and the best choice for solving a particular problem may be just a simple formula.

### Stimulating Session 3

### Managing salinity while irrigating with urban wastewater

Resource Person

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Agadir, Morocco

In arid and semi-arid regions with limited freshwater resources, urban wastewater reuse is becoming increasingly important as an alternative or additional water resource. This session presented a global environmental analysis of the reuse of urban wastewater and precautions to prevent negative impacts on plants, soil and groundwater. The use of poor-quality water in downstream irrigation often raises questions about the fate of nutrients and heavy metals, and the long-term effects of water salinity on soil characteristics. Therefore, successful use of treated wastewater for crop production and landscaping requires appropriate strategies for optimizing crop yields and quality, maintaining soil productivity and safeguarding the environment.

The session addressed three questions: (i) What are the most important constraints (both technical and economic) in using treated wastewater? (ii) What are the viable options for reuse of waste water while controlling salt accumulation and nitrogen pollution? (iii) What are the best practices for managing salinity while irrigating with urban wastewater?

The session began with a presentation on the potential of wastewater reuse in the Middle East and North Africa, discussing health risks, salinity hazards, and possible groundwater pollution. Using examples from Morocco and Tunisia, the presentation illustrated the economic importance of the nutrients contained in treated wastewater. For example, wastewater reuse can reduce fertilizer costs. The benefits of wastewater irrigation (measured in terms of nitrogen, potassium and phosphorus content) were calculated for different crops. They varied from US\$ 210 to 347 per hectare. This could be a strong incentive to farmers, encouraging reuse of treated wastewater. In fact, typical wastewater effluent from domestic sources could supply all of the nitrogen and much of the phosphorus and potassium normally required for crop production.

Adequate treatment of wastewater, to meet accepted standards and regulations, can prevent health risks – but other challenges still remain. Depending on the quality of the raw wastewater, and the desired effluent quality (which will depend on the expected uses), there is still the issue of increase in soil salinity – for example domestic wastewater adds 200-400 mg/L of dissolved sodium salts. This changes osmotic pressure at the root, provokes specific ion toxicity (chloride, boron or sodium), interferes with uptake of essential nutrients (potassium and nitrogen), and may destroy soil structure. Also, nitrogen content is relatively high even in treated wastewater, and could induce nitrate pollution of groundwater.



Several research studies undertaken in the region were presented, focusing on three questions: (i) What type of irrigation management is optimal for increasing water use efficiency, considering both crop production and reduction of nitrates leaching? (ii) Can nitrogen pollution and salt build up in the soil be alleviated by using irrigation at different depths? (iii) Can salt build up and nitrate pollution be alleviated by alternating freshwater with treated wastewater?

Efforts to promote reuse of domestic wastewater must center on promoting and further developing low cost, easy-to-handle technologies with a low degree of complexity, preferably developed within the region. Special weight must be placed on minimizing the energy needs for these technologies. The presentation discussed the use of lagoons, sand filters, and constructed wetlands as affordable and reliable technologies to treat wastewater to achieve the required quality for irrigation.

Irrigation techniques wetting only the roots, and not the leafy part of vegetables, were suggested as good practice for minimizing risk of contamination. Mulching, drip systems and other techniques (sub-irrigation) applying water close to the root systems can reduce health risks and salt effects, and also minimize infiltration into groundwater. Rotating wastewater application over fields, if possible, is another means to limit over-fertilization and nitrogen pollution of groundwater. The amount of nitrogen lost to the underground water varies depending on the crop, the water depth, and the quality of the treated wastewater.

Results were presented showing the high value of using treated wastewater for supplementary irrigation. If water is the limiting factor, and land is available, it appears more effective to use lower doses on large acreage. Equal amounts of supplemental irrigation at flowering and grain filling stages produced satisfactory yield.

The final part of the presentation focused on strategies for optimizing crop yields and quality, maintaining soil productivity and protecting the environment using treated wastewater. These included a combination of practices: selection of crop(s) and irrigation methods, management practices, blending conventional water with treated effluent, leaching, and organic and chemical amendments. The ability of a crop to adjust to salinity is crucial. In areas where soil salinity build-up cannot be controlled to an acceptable concentration for the crop being grown, an alternative crop can be selected that is more tolerant of the expected soil salinity and able to produce economic yields. However, crop response to saline water irrigation will depend on climatic conditions, e.g. amount and distribution of rainfall. Soil characteristics (e.g. texture) and the selection of appropriate crops play important roles in addressing elevated levels of salinity and sodicity. The leaching requirements of soils increase with the salinity of the irrigation water and the sensitivity of the crop to salinity.

## Stimulating Session 4      New crops for salt-affected environments

Resource Person

Sven-Erik Jacobsen  
University of Copenhagen,  
Faculty of Life Sciences, Denmark

With the objective of highlighting the role of new crops for productivity enhancement of saline water and salt-affected soil resources, this session focused on quinoa (*Chenopodium quinoa Willd.*). Quinoa is a highly promising new crop for saline agriculture worldwide. It is a highly nutritious food product, cultivated for several thousand years in South America, with outstanding protein quality and a high content of several vitamins and minerals. Other characteristics are saponins in the seed hull and lack of gluten. Quinoa is one of the main food crops in the Andean region, but is also attracting interest in the USA, Europe, Africa and Asia. The genetic variability of quinoa is huge: cultivars are adapted to environments from sea level to 4000 meters, from 40°S to 2°N, and from cold, highland climates to subtropical conditions. This makes it possible to select and breed cultivars for a wide range of environmental conditions. In developing countries of Africa and Asia, quinoa could provide highly nutritious food under dry conditions. Quinoa has been selected by FAO as a key potential food security crop for the next century.

The session addressed the following questions:

- What is the potential of quinoa globally?
- What is the potential for using halophytes as seed or forage crops?
- How can food production be increased under saline conditions?
- What role will various strategies have for crop production under saline conditions?
- How do salt ions interact in quinoa?

It is obvious that halophytes have a potential as seed and forage crops under saline conditions, and could help increase food and feed production under such conditions. This question was not discussed at the workshop. Neither was the specific question on the salt ions effect in quinoa, which is currently under study. Quinoa is considered a multipurpose agro-industrial crop. The seed can be utilized for human food and in flour products, and in animal feedstuff because of its high nutritive value. The specific advantageous properties of agricultural raw materials from quinoa must be identified and exploited, and processing developed, because they may have to compete with other raw materials which are often cheap, readily available and of acceptable quality. The starch with its uniformly small granules has several potential industrial applications. Possible industrial products from quinoa are flow improvers to incorporate into starch flour products, fillers in the plastic industry, anti-offset and dusting powders, and complementary protein for

improving amino acid balance in human and animal foods. Saponins may be interesting as potential insecticides, antibiotics and fungicides, and also in the pharmaceutical industry as a mediator of intestinal permeability which could aid the absorption of specific drugs, and for reducing the level of cholesterol.

Plant characteristics advantageous for the adaption of quinoa to other environments are available, but scattered throughout the existing germ-plasm. Further breeding of quinoa in new regions should concentrate on uniformity, early maturity, high yield, quality aspects, and industrial uses of the seed and of specific ingredients. The ideal variety for seed production would be one maturing uniformly and early, typically in less than 150 days. Beside earliness, quinoa should have a consistently high seed yield and a low saponin content, it should be short and non-branching, to facilitate mechanical harvesting. Size, shape and compactness of the inflorescence may be important for the rate of maturation. A large open inflorescence will dry quicker after rain and morning dew than a small, compact one, but it may also be prone to seed scattering. Fodder types should be tall, leafy and late-maturing, with a high dry-matter yield and preferably low saponin content.

Quinoa may be used as a break crop in crop rotations, being non-susceptible to cereal diseases, and only slightly susceptible to soilborne nematodes. Quinoa seems to have a specifically high potential in organic production systems; this is being tested both in South America and in Europe. Commercial production of organically grown quinoa is increasing.

Considerable variation exists between cultivars for many of the examined characters, so it should be possible through selection and breeding to combine many of the desired characters in single cultivars, which in turn could establish quinoa as a novel crop for agriculture in other parts of the world.

## **Stimulating Session 5      Seed-based treatments/interventions for improving germination and crop establishment under salt-affected environments**

Resource Person

Shahzad Maqsood Ahmed Basra  
Department of Crop Physiology, University of  
Agriculture, Faisalabad, Pakistan

This session discussed the importance of seed-based interventions, such as pre-sowing seed treatment, for improving germination and crop establishment under salt-affected environments. The session started with a presentation highlighting different pre-sowing seed treatments that could improve germination and crop establishment under such environments.

The presentation highlighted seed germination and crop establishment as two key factors determining yield in salt-affected environments. Development of salt-tolerant crop plants is a priority, to help meet the ever increasing food needs of developing countries. Recent advances in biotechnology have unraveled the salinity tolerance mechanism at the molecular level. Plants' basic cellular responses to environmental stresses are very similar; nonetheless, there may be inter and intra-specific variations for tolerance mechanisms at different developmental stages. Similarly, oxidative and osmotic stresses, and protein denaturation are observed in plants exposed to saline environments. These may all lead to adaptive responses e.g., stress protein expression, accumulation of compatible solutes, and antioxidant system at cellular level.

Salinity arrests germination at high levels, but induces a state of dormancy at lower levels. Salinity slows down the imbibition of water due to lowered osmotic potential of the germination medium. It also causes toxicity by changes in the activity of enzymes of nucleic acids metabolism, alters protein metabolism, upsets plant growth regulator balance and reduces the utilization of seed reserves. It may cause changes at ultra-structural, cell, tissue and organ levels.

Foliar application of various organic and inorganic compounds and seed invigoration are widely used to mitigate salinity effects on crop plants. Seed invigoration is a broad term referring to numerous methods aimed at improving seed delivery and crop performance under a range of environmental conditions. Different seed invigoration tools have been used for improving seedling establishment and plant development/yield under stressful environments. Seed invigoration describes the techniques applied on a given seed lot for value-addition and improved field performance. It includes pre-sowing hydration treatments, low molecular weight osmoprotectant seed treatments, coating technologies and pre-sowing thermal

treatments. Pre-sowing hydration or seed priming includes many pre-sowing seed treatments. There are also post-harvest treatments to improve germination and seedling growth or help in the provision of seeds and other materials required at the time of sowing. These treatments focus on shortening the time to seedling emergence and protecting seeds from biotic and abiotic factors during critical phases of seedling establishment. Such treatments synchronize emergence, resulting in uniform and vigorous stands, and improved yield.

Seed invigoration tools have the potential to improve emergence and stand establishment under a range of field conditions. Of particular interest are hydropriming, osmopriming, halopriming, hormonal priming and use of highly soluble and low molecular weight chemicals. Organic sources for priming are also being introduced by our laboratory: *Moringa oleifera* has given excellent results with environmentally friendly impact. Many seed priming strategies (CaCl<sub>2</sub>, glycinebetain, proline, ascorbate, jasmonate, salicylate, H<sub>2</sub>O<sub>2</sub>, etc) are successfully being used to mitigate salinity stress on a variety of crops. The mechanisms involved in priming-induced tolerance are increase in speed and spread of germination, early and healthy stand establishment, and increase in plant defence mechanisms like anti-oxidation. These techniques can enhance crop performance under saline, submerged and drought-prone conditions, and on marginal land. Variation exists within crops and varieties/genotypes/hybrids in their response to various priming treatments. This will enable researchers to identify areas for further work such as:

- Development of crop specific precise priming techniques using a range of salts, plant growth regulators and osmolytes at varying concentrations with different durations.
- Storage potential of primed seeds – prolonged storage of primed and hardened seeds may be critical for technology transfer and marketing of primed seeds.
- Exploration of the molecular and genetic basis of priming-induced salinity tolerance.

## Stimulating Session 6      Policies and institutions facilitating productive use of saline water in agriculture

Resource Person

Dennis Wichelns  
International Water Management Institute  
(IWMI), Colombo, Sri Lanka

This session aimed to stimulate discussion on the ways in which public policies and institutions influence the development of salinity and drainage problems, and the use of marginal quality water in agriculture. It also discussed how policies and institutions can help alleviate problems of soil and water salinity, and improve the use of marginal quality water.

First, reviewed the working definitions of policies and institutions were reviewed: Public policies might be considered the rules by which a society operates. Policies also can involve programs and interventions, such as prices and subsidies. Institutions, by contrast, are a form of social infrastructure. Examples include government ministries, churches, markets, and legal constructs, such as the types of property ownership.

Participants then formed four groups to discuss the following questions:

- How have policies and institutions influenced the development of salinity and drainage problems, and the use of marginal quality water in agriculture?
- How can policies and institutions help alleviate problems of soil and water salinity, and improve the use of marginal quality water?
- What would you recommend to policy makers, if given the opportunity?

Participants were asked to consider these questions from a conceptual perspective, and also in terms of their country-specific settings.

Discussions within each group were presented in a subsequent plenary session. The group discussions were lively and informative, as participants from a wide range of countries proposed and discussed a rich array of policies and institutions, and implications for salinity and drainage problems and the use of marginal quality waters in agriculture. The key messages can be summarized as follows:

- Policies and institutions have notable implications for the development of salinity and drainage problems, particularly in arid regions. If water is not priced or allocated correctly to reflect water scarcity conditions and the off-farm impacts of irrigation, farmers will apply excessive amounts of water. Excessive irrigation increases salt loads, while contributing also to the development of saline, shallow groundwater.
- The technical issues relating to waterlogging, salinity, and drainage

problems are well known. Fundamental biophysical relationships involving water, salt, and soils have been understood for hundreds of years. The key to preventing the development of waterlogged and saline soils is to implement correct policies and ensure that policy parameters, such as prices and allocations, are established at appropriate levels.

- Economic incentives can be used to motivate farmers to re-use saline drainage water and utilize shallow groundwater. Incentives might include differential pricing for water of different qualities, payments for pumping water from shallow aquifers, and cost-sharing arrangements that encourage farmers to invest in groundwater pumping capability.
- Policies and programs are needed in many areas to ensure safe use of wastewater in agriculture. Consumers and producers must be protected from the potentially harmful effects of using wastewater for irrigation. Outreach programs can inform farmers and consumers of potential health hazards and provide them with recommendations for reducing health risks.

In summary, this session highlighted the important roles of policies and institutions in soil and water issues, and enabled participants to compare examples from different countries. The small-group and plenary session discussion of economics, incentives, and public programs provided a helpful complement to the technical information presented in other sessions regarding salinity, drainage, and the use of marginal quality water in agriculture.





# Technical Papers



# Conversion Factors to Estimate Soil Salinity Based on Electrical Conductivity for Soils in Khorezm Region, Uzbekistan

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## Abstract

This paper compares different procedures for soil salinity analyses to determine electrical conductivity: saturated paste extract ( $EC_e$ ), fixed soil:water ratio extracts  $EC_{1:1}$  and  $EC_{1:5}$ , and soil solution paste prepared with 1:1 soil:water ratio and measured directly in the solution above the paste ( $EC_p$ ), apparent electrical conductivity ( $EC_a$ ) of a soil down to a depth of 0.75 and 1.5 m measured by electromagnetic device, and laboratory analyses for total dissolved solids (TDS) and ion composition. Conversion factors between these different methods to estimate salt content of soils are presented and can be applied for the predominant textures in the Khorezm region in Uzbekistan. The procedures described allow easy follow-up and replication of the approach.

**Key words:** saturation extract, electromagnetic induction, salinity, classification.

## Introduction

Traditional soil salinity analysis in Uzbekistan involves determining the amount of total dissolved solids (TDS) in a given soil sample. Conductivity of the saturation extract ( $EC_e$ ) is recommended as a general method for appraising soil salinity in relation to plant growth (USSL 1954). This is explained by the fact that plants are generally responsive of the salt concentration of the soil solution that highly correlates with the electrical conductivity (EC) of this solution (USSL 1954). Although TDS and  $EC_e$  are realistic estimates of soil salinity, their estimation require considerable time and resources. Simplified measurements and proxy instruments for estimating TDS and  $EC_e$  values are commonly used to overcome such requirements.

This paper describes procedures and conversion factors to estimate soluble salts from electrical conductivity of the saturation extract, soil solutions (and paste), and electromagnetic (EM) conductivity. There is a range of conversion factors in the literature to estimate soluble salts for diverse soils. This paper presents similar factors for the conditions of the Khorezm region in Uzbekistan. This exercise was part of the development of a soil salinity monitoring system for large areas. Results from this exercise are applicable to all locations with similar soil textures and can thus be generally employed throughout the Khorezm region as well as, possibly, adjacent regions such as Karakalpakstan in Uzbekistan, and Dashoguz in Turkmenistan.

### Materials and methods

#### Soil sampling and analysis

The study was conducted at the Cotton Research Station, east of Urgench city, Khorezm region, Uzbekistan. The area is fed by the Shavat canal, which runs along the northern side of the station. Topsoil of the station is of loamy texture, with textures ranging from loamy sands to clays in the middle of the soil profile, and deeper layers consisting of sands. Soils were sampled and measured in March and April 2008. These observation periods coincided with pre- and post-leaching events in the region. Random samples were collected from four fields, with an average field size of around 7 ha each. Soil samples were collected from 5 layers at 30-cm intervals (0-30, 30-60, 60-90, 90-120, 120-150 cm). The locations of the sampling points before leaching were recorded by GPS, which allowed revisiting the same points after leaching. In total, 15 locations were sampled before leaching and 21 locations after leaching.

Samples were analysed for TDS and ionic composition by the Soil Research Institute laboratory using methods described by Vorobyova (1998). Additional analyses were conducted in the ZEF/UNESCO project laboratory including electrical conductivity of saturation extract ( $EC_e$ ), fixed soil:water ratio soil solution extracts ( $EC_{1:1}$  and  $EC_{1:5}$ ) following the procedures in USSL (1954).

The EC of the water ( $EC_p$ ) was measured by inserting the electrical conductivity cell directly in the solution above a 1:1 soil:water paste. This is different from measuring the apparent EC of the soil paste where the electrodes are embedded in the wall of the container (Rhoades et al. 1999). Soil texture analyses were conducted by the feel method.

For our purpose two electrical conductivity meters (Eijkelkamp 18.21 and Hanna Instruments HI 98312) were selected to cross-check the measurements for quality control.

#### Electromagnetic conductivity measurement

The apparent electrical conductivity ( $EC_a$ ) of the sampling locations was measured with the electromagnetic induction device (EM38) before and

after leaching. Electromagnetic induction devices can be used in two modes, vertical and horizontal, in regard to the orientation of the meter to the soil surface to measure  $EC_a$  (mS/m). In the vertical mode (EMv), 70% of the conductivity contribution to the meter reading comes from the 0–1.5-m depth interval as compared to 0–0.75-m in the horizontal mode (McNeill 1980).

### Temperature standardization

It is important to emphasize that all readings by electrical (i.e. Eijkelkamp, Hanna Instruments) and electromagnetic (EM38) conductivity devices need to be expressed at the standardized reference temperature of 25°C. Soil temperature to reference EM38 readings were measured at several locations down to the depth of 50-70 cm by inserting a temperature sensor. The formula provided in Sheets and Hendrickx (1995), is used:

$$EC_{25} = EC_a \times 0.4470 + 1.4034 \Sigma^{(T/26815)}$$

where  $EC_{25}$  is the standardized  $EC_a$  and T is the soil temperature in degrees Celsius.

## Results and Discussion

### Saturation percentage (SP)

SP for the 75 soil samples taken before leaching in our test ranged from 27% to 55%, with an average of 41% ( $\pm 6\%$ ). These values are similar to the values reported by USSL (1954) for a selection of medium soil textures that included very fine sandy loams, loams, silt loams and silts.

### Estimation of $EC_e$ from $EC_p$ , $EC_{1:1}$ and $EC_{1:5}$

Electrical conductivity ( $EC_e$ ) readings were graphed using scatter plots and the data was fit a linear regression forced through zero. In general, the fit of the regression line was accurate as demonstrated by the high  $R^2$  of 0.84-0.94 (Table 1). The only notable difference in the regression coefficient for pre- as compared to post-leaching was for  $EC_p$ . Since  $EC_p$  was determined in the water above a 1:1 paste,  $EC_p$  should be about equal to  $EC_{1:1}$  as should the regression coefficient relating  $EC_p$  and  $EC_{1:1}$  to  $EC_e$ . This was the case for post-leaching, where the respective regression coefficients were 2.08 and 2.16, a difference that likely is not statistically significant. For pre-leaching, the regression coefficient for  $EC_p$  was greater than that for  $EC_e$ . This could be attributed to measurement technique: before leaching  $EC_p$  was measured in the water above the paste before letting the suspended soil particles settle; whereas after leaching the EC was measured in the water above the paste after the water was let to settle and clear.

The regression coefficients were similar for pre- and post-leaching for  $EC_{1:1}$  and  $EC_{1:5}$  as would be expected if leaching did not result in a major change

Table 1. Relationships for predicting electrical conductivity of the saturation extract from fixed soil:water ratio soil solutions

Pre-leaching	R <sup>2</sup>	N	Post-leaching	R <sup>2</sup>	N	Combined	R <sup>2</sup>	N
$EC_e = 2.97 \times EC_p$	0.92	75	$EC_e = 2.08 \times EC_p$	0.92	105	$EC_e = 2.42 \times EC_p$	0.86	180
$EC_e = 1.98 \times EC_{1:1}$	0.88	75	$EC_e = 2.16 \times EC_{1:1}$	0.93	105	$EC_e = 2.06 \times EC_{1:1}$	0.90	180
$EC_e = 6.53 \times EC_{1:5}$	0.89	75	$EC_e = 2.08 \times EC_{1:5}$	0.92	105	$EC_e = 2.42 \times EC_{1:5}$	0.86	180

in the amount of gypsum and calcite present as a solid phase in the soil. Therefore, it was thought reasonable to use regression for combined pre- and post-leaching datasets.

Among the few studies reported for Uzbekistan, Shirokova et al. (2000) estimated conversion factor of 3.64 for the soil types dominant in the Syrdarya region whilst the  $EC_p$  was measured in a soil-water suspension as defined in our report. For soils in the Khiva region, Akramkhanov et al. (2008) estimated a conversion factor of 2.47.

A factor of 2.06 was required to estimate  $EC_e$  from  $EC_{1:1}$  from the datasets in this study. This is close to the conversion factor of 2.2 reported by Landon (1984). To convert  $EC_{1:1}$  to  $EC_e$  for soils in Oklahoma (USA), Zhang et al. (2005) reported coefficients of 1.79 (with an intercept 1.46) and of 1.85 if plotted without intercept. Hogg and Henry (1984) reported a conversion factor of 1.56 (with an intercept -0.06) based on their findings from Saskatchewan (Canada). For soils in Saudi Arabia, Al-Mustafa and Al-Omran (1990) reported a coefficient of 3.03 (with intercept -0.638). The theoretical value suggested by USSL (1954) for chloride salts was 2.7.

To convert  $EC_{1:5}$  to  $EC_e$  for Iran soils, Alavi Panah and Zehtabian (2002) reported conversion factors of 6.92 and 8.79 for topsoil and the whole soil profile samples, respectively. In Saudi Arabia, the conversion factor from  $EC_{1:5}$  to  $EC_e$  suggested was as high as 9.57 (Al-Mustafa and Al-Omran, 1990). Landon (1984) reported a factor of 6.4. For soils under irrigated cotton in Australia Triantafyllis et al. (2000) reported value of 6.3. Shirokova et al. (2000) established a conversion factor of 5.6 for soils from Syrdarya region, Uzbekistan.

### Estimation of salt content from electrical conductivity

Many recommendations are based on the salt content in a soil sample. Different types of salts present in the soil and the various analyses of the samples complicate the direct conversion of EC into (TDS), and vice versa. Some salts have a higher EC compared to other salts. In this study, there was a good correlation between EC of various soil solutions and TDS, and individual ions (Table 2).

Table 2. Correlation coefficients between EC of various solutions and TDS and individual ions

	TDS %	HCO <sub>3</sub> %	Cl %	SO <sub>4</sub> %	Ca %	Mg %	Na %	sum %
EC <sub>e</sub>	0.78	-0.59	0.96	0.62	0.53	0.79	0.93	0.78
EC <sub>1:1</sub>	0.81	-0.63	0.90	0.68	0.58	0.80	0.91	0.81
EC <sub>1:5</sub>	0.87	-0.65	0.88	0.76	0.66	0.81	0.91	0.87
EC <sub>p</sub>	0.81	-0.60	0.91	0.68	0.57	0.77	0.90	0.80

USSL (1954) provided a general formula to estimate TDS from EC, where TDS (% or g/100g dry soil) was equal to EC<sub>e</sub> (dS/m) via a coefficient of 0.064. However, other conversion coefficients reported in the literature ranged from 0.05 to 0.1. The coefficients estimated in this study were 0.0574 (with intercept of 0.0787) and 0.0655 (when forced through zero). It is essential to mention which salinity classification system is used because it is complicated to compare between classifications based on TDS and salinity type and those based on EC<sub>e</sub>.

Alternatively, some recommendations are made based on the chloride ion content, which often constitutes the major anion in the extract and is used as an indicator of total salt content. There was a high correlation coefficient between EC<sub>e</sub> and chloride anion (Cl), hence the regression equation [Cl=EC<sub>e</sub> × 0.0093 – 0.0073; R<sup>2</sup> = 0.92] could be used to estimate Cl with a high accuracy. Safe Cl ion content for normal plant growth in the Khorezm region reported in Nerozin (1980) is around 0.03-0.04%. Compared to salinity classification based on TDS, the use of salinity classification based on Cl offers more uniform ranges between various levels of salinity and is comparable to EC<sub>e</sub> salinity classification.

**Relationship between ECe and EM38 readings**

Linear regression was used to calibrate the EM38 readings with EC<sub>e</sub>. Average values of ECe for the depth of 1.5 and 0.90 m were plotted against EMv and EMh, respectively, since most of the conductivity contribution to EMv and EMh comes from their respective sensing depths. Figure 1 shows that about 57% and 60% of the variation in soil salinity at the 1.5 and 0.9 m soil layer can be explained by EMv and EMh readings respectively.

Although an effort was made to obtain a wide range of salinity values, the highest readings rarely exceeded 150 mS/m (unit EM device expresses EC). Given the fact that most soil types in the Khorezm region are similar, differences between soil textures were not considered during the study.

Our study gave somewhat lower R<sup>2</sup> values compared to other reported studies in the literature. This could be due to the narrow salinity range (0-180 mS/m) for calibration. However, there is clear trend suggesting that values of EC<sub>e</sub> measured by EMv and EMh above 150 mS/m indicate very saline soils.

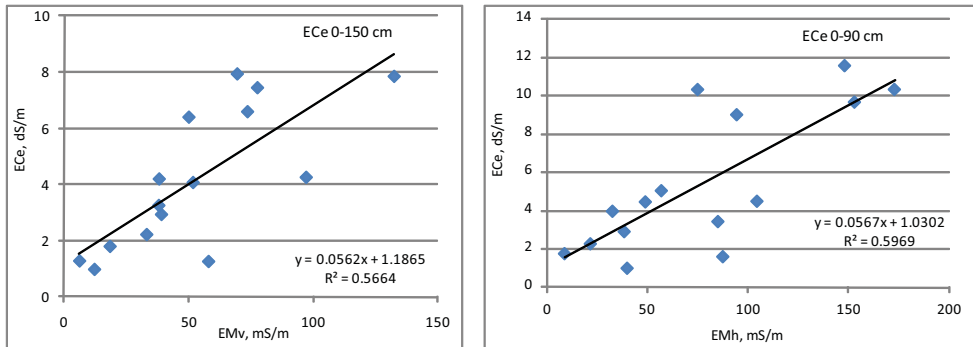


Figure 1. Relationships between EM38 readings in the vertical and horizontal modes of operation and  $EC_e$  of 150 and 90 cm soil layers

## Conclusions

Irregular analysis of soil salinity and the lack of facilities and time often deter the routine estimation of  $EC_e$  in the laboratory. It has become common practice to estimate  $EC_e$  by  $EC_p$ ,  $EC_{1:1}$ ,  $EC_{1:5}$ . The EM38 readings can also be regressed against  $EC_e$ ,  $EC_p$ ,  $EC_{1:1}$ ,  $EC_{1:5}$  to classify EM38 readings into salinity classes. Results obtained in this study are applicable to loamy soils predominant in the region and hence can be applied to areas with similar soil textures. Therefore, the user can select which method to pursue, how much time will be required, and what accuracy to expect when relating EM38 readings to salinity levels.

## Acknowledgments

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# Using Hyperspectral VNIR Spectroscopy for the Characterization of Soil Salinity

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## Abstract

The quality of lands may be degraded by the accumulation of salts in soils, which is typically measured as  $EC_e$ . Monitoring of soil salinity with conventional methods is time consuming and expensive. High-salinity soils started to develop in low elevation spots in the Harran Plain after launching intensive irrigation and crop production on clayey soils under high evaporation. The goal of this study was to evaluate the feasibility of using hyperspectral Visible and Near Infrared Reflectance Spectroscopy (VNIRRS) for the characterization of soil salinity quickly and cheaply. Randomly selected 150 locations were sampled at 0-15 cm depth from an area of around 1000 ha in the Harran Plain with salinity levels ranging from zero to very high.  $EC_e$  was determined on saturation-paste extracts. VNIRRS spectra were obtained on both air-dried and oven-dried soils. For spectral preprocessing, continuum removal (CR) method was applied throughout the whole spectrum. Calibration models between spectra and  $EC_e$  were performed using Multiple Adaptive Regression Splines (MARS). The ability to estimate  $EC_e$  from VNIRRS ranged from low to high depending on the approach used.

**Keywords:** soil salinity, Visible Near Infrared Reflectance Spectra, MARS

## Introduction

In Turkey a large irrigated area (~140,000 ha) exists in the Harran Plain, where salt-affected areas cover about 10% of the irrigated area (Cullu et al 2000). These are mainly located in the low lying parts of the plain where elevation ranges from 350 to 400 m, and salinity levels have increased after initiating intensive irrigation. Inefficient flood irrigation combined with poor natural drainage amplifies the problem, preventing salts from being washed out of the soil profile, and allowing groundwater tables to rise. These soils are

mostly fine textured and groundwater and salts rise to the land surface by capillary movement because of shallow water tables (depths less than 1.5 m at some locations) under high evaporation rates (~1800 mm/year). Soil salinity is generally assessed by measuring soil electrical conductivity ( $EC_e$ ). Monitoring soil salinity on a regular basis is important for efficient soil and water management and sustainability of agricultural lands. Conventional laboratory methods to determine  $EC_e$  can be tedious and relatively costly. Also, the spatial variability of soil salinity is high and the extent of soil salinity can change rapidly over time (Pozdnyakova and Zhang 1999). Therefore, large numbers of samples must be collected and analyzed to adequately characterize soil salinity.

Reflectance spectroscopy shows promise for its speed, accuracy and cost effectiveness in characterizing soil salinity (Farifteh et al 2008). However, it is necessary to demonstrate that useable correlations exist between spectra obtained using Visible and Near Infrared Reflectance Spectroscopy (VNIRRS) characteristics and soil salinity.

## Material and Methods

### Study area

The study area is located in the southeastern part of the Harran Plain, near Sanliurfa, Turkey (36° N, 39°E; Fig. 1), covering a total area of 1000 ha (5 x 2 km). The study area is mainly under cotton crops and has a semi arid climate with a mean annual temperature, precipitation and evaporation of 17.2°C, 365 mm and 1850 mm, respectively. Elevation of the study area ranged from 360 m to 370 m. The soils were formed on calcareous materials, and are rich in iron. They are classified as Typic Torrert, Typic calciorthid and Vertic Calciorthid (Dinc et al. 1997). They are mostly finely textured (clay loam to clay) and contain very low to low amounts of organic matter (0.5-1.5 %), and high amounts of  $CaCO_3$  on average (25-35%).

### Soil sampling and laboratory analysis

In the summer of 2006, a total of 150 soils were randomly sampled from the surface layer (0 -15 cm) (Fig. 1), and subsequently air dried and sieved (2 mm) for laboratory analysis and spectral measurements.  $EC_e$  was determined from soil water extracts obtained from saturation pastes prepared using 100 g air dried, sieved soil.

### Soil reflectance

Both air dried and oven dried (105°C for 24 hr) soil samples were scanned. Absolute reflectance of the samples was obtained for 350 to 2500 nm at 1-nm spectral resolution, using a FieldSpec Pro hyperspectral sensor (Analytical Spectral Devices, Colorado) in the laboratory, yielding a total 2150 data

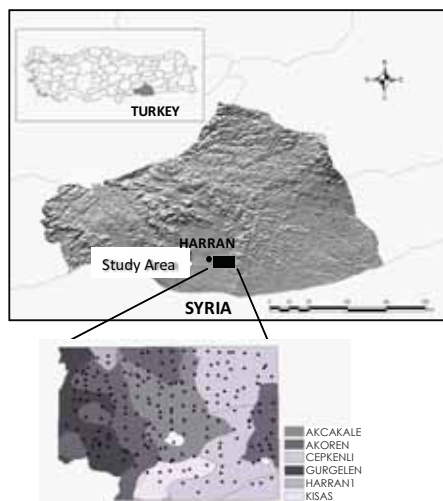


Figure 1. The study area, and sampling points on different soil series

points per spectrum. Scanning was performed by placing around 20 g of 2-mm sieved soil samples into 4-cm diameter optical quality petri dishes and illuminating with a Tungsten Quartz halogen Lamp light source. In addition to raw spectra, spectral data were also processed using a Continuum Removal (CR) procedure as described by Clark (1984). CR was performed using ENVI 4.5 (ITT Visual Information Solutions, USA), which is known to remove unwanted spectral absorption features and is also effective in enhancing distinguishing spectral features. For the characterization of soil reflectance, Principal Component Analysis (PCA) was first applied to the raw spectra of soils using all spectral bands (350-2500 nm).

### Data mining (Multiple Adaptive Regression Splines - MARS)

MARS is an explanatory data analysis (data mining) technique developed by Friedman (1991) to model predictor and response variables. For constructing the basis functions, MARS splits the data into sub regions (splines) with different interval ending knots, which are the points in the slopes where the regression coefficients change, and fits the data in each sub region using a set of adaptive piecewise linear regressions. These basic functions are then used as new predictor variables for modeling purposes. Each basis function may contain nonlinear and interaction factors (second and third order) among variables, as well as linear combinations. MARSTM software (Salford Systems, San Diego, CA) was used in this study.

### Prediction accuracy

The prediction ability of the VNIR technique was evaluated using the coefficient of determination ( $R^2$ ) of measured and predicted values of samples, the root mean square error of prediction (RMSEP), and the ratio of standard

error of prediction to standard deviation (RPD), which is calculated by dividing the SD of reference values used in the validation set by the RMSEP. RPD values in the ranges  $>2.0$ ,  $1.4$  to  $2.0$ , and  $< 1.4$  were considered as excellent, acceptable and poor predictions, respectively (Chang et al 2001).

## Results and Discussion

### Soil reflectance characteristics

The first two principal components (PC) explained 87 and 12 % of the overall variation within the spectra. In the PC score plot (Fig. 2a), two groups clustered along the PC2 axis. This means that the spectral reflectance of the whole soil samples separated into two different groups with different characteristics. Soils in PC group I (samples within the dashed line) had  $EC_e$  values ranging from 0.5 to 25 dS/m. Soils in PC group II were all saline with  $EC_e$  ranging from 3.5 to 52 dS/m.

The reflectance of the soils in PC group I had absorption peaks near 1000, 1783, 2220, 2251 and 2348 nm (Fig. 2c). Howari 2003 obtained absorption peaks at the same positions using silty clay soil contaminated with halite mineral ( $NaCl_2$ ) and a mixture of halite and gypsum salts.

The reflectance of saline ( $EC_e \geq 4$ ) and nonsaline soils ( $EC_e < 4$ ) in PC group I are plotted separately in Figures 2c and 2d, respectively, and show that both salinity classes had similar reflectance characteristics. This was not expected because reflectance of saline soils is usually greater than for nonsaline soil – in other words, saline soils have white colored crusts whereas nonsaline soils have dark colors. Saline soils had even slightly lower reflectance than nonsaline soils. This could be due to higher clay and moisture contents reducing the overall reflectivity.

The soils in PC group II had absorption peaks around 1447, 1750, 1940, 2215 and 2260 nm (Fig. 2e). Howari 2003 obtained similar absorption peaks from soils spiked artificially with  $CaSO_4 \cdot 2H_2O$ . Similarly, wavelengths in the 1945-1950 nm interval had the highest loading weights in PC2 which separated the samples into two groups (Fig 2 b). The absorption peaks in this range are distinguishing for gypsum (Howari 2003, Tamas and Lenart 2006).

### Estimation of $EC_e$

The first step in the attempt to use reflectance spectra to estimate  $EC_e$ , was to obtain the relationships between  $EC_e$  and reflectance for the samples in groups PCI and PCII for both air dry and oven dry soils (Table 1).

The data in Table 1 for raw and continuum removed spectra are the results obtained using separate calibration models which were constructed using MARS for each group and validated using cross validation. The accuracies

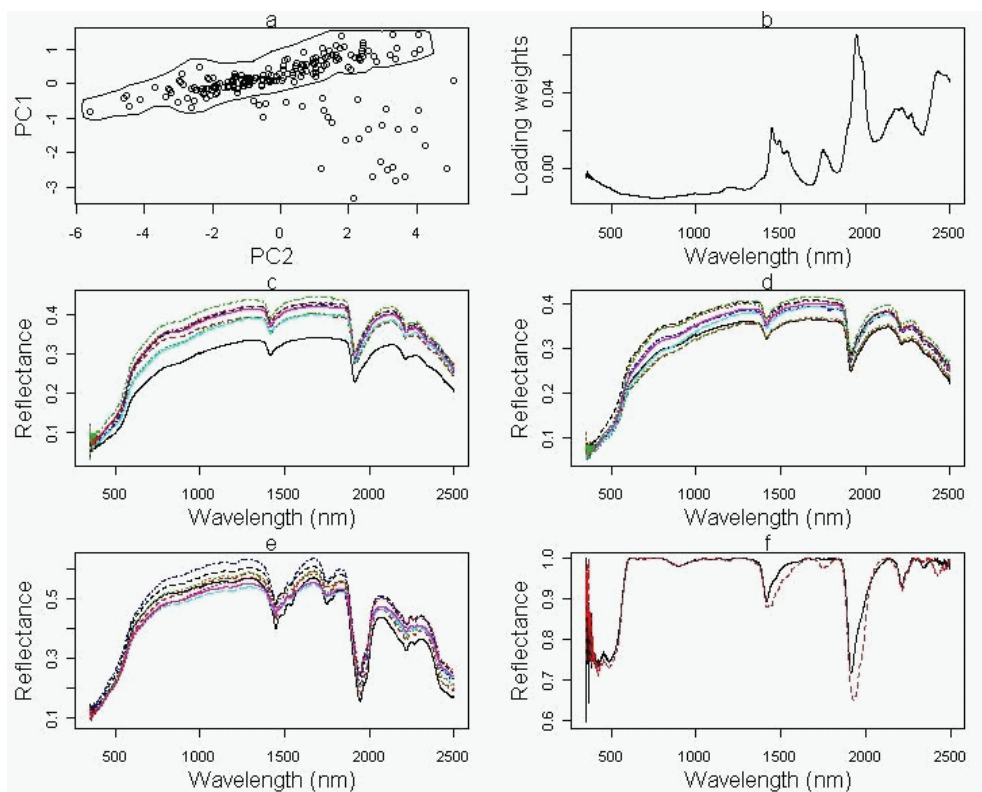


Figure 2. PCA analysis results and reflectance characteristics

of the estimations changed depending upon different approaches used (Table 1). The RPD values showing the quality of the estimations ranged from 1.0 to 2.2, 1.3 to 2.70, and 1 to 1.2 for group All (all samples), I (samples in PC group I) and II (samples in PC group II), respectively. In general, calibrations constructed using the samples in group I with presumed halite salt minerals were better than group All, indicating that separate calibration models for soils with different salt mineral would have been more successful. The improvements in  $EC_e$  estimation for both raw and continuum removal were enhanced using oven dried samples. This may be due to increased spectral presence of the salts in crystallized form after more complete drying. For the soil samples in groups All and II, results were not ostensibly improved by using reflectance from oven dried samples, and in some cases the results were in fact better for air dried samples. The dominant salt mineral type of soils in group II was gypsum, and so the crystallized form of the gypsum may have changed with increasing drying temperature time. Also the number of samples is much less than the other two groups.

Table 1. ECe estimations using MARS software

Group	Raw Reflectance			Continuum Removal		
	R <sup>2</sup>	RMSEP	RPD	R <sup>2</sup>	RMSEP	RPD
<b>Air dried</b>						
All	0.79	3.18	2.17	0.14	6.40	1.08
I	0.37	3.46	1.25	0.77	2.40	1.81
II	0.28	12.17	1.20	0.22	13.23	1.11
<b>Oven dried</b>						
All	0.10	6.74	1.02	0.49	4.92	1.40
I	0.57	2.85	1.52	0.86	1.61	2.70
II	0.23	13.27	1.11	0.00	15.07	0.97

The best estimation results for EC<sub>e</sub> were obtained for group I with RPD and R<sup>2</sup> values of 2.7 and 0.86, respectively using continuum removed spectra. Continuum removal enhances spectral absorption features (Clark 1984) and can therefore help improve the estimations.

### Conclusions

VNIRRS showed promising results for characterizing saline soils in the Harran Plain. Common salt minerals existing in soils could be identified with use of VNIRRS-Principal Component Analysis, which helped to differentiate soils with different types of salt minerals. Good estimations were possible by collecting reflectance of soils after oven drying and using spectral pretreatment methods such as continuum removal and constructing separate calibration models for soils with different common salt minerals. The estimation quality was poor for samples containing gypsum, but improved after these samples were removed.

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# Improved Germination and Seedling Vigor Enhancement of Quinoa (*Chenopodium quinoa Willd.*) Grown at Different Salinity Levels

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## Abstract

Two accessions of quinoa PI 634919 (Pichaman) and PI 596293 (Colorado 407D) were tested for their germination and vigor in response to priming under saline conditions. An adverse effect of salinity was observed for both accessions. These effects were mitigated by different priming techniques. Priming techniques were found effective in reducing the deleterious effects of NaCl even at 30 dS/m regardless of accession tolerance level. Seed priming with plant growth regulators i.e. ascorbate, BAP and halopriming with  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  were found effective in improving germination and seedling vigor. Delayed germination was observed in non-primed seed at all salinity levels compared to primed seed. BAP priming reduced the time to 50% germination in EC 10 and 20.

**Key words:** Quinoa, salinity stress, priming, salinity tolerance.

## Introduction

Quinoa (*Chenopodium quinoa Willd.*) is an edible seed species of the family Chenopodeaceae. It originates from the Andean region of South America, and has dietary importance: rich in proteins, fibre and fat, gluten free, and a balanced food (Burnouf-Radosevich 1988, Repo-Carrasco et al. 2003). Quinoa has considerable resistance to several important stresses including drought, frost and high soil salt content (Vacher et al, 1988, Jacobsen et al. 2005, 2007, 2009, Garcia et al. 2007). This tolerance has made it an attractive alternative crop for arid and semi arid regions with problem soils (Aronson 1985).

Although the species is fairly resistant to salinity, production may still be affected by salinity stress. Several strategies may be used to address this. One option is seed priming, which can enhance the performance of plants at early seedling stage by reducing time to germination and increasing germination percentage, leading to a better crop stand for food crops (Basra et al. 2004, 2005, Farooq et al. 2006, 2007a,b,c) and horticultural crops (Heydecker and Coolbaer 1977, Bradford 1986).

With seed priming, seeds are partially hydrated to a point where germination processes begin without radicle emergence (Heydecker and Coolbear 1977, Bradford 1986). Osmohardening with  $\text{CaCl}_2$  solution ( $\psi_s = -1.25 \text{ MP}_a$ ) was found to be better for vigor enhancement than other priming strategies (Farooq et al. 2006, Basra et al. 2005). Hydroprimed seeds, soaked in distilled water for 24 h and redried, improved emergence and tillering (Bennett and Waters 1987). Seeds soaked in 50 mg/l ascorbate solution for 12 h improved the speed of germination (Sundstrom et al. 1987). A plant growth spray made from *Moringa oleifera* leaves increased crop production with larger fruits and 20-35% higher yield (Foidl et al. 2001).

This study examined the potential of seed priming to improve seed germination and seedling vigor of quinoa accessions under saline conditions.

## Material and Methods

### Planting material

Two quinoa accessions PI 596293 (COLORADO 407D) and PI 634919, originating from Colorado, USA and Pichaman, Chile respectively, were multiplied under Pakistani conditions. Germination rates were 82% in PI 596293 and 85% in PI 634919.

### Priming operations

Seeds of both accessions were treated for 2 h at  $20 \pm 2^\circ\text{C}$  under controlled conditions with the following seed-soaking media: (i) T0: unsoaked seed (control), (ii) T1: osmopriming with *Moringa oleifera* leaf extract (MLE) with 1:30 water dilution, (iii) T2: hydropriming with distilled water, (iv) T3: Halopriming with  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  ( $\psi_s -1.25 \text{ MPa}$ ), (v) T4: Ascorbate priming in 50 mg/l solution, (vi) T5: hormonal priming with Benzyl Aminopurine (BAP) 50 mg/l, (vii) T6: Osmopriming with  $\text{H}_2\text{O}_2$  40  $\mu\text{M}$  solution. These seed priming treatments were selected based on previous experience (Basra et al. 2005, 2006, Iqbal and Ashraf 2006). The ratio of seed weight to solution volume was kept 1:5 (g/ml) (Basra et al. 2004).

### Post-priming operations

NaCl solution was used as the source for inducing salinity in double layered Whatman's filter paper No. 41 in 100-mm-diameter Petri-dishes moistened with 3 ml solution of different salinity levels: 10, 20 and 30 dS/m. Fifteen seeds each were sown in petri-dishes placed in a germinator at  $20 \pm 2^\circ\text{C}$  in darkness. A completely randomized design with three replications was used. Seeds with 3 mm radicle protrusion were scored as germinated and counted at 24 hour intervals until stable seedling count was achieved. The seedlings were evaluated for the following parameters at 12 days age as described in the Seedling Evaluation Handbook (AOSA1990): Final germi-

nation root and shoot length, seedling fresh and dry weights. Experimental data were analyzed using Fisher's analysis of variance technique at 5% probability level (Steel and Torrie 1984).

## Results

Accession 634919 showed non-significant ( $p \geq 0.05$ ) differences for final germination percentage when grown in 10 and 20 EC NaCl solutions except for osmopriming in which final germination obtained in 20 EC solution was significantly lower than in 10 EC solution (Figs. 1a,b).

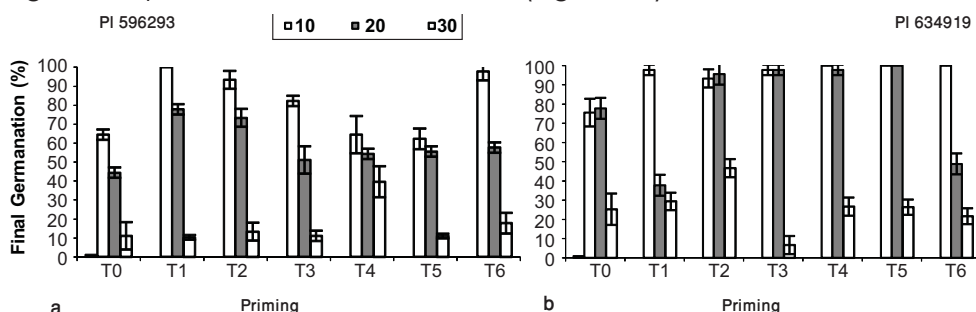


Figure 1. Effect of seed priming on final germination of two accessions of *C. quinoa* under 3 saline conditions and different treatments (T0: Control, T1: MLE, T2: Hydropriming, T3:  $CaCl_2 \cdot 2H_2O$ , 3 saline conditions and different treatments T4: Ascorbate T5: BAP T6:  $H_2O_2$ )

Furthermore, seeds of this accession, when primed, shown higher germination percentage at all salt concentrations, compared to accession PI 596939, suggesting that PI 634919 is more tolerant to salinity than PI 596293. Final germination percentage was severely affected when seeds were germinated in salt solution of 30EC. Both accessions showed variable response to seed priming in this salt solution. Accession PI 596293 showed the highest final germination percentage when primed with ascorbate while hydropriming gave better results in seeds of PI634919 grown in 30EC NaCl solution.

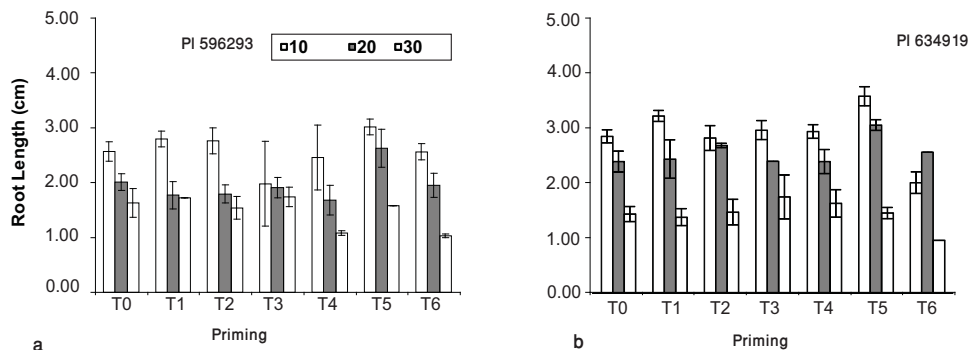


Figure 2. Effect of seed priming on root length of two accessions of *C. quinoa* under 3 saline conditions and different treatments (T0: Control, T1: MLE, T2: Hydropriming, T3:  $CaCl_2 \cdot 2H_2O$ , T4: Ascorbate T5: BAP T6:  $H_2O_2$ )

Suppressing effects of salt solutions were observed on root length (Figs. 2a,b). Root length decreased with the increase in EC of the solution in both accessions. PI 634919 had greater root length than PI 596293. Both accessions produced the highest root length when seed was primed with BAP in 10 and 20 EC solutions. Osmoprimering with  $\text{CaCl}_2$  led to better response in both accessions under 30 EC salinity regime.

Similar to the root length, seedling shoot length decreased with salt treatments (Figs. 3a,b). However, shoot length differences were non-significant in 10 and 20EC solutions in both accessions. For accession 596293, priming with BAP was successful in 10 and 20 EC while  $\text{CaCl}_2$  primed seed produced significantly higher shoot length in 30 EC. For accession PI 634919, seed primed with BAP showed the highest shoot length in 10 and 20 EC solutions, whereas ascorbate priming was successful in 30EC solution.

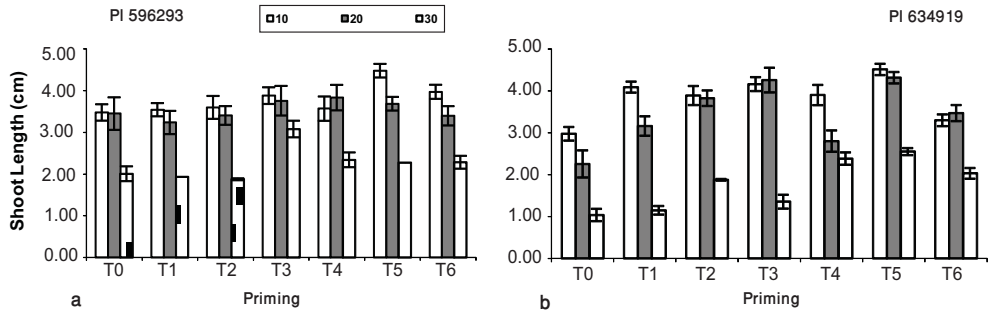


Figure 3. Effect of seed priming on shoot length of two accessions of *C. quinoa* under saline conditions (T0: Control, T1: MLE, T2: Hydropriming, T3:  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , T4: Ascorbate T5: BAP T6:  $\text{H}_2\text{O}_2$ )

Accession PI 634919 produced relatively higher seedling fresh weight (SFW) than PI 596293 (Fig. 4 a,b).  $\text{CaCl}_2$  primed seed showed the highest SFW in 10 EC solution for accession 634919. BAP produced the highest seedling fresh weight in 20 EC solution for PI 634919 and in 10 EC solution for PI 596293. In 30 EC solution, ascorbate primed seed of PI 634919 performed excellently while  $\text{H}_2\text{O}_2$  priming of PI 596293 produced relatively higher SFW.

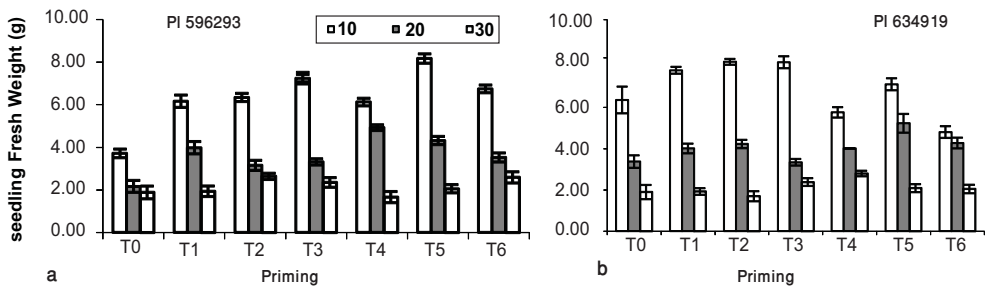


Figure 4. Effect of seed priming on seedling fresh weight of two accessions of *C. quinoa* under saline conditions (T0: Control, T1: MLE, T2: Hydropriming, T3:  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , T4: Ascorbate T5: BAP T6:  $\text{H}_2\text{O}_2$ )

BAP priming produced the highest seedling dry weight in 10 and 20EC solutions in both accessions (Fig. 5). In 30EC solution, hydropriming of PI 634919 produced the highest seedling dry weight (SDW) while  $\text{CaCl}_2$  priming produced highest significant effects on SDW in PI 596293.

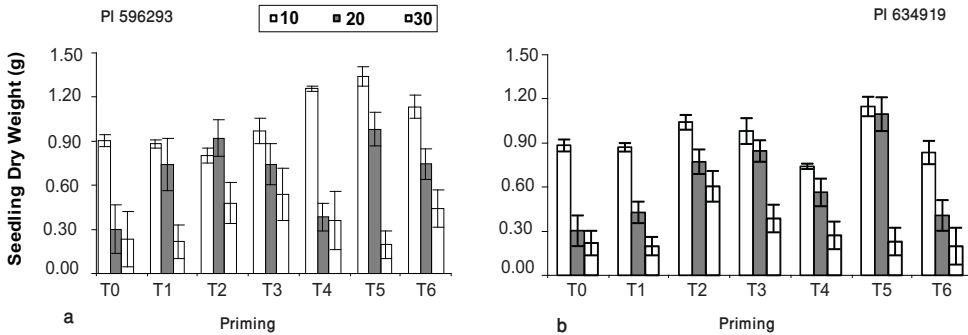


Figure 5. Effect of seed priming on seedling dry weight of two accessions of *C. quinoa* under saline conditions ( T0: Control, T1: MLE, T2: Hydropriming, T3:  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , T4: Ascorbate T5: BAP T6:  $\text{H}_2\text{O}_2$ )

## Discussion

Repressing effects of salinity were observed on traits linked with seed germination and seedling vigor. This is well documented. Previous studies have shown that in wheat, salinity can lead to lower germination and delayed emergence (Francois et al. 1986). Germination rate and emergence is important for successful establishment (Harris 1996). Quinoa accessions showed differential level of salinity tolerance. Generally, accession 6934919 showed better tolerance to salinity. Substantial variation for abiotic stress tolerance has been reported earlier (Vacher et al. 1988, Jacobsen 2003).

Seed priming is reported to improve the germination rate and seedling growth in various field crops such as rice and wheat (Basra et al. 2004, 2005, Farooq et al. 2006). Our study examined the effect of different priming techniques to mitigate the effects of salt stress on seed and seedling traits in quinoa accessions. Priming techniques were found effective in reducing the deleterious effects of salts at all salinity levels, regardless of accession tolerance. Seed priming with plant growth regulators, i.e. ascorbate, BAP and halopriming ( $\text{CaCl}_2$ ) were found effective in reducing the deleterious effects of salts. Previous results have shown a positive impact of priming on seed and seedling traits. Sundstrom et al. (1987) soaked seeds in 50 mg/l ascorbate solution for 12 h and enhanced growth and early crop stand under saline regime. Afzal et al. (2008) improved seed germination and seedling vigor in wheat when seeds were primed with different salts.

Seed priming allows some of the metabolic processes necessary for germination to occur without affecting germination. Increased germination rate and uniformity have been attributed to metabolic repair during imbibition (Burgass and Powell, 1984), a buildup of germination-enhancing metabolites (Basra et al. 2005), osmotic adjustment (Bradford 1986), and, for seeds that are not redried after treatment, a simple reduction in the lag time of imbibition (Heydecker and Coolbear 1977).

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# Common Weeds Among Fodder Crops Under Saline Conditions in Syria

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## Abstract

Weeds compete with forage crops for water and nutrients. However, some weeds are used locally as human feed and others as animal feed. Nine weeds of different families were detected in one experiment, involving sorghum (var. Izraa 7) under saline conditions in the lower Euphrates basin in Syria. The experiment was conducted at Al-Mreiya station of the General Commission for Scientific Agricultural Research. The crop was sown on 25 June 2008 and irrigated using long furrows with three levels of water salinity (1.14, 8.49 and 12.59 ds/m). The average salinity for saturated paste was 5.09 dS/m. The first cut for sorghum was on 8 September. Weeds appeared in all treatments without significant differences in weed yield; average weed yield was 10 t/ha every weeding before the first cut of sorghum. The most dominant weed was *Echinochloa colona* which endured saline drainage water in the irrigation treatment where  $EC_{iw} = 12.59$ . This weed was observed to spread under sodic conditions, where ESP reached 22.02 in this treatment.

**Keywords:** Salinity, sorghum, weeds, fodder crops, Syria.

## Introduction

The most severe agricultural soil salinity problems in Syria occur in irrigated areas in the Euphrates basin. An estimated 530,000 ha of irrigated land in the basin (more than 40% of total irrigated land in Syria) is affected by varying degrees of salinity (World Bank 2004). Another problem is weeds, which cause 17-25% losses in wheat annually (Shad 1987). However, weeds also have a beneficial value from their use as feed, especially when fodder is lacking (Al Sherif et al. 2008).



The objectives of this study were two fold:

- characterize weeds used for fodder in Al-Mreiya station, growing under saline conditions.
- estimate the productivity of weeds in an experiment with sorghum under three salinity levels.

## Materials and Methods

The study site is located in the Al-Mreiya station of the General Commission for Scientific Agricultural Research (GCSAR) in Deir Ezzor, Syria (35°N, 40°E, elevation 203 m). Table 1 shows some properties of the soil. The weeds accompanying four forage crops were observed and quantified.

Table 1. Soil properties at the experiment site.

Depth, cm	Clay %	Silt %	Sand %	Texture	$\rho_b$ , g/cm <sup>3</sup>	EC <sub>e</sub> , dS/m	pH
0- 15	44	24	32	Clay	1.46	19.4	8.4
15 – 30	44	28	28	Clay	1.55	12.9	8.2
30 – 45	42	26	32	Clay	1.60	7	8.2
45 – 60	38	32	30	Clay Loam	1.58	6.8	8.2

Another experiment at the same site examined the effects of irrigation water salinity on sorghum yield (variety Izraa 7). Three levels of irrigation water salinity were used:

- Treatment E = Euphrates river water, 1.14 dS/m,
- Treatment S1 = Mixture of agricultural drainage water with Euphrates water, 8.49 dS/m
- Treatment S2 = Agricultural drainage water, 12.59 dS/m

Each treatment was replicated three times. Spacing was 70 cm between furrows and 20 cm between plants. Samples of irrigation water were taken at each irrigation (Table 2).

EC<sub>e</sub> of the soil samples taken before sowing was 5.09 dS/m. Nitrogen and phosphorus fertilizer were applied according to the Ministry of Agriculture and Agrarian Reform recommendations. Weeds appeared 10 days after sowing sorghum variety Izraa 7.

Table 2. Analysis of irrigation water.

Irrigation water	SAR, dS/m	EC <sub>iw</sub> , dS/m
E	2.96	1.19
S1	15.37	8.49
S2	24.50	12.59

Weeds growing with sorghum were collected from plots of 1 m<sup>2</sup> to measure weed yield. Two weedings were performed, one before and one after the first cut. Weeds were collected and fed to animals. After the first cut, soil samples were taken every 30 cm to 90 cm depth (Table 3).

Table 3. EC<sub>e</sub> and ESP after first cut, 0-90 cm depth.

Depth, cm	Treatment F			Treatment S1			Treatment S2		
	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
EC <sub>e</sub> , dS/m	3.32	3.23	4.63	3.73	4.43	4.74	6.96	8.86	9.74
ESP	4.50	3.43	8.26	6.52	8.13	10.04	15.14	20.28	22.02

We observed weeds spreading under saline conditions in the station. These weeds were used as feed. In the experiments, we used four forage crops: fodder beet, barley, pearl millet under irrigation, with three salinity levels of irrigation water (E, S1, S2). Weeds were also measured on Common Reed growing in salt-affected soils and in open agricultural drainage system.

**Fodder beet** *Beta vulgaris v. crassa*: Sprinkler irrigation with three levels of irrigation water salinity (E = 1.02 dS/m, S1 = 7.93 dS/m, S2 = 14.64 dS/m). Sowing date 2 October 2007.

**Barley**: Long furrow irrigation was applied (E = 1.02 dS/m, S1 = 7.93 dS/m, S2 = 14.46 dS/m). Sowing date 4 December 2007.

**Pearl millet** *Pennisetum glaucum*: Long furrow irrigation was applied (E = 1.12 dS/m, S1 = 7.44 dS/m, S2 = 11.66 dS/m). Sowing date 2 July 2008.

**Common reed**: Measurements were taken at early and flowering stages, on 10 March and 22 August 2008 respectively. In early stage: SAR = 20.97, EC<sub>iw</sub> = 12.26 dS/m. In flowering stage: SAR = 28.28, EC<sub>iw</sub> = 15.56 dS/m.

## Results and Discussion

### Occurrence of common weed species

Nine weed species were commonly found in the selected areas.

1. *Echinochloa colona* (L.) Link, family Poaceae. It was found in sorghum and millet crops. This species reproduces from seeds. In West Africa, it is widely distributed and widely used as fodder plant for livestock (Müller 2006).
2. *Portulaca oleracea* L., family Portulacaceae. It was found in sorghum and millet crops. This species reproduces from seeds. It provides essential nutrients for humans and animals, and is grazed by livestock only during drought (Sincich 2002).
3. *Chenopodium* sp., family Chenopodiaceae, also known as White Goosefoot. It was found in irrigated fodder beet. This species reproduces from seeds. It is suitable not only for cattle fodder but also for human food (Lietuvos 1961).
4. *Sisymbrium irio*, family Brassicaceae. It was found with fodder beet and barley. This species reproduces from seeds and is considered good feed for animals (Al Asha Pub # 370).

5. *Prosopis stephaniana*, family Fabaceae. It was found in sorghum and millet crops and on the sides of the plots. This species reproduces from seeds and rhizomes. Camels and sheep eat its fruits (Al Asha Pub # 370).
6. *Alhagi maurorum Medic.*, family Fabaceae. It was found in sorghum and millet field edges, and in open agricultural drainage system. This species reproduces from seeds and rhizomes. It is eaten by goats and stored as fodder in Central Asia (Al-Oudat 2005).
7. *Melilotus indicus* (L.), family Fabaceae. It was found in fodder beet and barley crops. This species reproduces from seeds and has high potential for use as a forage crop (Al Sherif et al. 2008).
8. *Cynodon dactylon* (L.) Pers., family Poaceae. It was found in sorghum and millet crops. This species reproduces from seeds, rhizomes and stolons. It is suitable for grazing and has high palatability (ACSAD 1979).
9. *Phragmites australis* (Cav.), family Poaceae. Also known as Common Reed. It was found in sorghum and millet crops and in open agricultural drainage system. This species reproduces from seeds and rhizomes. In the southern United States, it is described as a "high-quality, warm-season forage". Although mature plants are considered tough and unpalatable (Leithead 1971), it is not rated as a high-value or high-palatability livestock or wildlife food unless plants are young. Immature plants are considered palatable in southern and eastern Idaho (Hall 1997).

### Effect of three salinity levels of irrigation water on sorghum yield and soil salinity

This experiment measured the effect of the three salinity levels of irrigation water on sorghum yield (Var. Izraa 7) and soil salinity. Weeds appeared in all treatments and there were no significant differences in weed yield between treatments. Summer weeds were *Echinochloa colona*, *Portulaca oleracea*, *Chenopodium* sp, and *Cynodon dactylon*. They were seen on summer crops (sorghum, millet). The most common summer weed was *Echinochloa colona* which endured saline drainage water in S2 treatment where  $EC_{iw} = 12.59$ . We observed its distribution under sodic conditions in this treatment, where ESP reached 22.02.

Winter weeds consisted of *Sisymbrium irio*, *Melilotus indicus* and *Chenopodium album*, found in fodder beet and barley crops. The most common winter weed was *Melilotus indicus* which tolerated drainage water having  $EC_{iw} = 14.66$  dS/m in S2 treatment.

*Prosopis stephaniana* and *Alhagi maurorum* were found in spite of the high levels of salinity. *Prosopis stephaniana* was the most spread.

In the surface agricultural drainage systems, *Phragmites australis* tolerated a high level of water salinity.

## Conclusions

Different weed species appear with forage crops when irrigated with different levels of water salinity. *Echinochloa colona* and *Melilotus indicus* are the most tolerant to saline water. In field sides and waste areas, *Prosopis stephania* was the most tolerant to saline soils. *Phragmites australis* tolerated a high level of saline water in open agricultural drainage system.

Weeds that grow naturally under saline conditions can provide important benefits. It is even possible to plant some of these weeds as forage crops in salt affected soils, for example *Melilotus indicus*.

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# Effect of Irrigation with Saline Water on Three Acacia Species and Eucalyptus Seedlings

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## Abstract

A pot trial was conducted to study the effect of irrigation with saline water (NaCl) on three *Acacia* sp and *Eucalyptus camaldulensis*. Four-week old seedlings of *Acacia seyal* variety *Seyal*, *A. mellifera*, *A. tortilis* ssp. *raddiana* and *Eucalyptus camaldulensis* were grown in polyethylene bags filled with a sandy clay loam soil and irrigated with 250, 500, 1000 and 1500 mg/l NaCl for 12 weeks. Plants were monitored for growth (plant height) and symptoms of salt induced stress every 2 weeks. At the end of the experiment root length and root and shoot dry weights were measured. The results showed that seedling growth of all the species decreased significantly with increasing NaCl concentration in the irrigation water. However, the plants survived and continued to grow throughout the experiment period. *Acacia mellifera*, *Eucalyptus camaldulensis* and *Acacia tortilis* were more tolerant to salinity than *Acacia seyal*; and shoot parts were more adversely affected by salt stress than root parts.

**Keywords** : Tolerance, *Acacia*, saline irrigation water

## Introduction

The progressive decrease of water resources is leading to greater use of saline water for irrigation with the risk of salt accumulation in the root zone and consequent damage to crop production and soil fertility (Mass 1986, Laüchli and Epstein 1990). Sudan is dominated by arid and semi arid tropical climates that favor the formation of salt affected soil. Saline- sodic soils occur in Khartoum state, Northern state, Nile valley state, along both banks of the Nile, south of Khartoum between the Blue and White Nile and on both

banks along the White Nile north of Kosti (Mustafa 1986). The establishment of several private and cooperative farms, irrigated with deep or surface borehole water, along the bank of the Nile, has caused secondary salinization or alkalinization of these areas (Mustafa 1983). Two approaches are generally used to solve the problem of salinity: the first by using soil ameliorants and good irrigation water to reduce salt concentrations and improve growth (Baraka et al. 1999) and the second approach by selecting plant species tolerant to salinity and conditions associated with salt affected soils. Chaudhry et al. (2000) reported that *Eucalyptus* and *Acacia* have great potential for biodrainage. A 4 ha plantation of 6-year old *Eucalyptus* had water tables 30% lower than neighboring cropped land.

In Sudan, the high content of 2:1 clay minerals makes complete reclamation of saline sodic soils impracticable. The use of subsurface drainage system has not been successful (Mustafa 1986). These results suggested the application of biodrainage as biological means to reclaim salt affected soils. The extensive root structures of trees trap much of the water, using it for growth and returning the water, to the atmosphere via transpiration and evaporation. Planting of trees also aids in combating desertification and thus improves the physical and chemical conditions of the soil necessary for successful afforestation (Qureshi et al. 1993). However, unless these trees are adapted to salty environments, they will not survive in badly affected salty areas. The objective of this study was to measure the tolerance of the selected species to salt stress.

### Material and Methods

Three acacia species (*Acacia seyal* var. *Seyal*, *A. mellifera* and *A. tortilis* ssp. *raddiana*) and *Eucalyptus camaldulensis* were used in this study. The plants were sown in polyethylene bags filled with a sandy clay loam soil and irrigated with tap water for one month after germination. Salt treatment started one month later. Seedlings were irrigated daily with sodium chloride solution of the following concentrations: 250, 500, 1000 and 1500 mg/l. These corresponded to electrical conductivities of 0.835, 1.367, 2.07 and 3.26 dS/m, respectively. The control was irrigated with tap water, 0.307 dS/m. The amount of water added to seedling was 500 ml per bag, calculated as two thirds of field capacity. Therefore, there was no drainage or leaching through the bag. Plant height was measured before the start of the irrigation experiment (first reading) and then every two weeks. The difference in plant height between every reading and the previous reading was considered as the seedling growth for that interval. Roots were harvested together with shoots, three months after the start of salt applications and their length was recorded. Shoots were cut at the pot surface, 12 weeks after the start of salt applications, shoot and root dry weights were obtained after oven drying at 70°C for 24h.

The experimental design was completely randomised (CRD) arranged as a split plot with six replicates. Plant species were assigned to the main plot and salt stress as the subplots. Data were analysed using ANOVA test. Differences among treatments means were determined by least significant difference (LSD).

### Results and Discussion

The effect of irrigation with saline water on the growth (plant height) of the species studied is shown in Fig. 1. Generally for all seedlings, growth decreased significantly with increasing NaCl concentration in the irrigation water. However, the plant species survived and continued to grow. Rawat and Banerjee (1998) reported that salinity up to 160 mM has no effect on the survival of *Eucalyptus camaldulensis* seedlings. Reduction in plant height due to salt stress may be attributed to the effects of salts in retarding the processes of cell division and cell extension upon which growth depends (Netondo 1999). Retarded plant height and reduced dry weight may be due to ion toxicity which also has a role in decreasing the rates of cell division and cell expansion. For example, accumulation of Na<sup>+</sup> and Cl<sup>-</sup> ions occurs in the stem tissues of sorghum leading to ion toxicity (Netondo 1999). More than 50% reduction in plant growth was observed at higher NaCl concentrations. After 12 weeks of irrigation with low salt concentration (250 mg/l NaCl) the lowest reduction in plant height was observed for *Acacia tortilis* (16.9%), and the highest reduction (37%) in *Acacia seyal*.

Twelve weeks after irrigation with 1500 mg/l NaCl, the percentage reduction in plant height in comparison with control was 51, 65, 71 and 81.9% for *A. mellifera*, *Eucalyptus camaldulensis*, *A. tortilis* and *A. seyal* respectively. All four species were comparatively more tolerant to 500 mg/l NaCl concentration in irrigation water, with less than 50% reduction in plant height. Salt stress significantly reduced shoot dry weight of all species under study. The degree of reduction increased with increasing level of salts (Table 1). The highest reduction was observed in *A. seyal*, while the lowest reduction was in *A. tortilis*. Field trials elsewhere with acacias grown on salt affected marginal lands indicate that *Acacia tortilis* is tolerant to salinity (Tomar et al. 2003). The observed reduction in shoot dry weight is a common response to salinity. High salt concentration in root zone affects plant growth mainly through osmotic effects on water uptake and specific ion toxicities (Munns 2002, 2005). Salinity higher than 1.367 dS/m in irrigation water resulted in more than 50% reduction in final shoot dry weight of all species (Table 1). Salt stress from saline irrigation significantly reduced root length (Table 2) and root dry weight (Table 3) and the degree of reduction increased with increasing the level of salt in irrigation water. However, the percentage reduction in root length and root dry weight is less than the observed reductions in shoot parameters. The percentage reduction in root length in all species was less than 50%. It appears that root length is less affected by salt

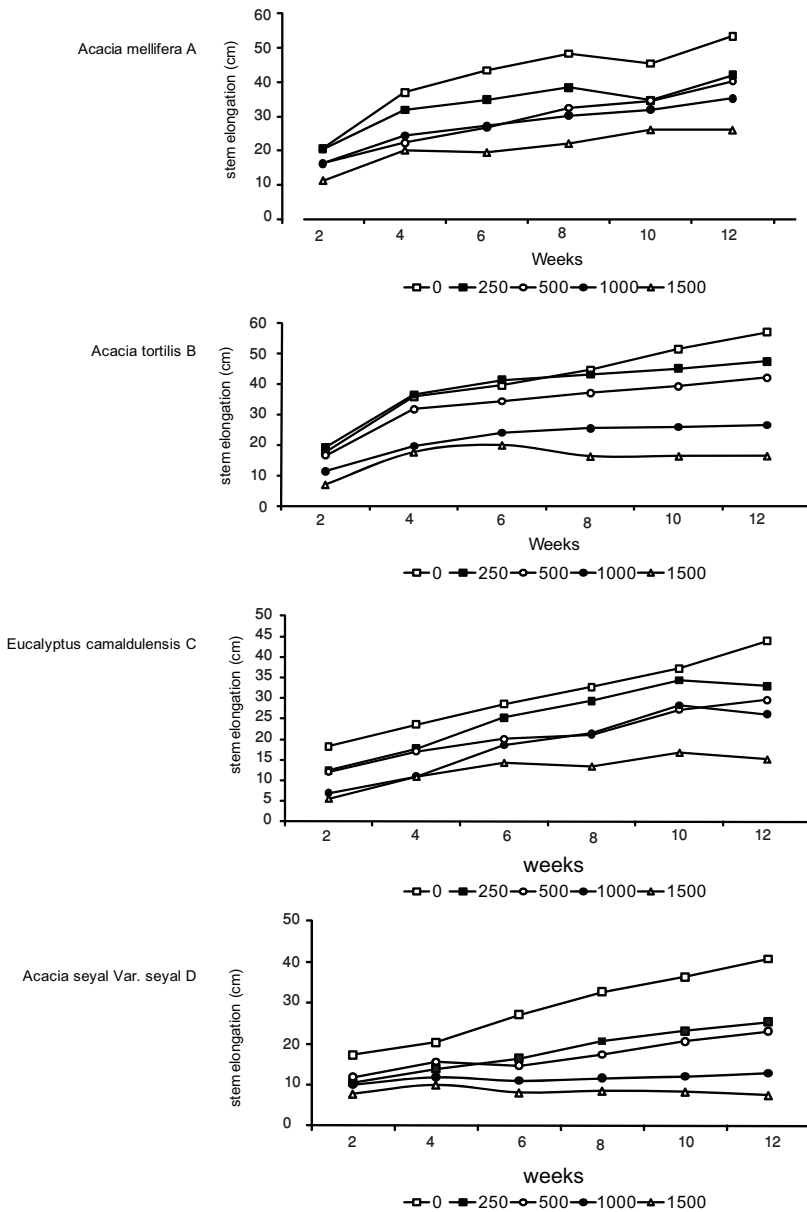


Fig. 1 Effect of irrigation with saline water on stem elongation of (A) *Acacia mellifera*. (B) *Acacia tortilis*. (C) *Eucalyptus camaldulensis*. (D) *Acacia seyal*.

stress although with increasing salt level there was continuous decrease in root length. These results are similar to those reported by Hatimi (1999) who found that root parts were less affected than the shoots in *Acacia cyanophylla*.



Table 1. Effect of irrigation with saline water (NaCl mg/l) on seedling shoots dry weight (g)

<b>Tree species</b>	<b>0 mg/l</b>	<b>250 mg/l</b>	<b>500 mg/l</b>	<b>1000 mg/l</b>	<b>1500 mg/l</b>	<b>Mean+ 0.56</b>
<i>Acacia mellifera</i>	4.78	3.81	3.22	2.52	1.67	3.20
		(20.21)	(30.66)	(47.39)	(65.16)	
<i>Acacia tortilis</i>	2.77	2.10	1.65	1.37	0.78	1.73
		(24.09)	(40.36)	(50.60)	(71.68)	
<i>Acacia seyal</i>	5.98	5.25	3.88	2.15	1.02	3.66
		(12.26)	(35.11)	(64.07)	(83.01)	
<i>Eucalyptus camaldulensis</i>	12.73	11.7	10.45	9.88	7.28	10.41
		(8.12)	(17.93)	(22.38)	(42.81)	
Mean + 0.50	6.57	5.72	4.8	3.98	2.69	
	LSD					
Interaction	0.99					

Table 2. Effect of irrigation with saline water (NaCl mg/l) on seedlings root length (cm)

<b>Tree species</b>	<b>0 mg/l</b>	<b>250 mg/l</b>	<b>500 mg/l</b>	<b>1000 mg/l</b>	<b>1500 mg/l</b>	<b>Mean+-10.72</b>
<i>Acacia mellifera</i>	99.33	88.17	76.33	60.17	51.5	75.1
		(11.24)	(23.15)	(39.42)	(48.15)	
<i>Acacia tortilis</i>	94.88	82.32	73.85	63.48	53.63	73.632
		(7.90)	(11.23)	(21.86)	(36.47)	
<i>Acacia seyal</i>	69	63.55	61.25	53.92	43.83	58.31
		(13.24)	(22.17)	(33.09)	(43.47)	
<i>Eucalyptus camaldulensis</i>	52.37	50.08	46.42	36.00	26.67	42.308
		(4.36)	(11.36)	(31.25)	(49.07)	
Mean +- 5.36	78.99	71.03	64.46	53.39	43.91	
	LSD					
Interaction	76.9					

Table 3. Effect of irrigation with saline water (NaCl mg/l) on seedlings root dry weight (g)

<b>Tree species</b>	<b>0 mg/l</b>	<b>250 mg/l</b>	<b>500 mg/l</b>	<b>1000 mg/l</b>	<b>1500 mg/l</b>	<b>Mean+-0.93</b>
<i>Acacia mellifera</i>	4.05	3.65	3.18	2.25	1.52	2.93
		(9.88)	(21.39)	(44.44)	(62.55)	
<i>Acacia tortilis</i>	2.38	2.28	1.70	1.32	1.07	1.75
		(4.20)	(28.67)	(44.76)	(55.24)	
<i>Acacia seyal</i>	5.17	3.1	2.63	1.17	0.93	2.6
		(39.42)	(48.53)	(77.19)	(81.76)	
<i>Eucalyptus camaldulensis</i>	6.16	5.23	4.3	2.9	2.25	4.168
		(14.91)	(30.08)	(52.84)	(63.41)	
Mean +- 0.47	4.44	3.57	2.95	1.91	1.44	
	LSD					
Interaction	0.71					

In all three tables, values in parentheses show the % reduction in root dry weight compared to the control

## Conclusions

*A. mellifera*, *Eucalyptus camaldulensis* and *A. tortilis* are more tolerant to salinity than *A. seyal* Var. *Seyal*. Therefore, these species are recommended for afforestation and reforestation of soil in arid and semi arid regions when irrigation water of moderate or low salinity is used. *Acacia seyal* var. *Seyal* is sensitive to irrigation with saline water even at low salt concentration.

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# Response of Wheat to Nitrogen Fertilizer at Reclaimed High Terrace Salt-Affected Soils in Northern State, Sudan

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## Abstract

A field trial was carried out at the Dongola Research Station Farm (Dongola, Sudan) for three consecutive seasons (2004-05 to 2006-07), to study the influence of nitrogen (N) fertilizer application on the growth and yield of wheat crop on reclaimed high terrace soils (Aridisols). Two wheat varieties were used: Wadielneel and Debeira. The experiment consisted of four N levels: 0, 43 (half of recommended dose for wheat), 86 (recommended), and 129 (1.5 times of recommended) kg N/ha. The N fertilizer source was urea. Phosphores in the form of triple superphosphate was applied to all treatments at sowing at a rate of 43 kg P<sub>2</sub>O<sub>5</sub>/ha. Straw and grain yields significantly increased with the increase in dose of N fertilizer in both varieties. Variety Debeira gave higher grain yield than Wadielneel, at the same N level. Application of 86 kg N/ha and 129 kg N/ha resulted in grain yield of 3.87 and 4.82 t/ha respectively for Debeira, and 3.64 and 4.03 t/ha respectively for Wadielneel.

## Introduction

Salinity is a major environmental stress, and severely affects crop productivity (Epstein et al. 1980), especially in arid and semi-arid regions (Speer et al. 1994). In certain situations, it is very difficult and expensive to reclaim salt-affected soils for improvement in crop production. Wheat is a major food crop in most of the countries where salinity is a threat, and is moderately tolerant to salinity (Qureshi and Barrett-Lenard 1998).

Optimal rates of fertilizer application to salt-affected soils partially alleviate the adverse effects of salinity on photosynthesis and photosynthesis-related parameters, and yield and yield components, by mitigating the nutrient demands of salt-stressed plants (Papadopoulos and Rendig 1983, Sultana et al. 2001). The proper use of Nitrogen (N) fertilizer in soils is important, but particularly so in saline soils where N may minimize the adverse effects of salinity

on plant growth and yield (Shen et al. 1994; Soliman et al. 1994, Albassam 2002, Flores et al. 2001; Abdelgadir et al. 2005) depending on plant species, salinity level, and environmental conditions (Grattan and Grieve 1999). Soil salinity is an important constraint to wheat production in the high terrace soils of northern Sudan. High terraced soils consist of a number of soil series with a range of limitations for sustainable agriculture. The main limiting factors are very poor soil fertility, sodicity, salinity and some physical limitations. High terrace soils generally have low N content. Although the importance of N fertilization in increasing wheat production has been well documented, it is difficult to determine the quantities to apply under reclaimed saline conditions. This is due to lack of information on N uptake and its distribution among plant parts under these conditions. The objective of this study was to study the influence of N fertilizer application on wheat yield in reclaimed high terrace soils of Northern State in Sudan.

## Materials and Methods

The experiment was carried out on a high terrace soil (Aridisols) at Dongola Research Station Farm, Dongola, Sudan (19°N, 30°E) during 2004-05, 2005-06 and 2006-07 cropping seasons. Although the research farm soils were salt affected and no soil reclamation program was undertaken, continued use of the farm fields for experimentation has resulted in improved crop performance and decrease in salinity levels over time. Currently, these farm soils are considered as reclaimed or partly reclaimed high terrace soils.

The experiment was conducted on these soils. Sirelkhathim (2001) reported that the initial average EC was 7.5 dS/m for the upper depth (30 cm) and 8.5 dS/m for the lower two depths (30-60 and 60-90 cm). Mean SAR values were 14.2, 14.7 and 15.4 for the three depths respectively. Some selected physio-chemical characteristics of the reclaimed soil are represented in Table 1.

Table 1. Some physio-chemical properties of the soil in the Dongola research station farm.

Parameter	Depth (cm)		
	0-25	25-50	50-75
pH(paste)	7.85	7.83	7.93
EC(dS/m)	1.06	1.34	1.98
CaCO <sub>3</sub> %	3.90	3.29	3.18
Na(meq/l)	8.3	9.7	13.6
Ca + Mg (meq/l)	14.2	15.7	17.5
SAR	3.1	3.9	5.0
ESP(%)	3	4	6
Sand (%)	26	30	36
Silt (%)	20	21	16
Clay (%)	54	49	48

The experiment consisted of 4 N levels: 0, 43 (half of recommended dose for wheat), 86 (recommended), and 129 (1.5 times of recommended) kg N/ha. The N fertilizer source was urea. Triple superphosphate at a rate of 43 kg P<sub>2</sub>O<sub>5</sub>/ha was applied to all treatments at sowing. Nitrogen fertilizer was applied in two equal doses with the first dose applied with second irrigation and the second with the fourth irrigation. Two wheat varieties were used, Wadielneel and Debeira. The experiment was replicated four times in a split-plot design with main plots allotted to N treatments and subplots to varieties. The plot size was 4x7 m with a net harvested area of 3x6 m. Sowing was done in late November with a seed rate of 125 kg/ha. Data were recorded for grain yield, biomass, 1000-seed weight, number of head/m<sup>2</sup> and plant height. Data was analyzed using MSTAT statistical package. Combined analysis of variance was carried out for all the data.

## Results and Discussion

### Crop growth and yield

Plant height for both varieties significantly increased with increasing application of N fertilizer; this effect was consistent for the three seasons. These results are supported by the findings of Saleem (1987) and Khan et al. (2000) who reported that increasing the level of N increased plant height. However, no significant differences were found among N treatments in terms of plant height. Similarly there were no statistical differences between both varieties for crop response to N application. Plant height was highest under 129 kg N/ha. There were no significant differences among N treatments and between wheat varieties in 1000-seed weight.

Nitrogen application resulted in significant increase in biomass yield for both varieties with the increasing application rates (from 0 to 43, 86 and 129 kg N/ha) in all seasons (Table 2). However, the effect of N application on yield was significantly different for the two varieties. Variety Debeira gave higher biomass yield than Wadielneel. Nitrogen application at 86 kg/ha and 129 kg/ha resulted in average biomass yield of 7.46 and 8.23 t/ha, respectively for Debeira and 5.94 and 6.97 t/ha for Wadielneel. These interactions clearly show the differential response of plants to N fertilizer under reclaimed high terrace soils. Latiri-Souki et al. (1998) reported that irrigation and N fertilizer application increased dry matter production and grain yield. They suggested that the increase might be due to increased leaf area index (LAI), green spikes area and an increase in green period of the leaves, which result in increased capture of radiation energy and consequently more dry matter production. Spiertz and Hole (1984) attributed increase in grain yield from N application to an increase in the number of kernels per unit area.

The response of wheat grain yield to different levels of N fertilizer during the three seasons is presented in Table 3. Variety Debeira produced higher grain yield than Wadielneel at the same N level. Grain yield progressively

increased as rate of N was increased from the control (no N application) to 129 kg/ha. Grain yields were significantly higher in the 129 kg N/ha treatment than other treatments for both varieties. Application of 86 and 129 kg N/ha resulted in grain yield of 3.87 and 4.82 t/ha, respectively, for Debeira and 3.64 and 4.03 t/ha, respectively, for Wadielneel.

Table 2. Effect of nitrogen fertilizer application to a reclaimed salt-affected terrace soil on biomass yield (t/ha) of wheat, average of three cropping seasons.

	Nitrogen level (kg/ha)				Wv main effect
	0	43	86	129	
<b>2004-05</b>					
Debeira	4.16	6.01	8.08	8.36	6.65
Wadielneel	2.17	3.89	4.57	5.83	4.12
N main effect	3.17	4.95	6.33	7.10	5.38
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.41 ,		Wv = 0.31,		NxWv = 0.63,
	CV = 23.3%				
<b>2005-06</b>					
Debeira	2.07	3.37	5.71	7.04	4.55
Wadielneel	1.63	4.34	5.59	6.44	4.50
N main effect	1.85	3.86	5.65	6.74	4.52
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.47 ,		Wv = 0.16,		NxWv = 0.33,
	CV = 13.7%				
<b>2006-07</b>					
Debeira	4.33	6.38	8.59	9.28	7.15
Wadielneel	4.07	6.17	7.65	8.63	6.63
N main effect	4.20	6.28	8.12	8.96	6.89
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.31 ,		Wv = 0.19,		NxWv = 0.39 ,
	CV = 11.4%				
<b>Combined (2004-05 to 2006-07)</b>					
Debeira	3.52c	5.92ab	7.46a	8.23a	6.28
Wadielneel	2.62c	4.80bc	5.94ab	6.97ab	5.08
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.23 ,		Wv = 0.13,		NxWv = 0.27 ,
	CV = 16.5%				

N = Nitrogen, Wv = Wheat varieties, N.S. = non significant at probability level  
\*\*\* = significant at P < 0.001, 0.01 and 0.05 respectively

Different letters in a column under combined effects of three years indicate significant difference at p=5%

Table 3. Effect of nitrogen fertilizer application to a reclaimed salt-affected terrace soil on grain yield (t/ha) of wheat, average of three cropping seasons.

	Nitrogen level (kg/ha)				Wv main effect
	0	43	86	129	
<b>2004-05</b>					
Debeira	1.43	2.65	3.14	4.64	2.97
Wadielneel	1.39	2.47	3.42	2.92	2.55
N main effect	1.41	2.56	3.28	3.78	2.76
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.23 , Wv = 0.25, NxWv = 0.51, CV = 36.4%				
<b>2005-06</b>					
Debeira	0.85	3.13	3.60	4.57	3.04
Wadielneel	0.29	2.72	3.27	4.30	2.65
N main effect	0.57	2.93	3.44	4.44	2.84
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.31 , Wv = 0.14, NxWv = 0.28, CV = 19.5%				
<b>2006-07</b>					
Debeira	1.69	3.76	4.87	5.26	3.90
Wadielneel	2.15	3.45	4.25	4.88	3.68
N main effect	1.92	3.61	4.56	5.07	3.79
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.31 , Wv = 0.18, NxWv = 0.19 , CV = 10.4%				
<b>Combined (2004-05 to 2006-07)</b>					
Debeira	1.32c	3.18b	3.87ab	4.82a	3.30
Wadielneel	1.28c	2.88b	3.64ab	4.03ab	2.96
Significance:	N ***	Wv ***	N x Wv: NS		
	N = 0.16 , Wv = 0.10, NxWv = 0.21 , CV = 22.3 %				

N=Nitrogen, Wv =Wheat varieties, N.S. = non significant at probability level.

\*\*\* = significant at P < 0.001, 0.01 and 0.05 respectively.

Different letters in a column under combined effects of three years indicate significant difference at p=5%.

### Economics of applied treatments

Partial budget analysis revealed the profitability of using 129 kg N/ha compared with 86 kg N/ha as shown by the marginal rates of return (MRR) for both varieties: (510% for Debeira and and 146% for Wadielneel. MRR was greater for Debeira due to the higher increase in productivity, leading to increased yield difference between 129 and 86 kg N/ha for variety Debeira.

Sensitivity analysis was conducted to examine the effect of changes in production costs and crop prices (crop price at farmgate, calculated as

Table 4. Partial budget analysis of using 86 and 129 kg N/ ha for wheat production in the reclaimed high terrace soils of Northern State, Sudan.

Total costs that vary (SDG/ha)	Wadielneel			Debeira		
	86 kg/ha	129 kg/ha	Difference	86 kg/ha	129 kg/ha	Difference
Cost of urea	193	290	97	193	290	97
Transportation to farm	10	14	4	10	14	4
Labor cost (application)	31	42	17	31	42	17
Total cost that vary (SDG/ha)	234	352	118	234	352	118
<b>Benefits (SDG/ha)</b>						
Average grain yield (t/ha)	3.87	4.82	0.95	3.64	4.03	0.39
Adjusted grain yield (t/ha) <sup>1</sup>	2.90	3.62	0.72	2.73	3.02	0.29
Field price (SDG/ha) <sup>2</sup>	1000	1000	1000	1000	1000	1000
Gross benefits (SDG/ha)	2900	3620	720	2730	3020	290
<b>Net benefits (SDG / ha)</b>	<b>2666</b>	<b>3268</b>	<b>602</b>	<b>2496</b>	<b>2668</b>	<b>172</b>
<b>MRR (%)</b>		<b>510</b>			<b>146</b>	

<sup>1</sup> Yield adjustment to 75% of total yield per ha of experiment results.

<sup>2</sup> Field price of wheat is calculated as the market price less harvesting, transportation and storage cost.

SDG = Sudanese pound.

market price less harvest and transportation costs). Total cost of production was increased by 25%, (table 4) and field prices reduced by 25%. The results indicated stability of both varieties with regard to input and output price fluctuations. The MRR changed to 266 and 47% for Debeira and Wadielneel, respectively. Wadielneel was found to be more susceptible to price changes, while Debeira showed high stability.

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# Effects of Induced Salinity on Four *Vicia faba* Cultivars Differing in their Broomrape Tolerance

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## Abstract

The effects of salinity on growth response, root characteristics and leaf ion accumulation were investigated in four faba bean (*Vicia faba* L.) cultivars: Giza 429, Giza 843 and Misr 1 (*Orobanche* tolerant) and Giza 3 (*Orobanche* susceptible). The plants were grown in a pot experiment for 11 weeks, supplied with a nutrient solution and exposed to different salinity levels (0, 50, and 100 mM NaCl) for 9 weeks. Salinity significantly decreased  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$  and  $\text{SO}_4^{2-}$  and significantly increased  $\text{Na}^+$ ,  $\text{Cl}^-$ , pH, and EC over the control treatment. Similarly, Sodium Adsorption Ratio (SAR) increased gradually with increasing concentration of NaCl in irrigation water. The total dry matter, root length density, root mass density and root dry weight were significantly reduced with the increase in salinity in the growth medium from 50 to 100 mM NaCl. Leaf N, P,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  contents decreased, while  $\text{Na}^+$  and  $\text{Cl}^-$  increased with increasing salinity levels. The  $\text{K}^+/\text{Na}^+$  and  $\text{Ca}^{2+}/\text{Na}^+$  ratios in faba bean leaves gradually decreased with increasing salinity levels, and reached their lowest values at the highest level of salinity. These results represent supportive evidence on the positive relationship between *Orobanche* tolerance and salt tolerance in the three cultivars.

**Key words:** Faba bean, ion accumulation, *Orobanche*, root characteristics, salinity.

## Introduction

Faba bean (*Vicia faba* L.) is the most important legume food crop in Egypt. Unfortunately, faba bean is one of the major hosts of *Orobanche crenata* Forsk., which is an obligate parasite lacking chlorophyll, so it depends on its host for water, metabolites and inorganic nutrients. Therefore, infestation of *Orobanche* severely affects faba bean productivity; in severe cases, the reduction in faba bean yield may reach 100% (Abdelhamid 1996, Abdelhamid et al. 2005). Therefore, improving faba bean yield in Egypt depends

to a great extent on the selection of *Orobanche* tolerant Egyptian cultivars such as Giza 429, Giza 843 and Misr 1.

Faba bean is often grown on saline soils in Egypt, yet few studies have been published on its response to salinity. But susceptibility of faba bean to salinity (Sharma 1995) restricts or even prevents its cultivation in newly reclaimed areas where saline water or even diluted seawater are the only source of irrigation available.

Breeding for salt tolerance in crops has usually been limited by the lack of reliable traits for selection (Noble and Rogers 1992). It is necessary to determine differences in resistance mechanisms between genotypes and to incorporate characters that improve tolerance into reasonably high-yielding backgrounds. Differences in the salt tolerance of faba bean genotypes were observed by Gaballah and Gomaa (2005). So far, there are no Egyptian faba bean cultivars released as salinity tolerant and recommended for cultivation in salt-affected soils where salinity is the primary constraint to crop production.

Faba bean has a shallow rooting system and is considered to be drought sensitive. Restricted root penetration and subsequent limited access to stored soil moisture may be one reason for the poor adaptation to sandy soils. The aim of this study was to evaluate the salt tolerance of three Egyptian faba bean cultivars (*Orobanche* tolerant) compared to an *Orobanche* susceptible cultivar, and their responses to salinity stress with regard to growth, root and shoot characteristics, and ionic distribution.

### Materials and Methods

This study was conducted at the wire house of the National Research Centre, Cairo, Egypt (30° N, 31° E) from 19 November 2007 to 4 February 2008. Plants were grown in pots constructed from 12-cm diameter and 30-cm long sections of PVC filled with 1.7 kg clay soil. To reduce compaction and improve drainage, the soil was mixed with sand in a proportion of 3:1 (v:v). Soil water content was maintained at about 65% of field capacity, and checked by weighing. Water losses were supplemented twice daily (morning and afternoon).

Four faba bean cultivars were used in this experiment: Giza 3 (G3), a susceptible cultivar for *Orobanche crenata* infestation, and Giza 429 (G429), Giza 843 (G843) and Misr 1 (M1), all tolerant to *Orobanche* infestation. Four uniform seeds of each cultivar were sown in each pot at 30-mm depth under three levels of salinity. A factorial experiment was laid out in randomized block design with four replicates. At sowing, a commercial rhizobium was incorporated into the top 30-mm of the soil in each pot with the seeds. Two weeks after sowing, the seedlings were thinned to one seedling per pot. Irrigation water with three levels of salinity (0, 50 and 100 mM NaCl) was

applied two weeks after sowing (WAS). The treatments were maintained for nine weeks. After this, the plants were harvested by cutting the top part at the soil surface to measure above and below ground biomass. The plant material was separated into leaves, stems, pods and roots. Plant material, except roots, was dried in a fan forced oven at 70 °C for 72 h and weighed. Root length was calculated using the formula of Tennant (1975). The concentrations of N, P, K<sup>+</sup>, Ca<sup>2+</sup>, Na<sup>+</sup>, Mg<sup>2+</sup> and Cl<sup>-</sup> were measured in oven dried leaves (70°C for 72 h).

The data were subjected to the analysis of variance (ANOVA) appropriate to the randomized complete block design. Differences between treatments were compared with the critical difference at 5% probability by the Duncan's Multiple Range Test.

## Results and Discussion

### Soil properties after harvesting

Irrigation with saline water (NaCl at 50 or 100 mM) significantly reduced Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, HCO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> and significantly increased Na<sup>+</sup>, Cl<sup>-</sup>, pH, and EC in the post-harvest soil samples compared with the control, where distilled water was used for irrigation (Table 1). Carbonate was not detected in soil solution after harvesting. In this study, both salinity levels caused an increase in the Na<sub>s</sub> concentration in soil and thus increased soil SAR (Table 1). Elevated concentrations of sodium ions create a plant growth hazard which

Table 1. Some soil properties, 11 weeks after sowing and after irrigating with saline water for 9 weeks

Treatment	pH	EC	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	SAR
			meq/l						meq/l	
0 mM	7.31c	1.71c	6.09a	2.50a	6.88c	1.50a	4.0a	6.00c	6.97a	3.32c
50 mM	7.51b	4.2b	3.50b	2.20b	37.30b	0.80b	3.0b	37.80b	3.00b	22.09b
100 mM	7.71a	5.1a	3.00c	1.00c	46.50a	0.57c	1.7c	47.87a	1.50c	32.88a

Means within a column followed by the same letters are not significantly different according to Duncan's test ( $p < 0.05$ )

is measured by one of two methods. The more common method, the Sodium Adsorption Ratio (SAR) (Sumner 1993), is the proportion of sodium (Na<sup>+</sup>) ions compared to the concentration of calcium (Ca<sup>2+</sup>) plus magnesium (Mg<sup>2+</sup>). Another hazard that excess Na<sup>+</sup> presents in natural soils is the danger of loss of soil structure with the resulting reduction in soil permeability and aeration. SAR increased gradually with increasing concentration of NaCl in irrigation water (Table 1).

Poor quality of irrigation water may result in an increase in soil salinity. Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth (Table 2). Excess salts in the root zone hinder

plant roots from withdrawing water from the surrounding soil. This reduces the amount of water available to the plant, regardless of the amount of water actually in the root zone (Sumner 1993).

Consequently, faba bean plants subjected to such soil conditions took up high amounts of  $\text{Na}^+$ , whereas the uptake of  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  was considerably reduced (Table 3). This finding is in line with Cramer et al (1991) who found that low  $\text{Ca}^{2+}/\text{Na}^+$  ratio in a saline medium plays a significant role in growth inhibition, in addition to causing significant changes in morphology and anatomy of plants.

### Root and shoot characteristics

Table 2 shows data on root length density (RLD), root mass density (RMD), root mass to root length (RM/RL), root dry weight per plant (RDW), shoot dry weight per plant (shoot DW), root to shoot ratio, total plant dry weight (TDW) and root dry weight to total dry weight (RDW/TDW). All these parameters were significantly reduced due to salinity at both 50 and 100 mM, compared with the control. The total root length of G3, G426, G843 and M1 was 21.88, 25.18, 26.33 and 28.40 m per plant, respectively. G3 had significantly less RLD, RMD, RDW, and RDW/TDW compared with other cultivars. There were no significant differences among G429, G843 and M1 in any of the traits measured. Faba beans are usually shallow rooting and have a reputation as drought sensitive plants. El-Shazly (1993) reported significant differences between 12 faba bean genotypes in total root length on the intact root system in pot and field experiments.

Table 2. Effects of salt stress and faba bean cultivars on root length density (RLD), root mass density (RMD), root mass to root length (RM/RL), root dry weight per plant (RDW), shoot dry weight per plant (shoot DW), root to shoot ratio, total plant dry weight (TDW) and root dry weight to total dry weight (RDW/ TDW) of faba bean plants, 11 weeks after sowing.

Treatment	RLD ( $\text{cm}/\text{cm}^3$ )	RMD ( $\text{mg}/\text{cm}^3$ )	RM/RL ( $\text{mg}/\text{cm}$ )	Root DW (g)	Shoot DW (g)	Root/ Shoot ratio	TDW /plant (g)	RDW /TDW
<b>Salinity</b>								
0 mM	1.12a	0.49a	0.45a	1.40a	5.80a	24.4a	7.20a	0.20a
50 mM	0.94b	0.36b	0.39b	1.03b	4.78b	21.7b	5.81b	0.18b
100 mM	0.64c	0.20c	0.32c	0.56c	3.51c	15.9c	4.07c	0.14c
<b>Cultivar</b>								
G3	0.77b	0.26b	0.33b	0.75b	4.79a	15.5b	5.53b	0.13b
G429	0.89ab	0.37a	0.40a	1.04a	4.63ab	21.9a	5.67b	0.18a
G843	0.93a	0.39a	0.40a	1.10a	4.46b	23.3a	5.57b	0.19a
M1	1.00a	0.39a	0.40a	1.10a	4.90a	22.0a	6.01a	0.18a

Means within a column followed by the same letters are not significantly different according to Duncan's test ( $p < 0.05$ )

### Ion accumulation in leaves

Ion content (N, P, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup>) in the faba bean leaves significantly reduced at higher salinity levels, reaching their lowest values at the highest level of salinity (Table 3). The reverse was true with Na<sup>+</sup> and Cl<sup>-</sup>, where ion concentration showed positive correlation with increasing salinity level. The K<sup>+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> ratios gradually decreased with increasing salinity to reach their lowest values at the highest level of salinity. The most interesting finding is that leaves of G429, G843 and M1 showed higher N, P, K<sup>+</sup>, and Ca<sup>2+</sup> concentrations, accumulated the lowest quantity of Na<sup>+</sup> and Cl<sup>-</sup> and had the highest K<sup>+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> ratios at the highest level of salinity compared with G3. Positive correlation was found between K<sup>+</sup>/Na<sup>+</sup> and total dry weight per plant ( $r = 0.93^{**}$ ).

It has been reported that salinity adversely affects the growth of several legume species, including faba bean (Cordovilla et al. 1996). The decreased N and P concentrations in plants under salt stress are attributed to increased Cl<sup>-</sup> uptake (Garg et al. 1990), Na<sup>+</sup> exclusion (Garcia et al. 1995), K<sup>+</sup>/Na<sup>+</sup> discrimination (Houshmand et al. 2005), and Cl<sup>-</sup> exclusion (Noble and Rogers 1992). These traits have proven valuable in screening germplasm for salinity tolerance. Experimentation with wheat indicated that salt tolerance was associated with enhanced K<sup>+</sup>/Na<sup>+</sup> discrimination trait (Gorham et al. 1997). In soybean, Läuchli and Wieneke (1979) found that the salt tolerant *cv. Lee* accumulated more K<sup>+</sup> in its leaves than did the salt sensitive *cv. Jackson*. Our results show that the Orobanche-tolerant cultivars had higher amounts of N, P, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, higher K<sup>+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> ratios, and lower amounts of Na<sup>+</sup> and Cl<sup>-</sup> (Table 3).

Table 3. Effects of salt stress and cultivars on nitrogen (N), phosphorus(P), potassium(K<sup>+</sup>), sodium (Na<sup>+</sup>), chloride (Cl<sup>-</sup>), calcium (Ca<sup>2+</sup>),magnesium (Mg<sup>2+</sup>), and K<sup>+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> ratios of leaves of faba bean plants at 11 weeks after sowing.

Treatment	N	P	K <sup>+</sup>	Na <sup>+</sup>	Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup> /Na <sup>+</sup>	Ca <sup>2+</sup> /Na <sup>+</sup>
	(%)							ratio	
<b>Salinity</b>									
0 mM	2.80a	0.33a	2.70a	1.31c	0.043c	0.99a	1.32a	2.06a	0.75a
50 mM	2.66b	0.31b	2.56b	2.05b	0.088b	0.84b	1.14b	1.25b	0.41b
100 mM	2.58c	0.26c	2.01c	2.73a	0.129a	0.66c	0.95c	0.74c	0.24c
<b>Cultivar</b>									
G3	2.40c	0.24c	2.10c	2.23a	0.098a	0.72c	1.14c	0.98b	0.32c
G429	2.66b	0.34a	2.41b	2.12b	0.088b	0.80b	1.28a	1.26a	0.38b
G843	2.99a	0.35a	2.69a	1.89c	0.079c	0.91a	1.21b	1.25a	0.48a
M1	2.67b	0.26b	2.48b	1.92c	0.083c	0.90a	0.92d	1.28a	0.47a

Means within a column followed by the same letters are not significantly different according to Duncan's test ( $p < 0.05$ )

## Conclusions

These results represent supportive evidence on the positive relationship between *Orobanche* tolerance and salt tolerance in the three cultivars (G429, G843 and M1). This adaptation is mainly due to the high degree of physiological tolerance in these cultivars through the accumulation of larger quantities of inorganic osmotic N, P, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and lower quantities of Na<sup>+</sup> and Cl<sup>-</sup>, as well as higher K<sup>+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> ratios. These results suggest that the three cultivars could tolerate irrigation with NaCl solutions up to 100 mM and can be used to develop new salt tolerant faba bean varieties.

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# Geochemistry of Salt-Affected Wasteland Resulting from Long-Term Wastewater Irrigation

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## Abstract

Long-term irrigation with partly treated urban wastewater can result in soil quality deterioration. We carried out a field study in a wastewater irrigated area around Aleppo, Syria, where farmers have abandoned cultivation because of poor crop germination and growth. It was expected that this situation was caused mainly by high level of salts accumulated in the soil over time. There were 12 sampling sites extending from the eastern side of the wastewater channel to a distance of 270 m. Four soil samples were collected from each site at depths of 0-10, 10-20, 20-50 and 50-80 cm. The samples were analyzed for texture, calcium ( $\text{Ca}^{+2}$ ), magnesium ( $\text{Mg}^{+2}$ ), sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), bicarbonate ( $\text{HCO}_3^-$ ), chloride ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4^{-2}$ ), calcium carbonate ( $\text{CaCO}_3$ ), pH, and electrical conductivity (EC). Sodium adsorption ratio (SAR) was calculated from the values of Na, Ca, and Mg to evaluate the severity of the sodicity problem in the soil. Texturally, the soil was classified as clayey soil, and silty clay loam at depth, but silty loam in the surface layer. There was a strong correlation between SAR and EC values, with  $R^2 = 0.84$ . The relation between EC with Na and Cl ( $R^2 = 0.98$  and  $0.97$  respectively) indicate sodium chloride as the main salt component in the soil of the area. The soil was classified as severe to high salinity except at three sampling stations which were classified as mild to low salinity. These three stations were away from the wastewater source, and salinity was possibly moderated because of the effect of the dispersed tillage soil, and the washing of salts by irrigation. Salinity decreased suddenly with depth at all sampling stations. The increase in salinity and sodicity was due to accumulation of wastewater salts in the top soil, especially in the non tillage area, affecting crop growth and leading to crop failure.

**Keywords:** Qweik river, EC, SAR, soil, salinity, wastewater

## Introduction

In addition to water scarcity, water quality deterioration is expected to intensify in the Middle East and North Africa (MENA) region, due to human activity and the increasing possibility of extreme events as a result of climate change (Bahri 2008). Households and industries generate increasing volumes of wastewater as more people move to urban areas. In order to narrow the gap between freshwater demand and supply, these countries will have to increasingly rely on use of wastewater for crop production (Kfoury et al. 2009). A large number of small-scale farmers already irrigate with wastewater, often because they have no alternative.

Wastewater generated by municipal and industrial activities contains a variety of constituents at levels higher than those usually found in freshwater, such as salts, metals, metalloids, residual drugs, organic compounds, endocrine disrupter compounds, active residues of personal care products, and/or pathogens. Irrigation with untreated, partly treated, and/or diluted wastewater creates multidimensional impacts, including environmental and health risks. Most farmers and some government agencies in many developing countries are not fully aware of these impacts – but the consequences could be severe, unless wastewater irrigation is carefully managed

Wastewater irrigation is commonly practiced in urban and peri-urban parts of Syria. In the case of Aleppo, 2.5 million inhabitants of the city generate wastewater that goes to a central wastewater treatment plant (functional, but receives more wastewater than its capacity). After treatment, the wastewater is transported to the Qweik River, a small river that used to receive freshwater from Turkey in the 1970s and 1980s, but later became almost dry because of water extraction in the Turkish part. The river gets treated wastewater from the treatment plant, carries it through 45 km and ends in a small lake. On the way to the lake, there are several small settlements and industries that add their wastewater to the river without treatment. Therefore, the treated wastewater again becomes untreated/partly treated along the river. The farmers along the river pump wastewater to irrigate a range of crops. This typical case represents several similar situations in developing countries of the dry areas.

The farmers in the urban and peri-urban areas of Aleppo used wastewater because (i) it is a reliable or often the only water source available for irrigation throughout the year, (ii) wastewater irrigation eliminates or reduces the need for application of fertilizer and organic matter because of nutrients it contains, (iii) energy cost savings when pumping wastewater, compared to pumping deep groundwater, (iv) wastewater generates greater income from cultivation and marketing of high-value crops because of higher cropping intensity.

Despite these benefits, there are problems with salinity and sodicity build up in wastewater-irrigated soils over time. This has resulted in substantial

decrease in crop yields at some locations. We carried out a field study to determine the contribution of salts and sodium in wastewater-irrigated soils, which has gone out of cultivation over time.

### Materials and Methods

The soil in the study area is considered as a Terra Rossa, which is common in the Mediterranean region (Foster et al. 2004). The study location was between Universal Transverse Mercator UTM coordinates 322778.8, 3983981-323030.4, 3983978 at the midstream of Qweik River. There were 12 sampling sites extending from the eastern side of the river to a distance of 270 m. The distance between the first 6 sites was 15 m, which was increased to 30 m in the remaining 6 sites (Fig. 1). The soil samples were collected from each site at depths of 0-10, 10-20, 20-50 and 50-80 cm. Thus, there were a total of 48 samples.

Soil samples were air dried and prepared for texture analyses. The determination of pH of the saturated soil paste and electrical conductivity (EC) of saturated paste extract was undertaken by pH and EC meters.

The concentrations of sodium (Na) and K were determined by flame photometer, while the concentrations of Ca and Mg were determined by titration with EDTA. The value of SAR calculated by the equation  $SAR = Na+ / [(Ca^{2++}Mg^{2+})/2]^{0.5}$ , The concentrations of Cl were determined by titration with AgNO<sub>3</sub> while the concentrations of CO<sub>3</sub> and HCO<sub>3</sub> were determined by titration with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). Calcium carbonate (CaCO<sub>3</sub>) equivalent was determined by titration with HCl. Sulfate (SO<sub>4</sub>) concentration was determined by precipitation method with barium chloride. Total organic matter (OM) was determined by using wet oxidation method with K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>.

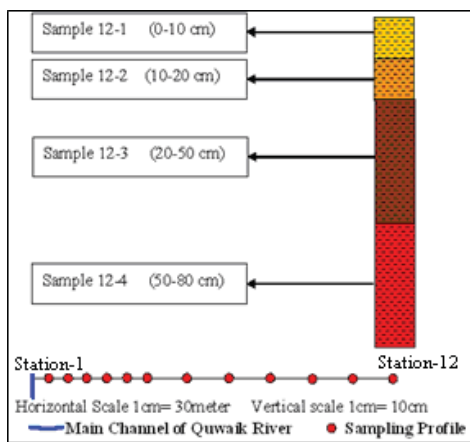


Figure 1. Sketch of the stations of soil profiles and representative samples of each profile.

Soil samples were air dried and prepared for texture analyses. The determination of pH of the saturated soil paste and electrical conductivity (EC) of saturated paste extract was undertaken by pH and EC meters.

## Results and Discussion

Texturally, the clay fraction forming the main component of the samples increased with depth (maximum 77%), while the silt and sand decreased with depth. The percentage of clay, silt and sand is stable at the last three stations as a result of tillage condition. By plotting the data on a soil texture triangle, all the samples at the deeper soil layers (20-80 cm) and the samples of tillage area were classified as clay, while the surface soil samples were classified as silt, silt loam, and silty clay (Fig. 2).

Salinity levels of soil can be tested using electrical conductivity (EC). The EC value of the topsoil is higher than that of the subsoil due to the rise of groundwater by capillary action to the top soil (especially in the dry season) and the evaporation of water, leading to the accumulation of salt in top soils. The studied area is located very close to the channel of the Qweik River as shown in Figure 1. The two sampling stations nearest the river were probably affected by the channel water which may causes a washing of the salts at the topsoil. The high EC indicates the high concentration of salts in other sampling stations, which has caused the area to become barren (Fig. 3).

At three stations furthest from the river, EC values showed low concentration of salts, probably due to seasonal tillage and washing of top soil by irrigation water. Based on EC values and the classification of Shirokova et al. (2000) the soil in the study area was classified as severe to high salinity except at the last three stations, which were classified as mild to low salinity.

The correlation coefficient and degree of determination between EC and concentrations of cations and anions indicate very high relation between EC with Na and Cl with coefficient of determination  $R^2= 0.975876$  and  $0.967784$  respectively. This indicates the major effect of the sodium chloride salt on EC (Figs. 4-5). The relation between EC and concentrations of other cations and anions was less important.

Seilsepour and Rashidi (2008) discussed the relation between SAR and EC. They suggest a linear regression model to predict SAR from EC value with high correlation coefficient.

Soil SAR indicates the likelihood of reduced soil permeability (water infiltration) and aeration, especially on heavy textured soils.  $SAR > 13$  is a suggested limit, beyond which there is a strong probability of reduced soil permeability and decreased plant survival and growth.

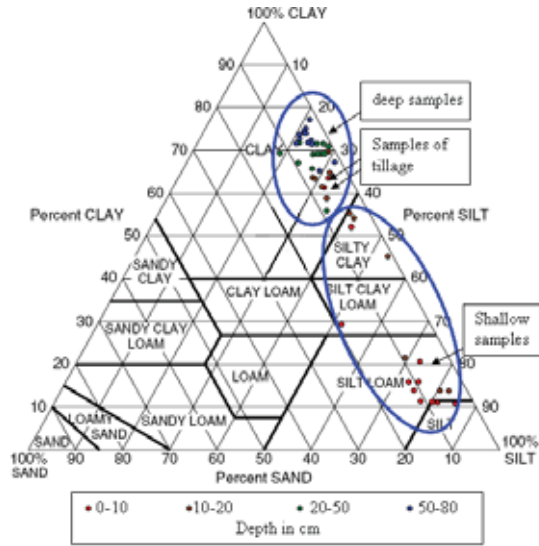


Figure 2. Classification of soil samples of selected horizons in the studied stations.

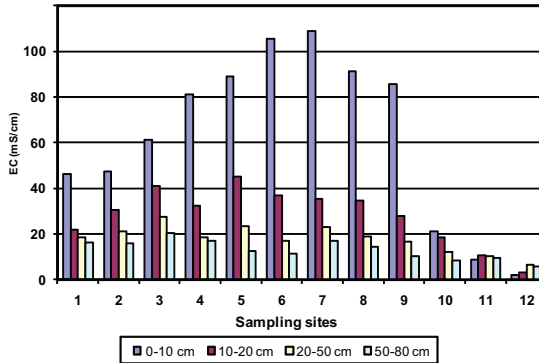


Figure 3. Horizontal and vertical variation of electrical conductivity EC in the soil of studied horizons.

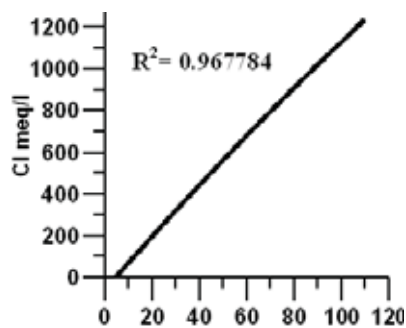
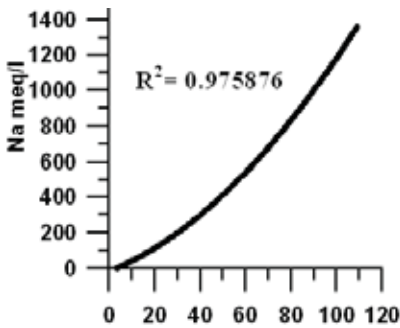


Figure 4. Relation between EC and Na. Figure 5. Relation between EC and Cl.

SAR in the study area was high in the middle of the studied traverse, suggesting an aggregate barren area. However, SAR values were lower than the suggested limits at stations close to the wastewater river channel and in the dispersed tillage area. SAR (as with EC values) decreased suddenly with depth (Fig. 6). There was a strong correlation between SAR and EC values, with  $R^2 = 0.84$ , and a linear relation  $SAR = 1.04592 * EC = 0.688364$ . This relationship can be used to calculate SAR from EC directly (Fig. 7).

Based on pH, the soil (which is of carbonate origin) is basic. High pH in the desertified area is likely due to the high concentration of salts.

Soil organic matter is the fraction of the soil that consists of plant or animal residues (Fenton et al. 2008). The total organic matter in surface soil (depth 0-10 cm) ranged between 1.7 and 8.19%. Organic matter decreased with the depth, ranging between 0.49 and 1.01% in the 50-80 cm layer. Also, organic matter was high near the river channel and declined away from the channel, probably due to the effect of the organic matter contained in the wastewater.

Calcium carbonate levels were high (25.4-37.2%), with a homogeneous horizontal and vertical distribution of  $CaCO_3$  content.

The concentration of Mg (5.1-314.6 meq/l) was higher than Ca (2.1-106.4 meq/l). This may be due to the high stability of Mg relative to Ca under leaching conditions. The wide range of these concentrations imply high variation in the soil properties with depth and with distance between sampling location and the source of wastewater. This could explain the high variation of Na (1.5-1429.0 meq/l), K (0.1-2.6 meq/l), Cl (20.2-1203.6 meq/l)

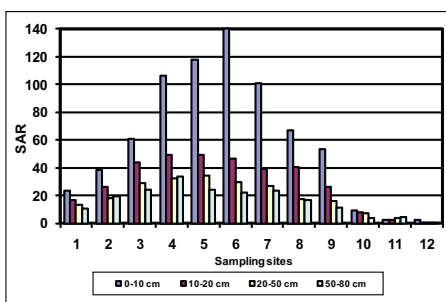


Figure 6. Horizontal and vertical of sodium adsorption ratio SAR in the soil of horizons.

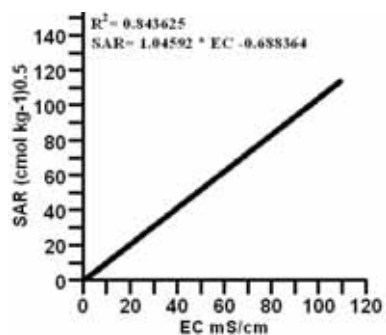


Figure 7. Relation and coefficient of determination between EC and SAR.

and  $\text{SO}_4$  (13.9-508.6 meq/l) which showing high concentration in the top soil except at stations 10, 11 and 12 which were characterized by soil dispersal by tillage and washing of soil by channel water. This agrees with EC and SAR results which indicate the high concentrations of salts in top soil (these cations and anions represent the main component of salt in the soil). The high concentrations of  $\text{HCO}_3$  (1.6-9 meq/l) in the two stations nearest the water channel may be due to the irrigation with wastewater with high organic matter content.

### Conclusions

The results show that clay content increased with depth with maximum content of 77%. The soil was classified as clayey soil and silty clay loam at depth, and as silty loam in the surface layers. EC values were higher in top soil than in subsoil. The soil of the area was classified as severe to high salinity except the three stations furthest from the water channel, which were classified as mild to low salinity. This explains why cultivation in the area has been abandoned. SAR values were high value in the middle of the studied traverse, indicative of aggregate barren area, but were lower at locations close to the wastewater river channel and in the dispersed tillage area. SAR and E values decreased suddenly with depth. There was a strong correlation between EC with SAR, and between EC with Na and Cl, indicating the major effect of sodium chloride salt on the EC. The high content of organic matter near the river channel may due to the organic matter contained in the wastewater. High concentration of  $\text{CaCO}_3$  (25.4-37.2%) may be because the soil was formed from carbonate rocks. Ca and Mg showed high concentration in the top soil. Mg levels were higher than Ca, due to higher stability of Mg under leaching conditions. It is necessary to carry out a study of heavy trace metals in soil, wastewater, and crops in the area to explain the effect of wastewater with time.

### Acknowledgements

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# Soil Salinity and Sodicity Levels in Wastewater Irrigated Soils in a Peri-Urban Area of Aleppo Region, Syria

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## Abstract

This study was part of an environmental impact assessment, focusing on the effect of wastewater irrigation on crop productivity using soil salinity and sodicity indicators around Aleppo, Syria. Water and soil samples were collected from upstream, midstream and downstream of the Qweik River, a carrier of wastewater from Aleppo city. Freshwater from the Euphrates River is also added to Qweik River to improve water quality. These samples were analyzed for different qualitative parameters. Qweik River water had high salinity but very low SAR levels. Soil EC and pH greatly varied from upstream to downstream. Soil salinity in the bottom layer (50-80 cm) and pH in the top layer (0-20 cm) gradually increased from upstream to downstream. This implies that freshwater from the Euphrates River into the Qweik River and precipitation assisted in leaching of salts from upper layer to lower layers. Soil EC and SAR were lower than the 'threshold' levels for saline and/or sodic soils (EC = 4 dS/m, SAR = < 13). Based on the EC and SAR levels in wastewater-irrigated soils, it can be inferred that the use of wastewater from Qweik River is not expected to pose salinity and sodicity problems for wheat production in the study area. However, further studies are needed to evaluate the implications of metal and metalloid concentrations in these soils.

**Key words:** Soil salinity, soil sodicity, irrigation, wastewater, Aleppo region, Syria.

## Introduction

In arid and semi-arid regions, irrigation is an important requirement for crop production. However, soil salinity and sodicity development can be major threats to sustainable crop productivity under irrigated agriculture without

proper water management (Hillel and Vlek 2005). In the Middle East and North Africa (MENA) region, 87% of the water withdrawn is used in crop production systems (FAO-AQUASTAT 2009). The increasing competition for good-quality water among different water-use sectors in the region has reduced allocation of freshwater for agriculture (Bahri 2008). The volume of wastewater produced by non-agriculture uses has increased with population, urbanization, improved living conditions, and economic development, and its use in agriculture has also increased, often because farmers have no alternative sources of reliable irrigation water (Qadir et al. 2007).

Considering the implications of wastewater use in agriculture, there is a need to undertake environmental impact assessment in areas where wastewater is used for irrigation. This paper examines the effects of wastewater irrigation on crop production using soil salinity and sodicity indicators in Aleppo region, Syria.

## Material and Methods

### Area description

The study area is located in the Euphrates-Aleppo Basin near Aleppo, the second largest city of Syria, with a population of 2.26 million. Until 2002, Aleppo city and its surroundings discharged untreated wastewater into a small river, called the Qweik River. The river ends in a lake about 40 km south of Aleppo. Treated wastewater is also delivered to the Qweik River from a wastewater treatment plant. Freshwater from the Euphrates River is also added to the Qweik River to further improve water quality. While the treated wastewater flows through the river, there are a number of villages along the Qweik River where several houses are not connected to the sewer system.

According to meteorological data (1999-2008), this area receives about 297 mm mean annual rainfall. The range of average air temperature is 5-13 °C in winter and 25-33 °C in summer. The seasonal rainfall pattern shows maximum rainfall in January (60.3 mm) and almost nothing from July to September. Class A pan evaporation values range from 37.2 mm in December to 471.6 mm in July.

### Study sites and sampling points

We divided the 40 km Qweik River into three major parts, upstream, mid-stream and downstream. In each part, there were six sampling sites to collect wastewater from the river; and six sites to collect soil samples where same wastewater was being used for irrigation.

Wastewater sampling was done on a monthly basis from January to August 2009, while soil samples were collected after the wheat harvest in July 2009.

Soil samples were collected by soil auger from 0-10, 10-20, 20-50 and 50-80 cm depths. Wastewater sampling was done at 40 cm depth with rapid and uniform currents in the river. At each field site, soil was collected from five sampling points and then mixed thoroughly. Samples were immediately transported to the laboratory for chemical analysis. Soil was air dried, gravel and plant residues were removed, ground and passed through a 2-mm stainless steel sieve. Sub-samples were used to determine physical and chemical properties.

### Analytical procedures

The EC and pH of water samples were determined using EC and pH meters. After filtration,  $\text{Na}^+$  and  $\text{K}^+$  concentrations were recorded through flame photometer, while  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  concentrations were determined through titration with EDTA solutions. This was followed by the determination of anions;  $\text{Cl}^-$  readings were taken by  $\text{AgNO}_3$  titration method,  $\text{SO}_4^{2-}$  concentration was measured by  $\text{BaCl}_2$  precipitation method, and  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  concentrations were recorded by titration to pH 4.3 and 8.5, respectively.

The saturation paste pH (pH<sub>s</sub>) and electrical conductivity of saturation paste extract ( $\text{EC}_e$ ) of soil were determined using EC and pH meters. The concentrations of soluble ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ ) were measured in the saturation extract by the same methods used for wastewater analysis. Sodium adsorption ratio (SAR) was calculated from the concentrations of soluble cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Na}^+$ . Soil particle-size distribution was measured by hydrometer method by using hydrogen peroxide and sodium hexametaphosphate as dispersing agents.

## Results and Discussion

### Wastewater characteristics

The characteristics of wastewater used for irrigation varied by season. The chemical composition of wastewater in the Qweik River indicated that  $\text{Na}^+$ ,  $\text{HCO}_3^-$  and  $\text{Cl}^-$  were the most abundant cation and anions, respectively. Electric conductivity and SAR values when compared with the standards of U.S. Salinity Laboratory (U.S. Salinity Lab. Stuff, 1954) showed that the river water had high EC but low SAR levels (Fig.1). In upstream, midstream and downstream, EC was 1.2, 1.2 and 1.3 dS/m respectively; SAR values were 3.7, 3.7 and 3.8 respectively; pH values were 7.6, 7.5 and 7.5, respectively. Low SAR values of the wastewater might be because the wastewater treatment plant in Aleppo does not use chlorine for water purification. Similarly there might be very little contamination of drainage from arable lands. Furthermore, water quality in the Qweik River improved after addition of fresh-water from the Euphrates River during the dry seasons of 2008 and 2009. At upstream, EC values decreased from 1.6 dS/m (March) to 1.1 dS/m (April), and SAR improved to 3.6 (April) from 5.1 (March).

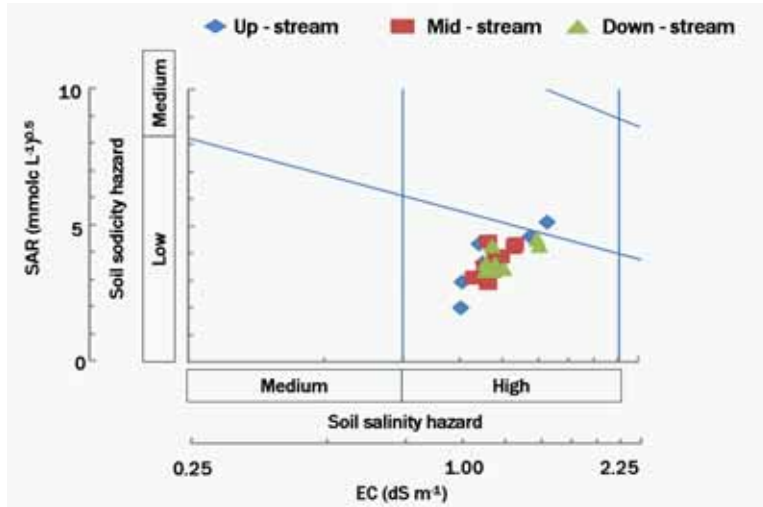


Figure 1. Electric conductivity and SAR of the Qweik River water from January to August 2009

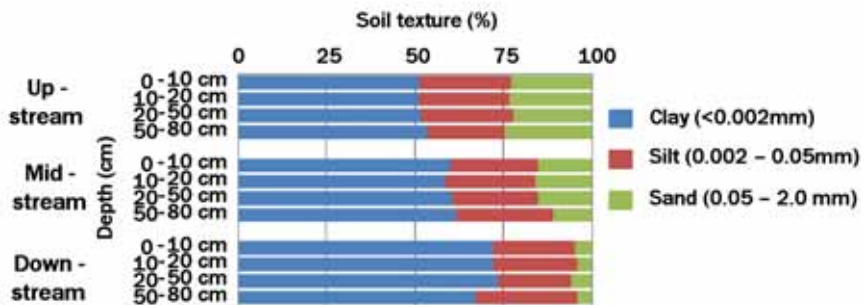


Figure 2. Soil texture at each stream under USDA classification

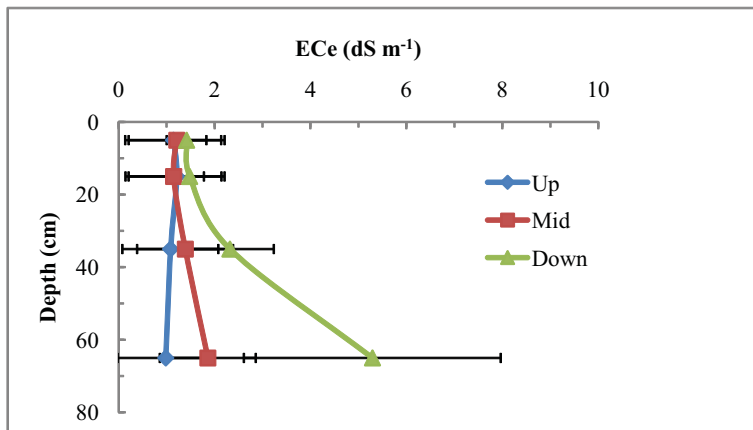


Figure 3a. Soil  $\text{EC}_e$  at each stream. Bars represent standard errors.

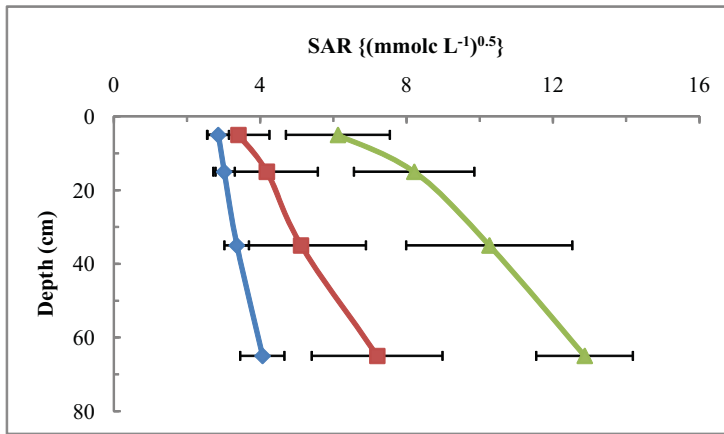


Figure 3b. SAR at each stream. Bars represent standard errors.

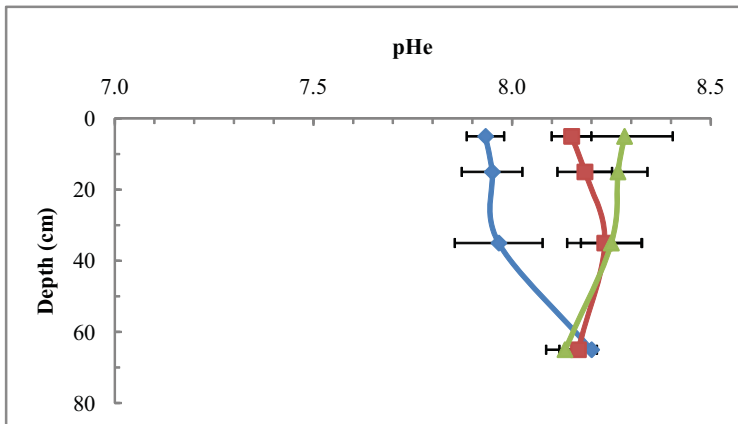


Figure 3c. pHe at each stream. Bars represent standard errors.

## Conclusions

The results of the study showed that the Qweik River water is saline but not sodic. Salts accumulated in top soil layer were leached down to bottom layers due to the contribution of freshwater from the Euphrates River into the Qweik River and due to precipitation. Based on the EC and SAR levels in wastewater-irrigated soils, it can be inferred that the use of wastewater from the Qweik River is not expected to pose salinity and sodicity problems for wheat production in the study area. However, further studies are needed to evaluate the implications of metal and metalloid concentrations in these soils. Furthermore, water quality might vary with any shift in the current treatment method used by the Aleppo wastewater treatment plant which can ultimately change the soil characteristics. Especially downstream soils will be under threat due to slightly higher SAR compared to upstream soils and specific soil texture. Therefore, periodic monitoring of the Qweik River water quality is required to minimize the risks of soil salinity and sodicity in the study area.

## Acknowledgments

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# Phosphorus Dynamics under Chloride and Sulphate Saline Environment

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## Abstract

In most arid and semi-arid countries, water availability is a major constraint to development. With continuously growing water demand and chronic water scarcity, saline water is becoming a common source for additional water for irrigation in some of these regions. Many studies have focused on the effect of saline irrigation on plant growth, response of plants to different organic materials and nutrient leaching under freshwater irrigation, but very few studies have investigated the fate of phosphorus (P) in  $\text{Cl}^-$  or  $\text{SO}_4^{2-}$  dominated saline environments. Therefore, our first study evaluated the leachability and phytoavailability of P from soil amended with composted cattle farmyard manure (CFM), poultry manure (PM) and urban sludge (US) (200 kg/ha) when irrigated with  $\text{Cl}^-$  ( $\text{NaCl}$ ) and  $\text{SO}_4^{2-}$  ( $\text{Na}_2\text{SO}_4$ ) dominated water. Our results showed that concentration of dissolved reactive P (DRP) was relatively higher in leachates under  $\text{SO}_4^{2-}$  than  $\text{Cl}^-$  treatments; while compost amendments differed for DRP leaching with the trend  $\text{US} > \text{CFM} > \text{PM} > \text{control}$ . The second part of our experiment further evaluated the P desorption characteristics under  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  ions. Soil was subjected to one salt and nine subsequent water extractions and different P fractions were analyzed. Four salt types ( $\text{NaCl}$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{KCl}$  and  $\text{K}_2\text{SO}_4$ ) were used at the rate of 0.5 M. Results showed that  $\text{SO}_4^{2-}$  salts released more P in subsequent water extractions than  $\text{Cl}^-$ . Phosphorus release decreased for salt types as  $\text{Na}_2\text{SO}_4 > \text{NaCl} > \text{K}_2\text{SO}_4 > \text{KCl}$ . These studies revealed that  $\text{SO}_4^{2-}$  has more ionic strength to replace P while  $\text{Cl}^-$  is more toxic for plant growth.

**Keywords:** Chloride salinity, sulfate salinity, saline irrigation, phosphorus, leaching.

## Introduction

The agricultural sector is estimated to be responsible for two-thirds of global water withdrawals, accounting for 90% of total water consumption (Shiklomanov 2007). Given the shortage of freshwater, irrigation with saline water is one option to meet crop water demands. There are many different situations where saline water is being used for irrigation. One situation is where high quality water is available during the early growing season, but is either

too costly or too limited in supply to meet the entire season's requirements. This situation is common in many parts of India and Pakistan. Rhoades (1988) has also demonstrated a strategy which uses both saline ( $EC_w \approx 4.0$  dS/m) and low-saline ( $EC_w \approx 1.25$  dS/m) water in rotation and found no reduction in yields of any crops. Application of organic fertilizers to soil is a common practice especially in saline environments due to the ameliorative effects of organic matter on soil chemical and physical properties and plant growth. Many studies have focused on the effect of saline irrigation on plant growth, response of plants to different organic materials and nutrient leaching under fresh water irrigation, but our knowledge about nutrient leaching and phytoavailability from different compost amendments under  $SO_4^{2-}$  or  $Cl^-$  dominated irrigation water is scarce. Further studies are needed to address the phenomenon of increased P desorption/release from soil particles when they are exposed to water dominated by  $SO_4^{2-}$  or  $Cl^-$ . Surprisingly, a large number of salinity studies on crops used only NaCl as a salt agent. Likewise, the majority of salinity studies have used  $Cl^-$  as the sole salinising anion yet most soil solutions contain a substantial amount of  $SO_4^{2-}$  and  $HCO_3^-$  (Grattan and Grieve 1992). Therefore, the current studies were mainly designed to evaluate the comparative effects of anions (in association with cations) on inorganic P release from different fertilizer sources.

## Materials and Methods

### Experiment I

A coarse textured "Masa soil" was amended with composted cattle farm-yard manure (CFM), poultry manure (PM) and urban sludge (US) each at the rate of 200 kg P/ha. Artificial saline water for irrigation was prepared by dissolving two sodium salts namely NaCl ( $Cl^-$ ) and  $Na_2SO_4$  ( $SO_4^{2-}$ ) each at the rate of 60 mmolc per liter along with a non-saline control (deionized water). Irrigation was carried out by the weighing method. The required amount of irrigation water was calculated from the difference between pot capacity plus leaching requirement (25% of applied water) and the actual weight of each individual treatment. After each irrigation event, leachate was collected for the entire 24 hr period and immediately transferred to the laboratory for chemical analysis. The amount of water leached out from each treatment was also recorded. To measure dissolved reactive P (DRP), leachate was passed through a cellulose acetate membrane filter (0.2  $\mu$ m). Thereafter, the concentration of DRP in the filtrate was measured colorimetrically. Pots were arranged in a randomized complete design on greenhouse benches under natural light and temperature conditions. Four composts and three saline irrigation treatments in triplicate gave a total of 36 treatments. Eight maize (*Zea mays* L., variety Yellow Dento) seeds were sown in each pot and thinned to four plants after germination. Pots were irrigated with deionized water (without causing leaching of water) during the first week of sowing to encourage seed germination. Maize plants were harvested at two growth stages. The first harvest (two plants) was taken



after three weeks of saline irrigation and the second harvest (two plants) was taken after six weeks of saline irrigation. Roots were collected after the second harvest. After the harvest, plants were separated into shoot (stem + leaves) and roots. Plant samples were oven dried at 65°C for 48 h and dry matter yield was recorded. Thereafter, they were crushed into powder and digested in a nitric-perchloric acid (5:1) mixture for elemental analysis.

### Experiment II

A fine textured paddy soil was used in this study. Five gram soil samples were placed in centrifuge tubes and amended with composted farmyard manure (OP);  $\text{KH}_2\text{PO}_4$  (IPk) or  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  (IPc) at the rate of 1ppm. Soil was saturated with 0.5 M NaCl,  $\text{Na}_2\text{SO}_4$ , KCl and  $\text{K}_2\text{SO}_4$  salts and shaken for 24 h at room temperature. The suspension was then centrifuged at 10,000 rpm for 10 min. and filtered. After first saline extraction, soil was shaken nine times with distilled water and P concentration was measured colorimetrically. Soil to solution ratio of 1:5 was maintained in all extractions. Inorganic P fractionation was done using the procedure of Hedley et al. (1982). After ten sequential extractions, soil was treated with, 0.5M  $\text{NaHCO}_3$  (pH 8.5) to remove labile inorganic P (IP) and P sorbed on the soil surface (Bowman and Cole 1978); 0.1M NaOH to extract IP associated with sesquioxide solid phases (Tiessen and Moir 1993) and finally with 1 M HCl to extract Ca-P (Tiessen and Moir 1993) but also could extract occluded P in more weathered soils (Williams et al. 1980). Each extraction was of 16 h duration with 1:5 soil to solution ratio. The data was statistically analyzed using the StatView software (SAS 1999). A probability level of  $p < 0.05$  was considered significant and means were separated by Fisher's LSD test.

## Results and Discussion

### Experiment I

The concentration of DRP was relatively steady during the early three leachings and then started to decrease under both saline conditions (Fig. 1). The concentration of DRP increased under  $\text{SO}_4^{2-}$  than  $\text{Cl}^-$  dominated saline irrigation. Salt types differed for DRP release in the order: non-saline  $\approx \text{SO}_4^{2-} > \text{Cl}^-$ . Non-saline and  $\text{SO}_4^{2-}$  saline irrigation substantially increased the DRP concentration in leachate from CFM and US amended pots. Concentration of  $\text{NO}_3^- \text{N}$  and  $\text{NH}_4^+ \text{N}$  was also recorded. The concentration of  $\text{NO}_3^- \text{N}$  and  $\text{NH}_4^+ \text{N}$  in leachate decreased steadily but after the fifth leaching event, only trace amounts of  $\text{NH}_4^+ \text{N}$  were detected in leachates (Fig. 1h). It was observed that  $\text{NO}_3^- \text{N}$  concentration in leachates was higher in  $\text{SO}_4^{2-}$  dominated irrigation water as compared to  $\text{Cl}^-$  treatment (Fig. 1e) while  $\text{NH}_4^+ \text{N}$  leaching increased under  $\text{Cl}^-$  than  $\text{SO}_4^{2-}$  saline irrigation (Fig. 1h). Irrespective of saline irrigation,  $\text{NO}_3^- \text{N}$  and  $\text{NH}_4^+ \text{N}$  concentration in leachate was higher from CFM and US amended pots, respectively. The increase in DRP release by  $\text{SO}_4^{2-}$  might be due to the reduced sulfur ( $\text{S}^{2-}$ ) formed after the input of

$\text{SO}_4^{2-}$  rich water and precipitation of FeS, which releases P adsorbed to iron into the water column (Smolders and Roelofs 1995). It was also observed that  $\text{Cl}^-$  dominated irrigation water severely reduced plant growth and P uptake, compared to  $\text{SO}_4^{2-}$ . Though, all the composts were applied on a total P equivalent base, maize plants vary greatly in P uptake under different compost types (US > PM > CFM > control), showing that availability of P depends on P source more than on the total amount applied.

### Experiment II

Irrespective of the salt types, soil pre-saturated with salts significantly increased the P release in subsequent water extractions as compared to the non-saline soil. The soil saturated with  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  salts of Na released more P in subsequent water extractions as compared to the K salts (Fig. 2).  $\text{Na}_2\text{SO}_4$  and NaCl released about 150% and 120% while  $\text{K}_2\text{SO}_4$  and KCl released 108% and 88% more P in subsequent water extractions than non-saline treatment, respectively. Sulfate salts induced more P release in subsequent water extractions than  $\text{Cl}^-$  (Fig. 2). Salts differed for P release in the order of  $\text{Na}_2\text{SO}_4 > \text{NaCl} > \text{K}_2\text{SO}_4 > \text{KCl}$ . No previous study was found to compare the results of more P release by  $\text{SO}_4^{2-}$  than  $\text{Cl}^-$  salt. Most of the previous studies focused on anion sorption capacities, namely oxalate (OX),  $\text{SO}_4^{2-}$  and  $\text{PO}_4^{3-}$  anions (Liu et al. 1999, Parfitt et al. 1977) but the mechanism for their adsorption and the structures of their surface complexes are not fully known. Liu et al. (1999) indicated that the order of addition of oxalate and  $\text{SO}_4^{2-}$  had a strong influence on the adsorption of these anions on goethite at low pH values: the anion added first prevented the adsorption of the anion added second. When  $\text{PO}_4^{3-}$  was added,  $\text{SO}_4^{2-}$  desorption was strongly promoted as compared to oxalate. Most studies have suggested that the mechanisms of  $\text{SO}_4^{2-}$  and  $\text{PO}_4^{3-}$  adsorption are similar, and that both ions compete for the same sorption sites (Couto et al. 1979, Pasricha and Fox 1993). Although adsorbed  $\text{SO}_4^{2-}$  does not compete strongly with  $\text{PO}_4^{3-}$  there is likely some competition for sorption between these anions which may cause comparatively more P release by  $\text{SO}_4^{2-}$  than  $\text{Cl}^-$  salts.

### Conclusions

Studies showed that not only cations differ for their ability to replace the P but associated anions also play a vital role in the fate of P under saline environment. Sulphate ions (being a divalent) have more ionic strength to replace the  $\text{HPO}_4^{2-}$  or  $\text{PO}_4^{3-}$  as compared to  $\text{Cl}^-$  (monovalent) ions. Chloride is more toxic for maize crop as compared to  $\text{SO}_4^{2-}$ . Phosphorus release in soil greatly depends on the type of P source used as compared to the total amount of P applied.

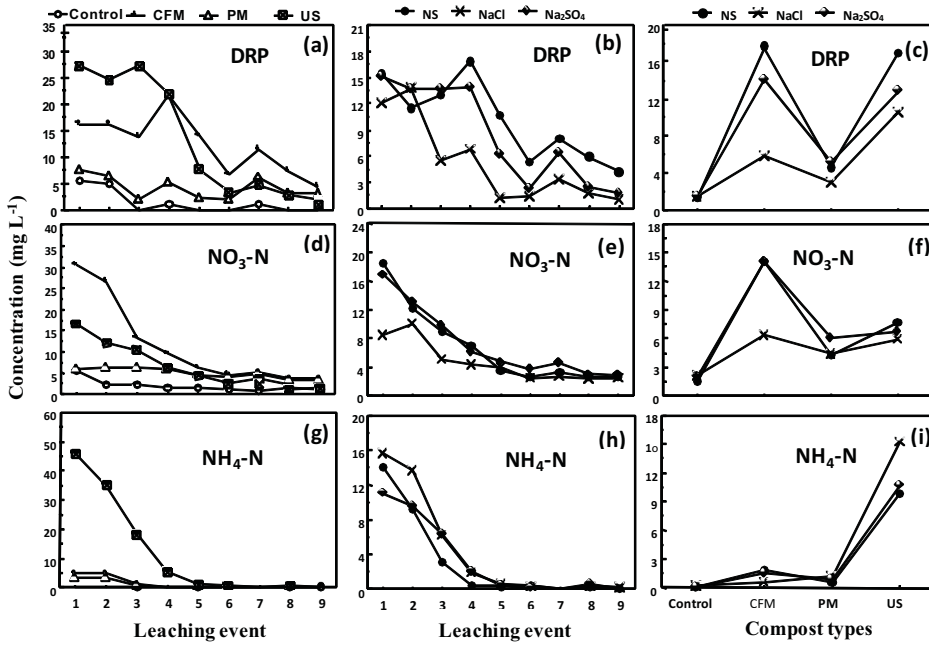


Figure 1. Effect of Cl and SO<sub>4</sub><sup>2-</sup> dominated saline irrigation water on DRP, NO<sub>3</sub>-N and NH<sub>4</sub>-N leaching from different compost amendments. (n=3), NS = Non-saline, CFM = Composted farmyard manure, PM = Poultry manure, US = Urban sludge

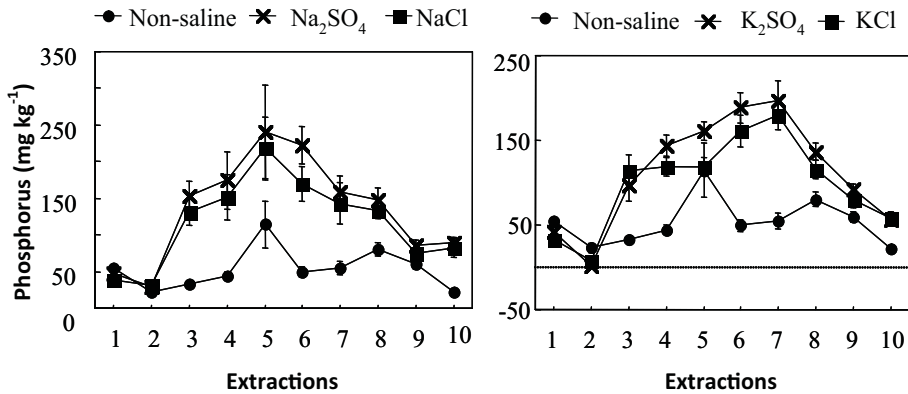


Figure 2. Release of P in sequential extractions with either H<sub>2</sub>O or 0.5M salts (extraction no. 1) followed by H<sub>2</sub>O (extraction no. 2-10)

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# Water Scarcity and Opportunities for Saline Water Use in Palestine

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## Abstract

Irrigated agriculture is a key sector in the Palestinian economy, contributing gross output of about \$500 million annually. However, it is also the dominant user of water. Water as a scarce and commonly shared resource is a sensitive and critical issue, and a major factor in the Israeli-Palestinian conflict. Palestine suffers from water scarcity and rapidly deteriorating water quality. There is an urgent need for new alternative water resources. Moderately saline water, which is available in the Jordan valley at the eastern part of the West Bank, has high potential for use in agriculture, to irrigate selected salt-tolerant crops. Using saline water in agriculture could help alleviate the mounting pressure on drinking water resources.

**Key words:** Water scarcity, saline water, agriculture, irrigation, water conflict, Palestine.

## Introduction

Most countries in the Middle East suffer from a shortage of water. The situation is most acute in Palestine and Jordan, and is worsening due to the decrease in useable water reserves as a result of pollution and climatic changes, as well as population growth and the rising demand for water (Water Authority 2009). It is likely that water shortages will increase dramatically in the next 30 years (Rosegrant 1997). Utilization of shared water resources is an extremely complicated issue, especially when accompanied by shortages and inequitable distribution (Farahneh 1998). Thus, the defining issue of the twenty-first century might be the control of water resources (Rosegrant 1997).

Irrigated agriculture, which covers about 12% of cultivated land, uses about two thirds of Palestine's water resources (World Bank 2009). The growing water scarcity has driven the search for new water resources for irrigation. The use of saline water has long been proposed as an option to augment limited freshwater resources, particularly for water-scarce regions of West Asia and North Africa (WANA) (Stenhouse and Kijne 2006).

## Water Scarcity in Palestine

Lack of access to adequate, safe, and clean water has been a longstanding problem in Palestine (Amnesty International 2009). The concentration of chemical pollutants in Gaza, including nitrate, chloride, and fluoride exceeds the recommended WHO standards (Palestinian Hydrology Group 2002). In fact, only 5-10% of water supplied through the network in the Palestinian territories meets portable standards. To meet the challenges of increasing water scarcity, both of the demand management and supply management are required (Rosegrant and Perez, 1997).

The West Bank, including East Jerusalem, and the Gaza Strip, has a total area of about 6210 km<sup>2</sup>. This small area contains great variation in topography and altitude, in the West Bank where variations range between 1020 m above sea level and 375 m below sea level. The Gaza Strip is essentially a coastal plain gradually sloping westward (Ministry of Agriculture 2004). The area is facing chronic water shortages because of its aridity and rapidly growing population (3.5-4% per a year) with high water demand (Farahneh 1998, Palestinian Central Bureau of Statistics 2009).

Most of the West Bank's natural water resources lie beneath its soil in three shared aquifers sometimes collectively known as the "Mountain Aquifer". These aquifers are the Western, the North Eastern, and the Eastern aquifer. All three aquifers derive most of their recharge from rainfall and snowmelt on the Palestinian side. Two of the three aquifers (the Western and North Eastern) also underlie Israel territory, with flow that follows the surface topography, from the West Bank toward Israel. The third aquifer – the Eastern – lies almost completely within the West Bank and discharges towards the Dead Sea (Salem and Isaac 2007, World Bank, 2009). Figure 1 provides an overall view of shared and non-shared groundwater aquifers in Israel, the West Bank and Gaza (World Bank 2009).



Figure 1. Shared and non shared groundwater aquifers (World Bank 2009)

The sole fresh water resource in Gaza is the coastal aquifer, which also runs beneath the coast of Israel. In contrast to the West Bank situation, Palestinian Gaza is "downstream" of the portion of the aquifer that underlies Israel, with flows coming from Israel into the Gaza portion of the aquifer (World Bank 2009). Gaza is characterized by scarcity of its natural water resources

and high water demand. Due to over-pumping and low rainfall, the extraction of groundwater exceeds recharge, thus lowering the groundwater level, and leading to invasion of seawater into the aquifer. This is causing severe salinization in both the water and the soil, which have affected agricultural productivity and could soon cause irreversible damage to land and water resources (El-Sheikh et al. 2000, Palestinian Hydrology Group 2002, Ministry of Agriculture 2004).

Water resources in the Palestinian Territory are restricted mainly to groundwater and springs (71.7 and 13.7% respectively), and water purchased from the Israeli Water Company (Mekorot). Water purchased from Mekorot represents 13.4% of water resources in the Palestinian territory (Palestinian Central Bureau of Statistics 2008). The Israeli authorities sell the Palestinians their own water for high prices (Farahneh 1998). For example, in Jenin, farmers are paying up to NIS 12 per cubic meter for water to irrigate plastic houses. These prices are considerably higher than those paid by (competing) Israeli farmers, who pay only 0.818 NIS per cubic meter (World Bank 2009).

### Water Scarcity and the Water Conflict

Prior to 1967, Israel had developed part of the water resources to which it had exclusive or shared access. This included about 60% of the total flow of the Jordan River and about 300 MCM of the groundwater of the Western Aquifer (World Bank 2009). Following the 1967 war, Israel took control of West Bank water resources, and developed wells in the West Bank (largely in the Jordan Valley), and a network serving settlements that is linked into the Israeli national network (Rosegrant 1997, World Bank 2009).

It is very clear that control over water resources has become at the center of the Israeli-Palestinian conflict (Isaac and Saade 1999, Salem and Isaac 2007). Because of the abnormal political conditions, Israel has been able to use more than 80% of the Palestinian groundwater resources and deny Palestinians access to water rights in the Jordan River (Ministry of Agriculture 2004, Salem and Isaac 2007, World Bank 2009). The Jordan River is the most important shared surface water resource for Israel and the West Bank. It supplies up to 650 million cubic meters per year of water to Israel and none to the Palestinians (Amnesty International 2009).

In 1978 Israel began establishing settlements above the water basins. According to Attili (2009), the estimated 9000 settlers residing illegally in the Jordan Valley utilize local water amounting to about one-third of the water withdrawn by nearly 2.4 million Palestinians in the West Bank from Palestinian well and springs. Palestinian consumption in the West Bank is about 70 liters a day per person – well below the 100 liters per capita recommended by the WHO, whereas Israeli daily per capita consumption is about 300 litres (Amnesty International 2009). Comparative figures are shown Table 1.

Table 1. Individual water consumption, in cubic meters per year (Farahneh 1998)

<b>Palestinians in West Bank</b>	<b>Israelis in Israel</b>	<b>Settlers in West Bank</b>	<b>Palestinians in Gaza</b>
106 - 107	375	640 - 1480	40

Another political constraint against the Palestinian water is the establishment of the expansion and annexation wall. This has led to a great loss of western basin water: Palestinians lost 23 wells and 51 springs which together produce about 7 million cubic meters of water (Palestinian Central Bureau of Statistics 2009). The water crisis is exacerbated by the Israeli refusal to give licenses to villages for drilling wells or to permit water treatment plants and the transfer of water between Palestinian districts (Ministry of Agriculture 2004).

### Saline Water in Palestine

Little is known about the appropriate mix of policies, institutions, and technologies that could help achieve water security in water stressed environment (Webb and Iskandarani 1998). There is usually no single way to achieve safe use of saline water in irrigation. Many different approaches and practices can be combined into satisfactory saline water irrigation systems; the appropriate combination depends upon economics, climate, social, as well as edaphic and hydrological situations. Thus, no procedures are given for selecting the appropriate set of practices for different situations. Rather, some important goals, principles, and strategies should be considered in the use of saline water for irrigation (FAO 1992).

The Jordan Valley is located in the eastern side of the west bank near Jericho city at the eastern aquifer in a region of high agricultural importance. It is a flat area characterized by low rainfall (100-170 mm per year) during the winter season, high temperature and evaporation during summer, and only limited recharge during the winter season. The water quality of this aquifer varies both horizontally and vertically depending on location. There are more than 130 wells distributed along the Jordan Valley. Most of them are suffering from continuous decline in water level and increasing salinity due to the existence of salt deposits in deep layers and to over-pumping (Palestinian Water Authority 2004).

In the last 5 years, near 450 water samples from different wells in Jordan Valley have been analyzed by the National Agricultural Research Center. Water in this area can be classified as moderately saline, with EC = 2-10 dS/m. However, values as high as 29 dS/m have been reported.

Irrigated agriculture is the largest productive sector of the Palestinian economy. It contributes gross output of about \$500 million annually, equivalent to 12% of gross domestic product. Overall, agriculture contributes 25% of



exports, and is the third largest employer: formal employment in the sector in 2005 was estimated at 117,000 people (World Bank 2009). On the other hand, it is the dominant user of water. Clearly, there is a pressing need to find alternative water sources for irrigation (such as saline water) to alleviate the mounting pressure on freshwater resources.

Given to the availability of saline water in the Jordan Valley, there are two major approaches that should be considered to improving and sustaining productivity in a saline environment: modifying the environment to suit the plant and modifying the plant to suit the environment (Sharma and Minhas 2005).

### Using Saline Water for Irrigated Agriculture in the Jordan Valley

Identifying salt-tolerant crops which can be irrigated by moderately saline water is an example of modifying the plant to suit the environment. The National Agricultural Research Center (NARC) and the Palestinian Ministry of Agriculture implement a joint research project "Saving freshwater resources with salt tolerant forage production in marginal areas of WANA region". The project was organized by the International Center for Biosaline Agriculture (ICBA) in the United Arab Emirates (UAE). The aim of the project is to increase incomes of the rural poor by facilitating cooperation between seven countries in the West Asia and North Africa (WANA) region, and identify species that can provide animal feed and other agricultural products under irrigation with saline water. The countries involved are: Jordan, Oman, Palestine, Pakistan, Syria, Tunisia and UAE.

The crops under the investigation in the Palestinian side were planted in the Jordan Valley (Jericho city) and irrigated by moderately saline groundwater ( $EC = 6 \text{ dS/m}$ ) extracted from a known well in Jericho. The results of the first phase of the project, which lasted four years, show that these crops can be irrigated with moderately saline water and can be considered as salt-tolerant: *Hordeum vulgare*, *Brassica nigra*, *Sorghum vulgare*, *Pennisetum glaucum*, and *Beta vulgaris*. The second phase of the project, which will begin in the near future, will focus on scaling out results on a large scale.

### Conclusions

Israeli policies have greatly restricted the availability of water for the Palestinian population. Palestinians, who are suffering from water scarcity, have access to only 20% of their own water resources. The inequality in water access is striking: Israeli consumption is about four times as much as the Palestinian's.

Water quality in Palestine has deteriorated because of over-extraction. Palestinians are therefore looking at saline groundwater as an alternative water source for agriculture.

Through cooperation between seven countries in the WANA region, and with support from ICBA, salt tolerant species have been identified in the Jordan Valley, and will be promoted on a large scale in the near future.

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# Economic Analysis of Policy Scenarios for Developing Degraded Drylands under Uncertainty of Irrigation Water Availability in the Khorezm Region of Uzbekistan

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## Abstract

Risk management options in degraded, irrigated drylands were simulated under different environmental and policy change scenarios using the case of the Khorezm region in Uzbekistan, which is representative of about 8 million ha of irrigated croplands in Central Asia. The model was elaborated following the Expected Value-Variance (EV) approach and combined with chance constrained programming. This combination allowed accounting of multidimensional sources of risk associated with irrigated agriculture. The findings of the baseline scenario were compared with those of various scenarios reflecting present considerations in Uzbekistan. These included a direct water price, water-wise technologies, a change in the state procurement policy (market liberalization), different water availability levels in the region under expected climate changes, and various combinations of these scenarios. The results highlighted the potential impact of targeted policy measures that could lead to economic development and simultaneously improvement of land degradation, while allowing farmers more flexible decision-making.

**Key words:** Soil salinisation, water use efficiency, income security, water scarcity, water pricing.

## Introduction

Irrigated cotton and wheat production forms the backbone of the rural economy in the Khorezm region, Northwest Uzbekistan, Central Asia. A decade long situation of low water productivity, poor irrigation system efficiency, and low field application efficiencies have caused widespread land salinization that has affected 50-60% of the total irrigated area in Uzbekistan, including Khorezm (Murray-Rust 2003, Saigal 2003). The ongoing land degradation significantly threatens the livelihoods of the rural population that constitutes 70% of the 1.3 million inhabitants of Khorezm (as of 2007). And an unstable production threatens the food security of the whole population (Vlek et al. 2007).

Uncertainty in irrigation water supply gained attention in Uzbekistan particularly catalyzed by recent droughts such as in 2000-01 (Müller 2006) and 2008. During these water-scarce years, this uncertainty and risk impacted most the population in the more remote areas and threatened income and health conditions in a population highly dependent on (irrigated) agriculture (Bucknall et al. 2003). Moreover, severe water shortages in the near future are predicted for the entire Central Asia region, because of increased water demand in the upstream regions of Tajikistan and Kyrgyzstan, the original sources of the irrigation water in Uzbekistan (Martius et al., 2009), and also due to climate change. These predictions are bound to increase the uncertainty in irrigated agriculture, which is already under risk caused by land degradation. Income security of the rural population in the Khorezm region is affected further by uncertainty caused by policies, such as the current state order which imposes minimum levels of cotton and winter wheat production and restricts farmers' decision-making in crop allocation and production (FAO 2000). Farming risk is also increased by yield and price distortions due to natural conditions and fluctuations in domestic and international markets.

On the other hand, water supply is still largely free of charge – this is frequently mentioned as the main reason for low water use efficiency (e.g. Bucknall et al. 2003). A lack of direct payments by farmers for irrigation water is one reason for overuse, which in turn has worsened the environmental degradation during the last two or three decades (Bucknall et al. 2003). Although irrigation water pricing in Uzbekistan is expected to be introduced in the near future, there is little information on price levels and possible consequences. Consequently, coping with increasing uncertainties and risks in agriculture, and reversing the environmental deterioration, have become major challenges. This study developed an analytical framework to examine the influence of policy scenarios on farm income security as well as on environmental improvements. It is based on the case of the Khorezm region, which is representative of about 8 million ha of irrigated croplands in Central Asia.

## Methodology

Different crop allocation and water use options were analyzed in a systems context, with explicit linkages defined between environment and socio-economic impacts so as to consider both economic and ecological factors. The Expected Value-Variance (EV) (Berg 2003), combined with chance constrained programming (Charnes and Cooper 1959), was selected as the most appropriate approach. This combination allowed us to account for multidimensional sources of risk by integrating agro-ecological and socio-economic aspects of land and water use decisions.

Empirical data were collected from the 1800 ha Shamahulum Water Users Associations (WUA), located in the Khiva district of the Khorezm region. Information about water and land allocation was collected from 300 fields, belonging to 99 farmers in this WUA. The spatial data (e.g. water distribution canals, distances) and agro-ecological properties (e.g., soil fertility, soil texture) of all fields were prepared in a GIS data set and imported into a mathematical programming model developed with the General Algebraic Modeling System (GAMS).

The optimal spatial cropping pattern and water distribution could be identified when allocating crops based on their agro-ecological comparative advantages (e.g. soil fertility, distance from water source) and risk associated with each crop. Several farm and WUA level constraints were considered in the optimization process. Cotton, winter wheat, rice, maize (for grain), fodder crops, potatoes, vegetables and melons were included.

After the model calibration with the empirically observed situation in the WUA, the findings of the base run were compared to those of five scenarios: the introduction of (i) a direct irrigation water price, (ii) reduced water availability levels so as to account for climate change effects and higher water use in upstream regions, (iii) water-wise technologies such as drip irrigation, (iv) a change in the state procurement policy (market liberalization), and (v) various combinations of these factors. These policy simulations were selected specifically in order to reflect discussions on ongoing policy reforms and changes in the environment (e.g. water scarcity, land degradation) in Uzbekistan. Several model parameters, e.g. input-output prices, level of state quotas, crops, and so on, were adjusted in each of these five scenarios in order to analyze the potential effects of each option. This allowed us to assess the potential effects of different policy measures on livelihood, social welfare and environmental improvements.

## Results and Discussion

Model simulations helped understand the scope for increasing overall water use and irrigation efficiency by introducing direct water pricing in Uzbekistan. Overall irrigation efficiency in the WUA increased from 65.2 to 68.5%

when a water price of 11.5 Uzbek Soums per cubic meter was introduced (UZS, 1 USD = 1250 UZS in 2005).

Under the existing state order regime, the introduction of water prices sharply decreased the expected income at WUA level from 283 to 174.3 million UZS. Hence, unless the existing state procurement system is changed, water pricing crates the danger of rising poverty and higher income risk for agricultural producers.

In contrast, water pricing seems a promising option for achieving an overall increase of irrigation efficiency under a liberalized market economy (scenario iv) since the expected income at WUA level rose from 283 to 903.2 million UZS. There are plans to modify the irrigation infrastructure to enable water accounting, but it may take several years before WUAs have the capacity and infrastructure to handle volumetric water charges.

Simulation findings showed also that the expected incomes at farm and WUA level may decrease by about 12% when the probability of water supply was expected to be 5% lower than the baseline scenario. In this scenario, which reflects the situation of increasing threats of water scarcity, farmers located at the tail end of the irrigation system were particularly affected; they would face the highest income losses during water scarce years. However, this could be buffered by measures such as insurance policies especially during dry years.

The model outputs also demonstrated that the introduction of water-wise innovations, such as drip-irrigated cotton production, which is currently favored by the government of Uzbekistan, will not automatically bring about widespread environmental improvements. This is because the high initial investment needed for such technologies limits the scope for widespread use (Table 1), unless this is cushioned by special measures such as the provision of cheap credits, higher farm gate prices etc.

Under the present policy framework, innovations such as drip irrigation and laser-guided land levelling would be economically beneficial on not more than 25% of the total area. Hence, unless farmers group together and share resources to reduce investment and running costs, their current levels will.

Table 1. Crop allocation (ha) under different irrigation methods in the WUA.

<b>Irrigation method</b>	<b>Traditional</b>	<b>Laser leveling</b>	<b>Drip irrigation</b>
Cotton	687	-	-
Winter wheat	233.1	-	-
Rice	-	35.5	-
Maize for grain	-	8.9	-
Fodder crops	-	78.6	-
Potato	-	174	6.7
Melon	-	0.13	-
Vegetables	-	2.7	-

not allow them to build up the necessary capital for the introduction of water-wise technologies, as was also previously postulated. The model findings further suggest that allocating the degraded croplands to less water demanding crops than cotton and rice, or using relatively low cost alternative irrigation methods, will help to secure farmer income. With such measures, food security can be achieved even during water-scarce years.

The overall expected income sharply increased from 283 million UZS in the baseline to 903.2 million UZS, as a result of modest liberalization of the agricultural sector. Under such policies farmers will have more opportunities to cultivate high value crops. This is due to the release of land from the mandatory cultivation of the less profitable cotton and wheat, as was also postulated earlier (Djanibekov 2008). Obviously, the overall risk premium increased but the relative difference to the expected income has decreased, compared to the base scenario.

### Conclusions

Results from model simulations highlighted the potential impact of targeted policy measures, which are currently under discussion. Appropriate measures could arrest land degradation and improve economic welfare in regions with degraded irrigated croplands. Such “win-win” scenarios are likely to occur if the area sown to cotton and wheat (the strategic state order crops) were to be reduced. By modeling a relaxation of this policy, income increased due to crop diversification. This allows farmers to build up capital and increases their ability to invest in water-wise innovations. When farmers are allowed more flexible decision-making, a chain reaction of benefits can be expected leading eventually to economic and ecological sustainability.

Although the model results refer to the case study region of Khorezm, this watershed is representative of conditions in many irrigated areas in the lowlands of Central Asia. The model could therefore prove useful for countries where irrigation water availability, yield and price variations are essential factors to consider in the optimization of resource use. The agro-ecological and socio-economic components of the model must obviously be adjusted to account for site-specific characteristics.



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# Concluding Sessions



## Concluding Sessions

### Concluding Session 1     Addressing salinity of water and soil resources through land-use planning

Resource Persons

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The goal of this final session was to stimulate discussion on a given salinity management problem from a developing-country perspective. Participants were given the task of designing a land-use plan to make best use of 100,000 ha for irrigation. About 40 minutes were allocated to the problem; participants were encouraged to work together to better appreciate the many factors involved in allocating soil and water resources in what could be considered a simple situation – a new irrigated area, a climate that offered opportunities to grow more than one crop per year, and moderate but manageable constraints on water resources.

The normal crops grown in the area were specified along with the salinities of the available surface water and groundwater. Assuming good irrigation practices, including provision for adequate surface and subsurface drainage, constraints posed by the salinity levels of both sources of water ranged from small to moderate for the crops grown in the area. Several primary conditions created potential constraints and opportunities:

- The available supply of surface water is not sufficient to irrigate the entire area during the summer – only about 350 mm for the 100,000 ha
- No natural drainage
- Most of the rainfall of 400 mm occurs during winter
- Summer temperatures range from moderate to hot, and winter temperatures were sufficiently high to cultivate winter crops (grains and vegetables)
- No previous cropping in the area, i.e. irrigation and drainage systems would need to be designed and built
- Groundwater resources from an unconfined aquifer underlying the area are sufficient to significantly supplement supplies of surface water and rain.
- Initial levels of soil salinity,  $4 < \text{ECe (dS/m)} < 6$ , pose little hazard to crop production because these levels are not hazardous to sugar beet, wheat or cotton if the amount of applied water exceeds the amount of water required by the crop.

Participants were divided into two groups representing: (i) a multidisciplinary group of experts, and (ii) a group of downstream farmers. After about 30 minutes of discussion within the separate groups, a representative of each group presented their findings.

Each group recognized the need for drainage and leaching to control soil salinity. Consideration was given to requiring the use of sprinkler irrigation. One group advocated growing forage crops that could be used for green manuring. The first group discussed the possibility of prescribing the crops that could be grown – by location and area cropped.

Due to time limitations, and the many factors that needed to be considered, the process was difficult for both groups. Each group had to organize itself, exchange ideas, and then formulate a plan, all within 30 minutes. A strong leadership team began to emerge in group 1, but not in group 2.

Neither group considered the possibility of conjunctive use of both surface water and groundwater. The groundwater available in the unconfined aquifer that is 500 m deep, assuming a volumetric yield of 10%, represents 50 m of water available beneath all the area to be irrigated. At a use rate of 0.3 m/yr, this represents a source of water that would last about 170 years. The use of groundwater would make it possible to provide the needed regional drainage, provided application rates were selected to maximize crop productivity per unit of applied water.

In future workshops the focus of this exercise might be improved by building on the policy problem presented in Stimulating Session 6. That problem addresses the role of public policies and institutions in the development of salinity and drainage problems and their alleviation, and in promoting better use of marginal quality water in agriculture. The focus of this exercise could include the policies needed before irrigation would begin in the region, such as how water would be allocated, including the possibility of regulation; how drainage needs would be handled, including the collection and management of surface runoff and subsurface drainage water. In addition, the participants could be asked to consider how water and land rights might be allocated among farmers, and across subregions within the area.



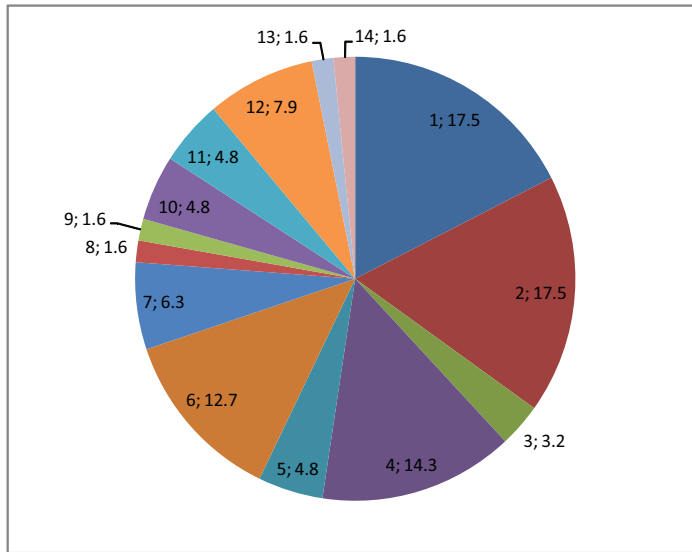


Figure 1. Response of workshop participants in terms of prioritizing research and best practices for addressing different aspects of saline water and salt-affected soils. Fourteen issues were cited: (1) drainage systems and reuse of drainage water to manage salts in irrigated soils; (2) use of modern irrigation systems; (3) new crops for salt-affected areas; (4) salt-tolerant crop cultivars and trees for salt-affected areas; (5) reclamation of salt-affected soils; (6) policies to create an enabling environment for salinity management; (7) crop diversification options for salt-affected areas; (8) effective storage and use of rainfall; (9) use of solar energy for desalination of highly saline water; (10) capacity building of farmers and linkages with agricultural extension services; (11) enhanced regional and international collaboration; (12) use of GIS and remote sensing and monitoring systems for the assessment and mapping of salt-affected areas; (13) rational use of fertilizers; and (14) measures to reduce seawater intrusion in coastal areas.



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