EIP-AGRI Focus Group

Soil salinisation

MINIPAPER: Decision Support Systems for Efficient Irrigation on High salinity Fields

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1 Introduction

1.1 State of the Art

Primary salinization occurs naturally where the soil parent material is rich in soluble salts, or in the presence of a shallow saline groundwater table. In arid and semiarid regions, where rainfall is insufficient to leach soluble salts from the soil, or where drainage is restricted, soils with high concentrations of salts ("salt-affected soils") may be formed. Several geochemical processes can also result in salt-affected soil formation. When an excess of sodium is involved in the salinization process this is referred to as sodification. Secondary salinization occurs when significant amounts of water are provided by irrigation, with no adequate provision of drainage for the leaching and removal of salts.

A Decision Support Systems (DSS) is a logical arrangement of information that includes engineering models, field data, Geographical Information System (GIS), and graphical user interfaces, and is used by managers to make informed decisions. In irrigation systems, a DSS can organize information about water demand in the service area and then schedule available water supplies to efficiently meet the demand. The desirable solution to this problem should be "demand driven," in the sense that it should be based on a realistic estimation of water demand.

At field scale, optimal irrigation scheduling can be achieved by (a) calculation of the water balance (Crop evapotranspiration (ET_c)), which is most easily done using simple software (Raes et al., 2006) or (b) direct measurement of the soil water volumetric content or the soil matric potential. Decision Support Systems are useful for making decisions at field, farm and regional scales that assist with sustainable water management (Maton et al., 2005). Decision Support Systems for large scale water management use simulation models and GIS-based approaches to calculate water demand for agriculture (Knox et al., 1996; Hartkamp et al., 1999). Two types of models are available: (i) models which provide an estimate based on crop water requirements (Herrero and Casterad, 1999; Mateos et al., 2002; Weatherhead and Knox, 2002), and (ii) models which estimate irrigation demand taking into account farmers' practices (Weatherhead and Knox, 2000; Leenhardt et al., 2004a).

Managing salt-affected irrigated land and marginally saline irrigation water requires understanding of the interactions between soil salinity, crop salt tolerance, soil physical properties, groundwater quality, irrigation water quality, irrigation management, water table depth, climate, and crop yield. A DSS that assists with managing salt-affected irrigated lands and marginally saline irrigation water is an interactive computer program that simulates interactions between these factors. Such a DSS demonstrates the effects of changing one factor on outputs of the crop system (e.g. crop yield) and on the other factors during one or more growing seasons. The user selects climate, crop, and soil characteristics from menu lists, then sets the water table depth, groundwater quality, irrigation water quality, and the DSS then develops an irrigation schedule. On running the DSS, outputs include:

(1) relative yield reductions due to over-irrigation, under-irrigation, and salinity, expressed numerically,
(2) surface runoff and water table fluctuations, expressed numerically, and
(3) soil water content, soil salinity, water table depth changes, and rain and irrigation events which can be shown graphically.

Using these DSSs, irrigation advisory services can considerably assist farmers with the adoption of new technologies and techniques to increase water use efficiency, while minimizing environmental risks, thereby contributing to sustainable agriculture. The value of DSSs based on simulation models to improving the management of moderately saline irrigation water and saline soils is apparent in the widespread related activity in many research institutions and universities throughout the world.

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1.2 Case studies

Typical examples of salty soils caused by farmers:

1. Improper irrigation schemes management
    - Insufficient water application
    - Insufficient drainage
    - Irrigation at low efficiency
    - Irrigation with saline or marginal quality water
2. Poor land levelling
3. Dry season fallow practices in the presence of a shallow water table
4. Misuse of heavy machinery leading to soil compaction and poor drainage
5. Excessive leaching during reclamation techniques on land with insufficient drainage
6. Use of improper cropping patterns and rotations
7. Chemical contamination. e.g. as a result of intensive farming, where large amounts of mineral fertilizers have been applied over a long period of time.

According to what causes high salinity in fiends, the main problem is the method of applying the water in the field, the climate, the drainage system and agronomic practices with agricultural machinery. Basic measures for preventing salinization and sodification of cultivated soils concerning **mainly on** how to apply the irrigation Water:

- Soil moisture monitoring, accurate determination of water requirements and efficient irrigation of crops
- Choice of appropriate drainage system
- Continuous monitoring of water by salinity checks

In Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Land and Water has developed a group of models called SWAGMAN (Salt Water and Groundwater MANagement). The individual models of SWAGMAN are SWAGSIM (Salt Water and Groundwater SIMulation) (Prathapar et al., 1995), SWAGMAN Destiny (Meyer et al., 1996) and SWAGMAN Farm (Khan et al., 2002). Of these, SWAGMAN Farm is a combination model of water balance and salt balance for a field, and is used both as an educational tool and as a management tool by different administration bodies and by farmers as occurs in the Coleambally area of South Australia.

In Israel, the ANSWER (ANalytical Salt-WatER) model has been developed to assist with practical irrigation management of crops using moderately saline water (Kaner et al., 2018). This model couples (a) an agronomic component that calculates crop yield as a function of soil type, water salinity, irrigation amount, with (b) an economic component that enables farmers to maximise farm income for different combinations of inputs e.g. species and salinity of irrigation water. Once input parameters are established, users can calculate and plot relative expected yield and profit in relation to irrigation water quality and amount. A user-friendly DSS based on the model has been prepared as a planning tool for regional and local administrators, farmers and Extension staff (Kaner et al., 2018). An example of the use of this DSS is a vegetable grower with irrigation water salinity of 3 dS/m, being informed that he/she could only achieve 70% of potential yield for a pepper crop whereas with melon, 90% of potential yield could be achieved with the same quality and quantity of water (Shani et al., 2007).

In Canada, various irrigation advisory agencies have been established, mainly in the western part of the country. Traditionally in Canada, advice for irrigation was the responsibility of the public sector, but recently an increasing involvement of private entities has occurred. In the province of Manitoba, irrigation is the farmers' responsibility and is carried out through the growing use of measuring devices for soil moisture. In the province of Alberta, the local government trains employees of private companies and groups of farmers in the use of a DSS (Alberta Irrigation Management Model - AIMM) that was developed and designed specifically for the climate of the region (Tollefson et al., 2002). In Italy, the demand for irrigation advisory services increased during the 1990's. For this reason, the regional agency ARSIA (Agenzia Regionale per lo Sviluppo e l'Innovazione Agricolo-forestale) in collaboration with the universities of Pisa and Florence developed a methodology for irrigation scheduling of about 50 fields informing farmers by using SMS messages and through web (Giannini and Bagnoni, 2002).

In the USA, a variety of government agencies, consulting companies and other organizations contribute to irrigation scheduling with a variety of services. One of the most famous of these services is CIMIS (California Irrigation Management Information System) which was developed in 1980 by a joint action of the California Department of Water Resources (CDWR) and the University of California. CIMIS provides data to farmers of daily evapotranspiration, through a network of meteorological stations, remote sensing and a Geographical Information System. All these data are used for the estimation of irrigation water demand and for irrigation scheduling of local crops.

In Greece, there are few services to assist farmers with irrigation scheduling. A pilot system of tele-information for farmers in two small areas in Crete was introduced in 2005. For each area, a database was created in a GIS environment containing information on soil properties, specifically: the slope, soil texture, bulk density, field capacity, permanent wilting point, porosity and infiltration rate. Based on these data, and considering crop location, the species, soil type, and the date of the last irrigation, a recommended irrigation volume is sent to participating farmers through a simple phone call or SMS (Chartzoulakis, 2005).

2 Developing a decision support system for efficient irrigation on high salinity fields

This could be the proposed methodology for the rational management of water resources through the proper irrigation of crops by using meteorological data and talking into account parameters such as soil salinity, bad quality of irrigation water and shallow groundwater table. Proper irrigation aims at achieving qualitative and quantitative yield. The farmers will be instructed to sufficiently irrigate at the beginning of the irrigation period in order to reach field capacity, based on their previous experience. Using data provided from meteorological stations, daily evapotranspiration is calculated for each of the common crops of the area (e.g. maize, cotton, alfalfa). Farmers are informed of the crop water requirements of each field via a dedicated web page or an app, when they decide empirically to irrigate. Thus, irrigation is organized based on the actual consumption of crop water, ensuring the qualitative and quantitative yield.

2.1 Methodology

A network of meteorological stations, with effective telecommunication, should be installed for recording hourly values of: depth and duration of precipitation, maximum, minimum and mean air temperature, maximum, minimum and average relative humidity, wind speed and direction and sunshine duration. Using the collected data from these stations the daily crop evapotranspiration is calculated through specific software, which was developed for this application. Since crop coefficient values were not available for the pilot area, estimates were made after consulting the literature (Allen et al., 1998; Papazafiriou 1999; Paltineanu et al., 1999; Panoras et al., 2001). The daily effective precipitation and the daily net crop water requirements are also calculated with the same software. Soil moisture change in the root zone between start and end of the cultivation period is assumed to be negligible, since it never exceeded field capacity during the irrigation period. So it is not accounted for the calculation of the daily net crop water requirements. Also since observations in the area suggest that the contribution of the ground water level is too low to affect the crop rooting zone, the contribution of phreatic groundwater is omitted (Van Hoorn, 1979). Finally adding to the net crop water requirements, a percentage of 15% to account for inaccuracies to input data, the daily water need for each crop is calculated (figure 1).

As already stated, farmers were instructed to irrigate at the beginning of the irrigation period sufficiently in order to approach field capacity based on their previous experience. It is therefore assumed that at the beginning of each irrigation period, soil moisture is near field capacity and the daily water requirement of each crop is calculated as above, hence the necessary water volume for restoring the soil moisture to field capacity is recommended to the farmer. This way the farmer irrigates according to the water requirements of each

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crop. Thus, each one of the cultivations receives throughout the irrigation period, the necessary amount of water required for optimum growth, without wasting irrigation water.

The proposed methodology was applied for several cultivation periods by NAGREF, Greece in an area of Northern Greece. Two fields of 1 ha each from each crop type (maize, cotton, alfalfa) were selected in order to test the methodology. Three of them were used as experimental trials and the other three as control. At the beginning of the cultivation period, the main soil properties of each field were measured (e.g. field capacity, permanent wilting point etc). During the irrigation period, measurements of soil moisture content were carried out twice a week. The experimental fields' volumetric soil moisture content was measured by responses to changes in the dielectric constant of the soil using Diviner 2000 device of SENTEK. Soil moisture was measured at 10 cm intervals to 60 cm depth, and at three different points of each field. Finally, crop yield and the applied water volume were measured in all fields in order to evaluate and validate the methodology. The yield was determined by weighing the total yield of each field, and the irrigation water was measured with volume meters during irrigation application.

The evaluation and validation of the methodology was carried out by comparing the yield between the experimental fields and the corresponding controls taking into account the volume of water applied. Finally, since soil moisture content values were monitored, the crop coefficient was calculated

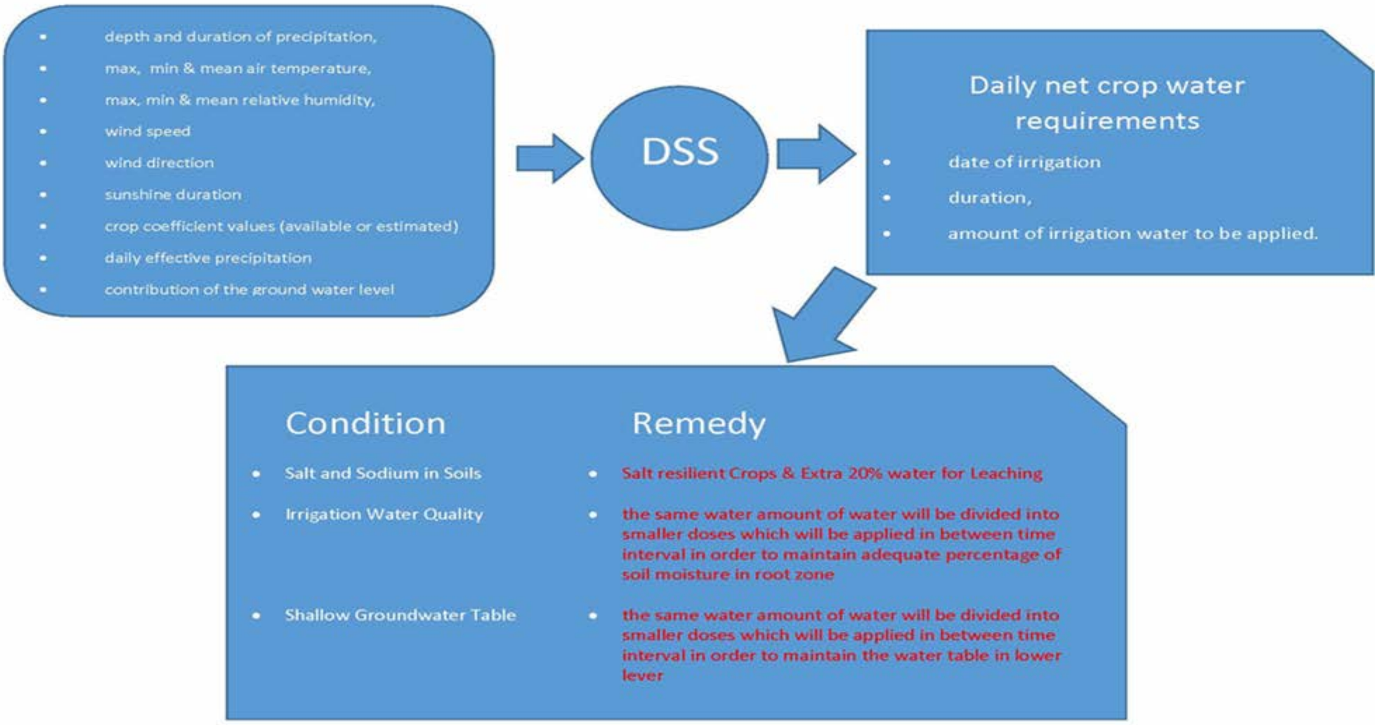

Figure 1: Flow chart for a reliable DSS for irrigation, concerning High salinity

2.2 Conclusions from the proposed methodology

This irrigation methodology using meteorological data was applied for the first time in Greece at Nigritas' network irrigation system for the common crops of the area. Application of this methodology resulted in savings of irrigation water of 19 to 74% depending on the crop, when compared to the control consumption. There were no significant differences in yield and product quality between the experimental fields and controls. Crop coefficients that were calculated experimentally were very close to those selected from the literature.

The main issues for scheduling irrigation are two:

a) the date that the cultivation should be irrigated (when?) and
b) the irrigation dose (how much?).

The methodology, described above, answers the second question by obtaining information on the date from the farmers, who select the irrigation date empirically and occasionally on the basis of water availability on the collective irrigation network that normally operates on a rotation system.

The farmers select the date of irrigation in almost a correct way, based on low soil moisture content. This methodology informs the farmers of the necessary amount of water required for each one of the crops for optimum growth, without wasting irrigation water, leading to rational irrigation management. The proposed methodology does not require extensive or detailed soil measurements since it relies on simple mass balance equations and meteorological data, which are generally readily available. It is a handy methodology that can be easily applied giving very good results with very low cost. The only drawback of the method is that the farmers should have enough experience in order to administer during the first irrigation enough water to approach field capacity.

Overall, the proposed methodology is based on simple yet robust data that are easy to collect and use through a straightforward low investment cost infrastructure. The cost benefit ratio of the methodology is deemed extremely favourable on the basis of the water savings achieved. These may be translated to environmental protection (used water volumes reduction, reduction of potential pollution through reduced runoff and leaching, less energy consumption for water abstraction-transportation), and also savings on energy bills due to the reduced water volumes used.

2.3 Relationships between different methods

The DSS Tool allows the user to examine the rainfall pattern for the climate regime chosen, and to select the irrigation water source (river water or well water), the salinity level in the case of well water, the ratio of different waters used, and **the dates, durations, and amount of irrigation water applied**. The rainfall pattern and intensity can also be modified by this tool.

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3 Knowledge gaps, potential innovation, and sustainability of innovations (problems and opportunities)

METHDS	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
Optimization of applying irrigation water to high salinity fields	Lack of knowledge to estimate the exact Leaching Fraction	Develop specific equations for different soil types of different edaphic-climatic conditions	Very complex problem due the implementation of many variable parameters (Climatic, soil, drainage, water quality)	Analyze if general equations could be developed to save time and money
Optimization of drainage in high salinity fields / effective monitoring	1.correlation of effective irrigation /drainage in fields with **shallow water table**	1. Improve drainage material 2. Develop protocols/methods for validation/calibration monitoring in soil salinity 3. Integrate technological solutions (mounted sensors, drones, robotics) to enhance ground-truthing capacity	Cost of drainage installation Maintenance of drainage installation irrigation water quality, shallow groundwater level and quality,	Reducing the cost with new installation techniques with new machinery and equipment. Automation and remote monitoring systems for sustainable drainage
	2.correlation of effective irrigation /drainage for removing **salt residual from root zone**	1. Improve drainage material 2. Develop protocols/methods for validation/calibration monitoring in soil salinity 3. Integrate technological solutions (mounted sensors, drones, robotics) to enhance ground-truthing capacity	Cost of drainage installation Maintenance of drainage installation irrigation water quality,	Reducing the cost with new installation techniques with new machinery and equipment. Automation and remote monitoring systems for sustainable drainage

4 Suggestions of ideas for innovative projects/Operational Groups

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
innovative water management irrigation in high salinity fields with shallow water table	DSS for irrigated fields with high salinity taking into account real time monitoring of crucial parameters – with supplementary Support of farmers with advisory services	Researchers, Agronomists, Farmers, Irrigation Land Reclamation Organisations, Department of Agriculture/Soils (e.g. Directorate of Agriculture at Regional Level),	Irrigation/farming practices responsible for higher crop yield in a sustainable way; identification of best practices for farmers; improve salinity management; establishment of surveillance programs of soil salinity in irrigated agriculture

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5 Needs from practice and further research

5.1 Needs from practice

In order the provided DSS Tool for Efficient Irrigation on High salinity Fields to be effective we must take into consideration the following:

- Reclamation strategies could be implemented **only though advisory services** because of the complexity and variability of factors that cause salinity and sodicity problems. Each situation must be evaluated separately because of economic, political, climatic, and resource differences.
- In order to let all this information be familiar with the farmers, training session about Understanding Salt and Sodium in Soils, Irrigation Water and Shallow Groundwater should be organised to explain soil salinity terms, problems, and possible solutions in an easy-to-understand format.

The training should be explaining the terminology of salt-affected soils and then **describe the effects** of soluble salts and exchangeable cations **on soil properties and on growing plants**.

- Lack of accurate inventory of salt-affected areas (extent, severity) at local, regional, national, and EU levels (required for field management, crops and irrigation water planning, identifying recharge and discharge saline areas, prioritising salt-affected land for alternative land uses, and for providing information to guide development of policies)
- Need of EU network of salt-affected soils for sharing data and knowledge (e.g., development of monitoring grids and data transfer tools to inventory information available in the existing farmer networks)
- Lack of policy instruments for encouraging soil salinity mapping and monitoring: Develop policies/programmes on salinity surveillance.

5.2 Further research

- New modelling approaches combining multiple sources data (RS, terrain attributes derived from DEM, geological maps, land use, meteorological data, irrigation water quality, groundwater level and quality, etc.) for mapping soil salinization and assessing salinity risk at regional levels
- Introducing of new salinity tolerant crops and new farming practice to improve low yield
- Modelling salinization risk in critical areas considering different climate change scenarios
- Integrating new technologies in mapping (drones, robotics, novel sensors and data upload systems)

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6 References

Kaner, A., Tripler, E., Hadas E., Ben-Gal, A. (2018). Agronomic-economic Coupled Decision Support Application for Irrigation with Water Containing Salts. In: O. Wendroth, Robert J. Lascano, L. Ma (Eds). Bridging Among Disciplines by Synthesizing Soil and Plant Processes. Advances in agricultural systems modelling Volume 8, ASA, CSSA, and SSSA, Madison, WI. doi:10.2134/advagricsystmodel8.2017.0013

SWAGMAN Destiny. A tool to project productivity change due to salinity, waterlogging and irrigation management, Meyer W.S., Godwin D.C. and White R.J.G. (1996), Proc. 8th Aust. Agron. Conf. Toowoomba Qld, 425-428.

"AQUATER Software as a DSS for Irrigation Management in Semi-Arid Mediterranean Areas" Marco Acutis, Alessia Perego, Ettore Bernardoni, Michele Rinaldi Ital. J. Agron. / Riv. Agron., 2010, 5:205-215

"Decision Support Systems for Efficient Irrigation in the Middle Rio Grande Valley" Ramchand Oad; Luis Garcia; Kristoph-Dietrich Kinzli; Dave Patterson; and Nabil Shafike JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING © ASCE / MARCH/APRIL 2009 / 177

Allen R., Pereira L., Raes D. and Smith M. (1998), Crop evapotranspiration. Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56, FAO, Rome.

Arambatzis G., Hatzigiannakis E., Evangelides C., Panagopoulos A. "A handy Irrigation Management Method through Meteorological Data. Case Study in N. Greece" Global NEST Journal, Vol 16, No 2, pp 219-228, 2014

Chartzoulakis K. (2005), Advisory tele-information system for farmers to irrigate cultivations, NAGREF Journal, 22, 7-9.

Papazafiriou Z. (1999), Crop water requirements, ZITI publications (In Greek).

Paltineanu C., Panoras A.G., Mavoridis I.G. and Louisakis A. (1999), Estimating reference evapotranspiration and irrigation water requirements in the Gallikos river basin, Greece, International Agrophysics, 13, 49-62

Panoras A., Papazafiriou E. and Poultsidou Th. (2001), Estimation of crop coefficients for six relations of evapotranspiration in the Southern part of Thessaloniki plain, Agricultural Research, 24(1), 37-45

Ritzema H.P. (1994), Drainage principles and applications, I.L.R.I. Wageningen, The Netherlands.
Shani, U., Ben-Gal, A., Tripler, E., Dudley, L.M. (2007). Plant response to the soil environment: An analytical model integrating yield, water, soil type, and salinity. Water Resources Research. 43, W08418 doi: **https://doi.org/10.1029/2006WR005313**

Van Hoorn J.W. (1979) Effect of capillary flow on salinization and the concept of critical depth for determining drain depth, Proc. Int. Drainage Workshop, I.L.R.I. Publication No 25, Wangeningen, 686-700.

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