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THE USE OF NON CONVENTIONAL WATER RESOURCES

Proceedings of the International Workshop
Alger, Algeria, 12-14 June 2005

Edited by
Atef Hamdy

CIHEAM / IAMB -EU DG Research

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Centre International de Hautes Etudes Agronomiques Méditerranéennes

International Centre for Advanced Mediterranean Agronomic Studies

Président / *Chairman:* Mouïn HAMZÉ
Secrétariat Général / Secretary General: Bertrand HERVIEU

11, rue Newton
75116 PARIS
Tel. +33 1 5323 9100 - Fax +33 1 5323 9101
Email : secretariat@ciheam.org

IAM

Instituts Agronomiques Méditerranéens
Mediterranean Agronomic Institutes

Bari - Chania - Montpellier - Zaragoza

IAM - Bari
Directeur : Cosimo LACIRIGNOLA
Via Ceglie 9 - 70010 Valenzano, Bari, ITALIE
Tel. + 39 080 4606 111 - Fax + 39 080 4606 206
Email : iamdir@iamb.it
www.iamb.it

IAM - Chania
Directeur : Alkinoos NIKOLAIDIS
P.O. Box 85 - 73100 Chania, Crete, GREECE
Tel. 30 2821 03 50 00 - Fax 30 2821 03 50 01
Email : alkinoos@maich.gr
www.maich.gr

IAM - Montpellier
Directeur : Vincent DOLLé
3191, route de Mende
34033 Montpellier Cedex 5, FRANCE
Tel. 33 04 6704 60 00 - Fax 33 04 6754 25 27
Email : sciuto@iamm.fr
www.iamm.fr

IAM - Zaragoza
Directeur : Luis ESTERUELAS
Apartado, 202 - 50080 Zaragoza, SPAIN
Tel. 34 976 71 60 00 - Fax 34 976 71 60 01
Email : iamz@iamz.ciheam.org
www.iamz.ciheam.org

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PART FOUR – NON CONVENTIONAL WATER RESOURCES MANAGEMENT

FOREWORD

In arid and semi-arid regions, growing water scarcity threatens economic development, sustainable human livelihoods and environmental quality.

The non-conventional water resources, the treated wastewater can be used to compensate for the shortage in irrigation water needed to meet the water needs of the expanding irrigated areas, thereby allowing valuable freshwater to be saved for drinking and other domestic recreational uses.

Municipal wastewater is an increasingly renewable water resource, it is roughly estimated to be about 10% of the available water resources in the Southern Mediterranean countries. Technically and politically, the importance of this complementary water source for irrigation is well recognized.

The biggest question, however, is: *what are the reasons limiting the full use of wastewater, even the treated one?* The immediate answer to the raised question is to be mainly attributed to the absence of practical, affordable safeguards that do not threaten the sustainable livelihoods dependent on wastewater or diminish the important role this resource plays in achieving food security. Equally, the way of thinking of decision-makers, the water users and the consumers has to be changed from feeling they have to deal with a costly nuisance, to trying to harvest a potentially valuable source for irrigation. To achieve such goal in the Mediterranean countries, those facing acute shortage in the freshwater resources, there is an urgent need to have a realistic, effective and sustainable management approach that takes into consideration the tradeoffs between the health of the producers and the consumers of wastewater irrigated produce, the quality of soils and water, wastewater irrigation benefits, farmers' opinion, public perceptions and institutional arrangements. Those are the major issues to be discussed and debated during the non-conventional water resources workshop.

I am quite sure that during yours presentations and discussions we can come up with concrete recommendations and valuable proposals to set new strategies for the sustainable use of such non-conventional water source.

Cosimo Lacirignola

Director, CIHEAM-IAM Bari

INTRODUCTION

Million of small-scale farmers around the world irrigate with marginal quality water. There are two major types of non-conventional water resources (marginal quality water): wastewater from urban and peri-urban areas, saline and sodic agricultural drainage water and groundwater.

The use of wastewater and saline or sodic water in agriculture increases the total volume of irrigation water in many areas, but the off-farm and long-term negative implications can be substantial. Wastewater use can have health impacts for farmers and consumers, while un-sustained use of saline and sodic water can impair soil quality and productivity, reducing crop yields. The challenges for public officials is to set policies that enable farmers to maximize the resources, while protecting public health and the environment.

Risk management is essential for preventing adverse impacts when irrigating with wastewater or saline sodic water. Untreated wastewater disposal pollutes freshwater and causes harmful health and environmental impacts, while inappropriate use of saline and sodic water causes soil salinization and water quality degradation that can limit crop choice and reduce yields.

Nowadays, on the globe, the use of non-conventional water resources is becoming a reality. However, most countries are still facing many obstacles when trying to use and manage this water in order to maximize the potential benefits, while minimizing the potential risk.

Those are the two key points should be carefully considered and should be incorporated in an integrated management approach that must be sustained intuitionally over a long period of time.

Safe and sustainable use and management of non-conventional water resources is a complex process. The complex challenges of managing water resources of marginal quality require a programmatic, proactive and forward-looking perspective.

In the Mediterranean region there is an urgent need for a framework that provides a safe, sustainable and profitable use of non-conventional water resources in the irrigation sector.

The tasks are difficult, but the acute shortage in freshwater resources most developing countries are now facing implies that every drop of wastewater should be collected, treated, used and recycled.

Aware of this, Bari Institute centred a great part of its activities on the sustainable use and management of non-conventional water resources. The topic received priority in most countries of the Mediterranean region and this encouraged the Institute to establish an information research network on this subject with the involvement of more than 40 experts covering most countries of the region and researchers from nearly 20 international, regional and local institutions and organizations.

The networking activities, those are running for more than 15 years, had resulted in increasing and updating our know-how on the subject, improving the institutional capacity building and the human resources capability not only in identifying the problem, but, equally in finding the sustainable solutions.

This workshop held today in Algeria, gathering many Algerian experts and several experts from the region, represent a part of the networking activities.

The meeting is held to discuss, among each others, the ideas and views, to exchange the experience and to evaluate the lessons learned concerning the successful cases as well as the failure ones to set together the needed plans and strategies to be easily implemented in order to achieve our final goal in having a sustainable and safe use of such non-conventional water resources.

Prof. Atef Hamdy

Director of Research, CIHEAM-IAMB Bari

PREFACE

La problématique de **l'utilisation de l'eau non conventionnelle** est plus que jamais posée en Algérie. La recherche de la maîtrise des techniques liées d'un côté aux opérations de traitement et d'épuration et de l'autre côté à l'utilisation des eaux traitées et épurées constitue un des principaux objectifs de la politique agricole en Algérie.

L'utilisation rationnelle des ressources naturelles et notamment l'eau constitue une préoccupation majeure partout dans le monde et particulièrement dans le bassin méditerranéen connu par la fragilité de ses sols et la rareté des apports en eau de pluie.

La demande croissante des populations pour la consommation en eau potable, associé aux risques multiples de pollution, justifient le recours à la réutilisation des eaux traitées. Cette alternative constitue une réponse aux préoccupations liées à la préservation de l'environnement et à l'utilisation économique de l'eau.

Pays de la rive Sud de la méditerranée, l'Algérie est confrontée à un climat qui se caractérise par des étés chauds et secs et des hivers doux et humides. Aussi, le problème de l'eau se pose – t – il avec acuité, et le recours à une utilisation économique de ce précieux élément reste de rigueur et ce, dans la perspective de répondre aux besoins de plus en plus croissants de la population, de l'agriculture et de

Ce séminaire, animé par des experts nationaux et internationaux destiné aux algériens en charge de l'utilisation des eaux non conventionnelles constitue une excellente opportunité pour le transfert de connaissances scientifiques sur l'utilisation rationnelle des eaux non conventionnelles, conformément aux normes sanitaires internationales.

Il contribuera en outre, au renforcement des potentialités existantes et à leur dotation en instruments scientifiques et techniques nécessaires à la prise en charge des activités liées à l'utilisation des eaux non conventionnelles.

Le déroulement de ce séminaire a été rendu possible grâce à l'initiative de Monsieur le Secrétaire Général du CIHEAM et la collaboration exemplaire de l'IAM de Bari.

AZIB Makhlouf

Vice Président du CIHEAM

PART ONE

NON-CONVENTIONAL WATER RESOURCES: AN OVERVIEW

URBAN WASTEWATER: PROBLEMS, RISKS AND ITS POTENTIAL USE FOR IRRIGATION

M. Shatanawi*, A. Hamdy ** and H. Smadi*

*University of Jordan, Amman, Jordan

Mediterranean Agronomic Institute of Bari (CIHEAM-IAMB), Via Ceglie 9, Valenzano (BA), Italy
E-mail: hamdy@iamb.it

BACKGROUND ABOUT MEDITERRANEAN REGION

The Mediterranean region comprises the Mediterranean Sea and its coastal area. It can be roughly located between 30°N – 50°N latitude and 10°W -40°E longitude. The Mediterranean countries can be grouped according to similar climatologically and socio-economic characteristics: northern basin countries (Spain, France, Monaco, Italy, Former Yugoslavia, Albania, and Greece) and southern basin countries (Turkey, Cyprus, Syria, Lebanon, Palestine, Egypt, Libya, Malta, Tunisia, Algeria, and Morocco) (Rosenzweig and Tubiello, 1997; Massoud, Scrimshaw and Lester, 2003).

Total population of the region is actually around 427 million inhabitants with 145 million living near the sea and an additional 180 million tourists each year. By 2025, the population is expected to increase by 17-19% and the tourist population by 40%. The demographic evolution of population is fundamentally different in Eastern and Southern countries (intensively growing) compared to the Northern ones (stabilizing or decreasing). It is aggravated by a very intensive urbanization often along the coastal areas (Kamizoulis *et al.*, 2003; Massoud *et al.*, 2003).

Climatically, it is characterized by mild temperature, winter-dominated rainfall, and dry summer (Wigley, 1992). Annual precipitation ranges between 275 and 900 mm, the average temperature in winter months is below 15ºC and the hours per year at which the temperature falls below freezing (0ºC) do not exceed 3% of the total. Northern regions are relatively more temperature and humid. While southern regions are warmer and drier with endemic water shortages due to the interaction of relatively low seasonal rainfall and high evapotranspiration rates (Rosenzweig and Tubiello, 1997).

WATER RESOURCES IN THE MEDITERRANEAN BASIN

Renewable water resources are very unequally shared across the Mediterranean basin with around 72% located in the north (Spain, France and Monaco, Italy, Malta, Bosnia-Herzegovina, Croatia, Slovenia, R.F. of Yugoslavia, Albania, and Greece), 23% in the east (Turkey, Cyprus, Syria, Lebanon, Israel, Palestinian, Territories of Gaza and the West Bank, and Jordan), and 5% in the South (Egypt, Libya, Tunisia, Algeria, and Morocco). Countries of the Southern Mediterranean and Middle East region are facing increasingly more serious water shortage problems. Some countries of the Southern Mediterranean and Middle East region have few naturally available fresh water resources and rely mainly on groundwater. Surface waters are already in most cases utilized to their maximum capacity. Groundwater aquifers are often over-drafted and sea and brackish water intrusion in coastal areas has reached threshold limits in some locations. Non-renewable deep or fossil aquifers are being tapped to varying degrees. Exploitation of non-renewable resources of Saharan aquifers is intensive in Libya, Egypt, Tunisia and Algeria. Desalination of brackish and seawater is already under implementation or planned in some countries despite its high cost (Margeta and Vallée, 2000; Shelef and Azov, 1996; Kamizoulis *et al.*, 2003)

Due to rapid population growth, the average annual per capita renewable water is rapidly decreasing since 1950 (Fig. 1). It varies across a wide range from a little over 100 to more than 1000 cubic meters per year (Margeta and Vallée, 2000). All the Mediterranean countries of the EU are expected to maintain themselves at or above 3000 m^3/inh.yr when in the major part of the other

Mediterranean countries, the projected water availability is below the level of "chronic water scarcity" (< 1000 m^3/inh.yr) (Massoud *et al*., 2003; Hamoda, 2004; Wigley,1992).

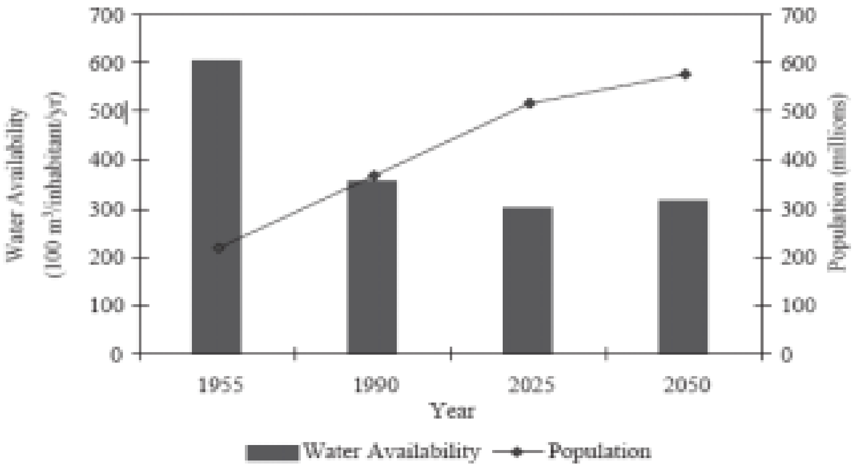

Figure 1.Population growth and annual renewable freshwater availability / inhabitant in the Mediterranean region

In the Mediterranean basin as a whole, 72 % of water resource is used for irrigation, 18 % by industry, and 10% for domestic consumption (Massoud *et al.*, 2003; Redwood, 2004).

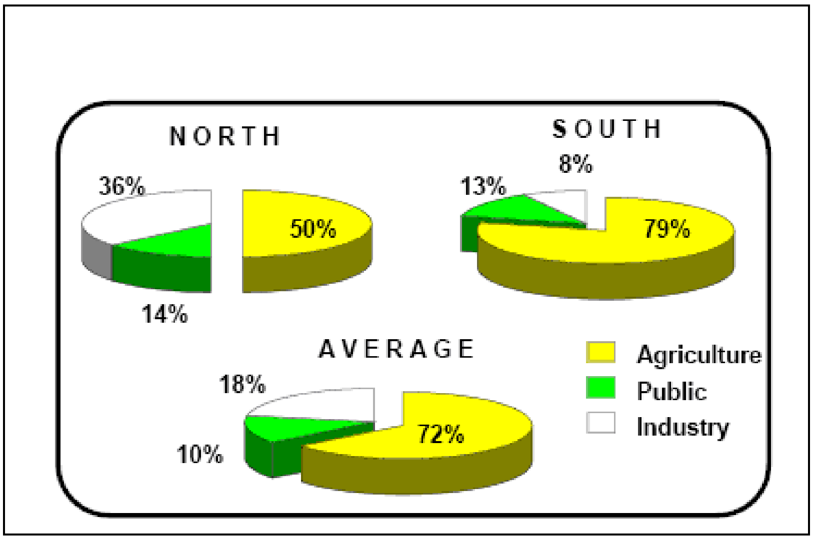

Figure 2.Water use in the Mediterranean countries (Hamdy and Lacirignola, 2005)

Agriculture is the main water-consuming sector. It accounts for 72% of the total demand in the Mediterranean Basin (48% in the North and approximately 80% in the South and East), (Plan Bleu, 2006).

WASTEWATER DEFINITIONS AND CHARACTERISTICS

-Definitions of wastewater

It is assumed that urban wastewater maybe a combination of some or all of the following: Domestic effluent consisting of black water (excreta, urine, and associated sludge) and grey water (kitchen and bathroom wastewater) water from commercial establishments and institutions, including hospitals industrial effluent Storm water and other urban runoff (Hamdy . and Ragab, 2005).

In irrigation, sometimes the term marginal quality water is used. This is refers to water whose quality might pose a threat to sustainable agriculture and or human health, but which can be used safely for irrigation provided certain precautions are taken. Marginal water quality water is water that has been polluted as a consequence of mixing with wastewater or agriculture drainage (Cornish *et al.*, 1999). The term can also refer to water with a high salt content. Marginal quality water can also be considered wastewater (Hamdy and Ragab, 2005).

Also wastewater is defined by (AL-Shreideh, 2001), it is the water that results from domestic use and could be mixed industrial wastewater of a quality which meets the connection requirements set by the official body.

-Characteristics of wastewaters

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. (Table1) shows the levels of the major constituents of strong, medium and weak domestic wastewaters. In arid and semiarid countries, water use is often fairly low and sewage tends to be very strong (Pescod, 1992; Crites and Tchobanoglous, 1998).

Table 1.Major of typical domestic wastewater (Pescod, 1992)

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)	850	500	250
Suspended solids	350	200	100
Nitrogen	85	40	20
Phosphorus	20	10	6
Chloride	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

Municipal wastewater also contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, etc. Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use. However, from the point of view of health, a very important consideration in agricultural use of wastewater, the contaminants of greatest concern are the pathogenic micro- and macro-organisms. Pathogenic viruses, bacteria, protozoa and helminthes may be present in raw municipal wastewater (Table 2) and will survive in the environment for long periods. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as total coliforms/100ml). Escherichia coli are the most widely adopted indicator of fecal pollution and they can also be isolated and identified fairly simply, with their numbers usually being given in the form of fecal coliforms (FC)/100 ml of wastewater (Crites and Tchobanoglous, 1998; WHO, 2006; Pescod, 1992).

Table 2.Type of Pathogens in Wastewater (Pescod, 1992)

Type of pathogen	
Viruses	Enteroviruses
Bacteria:	Pathogenic E. coli
	Salmonella spp.
	Shigella spp.
	Vibrio cholerae
Protozoa	Entamoeba

Wastewater treatment

The aim of wastewater treatment could be described as the process required to enable wastewater to be disposed safely, without being a danger to public health, and without polluting watercourses or causing other environmental nuisance. The necessary quality of reclaimed water varies according to the use, and consequently different unit processes and combination of unit processes are required for the achievement of the required quality (Fatta *et al.*, 2005; Crites and Tchobanoglous, 1998; Tchobanoglous Angelakis, 1996). Steps and objectives of wastewater treatment process are given in (Table 3).

Table 3.Steps and objectives of wastewater treatment process (Pescod, 1992)

Step	Objective
Preliminary treatment	The removal of coarse solids and other large materials often found in raw wastewater to enhance the operation and maintenance of subsequent treatment units
Primary treatment	The removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float by skimming.
Secondary treatment	The further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes
Tertiary and/or advanced treatment	Employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. As individual treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, and heavy metals and dissolved solids.
Disinfection	Involves the injection of a chlorine solution at the head end of a chlorine contact basin. Ozone and ultra violet irradiation can also be used
Effluent storage	Storage facility is, a critical link between the wastewater treatment plant and the irrigation system

Some degree of treatment must normally be provided to raw municipal wastewater before it can be used for agricultural or landscape irrigation or for aquaculture. The most appropriate wastewater treatment to be applied before effluent use in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements (Arar, 1988; Pescod, 1992; Asano *et al.*,1985).

DRIVING FORCES FOR THE DEVELOPMENT OF WASTEWATER RESOURCES

-Water resources problems

In the majority of developing countries of the Mediterranean, the legacy of past and current practices that threat water as an unlimited resource is leading to fast depletion of this valuable resource on which human life, food security and ecosystems survival depend (Hamdy and Lacirignola, 2005; Pereira *et al.*, 2002).

The mismanagement of the water resources and the notable water losses in all sectors, in particular, agriculture where efficiency below the 50% is a very clear indication of how weak the water sector in the majority of the Mediterranean countries. This also leads us to the conclusion that the current water crisis is mainly of water governance. The water sector is still characterized by ill funded and badly organized institutions. Legislation is generally incremental and out-dated and relevant rules and regulations are poorly enforced. Water activities are fragmented and divorced from the environmental management where ecosystem functions and services are ignored. Data and information on hydraulic, meteorological and socio-economic features are often inadequate, inconsistence and unreliable (Hamdy and Lacirignola, 2005; Pereira *et al.*, 2002).

-Structural imbalance

The dominant fact that will be strongly evident over next few decades is the structural imbalance between the constantly increasing demand for water to meet the needs and the natural available resources (Fig. 3).

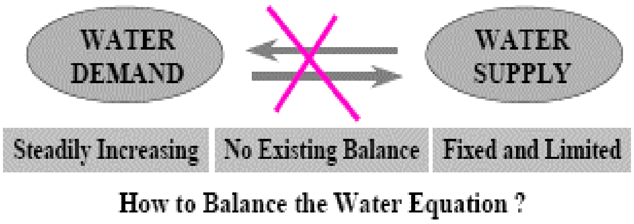

Figure 3.Water resources dilemma in the Mediterranean region (Hamdy and Lacirignola, 2005)

In the majority of countries in the region, the imbalance has appeared around the year 2000 and beyond. These countries will be facing similar problems that could outlines as follows:

i. Decline water resources per inhabitants both in terms of water availability and water withdrawals. It is expected that the available water per capita will be reduced by nearly 50% of the present one.
ii. Exploitation of water at a relatively high rate with the risk of water quality deterioration
iii. Excusive reduction in water withdrawals per capita
iv. Progressive degradation in the quality of available water resources because of increase waste load discharged in to water bodies and the atmosphere.

Water demand for the years 1990 together with the projections for 2010 and 2025 are given in (Fig. 4). This figure clearly indicates that there will be a progressive increase in the water demand within the next 25 years. Globally for the whole Mediterranean countries, it is expected that the water demand will be increased by nearly 50% in the year 2025 with respect to actual demand values (1990), (Hamdy, 2003).

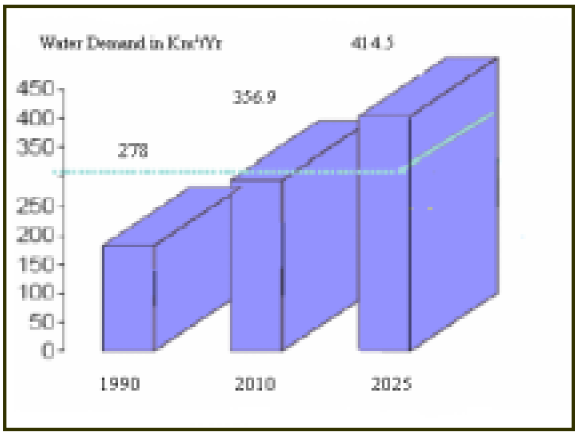

Figure 4. Actual water demand in 1990 and foreseen water demand for 2010 and 2050, in km^3/year (Hamdy, 2003)

The question emerging nowadays is how to meet this water demand at a time when pressures on resources are increasing and becomes increasingly. The solutions of those problems require new management strategies towards a more balanced approach (Hamdy, 2003).

-Water scarcity

Water in the Mediterranean region is a rare, fragile and unevenly distributed resource. Water demands are increasing; in numerous Mediterranean countries water use is approaching the limit level of available resources. Pressures on water resources will increase significantly in the South and East, and it is expected that, by 2025, 63 million people in the Mediterranean will be limited to less than 500 m^3 per capita per year (defined as the "shortage" threshold). The increase in water demand for agriculture and for urban use and the scarcity of resources signify that one out of every three Mediterranean countries will withdraw over 50% of the annual volume of its renewable natural resources (Plan Bleu, 2006; Massoud *et al.*, 2003; Pereira *et al.*, 2002).

Due mainly to very high population growth some countries, such as Jordan, Tunisia, and Malta, experience "absolute water stress" with per capita water availability of less than 500 m^3/inh/yr. In Malta, domestic water consumption exceeds 50% of the available water resources. In such places, the conventional water resources will be insufficient to even meet the domestic water demand, indicating that major developing countries in the region are experiencing chronic and absolute water stress (Hamdy, 2003).

Table 4.Mediterranean countries experiencing water scarcity in 1955, 1990 and 2025 projected, based on availability of less than 1,000 m^3 renewable water/ person/year. (Hamdy, 2003)

Water scarcity countries in 1955	Countries added to scarcity categories by 1990	Countries added to scarcity categories by 2025 (UN population projections)
Malta	Israel	Libya
Jordan	Tunisia	Morocco
	Algeria	Egypt
		Syria
		Cyprus

-Population trends and explosive urban growth

It is estimated that the population of the countries of the Mediterranean basin as a whole, currently around 400 million, will have reached between 520 and 570 million by 2025. The northern countries of the basin, from Spain to Greece, will account for only about one-third of the total population in 2025, whereas the countries in the south and east of the basin, from Morocco to Turkey, will contribute almost two-thirds of the total Mediterranean basin population in 2025, (Kamizoulis *et al.*, 2003; Plan Bleu, 2006).

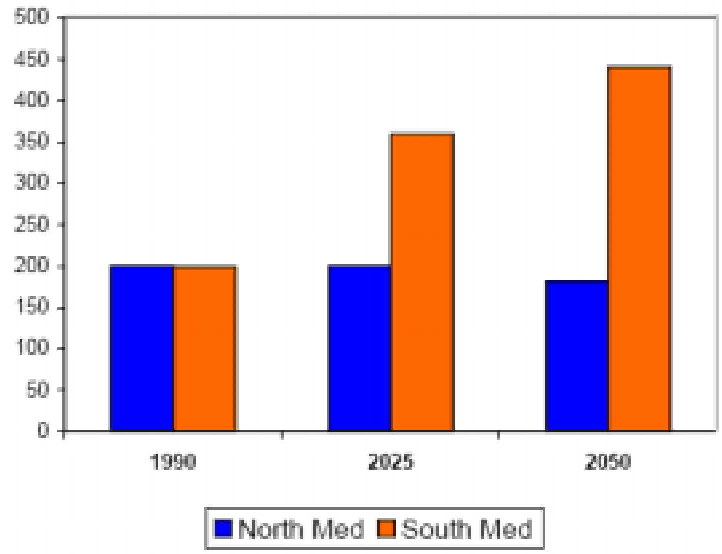

Figure 4. Population in the Mediterranean countries (Hamdy, 2003)

Rapid population is always linked with rapid urbanization. Urban growth will be explosive in the southern and eastern countries, where it is, on average, five times faster than it was in Europe last century. The rate is not the only factor to be considered. The size of urban population will be very large: 200 million more urban inhabitants in 2025 in the south and east of the basin. The urban population of the Mediterranean basin could in fact amount to between 380 and 440 million compared to a little over 200 million today. Generally, the annual growth of urbanization is high in the Mediterranean region, but it is much higher in the south (4.5%) compared to the north (2.8%). This population increase with a high urbanization rate will place serious stress on fresh-water resources, particularly with consumptive uses in the developing countries of the Mediterranean region. Under such conditions, Southern and Eastern Mediterranean countries will experience difficulties in ensuring self-sufficiency in meeting agricultural, domestic and industrial water needs. The supply of drinking water to urban areas will be one of the most critical problems in those countries (Hamdy and Lacirignola, 2005; Plan Bleu, 2006).

BENEFITS AND NEGATIVE EFFECTS OF USING TREATED WASTEWATER

A. Benefits

- ***Environmental benefits***

Treated wastewater may be used for different purposes without endangering human health or damaging the environment (AL-Shreideh, 2001).

Reusing treated wastewater, rather than disposing of it, may help improve the environment by:

- Prevention of surface water pollution which could occur when wastewater is not used but is discharge in rivers and lakes. Planned reuse of wastewater for irrigation will greatly help in the elimination of several environmental pollution problems: dissolved oxygen depletion, eutrophication, foaming, fish deaths, etc. (Friedler, 2001).
- The use of treated wastewater for irrigation will help in reducing the over-pumping and exploitation of groundwater, thus avoiding sea-water intrusion and deterioration of exploitation of ground water quality, groundwater being main source of drinking water supply (Choukr-Allah and Hamdy, 2003; Cornish *et al.*, 1999).
- Better rational use of the water resources with low quality being used for irrigation purposes and good quality freshwater is being used for potable water and other special uses (Hamdy and Ragab, 2005).

- The use of treated wastewater serves also as a nutrients source; this reduces the use of artificial fertilizers with a reduction in energy expenditure and industrial pollution elsewhere (Hamdy and Ragab, 2005).
- Helping control dust storms and desertification in arid zones through irrigating and fertilizing tree belts (AL-Shreideh, 2001).
- Improving the soil quality by reusing treat and wastewater in poor desert soils (AL-Shreideh, 2001).

- ***Social benefits***

Much of the population growth has been attributed to rural urban migration in search of jobs and better living conditions. Reusing reclaimed wastewater can alleviate unemployment of unskilled laborers, improving the quality of life and income distribution of the rural population and providing jobs and settlement opportunities in rural areas (AL-Shreideh, 2001).

- ***Economic benefits***

In the developing countries of the region, the value added locally to production in agriculture is normally high, giving a further advantage to agricultural use of wastewater over other potential uses.
Reclaiming and reuse of wastewater has a clear positive impact in sustaining tourism and related activities which otherwise would be adversely affected by disposing of untreated or partly treated sewage. It will also lower costs incurred otherwise in treating epidemics and diseases (AL-Shreideh, 2001; Friedler, 2001).

B. Negative effects

- ***Health risk***

Irrigation with untreated wastewater can represent a major threat to public health, food safety and environmental quality (Hamdy and Ragab, 2005). As a consequence, its acceptability to replace other water resources for irrigation is highly dependent on whether the health risks and environmental impacts entailed are acceptable (Asano *et al.*, 1985). Examples of the different microbial pathogens and the major diseases they cause are given in (Table 5),

Table 5. Microbial pathogens detected in untreated wastewaters (Toze, 1997)

Microbial type	Major diseases
VIRUSES	
Poliovirus	Poliomyelitis
Enterovirus	Gastroenteritis
Echovirus	Heart anomalies, Meningitis
Hepatitis A virus	Hepatitis
Adenovirus	Respiratory disease, conjunctivitis
Reovirus	Not clearly established
Norwalk agent	Gastroenteritis
SSRV	Diarrhoea, vomiting, fever
Rotavirus	Gastroenteritis
Astrovirus	Gastroenteritis
BACTERIA	
Vibrio cholerae	Cholera
Salmonella typhi	Typhoid, Salmonellosis
Enteropathogenic E.coli	Gastroenteritis
Campylobacter jejunei	Gastroenteritis
Shigella dysinterae	Dysentery
Yersinia enterocolitica	Yersiniosis
PROTOZOAN	
Giardia intestinalis	Giardiasis

Cryptosporidium Parvum	Diarrhea, fever
Entamoeba histolytica	Amoebic dysentery
HELMINTHS	
Ascaris lumbricoides (Round worm)	Ascariasis
Trichuris trichiura (Wrip worm)	Trichuriasis

Wastewater does carry pathogenic organisms and, in general, modern treatment methods (for example, activated sludge) are not designed to eliminate them. Wastewater disinfection eliminates them, but it is relatively costly and beyond the technological and financial capabilities of most developing countries in many regions. Organisms that can survive wastewater treatment (without disinfection) include bacteria, protozoa, helminths, and viruses. Most of these pathogens affect the human body only through ingestion of waste-contaminated water and food. The major factors that control the degree of microbial health risk include, (Khouri, 1994): i) the ability of pathogens to survive or multiply in the environment, ii) the dose required for infection, iii) the need for, and the presence or absence of, intermediate hosts and iv) the susceptibility of the person at risk (constant exposure may have created (immunity) (Fatta *et al.*, 2005; FAO, 2000).

The health conditions of the population living in the areas of intensive use of untreated wastewater also degraded. Diseases such as typhoid and hepatitis spread at a much greater rate in these regions. Animals were also subjected to several waterborne diseases such as tapeworm and tuberculosis and other infectious diseases, (Bazza, 2002; Angelakis, 2003).

-Negative environment impacts

The use of wastewater in agriculture has the potential for negative environmental impacts on soil and water bodies:

-Impact on soil

The most important negative effect on the environment caused by agricultural wastewater use is the increase in soil salinity, which, if not controlled, can decrease productivity in the long term. There are four ways in which salinity affects soil productivity: (WHO, 2006; Pereira *et al*., 2002).

- It changes the osmotic pressure at the root zone due to high salt content.
- It provokes specific ion (sodium, boron or chloride) toxicity.
- It may interfere with plant uptake of essential nutrients (e.g. potassium and nitrate) due to antagonism with sodium, chloride and sulfates.
- It may destroy the soil structure by causing soil dispersion and clogging of pores spaces.

In the long term, wastewater use will always increase salinity of the soils and groundwater, as it contains more salts than fresh water. And therefore, it is necessary to combine the use of wastewater with practices to control salinization, (WHO, 2006).

-Impact on water bodies

Application of wastewater in agriculture may cause percolation of wastes to the ground water or flushing into surface water. A high organic load will affect the dissolved oxygen levels, thus impacting aquatic organisms. Additionally, the nitrogen or phosphorus washed into water bodies will lead to eutrophication and subsequent oxygen depletion and will facilitate the growth of toxin-producing algae. Nitrogen can contaminate ground water and surface water bodies by infiltration and agricultural runoff. High concentrations of biodegradable organic matter in agricultural runoff water can lead to the consumption of dissolved oxygen in lakes and rivers (WHO, 2006; Choukr-Allah and Hamdy, 2003). The discharge of the wastewater in a non-treated form into watercourses and rivers led to the degradation of surface water quality to the point where it became unsuitable for direct use for drinking purposes. The most important results of this noticeable pollution of rivers and other water bodies were the disappearance of living organisms because of the lack of oxygen, the appearance of undesirable plants and weeds that clog water canals in certain regions, hateful odors resulting from decomposition of organic materials and the abundance of insects and rodents.

WASTEWATER USE: MAJOR CONSTRAINTS

-Institutional manageability

In most of the Mediterranean countries, few governmental agencies are adequately equipped for wastewater management. In order to plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This require the availability of a substantial number of engineers, access to a local network of research for scientific support and problem solving, access to good quality laboratories and monitoring system and experience in management and cost recovery. In addition, all technologies, included the simple ones, require devoted and experienced operators and technicians who must be generated through extensive education and training (Choukr-Allah and Hamdy, 2005).

For adequate operation and minimization of administrative conflicts, a tight coordination should be well defined among the ministries involved such as those of agriculture, health, water resources, finance, economy, planning, environmental protection and rural development (Choukr-Allah and Hamdy, 2005).

-Public awareness and acceptance of wastewater

This is the bottleneck governing the wastewater use and its perspective progress. To achieve general acceptance of re-use schemes, it is of fundamental importance to have active public involvement from the planning phase through the full implementation process.

Some observations regarding social acceptance are pertinent. For instance, there may be deep-rooted socio-cultural barriers to wastewater re-use. However, to overcome such an obstacle, major efforts are to be carried out by the responsible agencies (Choukr-Allah and Hamdy, 2005).

Gaining public acceptance is easier once the need to use wastewater is established. If a community is aware of water scarcity and the need to conserve high quality water sources for domestic purposes, they will be more willing to accept wastewater use (WHO, 2006).

-Financial aspects

Financial factors are important especially when studying and appraising the feasibility of a new scheme for the use of wastewater. Even an economically worthwhile project can fail, however, without careful financial planning.

Economic and financial considerations are critical for encouraging the safe use of wastewater. Economic analysis seeks to establish the economic feasibility of a project and enables comparison between different options. The (often hidden) cost transfers to other sectors (e.g. the health and environmental impacts on downstream communities) need to be included in a cost analysis (Choukr-Allah and Hamdy, 2005; WHO, 2006).

POLICIES AND GUIDELINES

Guidelines on wastewater recycling and reuse are essential. They help protect public health, increase water availability, prevent coastal pollution and enhance water resources and nature conservation policies. Unifying wastewater recycling and reuse regulations around the Mediterranean basin would contribute to secure economic and touristic exchanges in the region (Kamizoulis *et al.*, 2003).

The existence of such guidelines means an important step in the planning and implementation of safe use of reclaimed wastewater for irrigation, because it contributes to sustainable development of landscape and agricultural irrigation. Guidelines for reclaimed wastewater use for irrigation must clearly define what is allowed and what is forbidden to execute (Ursula *et al.*, 2000). This can be defined in great detail or in a broad manner, but must take into account some important specific local conditions, such as the quality of reclaimed wastewater, soil, climate, relevant crops and agricultural practices (Helena *et al.*, 1996; Papadopoulos, 1997).

There is not a common regulation of wastewater reuse in the world due to various climatic, geological and geographical conditions, water resources, type of crops and soils, economic and social aspects, and country policies towards using wastewater influents for irrigation purposes (Fatta *et al.*, 2005).

International guidelines for use and quality standards of wastewater exist but policies for each country are necessarily to reflect local conditions. In many countries where wastewater use in agriculture takes place, national polices and guidelines are lacking (Van der Hoek, 2004; Kypris, 1988).

Some countries and organizations have already established reuse standards such as US.EPA, California, WHO and FAO. Most of the developing countries have adopted their own standards from the leading standards set by either FAO, WHO, California, etc. Most countries where wastewater irrigation is practiced have public health regulations to protect both the agricultural workers and the irrigated crops consumers (Fatta *et al.*, 2005).

International policy may affect the creation of national wastewater use policies. Countries agree to treaties, conventions, international development targets, etc. that may commit them to carry out certain actions (WHO, 2006).

Some countries have taken the approach of minimizing any risk and have elaborated regulations close to the California's and US.EPA criteria, but because these criteria are strict, expensive and take specific conditions into account, other countries adopted the wastewater criteria based on the guidelines of (WHO, 1989), which are more flexible. But some guidelines were not sustainable and would lead to reduced health protection, because they would be viewed as unachievable under local circumstances. According there was a particular need to conduct a review of these guidelines, so the WHO published the volume of the guidelines *for the safe use of wastewater, excreta and greywater (2006),* so many countries can adopt or adapt them for their wastewater excreta use practices (WHO, 2006; Fatta *et al.*, 2005).

However, it is now widely recognized that treated wastewater reuse constitutes an important and integral component of the comprehensive water management programs of the majority of countries, more so in the water scarce ones. This implies that these countries should have national policies and strategies relating to wastewater management in general and wastewater reuse for agriculture, in particular, in order to guide programs, projects and investments relating to wastewater collection, treatment, reuse and disposal in a sustainable manner (Hamdy and Karajeh, 2001; Angelakis, 2003).

This requires the establishment of a clear policy with regard to wastewater management (Hamdy and Karajeh, 2001), the policy should be compatible with a number of related sectoral or sub-sectoral policies such as national water management and irrigation policy, national health, sanitation and sewage policy, national agricultural policy and national environmental protection policy. Such policy should give guidance on the following issues:

-The current and future contribution of treated wastewater to the total national water budget.

- Criteria required to achieve maximum benefit of treated wastewater reuse for the different water sectors uses.
- Modalities for strengthening the national capacity building in this sector (Hamdy and Karajeh, 2001).

International guidelines

-WHO Guidelines

WHO (1989) Guidelines for the safe use of wastewater in agriculture took into account all available epidemiological and microbiological data and specified the microbiological quality and the treatment method required to achieve this quality, such quality is limited to the use of stabilisation ponds since it is cheap, simple and ensure removal of parasites which is the most infectious agent in the developing world. WHO (1989) guidelines are presented in (Table6).

Table 6. Guidelines for the use of treated wastewater in agriculture (Source: WHO, 1989)

Category	Reuse conditions	Exposed group	Intestinal nematode. eggs per litre[a]	Fecal coliforms (MPN per 100ml)[a]	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [b]	Workers, consumers, public	≤1	≤1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [c]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by irrigation technology, but not less than primary sedimentation

a During the irrigation period.

b A more stringent guideline (200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may cone into direct contact.

c In the case of fruit trees, irrigation should cease two weeks before fruit is picket, and no fruit should be picked off the ground. Sprinkler irrigation should be used.

The main features of the WHO (1989) guidelines for wastewater reuse in agriculture are as follows:

- Wastewater is considered as a resource to be used, but used safely.
- The aim of the guidelines is to protect exposed populations (consumers, farm workers, populations living near irrigated fields) against excess infection.
- Fecal coliforms and intestinal nematode eggs are used as pathogen indicators.
- Nematodes are included in the guidelines since infectious diseases in developing countries are mainly due to the presence of parasites which are more resistant to treatment.

It was necessary to update the 1989 WHO guidelines to take into account recent scientific evidence concerning pathogens, chemicals and other factors, including changes in population characteristics, changes in sanitation practices and better method for evaluating risk. There was a particular need to conduct a review of both risk assessment and epidemiological data. And for better package the guidelines the third edition (WHO 2006) of *the "Guidelines for safe use of wastewater,* *excreta and greywater"* is presented in four separate volumes: volume 1: Policy and regulatory aspects, volume 2: Wastewater use in agriculture, volume 3: Wastewater and excreta use in aquaculture, and volume 4: Excreta and greywater use in agriculture. These updated guidelines are based on scientific consensus and best available evidence and designed to protect the health of farmers, their families, local communities and product consumers.

These guidelines were published following an expert meeting in Stockholm, Sweden (1999), that based on the Stockholm framework which is an integrated approach that combines risk assessment and risk management to control water-related disease. The framework is flexible, allows countries to take into consideration associated health risks that may result from microbial exposures (Fig. 6) and provides the conceptual framework and integrated approach to the WHO 2006 guidelines.

Figure 6. The Stockholm framework for developing harmonized guidelines for the management of water-related infectious disease.

For *assessment of health risk*, associated with human exposure to pathogens in wastewater, three types of evaluations are used: microbial analysis, epidemiological studies and quantitative microbial risk assessment (QMRA).

A health based targets (which is adopted in WHO guidelines 2006) uses the tolerable risk of disease as a baseline to set specific performance targets that will reduce the risk of disease to this level (WHO, 2006). Such WHO guidelines define a level of health protection that is expressed as health based target of 10^{-6} DALYS (loss of 1 healthy life year per million people or 31.5 seconds of a person life per year) to provide the level of health protection that is relevant to each hazards. Health based target can be reached when all protection measures are used. Usually a health-based target for agriculture can be achieved through a combination of health protections measures targeted at different components of the system, result in pathogens reduction 6-7 log units, and helminthes eggs reduction to a value around ≤ 1 egg/l (Table 7).

Table 7.Health-base targets for treated wastewater use in agriculture

Exposure scenario	Health-based target (DALY per person per year)	Log 10 pathogen reduction	Number of helminth eggs per liter
Unrestricted irrigation Lettuce onion	$\le 10^{-6}$ [a]	 6 7	 ≤ 1[b,c] ≤ 1[b,c]
Restricted irrigation Highly mechanized Labor intensive	$\le 10^{-6}$ [a]	 3 4	 ≤ 1[b,c] ≤ 1[b,c]
Localized irrigation High-growing crops Low-growing crops	$\le 10^{-6}$ [a]	 2 4	 No recommendation [d] ≤ 1[c]

[a] Rotavirus reduction. The health-based target can be achieved, for unrestricted and localized irrigation, by a 6-7 log unit pathogen reduction obtained by a combination of wastewater treatment and other health protection, including an estimated 3-4 log unit pathogen reduction as a result of natural die-off of pathogens.
[b] when children under 15 are exposed, additional health protection measures should be used (e.g. treatment to ≤0.1 egg per liter, protective equipment such as gloves or boot
[c] the mean value of ≤1 egg per liter should be obtained for at least 90% of samples
[d] no crops to be picked up from the soil.

The most effective means ensuring safety in wastewater use in agriculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the process, from generation and use of wastewater to product consumption. Three components of this approach are important for achieving the health based targets: system assessment, identifying protection control measures and methods for monitoring them.

-FAO guideline

FAO irrigation and drainage paper number 47 presents a guide to the use of treated effluent for irrigation and aquaculture, which is based on the WHO guidelines for the health protection measures (Table 8), (Pescod, 1992).

Table 8.Recommended microbiological quality guidelines for wastewater use in agriculture

Category	Reuse conditions	Exposed group	Intestinal nematode (eggs per litre)	Fecal coliforms (MPN 100ml)[a]	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	≤1	≤1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by irrigation technology, but not less than primary sedimentation

FAO suggested water quality guidelines, are equally applicable to evaluate wastewater for irrigation purposes in term of their chemical constituents, such as dissolved salts, relative sodium content and toxic ions (Table 9). (Table 10) presents phototoxic threshold levels of some selected trace elements.

Table 9.Water quality guidelines for maximum crop production (example)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity	ds/m	< 0.7	0.7- 3.0	> 3.0
Na, surface irrigation	me/l	< 4.0	4.0-10.0	>10.0
Na, sprinkler irrigation	m^3/l	< 3.0	>3.0	
Nitrogen (NO_3-N)[3]	mg/l	< 5.0	5.0- 30.0	>30.0
pH		Normal range 6.5-8		

Table 10.Threshold levels of trace elements for crop production (example)

Element	Recommended maximum concentration (mg/l)	Remarks
Cd	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cu	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions
Zn	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils
Pd	5.0	Can inhibit plant cell growth at very high concentrations.

-EPA water reuse guidelines

In 1992, Environmental Protection Agency (EPA) developed the Guidelines for water reuse (US-EPA, 1992). The guidelines were updated in 2004, by a committee, made up of national and international experts in the field of water reclamation and related subjects (US-EPA, 2004).

The major reuse categories are: urban, industrial, agricultural, environmental and recreational, groundwater recharge and augmentation of potable supplies. EPA's guidelines for each water reuse are given in (Table 11).

Table 11.EPA's guidelines for water reuse; source (US-EPA, 2004)

Types of reuse	Treatment	Reclaimed water quality	Reclaimed water monitoring
Urban reuse: all types of landscape irrigation(e.g., golf courses, parks, vehicle washing, toilet flushing, use in fire protection)	• Secondary • Filtration • Disinfection	• pH=6-9 • ≤10mg/l BOD • ≤2 NTU • No detectable fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • Turbidity-continuous • Coliform-daily • Cl_2 residual-continuous
Restricted Access area	• Secondary	• pH=6-9	• pH= weekly

irrigation where public access is prohibited or restricted	• Disinfection	• ≤30mg/l BOD • ≤30 mg/l TSS • ≤200 fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Industrial reuse:Cooling (once-through)recalculating cooling towers	• Secondary • Disinfection	• pH=6-9 • ≤30mg/l BOD • ≤30 mg/l TSS • ≤200 fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Agricultural reuse – Food crops not commercially processed (surface or spray irrigation)	• Secondary • Filtration • Disinfection	• pH=6-9 • ≤10mg/l BOD • ≤2 NTU • No detectable fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • Turbidity-continuous • Coliform-daily • Cl_2 residual-continuous
Agricultural Reuse – Food Crops Commercially Processed Surface Irrigation of Orchards and Vineyards	• Secondary • Disinfection	• pH=6-9 • ≤30mg/l BOD • ≤30 mg/l TSS • ≤200 fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Agricultural Reuse – Nonfood Crops Pasture for milking animals; fodder, fiber, and seed crop	• Secondary • Disinfection	• pH=6-9 • ≤30mg/l BOD • ≤30 mg/l TSS • ≤200 fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Recreational Impoundments Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed	• Secondary • Filtration • Disinfection	• pH=6-9 • ≤10mg/l BOD • ≤2 NTU • No detectable fecal coli/100ml • 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • Turbidity-continuous • Coliform-daily • Cl_2 residual-continuous
Landscape Impoundments Aesthetic impoundment where public contact with reclaimed water is not allowed	• Secondary • Disinfection	pH=6-9 ≤30mg/l BOD ≤30 mg/l TSS ≤200 fecal coli/100ml 1 mg/l Cl_2 residual minimum	• pH= weekly • BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Environmental reuse Wetlands, marshes, wildlife habitat, stream augmentation	• Variable secondary and disinfection (minimum)	Variable but not exceed: ≤30mg/l BOD ≤30 mg/l TSS ≤200 fecal coli/100ml	• BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-continuous
Groundwater recharge by spreading or injection into aquifers not used for public water supply	• Site-specific and use dependent • Primary (minimum) for spreading • Secondary (minimum) for injection	• Site-specific and use dependent	• Depends on treatment and use

Indirect potable reuse Groundwater recharge by spreading into potable aquifers	• Secondary • Disinfection	• Secondary • Disinfection • Meet drinking water standards after percolation through vadose zone	• Includes but limited to the following: • pH= weekly • BOD - weekly • TSS-daily • Coliform-daily • Cl_2 residual-Continuous • Turbidity-continuous • Drinking water standards quarterly
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary • Filtration • Disinfection • Advanced wastewater treatment	• Includes, but not limited to, the following: • pH = 6.5 -8.5 . • < 2 NTU 8. • No detectable total coli/100 ml. • 1 mg/l Cl2 residual (minimum) • Meet drinking water standards	• Includes, but not limited to, the following: • pH - daily . • Turbidity continuous • Total coliform daily. • Cl2 residual continuous. • Drinking water standards quarterly. • Other - depends on constituent
Indirect Potable Reuse Augmentation of surface supplies	• Secondary • Filtration • Disinfection • Advanced wastewater treatment	• Includes, but not limited to, the following: • pH = 6.5 -8.5 . • < 2 NTU 8. • No detectable total coli/100 ml. • 1 mg/l Cl2 residual (minimum) • Meet drinking water standards	• Includes, but not limited to, the following: • pH - daily . • Turbidity continuous • Total coliform daily. • Cl2 residual continuous. • Drinking water standards quarterly. • Other - depends on constituent
Construction Use Soil compaction, dust control, washing aggregate, making concrete	• Secondary • Disinfection	• 30 mg/l BOD 7. • < 30 mg/l TSS. • < 200 fecal coli/100 ml. • 1 mg/l Cl2 residual (minimum)	• BOD - weekly. • TSS - daily. • Coliform - daily. • Cl2 residual continuous

-European water directives

The legal status of wastewater reuse is not uniform across Europe. Many European countries do not have specific regulations. Some of them have national regulations, laws, recommendations and other (Helena *et al.*, 1996). So far no regulation of wastewater reuse exists at the European level. The only reference made by the EU on the matter of wastewater is Article 12 of the European Wastewater Directive (91/271/EEC), which specifies that "treated wastewater shall be reused whenever appropriate. Disposal routes shall minimize the adverse effects on the environment". The directive specified standards for discharge into fresh water and their catchments but no standards for reuse. It provides though regulations and permits for all discharge (Council of European Union, 1991; Kretschmer *et al.*, 2002).

Table 12.Requirements for discharges from urban waste water treatment plants: concentration and percentage of reduction values

Parameters	Concentration	Minimum percentage of reduction	Reference method of measurement
BOD_5	25 mg/l	70-90	Homogenized, unfiltered, undecanted sample.
COD	125 mg/l	75	Homogenized, unfiltered, undecanted sample Potassium dichromate
TSS	35 mg/l	90	Filtering of a representative sample.

Comparative analysis between international guidelines

-EPA vs. WHO

The EPA guidelines discussed in details the reclaimed water quality limits and wastewater treatment process. For the quality of reclaimed water, they have put limits to BOD, TSS, NTU and fecal coliform. WHO guidelines address concern of developing counties and thus are preserving limits for fecal coliforms and intestinal nematodes.

EPA (2004) has recommended the use of strict guidelines for wastewater use in irrigation of crops likely to be eaten uncooked, which are no detectable fecal coliforms/100ml, and for irrigation of commercially processed crops, fodder crops, etc. The guideline of EPA is 200 FC/100ml, and no nematode egg guideline is specified by EPA . In WHO 1989 guidelines, water quality of 1000 FC/100ml is allowed to irrigate crops likely to be eaten uncooked, and for irrigation of commercially processed crops, fodder crops, only a nematode egg is set by WHO 1989.

Regarding the treatment process, the WHO guidelines say that the microbiological water quality requirements can be met by a series of stabilization ponds whereas EPA stipulates secondary treatment followed by disinfection. Microbiological monitoring requirements also vary: the WHO guidelines require monitoring of intestinal nematodes, whereas the EPA guidelines rely on the sole monitoring of the total coliform count to assess microbiological quality and fecal coliforms removal (Table 13).

Table 13.Comparison of water quality guidelines between EPA 2004 and WHO 1989, for water reuse in agriculture

Agent	Type of reuse	Treatment required	BOD_5 (mg/l)	Helminths (egg/100ml)	Total coliform per100 ml	Fecal coliform per 100 ml	Type

EPA (2004)	Food crops not commercially processed (eaten uncooked)	Secondary (filtration and disinfection)	10	-	0	Not detectable	Guidelines
	Agricultural reuse food crops commercially processed	Advanced (filtration and disinfection)	30	-	-	200	
WHO (1989)	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Stabilization bonds	-	≤ 1	-	≤1000	Guidelines
	Irrigation of cereal, fodder, industrial crops, pasture and trees	Stabilization bonds	-	≤ 1	-	-	

-FAO vs. WHO

FAO guidelines are based on the WHO guidelines in respect to the microbial quality for health protection on one hand. On the other hand FAO suggested water quality guidelines for maximum crop production as (salinity, N and pH), and it recommended threshold levels of the trace elements, whereas WHO guidelines are only microbial guidelines and have put limits for fecal coliforms and intestinal nematodes.

-EPA vs. FAO

The EPA guidelines discussed in details the reclaimed water quality limits and wastewater treatment process. For the quality of reclaimed water, they have put limits to BOD, TSS, NTU and fecal coliform. FAO have put limits for fecal coliforms and intestinal nematodes and suggested some water quality for maximum crop production and recommended threshold levels of trace elements as (Cd, CU, and Zn).

Regarding to the treatment process, EPA stipulates secondary treatment followed by disinfection. In FAO guidelines, the treatment method required to achieve the microbial quality is limited to the use of stabilization ponds.

For the microbiological monitoring requirements, EPA guidelines rely on the monitoring of the total coliform count to assess microbiological quality and fecal.

EXPERIENCE OF SOME MEDITERRANEAN COUNTRIES

Background overview

Land application of recycled water is an old and common practice, which has gone through different development stages with time. In the Mediterranean basin, wastewater recycling and reuse are practiced since the Ancient Greek and Roman civilizations (Angelakis, 2003), also wastewater been used by the Mediterranean civilizations in the 14^{th} and 15^{th} centuries (Kamizoulis *et al.*, 2003; Hidalgo and Irusta, 2005).

Mediterranean countries are unequally developed; several being already equipped with wastewater treatment plants while others have virtually no equipment. wastewater at different level of treatment (secondary or tertiary) is used alone or mixed with fresh water, mostly on forage and cereals, fruit trees and vegetables, depending on national legislation and its enforcement and in many cases, raw or insufficiently treated wastewater is applied (Fatta *et al.*, 2005; Kamizoulis *et al.*, 2003). In other cases, wastewater treatment plants are often not functioning or overloaded and thus discharge effluents not suitable for reuse applications. This leads to the existence of health risks and environment impacts and to the prevalence of water-related diseases. In some other situations where conditions for reuse are met, wastewater is then submitted to adequate recycling systems and treated effluents are being reused for different purposes without presenting any risk for human health. In these cases, recycled water is an important alternative resource for sustainable development and food production. In Tunisia, recycled water accounted for 4.3% of available water resources in the year 1996, and may reach 11% in the year 2030. The volume of treated wastewater compared to the irrigation water resources is actually about 7% in Tunisia, 8% in Jordan. Approximately 20-30% of the treated effluent is being reused in Tunisia, 85% in Jordan (Angelakis *et al.*, 1999; Barrio *et al.*, 2005; Petta *et al.*, 2004).

The main reuse operations in the Mediterranean region are for agricultural and landscape irrigation and groundwater recharge. As a result, and because of chronic acute local water shortages, irrigation with domestic wastewater is a common practice, even without appropriate treatment or disinfection. Industrial reuse is very seldom practiced (Bahri, 2002; Kamizoulis *et al.*, 2003; Fatta *et al.*, 2004). Applications of treated wastewater reuse practices are shown in (Table 14).

Table 14.Application of wastewater use practices in Mediterranean countries (Source: Kamizoulis *et al.*, 2003)

Country / Practices	Urban and residential uses	Unrestricted irrigation industrial use	Restricted agricultural irrigation	No reuse
Albania				X
Algeria	X			
Bosnia and Herzegovina				X
Croatia				X
Cyprus	X	X	X	
Egypt	X		X	
France	X	X	X	
Greece	X		X	
Italy		X	X	
Jordan		X	X	
Lebanon			X	
Libya			X	
Malta			X	
Monaco				X
Morocco			X	
Slovenia				X
Spain	X	X	X	
Syria			X	
Tunisia	X	X	X	
Turkey			X	

Wastewater recycling and reuse: National guidelines categories

However many countries now consider the beneficial use of reclaimed water, in case of the northern European countries which have abundant water resources, they all give priority to the protection of water quality. A very limited number of European Mediterranean countries have guidelines or regulations on wastewater reclamation and reuse because first they usually do not need to reuse water and second their rivers have a sufficient dilution factor. The situation is different in the southern European countries, where the additional resources brought by wastewater reuse can bring significant advantages to agriculture (Kretschmer, et al, 2002; Papadopoulos, 1995).

Also, in most Mediterranean countries, wastewater recycling and reuse is increasingly integrated in the planning and development of water resources. Cyprus, France, Italy, Tunisia, Jordan, Spain and Turkey are the only Mediterranean countries to have established national regulation or guidelines. Other countries such as Lebanon and Greece are contemplating guidelines and/or regulations concerning wastewater recycling and reuse. While some countries don't have guidelines or regulation on wastewater recycling and reuse as Albania. There are three categories in respect to the water reuse guidelines in the region which are in (Table 15) as follows:

Table 15.Legislation for treated wastewater reuse in Mediterranean countries (Source: Kamizoulis *et al.*, 2003)

Country	Existing of legislation	Contemplating legislation	No legislation
Albania			X
Algeria		X	
Bosnia and Herzegovina			X
Croatia			X
Cyprus	X		
Egypt		X	
France	X		
Greece		X	
Italy	X		
Jordan	X		
Lebanon		X	
Libya		X	
Malta		X	
Monaco			X
Morocco		X	
Slovenia			X
Spain	X		
Syria		X	
Tunisia	X		
Turkey	X		

WASTEWATER RECYCLE AND REUSE: THE CASE OF JORDAN

Jordan is an arid to semi-arid country with scarce rainfall which is the most variable and the most important limiting factor in the rainfed agricultural system in Jordan. The total rain fall in Jordan is estimated at 8.5 billion cubic meters of which about 85% is lost to evaporation with the remainder flowing into wadis and partially infiltrating into deep aquifer (Mc Cornick *et al.*, 2004; Duqqah *et al.*, 2001). Low rainfall areas cover an area of approximately 81 million dunums, of which 9.1 million dunum receives between 100 to 200 mm rainfall, 12.8 million dunums receive 50 to 100 mm, and 58.7 million dunums receive less than 50 mm of rainfall annually. Rainfed lands constitute the largest cultivable area in Jordan, which is used mainly for cereals and fruits. Water resources come from three sources: surface water, groundwater and wastewater being used on an increasing scale for irrigation. Renewable water resources are estimated at about 750 MCM per year, consisting of approximately 275 MCM per year from groundwater, 505 MCM per year from surface sources. An additional 140 MCM per year are estimated to be available from fossil aquifers and about 79 MCM per year (2005) from treated wastewater (Shannag *et al.*, 2000).

Water in Jordan is used primarily for agriculture, which accounts for 63.4% of all water consumed (MWI, 2005), the rest being for domestic 31.8% and industrial use 4.8%. Annual growth in demand for water in Jordan is estimated at 25 Mm^3/year. This growth is related to urbanization and industrial expansion, as well as to increased domestic use, mainly as a result of population growth. In Jordan, the per capita share of renewable water resources is ranked among the world's ten most water scarce countries, and is declining with time. It is projected to fall from150 m^3/capita/year at present to 90m^3/capita/year by 2025 (WAJ, 2007).

Development of wastewater sector

Wastewater collection has been practiced in Jordan in a limited way since 1930 in the town of Salt. Some treatment was achieved by utilizing primitive physical processes. Mostly, however, septic tanks and cesspits were used with gray water often discharged to gardens. This practice resulted in major environmental problems, especially groundwater pollution. The pollution problems were complicated by the rapid urban growth (Malkawi, 2003; Duqqah *et al.*, 2001).

Modern technology to collect and treat wastewater was introduced in the late 1960s when the first collection system and treatment plant was built at Ain Ghazal utilizing the conventional activated sludge process (MEDAWARE, 2003).

However, due to the high strength of the raw sewage (i.e. the BOD_5 of the incoming sewage was greater than 600 mg/l) the effectiveness of the activated sludge process was drastically reduced. In deed the quality of the effluent of Ain Ghazal deteriorated the quality of surface, ground and irrigation water in the region (MWI, 1998; MEDAWARE, 2004).

Since the year 1980, the Government of Jordan carried out significant and comprehensive plans with regard to the different issues of wastewater management primarily related to the improvement of sanitation. About 52% of the total population (at that time) gained access to wastewater collection and treatment systems. This has raised the sanitation level, improved public health, and strengthened pollution control of surface and groundwater in the areas served by wastewater facilities, then direct reuse of treated wastewater in Jordan has been on the increase since about 1985, when Khirbet As-samra (the biggest wastewater treatment plant in Jordan) was established (MEDAWARE, 2005).

Presently, there are 19 domestic wastewater treatment plants (WWTPs) these treatment plants were established in big cities that actually serve big areas surrounding these cities. The largest plant is the Al Samra plant that serve, beside the capital Amman, several more relatively big cities which altogether called (Greater Amman). However, Jordan is currently planning to establish several new treatment plants that will serve the rest of the areas not covered by the current 19 plants which can be classified as communities (WAJ, 2004; Malkawi, 2003; MEDAWARE, 2004)). At 2005, it was estimated that about 68% of the total population of Jordan has an access to wastewater collection and treatment systems. Those can treat up to 88.5 MCM per year (Influent) as shown in (Table 16). The quantity of treated wastewater is about 79 MCM per year (2006) used for restricted and unrestricted agriculture (WAJ, 2007)

Table 16. Amount of influent, effluent (Mm^3) generated, (source: WAJ, 2007)

Year	Influent Mm^3	Effluent Mm^3	% used for irrigation
2004	102	74	67
2005	107	79	72
2006	109	86	79

Wastewater strategies, policies and legislations

The Water Strategy for Jordan 1997

The strategy places a high priority on the resource value of reclaimed water (MWI, 1997). The strategy states clearly:
"Wastewater shall not be managed as waste; it shall be collected and treated to standards that allow its use in unrestricted agriculture and other non-domestic purposes, including groundwater recharge."

The main objectives of water strategy are outlined in the followings:
1. Meeting water supply needs
2. Providing sanitation services that protect the public health
3. Preserving the resource value of reclaimed water
4. Ensuring environmental protection
5. Ensuring that the long-term export of Jordanian produce is not endanger

The national water strategy defined the goals for the water sector, and formulated the following four policies:

- Water utility policy
- Irrigation water policy
- Groundwater management policy
- Wastewater management policy

Wastewater management policy of 1998

In June 1998, the official wastewater management policy of 1998 was issued. The official policy demands that treated effluent should be considered as a water resource and not separated from other water resources. It stresses the improvement of the quality of treated effluent by blending with higher quality water, and suggests that crop selection should be made to suit the irrigation water, soil type, soil physical and chemical properties (MWI, 1998).

The Wastewater Management Policy institutionalizes 67points regarding the future use and management of wastewater, the following are parts of the national policy:

- Wastewater shall not be disposed, instead it shall be a part of the water budget
- Use of recycled and reclaimed water for industrial use shall be promoted
- Fees for wastewater treatment may be collected from those who use the water
- Any crops irrigated with wastewater or blended water should be monitored
- The role of government should be regulatory and supervisory and private operation and maintenance of utilities shall be encouraged.

Public health law no. 54/2001

The basic public health framework for wastewater is control by Public Health Law No. 54/2001, the law gave the ministry of health the authority to monitor and regulate wastewater discharges and the design of wastewater facilities. The law makes it necessary for developers to build all sewers and treatment plants according to the standards issued by the ministry of health. The law also regulates the development of sewers in many municipal areas. The law gave the ministry of health the power to approve the plants and specifications for sewers and treatment plants and to supervise all sewers and treatment plants and to supervise all sewer and treatment plant construction (MOH, 2001).

Wastewater reuse standards in Jordan

Prior to 1995, professionals in the water authority of Jordan relied on World Health Organization standards for wastewater plant design and effluent control. The usual practice was to obtain a BOD and TSS of 30 mg/l for effluent from treatment plants. By 1995, it was recognized that a comprehensive national standard was needed (Nazzal *et al.* 2000; MWI, 2001).

In 1995 Jordanian's Department for standards published a comprehensive reuse standard for treated domestic wastewater principally developed by the Water Authority of Jordan (The standard 893/ 1995).

In the standard of 893/ 1995, BOD_5 were limited to 150 mg/l for most forms of agriculture reuse and more stringent standard was created for amenity in areas that can be accessed by the public. Further more the standard 893/1995 prohibited the recharge of groundwater used for drinking with reclaimed water, although the Jordan Water Strategy (MWI, 1997) includes groundwater recharge as one of the desirable uses of reclaimed water. Updating the Standard attempted to resolve this discrepancy, but, protecting the drinking water supply remained the prime concern of stakeholders.

Table 17. Part of Jordanian standards for use of treated wastewater (893/1995)

Quality parameters	Vegetables eaten uncooked	Fruit trees, forest and grain	Discharges to wadis	Artificial recharge	Fisheries	Public parks	Fodder
BOD_5	150	150	50	50	Na	50	250
COD	500	500	200	200	NA	200	700
DO	>2	>2	>2	>2	>5	>2	>2
TDS	2,000	2,000	2,000	1,500	2,000	2,000	2,000
TSS	200	200	50	50	25	50	250
pH	6-9	6-9	6-9	6-9	6.5-9	6-9	6-9
Color	NA	NA	75	75	NA	75	NA
FOG	8	8	8	Nil	8	8	12
FCC (MPN/100ml)	1,000	NA	1,000	1,000	1,000	200	NA
Pathogens	NA	NA	NA	NA	100,000	Nil	NA
Giadara (cyst/l)	<1	NA	NA	NA	NA	Nil	NA
Nematodes (egg/l)	<1	NA	<1	NA	NA	<1	<1

In 2002 the government replaced the original JS 893:1995 standard with the new standard No. 893:2002. The primary purpose of this standard is to protect public health while still making the maximum use of reclaimed water, and this supported by Public Health Law No. 54 of 2001 which charges the Ministry of Health with undertaking all actions necessary to safeguard the health of the people.

The general structure has two groups. The first group is legally enforceable water reclamation standards aimed to protect public and farm-worker. (Table 18) is the standards for reuse in irrigation and (Table 19) concerns the standards for reuse artificial recharge and discharge to wadis, streams and water bodies.

Table 18.Standards for reuse in irrigation (893/2002)

Allowable limits per end use				
Parameter	Unit	Cooked Vegetables, Parks, Playgrounds and Sides of Roads within city limits	Fruit Trees, Sides of Roads outside city limits, and landscape	Field Crops, Industrial Crops and Forest Trees
		A	B	C
BOD_5	mg/l	30	200	300
COD	mg/l	100	500	500
DO	mg/l	>2	-	-

TSS	mg/l	50	150	150
pH	unit	6-9	6-9	6-9
Turbidity	NTU	10	-	-
Nitrate	mg/l	30	45	45
Total Nitrogen	mg/l	45	70	70
Escherishia Coli	MPN /100 ml	100	1000	-
Intestinal Helminthes Eggs	Egg/l	≤ 1	≤ 1	≤ 1

Table19. Standards for reuse artificial recharge and discharge to wadis, streams and water bodies (893/2002)

Allowable Limit			
Parameter	Unit	water discharge to wadis, streams and water bodies	artificial discharge of groundwater aquifers
BOD_5	mg/l	60	15
COD	mg/l	150	50
DO	mg/l	>1	>2
TSS	mg/l	60	50
pH	mg/l	6-9	6 – 9
Turbidity	NTU	_	2
NH_4	mg/l	_	5
NO_3	mg/l	45	30
T-N	mg/l	70	45
Escherishia coli	MPN /100 ml	1000	<2.2
Intestinal Helminthes Eggs	egg/l	≤ 1	≤1
FOG	mg/l	8	8

The 2002 standards defined conditions for each end use. The strictest standards are for artificial recharge of aquifers, while there is a range of standards for irrigation uses depending on the nature of the plants being irrigated. The three irrigation categories are:

- Class A: cooked vegetables, parks, playgrounds and sides of the road within the city.
- Class B: fruit trees, sides of roads outside city limits and landscape
- Class C: field crops, industrial crops and forest trees.

- Standards for each category focus on BOD_5, COD, DO, TSS, pH, turbidity, nitrates, total nitrogen, E.coli and intestinal helminth eggs. These standards are binding limits (JS, 2002).

Standards for discharge to streams, wadis and water bodies are more or less the same as those for Class A irrigation.

The second Group is a set of guidelines aimed at protecting the soil and maintaining the highest possible level of crop productivity. Unlike the Group 1 Standards, these guidelines are not legally enforceable. Rather, they are intended to assist the decision on a given use of an available source of reclaimed water. A list of guideline parameters and their limits is presented in (Table 20).

Table 20.Jordanian guidelines for reuse in Irrigation (893/2002)

No.	Group B	Unit	Allowable Limit	No.	Group B	Unit	Allowable Limit
1	FOG	mg/l	8	17	F	mg/l	1.5
2	Phenol	mg/l	<0.002	18	Fe	mg/l	5.0
3	MBAS	mg/l	100	19	Li	mg/l	2.5
4	TDS	mg/l	1500	20	Mn	mg/l	0.2
5	PO_4	mg/l	30	21	Mo	mg/l	0.01
6	Cl	mg/l	400	22	Ni	mg/l	0.2
7	SO_4	mg/l	500	23	Pb	mg/l	5.0
8	HCO_3	mg/l	400	24	Se	mg/l	0.05
9	Na	mg/l	230	25	Cd	mg/l	0.01
10	Mg	mg/l	100	26	Zn	mg/l	5.0
11	Ca	mg/l	230	27	Cr	mg/l	0.1
12	SAR	-	9	28	Hg	mg/l	0.002
13	Al	mg/l	5	29	V	mg/l	0.1
14	As	mg/l	0.1	30	Co	mg/l	0.05
15	Be	mg/l	0.1	31	B	mg/l	1.0
16	Cu	mg/l	0.2	32	CN	mg/l	0.01

-The future of wastewater reuse standard and law

Although much progress has been made in Jordan on laws and standards for wastewater reuse, the critical water situation suggests the need for further evolution of wastewater reuse standards and related law and due to the expected rapid growth of traded wastewater supplies, it will be necessary for Jordan to expand the agricultural reuse of wastewater and to enhance industrial recycling of water in the future (CDM, 2006).

In the long term, Jordan's standards for wastewater treatment may be modified to achieve even greater flexibility to meet specific conditions of effluent reuse. Such modifications may include suggest ranges of constituent concentrations in standards rather than single maximums, as well, there is a need to revise these standards (Nazzal *et al.*, 2000; CEHA, 2005). In deed such standard were established on the characteristics of wastewater after the treatment process, but this is not enough since the process is in continuation, when it is passing through the soil (in irrigation). Accordingly, the new modification should respect the criteria of treated wastewater after passing the soil (WHO, 2006). However, this requires the development of applicable intensive research combining the cost of treatment and safety use. Our thesis here is a part of the needed research. Recently this type of research is receiving the attention of several researchers; (Gilbert *et al.*, 1999; Tayim and Al-Yazouri, 2005; Chabaud *et al.*, 2006), the findings of the carried out researches all highlighted the important role the soil could play in improving the quality of the effluent and the irrigation with treated municipal effluent is a completion and continuity of the waste treatment process.

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SALINE IRRIGATION MANAGEMENT FOR A SUSTAINABLE USE

A. Hamdy*
* Director of Research, CIHEAM – Istituto Agronomico Mediterraneo di Bari,
Via Ceglie 9, 70010 Valenzano (BA), Italy. E-mail: hamdy@iamb.it

INTRODUCTION

The goal of sustainable development should be to make sure that the unlimited natural resources are available for future generation. Sustainable development of water resources requires that we respect the hydrologic cycle by using renewable water resources that are not diminished over the long term by their use. In many countries of the Middle East and the Mediterranean region, specially those in the arid climate zone with high rates of population growth, urbanization and industrialization, water is becoming a scarce resource. The increasing competition for water shall greatly affect the water supply for irrigated agriculture in these countries. Generally, available quantities will be reduced and costs will be increased. There is now growing realization that an increasing number countries in those regions are approaching full utilization of their surface water resources and that the quantity of good water quality supplies available to agriculture is diminishing. What is left is water of marginal quality and agriculture have to cope with this situation.

In the Mediterranean, the ambitious development activities tend to siphon off more and more water. Thus, water demand often exceeds reliable and exploitable water resources. Such existing imbalance between the limited water supply and the steadily increasing demand leads to serious conflicts over water and to the degradation of water quality in all users' sub-sectors within major countries of the region. We have to reach an appropriate balance between the limited supply and the increasingly demand which, at the moment, is heavily unbalanced. This is the dilemma challenging most developing countries of the region: *what are the options available and what are the alternatives that could provide a sustainable solution to avoid water conflicts and to meet the increasingly water demand in all the water user sectors and particularly the agricultural one?*

In the agricultural sector, the use of non-conventional water resources as an additional source for irrigation is one of the practical solutions to be recommended. Its use is nowadays a must in the arid and semiarid countries in the region to satisfy the increasingly water demand in irrigation; expanding the irrigated areas and thereby reducing the existing sever gap in food and fiber production.

In most countries of the region, particularly the arid ones, the importance role of the use of non-conventional water resources including the saline water and the treated wastewaters is well recognized. Considerable amounts of such water are available in various countries of the region, but, there are still marginally practiced in irrigation, although they could be successfully used to grow crops without long-term hazardous consequences to crops or soils by applying appropriate management practices.

There is ample evidence to illustrate the wide spread availability of saline waters and a wide range of experience exists around the world with respect to using them for irrigation under different conditions. This evidence and experience demonstrates that water of much higher salinities than those of customarily classified as "unsuitable for irrigation" can in fact, be used effectively for the production of selected crops under the right conditions. However, the reuse of non-conventional water resources, including the use of drainage and shallow saline groundwater for crop production, through an apparently simple and appropriate technology is indeed a complex one. It has a multidisciplinary inter-linkage with different sectors such as environment, health, industry, agriculture and water resources.

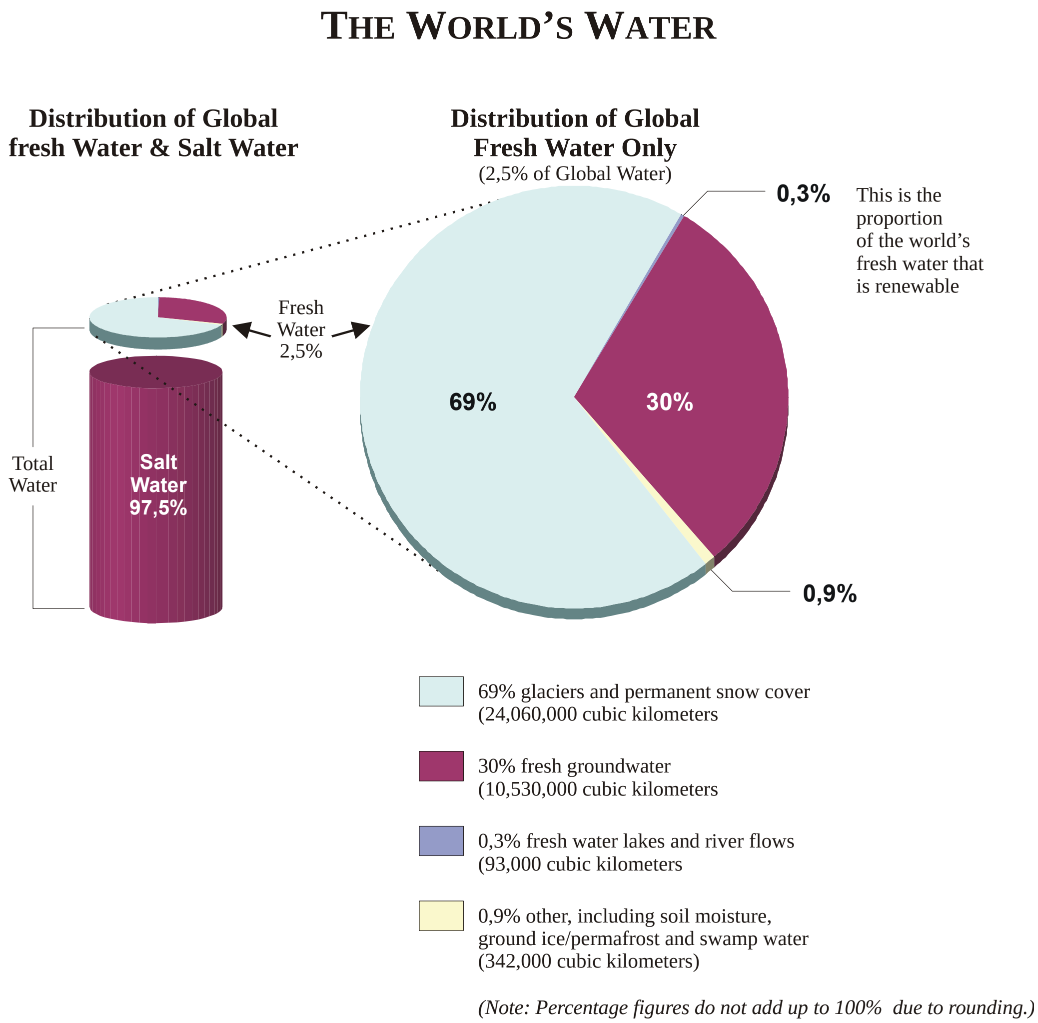
Aware of these complex inter-linkages, great efforts are now being directed to the development and use of non-conventional water sources notably artesian, drainage and brackish water for irrigation. This certainly will result in greater amounts of water for irrigation but to the detriment of its quality. In the long run, this could seriously affect crop production and deteriorate the soil productivity.

Thus, if low quality water is proposal to be used on a large scale for irrigation, the complex interaction of water, soil and crop in relation to water quality must be well understood before hand. Equally, the technology and concepts of using and managing saline water in irrigation must be available and well developed for sustained production on a permanent economic basis. The success of saline water use in irrigation requires the development of new scientific practices, new guidelines for use that cope with the prevailing local conditions and new strategies that facilitate its use on a relatively large scale.

This paper discusses the options and main guidelines which are necessary towards sustainable utilization and management of low quality water, particularly the saline one.

LIMITS ON FRESHWATER

Contrary to popular impression, water is a finite resource. There is a fixed amount on the planet - nearly 1.4 billion km^3 - which can be neither increased nor decreased. Most of it - 97.5% - is salt water and is of little direct use of people. A further 1.76% is locked away in permafrost, ice cups and glacials. Nearly all of the remainder is stored underground, leaving only 1.4 billion km^3- less than 0.4% of the world's fresh water- in rivers, lakes, reservoirs, the soil, swaps, the atmosphere and in living organisms (Fig.1).



Source: Igor Shiklomanov, "World Fresh Water Resources" in Peter H. Gleick, ed. *Water in Crisis: A Giude to the World's Fresh Water Resources*, 1993

Figure 1. The World's water

WATER SCARCITY IN THE MEDITERRANEAN

Although water remains abundant in some countries, in others like those of the Southern and Western parts of the Mediterranean, the continual subdivision of renewable water resources among more people is leading to unsustainable uses of water or sustainable declines in water availability and quality. In the year 2025, it is expected that water availability per capita in the Southern countries of the Mediterranean will drastically drop (50 to 70%) with respect to the year 1987, with an average around 60%, but availability will be reasonably stable in the Northern countries with very little differences not exceeding 10% (Hamdy and Lacirignola, 1993).

In the arid and semiarid countries of the Mediterranean, the efforts to encourage water conservation face special challenges not in counter with other natural resources. In much of those countries, water is not controlled by market mechanisms because it is either free for the taking or unmetered. Nor is water a global resource that can be treated like petroleum or given in aid like food or medicine. In addition, today, most easily accessible renewable fresh water resources already have been developed (Egypt, Syria, Jordan, Israel, and Libya). The cost of developing less accessible ones will be high and the process is time consuming. The environmental and human costs of projects can also be enormous. This, evidently, confirm that more and more marginal water quality should be used to meet the future increasingly fresh water demand, particularly in the irrigation sector.

More efforts should be directed towards the establishment of new management and practices strategies under irrigation with saline water that provide on the long term, on one hand, a favorable crop production and, on the other one, keeping the soil at good productivity level without further deterioration in its physical and chemical characteristics.

SALINE WATER ORIGIN AND SOURCE

The study of the origin of salinity is important for long term management of salinity problem and to foresee the durability of costly reclamation projects which depend upon a proper understanding of the regional climate, hydrology, geohydrology, geochemistry, salts input through mineral weathering process, rainfall, and redistribution and sink mechanism processes. (Doneen, 1958; Shalhevet and Kamburov, 1976; Rhoades, 1977; Singh, 1998).

A common source of saline water is ground water. Arid and semiarid areas of many countries are mostly underlain by saline ground water. In many regions, rivers or canals flow from humid and subhumid areas to semiarid and arid areas, where fresh and saline water exist in a close proximity. In sea coastal areas, fresh and saline waters also occur in proximity. The pumping of fresh ground water invites encroachment or upcoming of salts in inland areas while sea water intrusion occurs in coastal irrigation (Kovda, 1973; Tanwar and Kruseman, 1985; UNESCO/UNDP, 1970).

Ground waters render low in quality by the natural process of mineralization, contamination and pollution owing to human activities. Besides variation in quality, groundwater also varies in quantity as per the aquifer framework characteristics and intensity of recharge sources. It is imperative to carry out scientific investigation, exploration and assessment for the use of saline water in various situations.

The process of groundwater mineralization with aquifer salinization is more active in the arid and semiarid areas, which continuously increase the salinity in water under the process of evaporation and deposition of salts (Crag, 1980; Dhir, 1998). The salinity of ground water in inland closed basins is reported upto 55 dS/m (Tanwar, 1981; UNDP/FAO, 1985; CSSRI, 1998).

The world over important source of saline water are: (1) seawater intrusion in coastal regions, (2) tidal influence of sea on coastal surface water, (3) ground water mineralization in rock formations, (4) process of evaporation/evapotranspiration more so in arid and semiarid regions and enrichment of salts in surface and ground water, (5) waterlogging and secondary salinization of soils, (6) drainage effluent, and (7) sewage effluent. Numerous investigations have shown that water within sedimentary rocks becomes increasingly saline. The subsurface regime with increase in depth, reflects sulphate rich water near the surface, saline barcarbonate water at an intermediate level, and more concentrated chloride water at greater depth (Crag, 1980; FAO, 1992).

THE SALINE WATER IRRIGATION PROBLEM

The harmful effects of saline water irrigation are mainly associated with accumulation of salts in the soil profile and are manifested through reduced availability of water to plants, poor to delayed germination and slow growth rate (Feizi, 1998; Shalhevet, 1994; Letey *et al*., 1990; Mass, 1990; CSSRI, 1998). Osmosis is a normal process with the fresh water irrigation. But, if the irrigate water is saline, the plant has to work harder to absorb water from the soil.

When irrigation is practiced with highly saline water, the process of osmosis can become reserved. Where the solution outside the plant roots is higher in salt concentration than that of the root cells, water will move from the roots into the surrounding solution. The plant loses moisture and thus suffers stress. The symptoms of high salt damage are similar to those from high moisture stress damage. If saline water is sprayed directly on leaves, it can cause salt scorch and uaf damage even at lower salinities.

Some of the visual symptoms of saline water irrigation are that the plants look stunted and leaves are smaller but thicker and have often-dark green colour as compared to plants growing in a salt free soil irrigated with good quality (Bernstein, 1964; Van Hoorn, 1971; Minhas, 1998).

The salt concentration takes place more than two times in fine textured clay and clay loam soils. Saline water of a high salt concentration having ECw of 12 dS/m may be used for growing tolerant and semitolerant crops in coarse textured loamy sand and sandy soils under normal rainfall of more than 400 mm. But, in fine textured soils of clay and clay loam nature, waters with ECw more than 2dS/m would often create salinity problem (Tyagi, 1998; Abrol, 1982; Kandiah, 1990). The saline water of ECw more than 4 dS/m will cause salt toxicity in most of the crops in areas with annual rainfall less than 250 mm.

The chemical constituents of the irrigation water including the concentration of both cations and anions impose specific negative effects on the growing media as well as the crop production. As an example, the alkali or sodic water constitutes a significant proportion of groundwater in arid and semiarid areas. The sodium bicarbonate is the predominant salt in this water; calcium and magnesium salts are with relative proportion much smaller as compared to sodium salt which constitutes 70 percent of the total cations. In certain cases, the calcium salts may be nearly absent (Eaton, 1950; Hem, 1970; Abrol, 1972).

The harmful effects of alkali/sodic water irrigation are mainly associated with increased exchangeable sodium percentage (ESP) and reduced infiltration (Oster and Schroer, 1979; Bajwa, 1998). Long term use of water leads to breakdown of soil structure due to swelling and dispersion of clay particles (Richard, 1954; CSSRI, 1994; Bingham *et al*., 1979). Fine texture soils remain disposed and puddle when wet and then hard when dry. It does not attain proper soil moisture condition for activation.

A thin crust formed at the surface of soil acts as a barrier to penetrating irrigation water to the soil and to the emergence of seedling (Minhas, 1998; CSSRI, 1988). The increase in soil pH reduces availability of a number of plant nutrients like nitrogen, zinc, iron etc. Calcium and magnesium find decrease, and toxicity of sodium increases and consequent toxicity also increases of elements like boron, molybdenum, fluorine, lithium and selenium (Bottcher *et al*., 1981; FAO, 1992).

EXTENT OF AGRICULTURAL SALT PROBLEM

On irrigated lands, improper water use and systems management not only prevent attainment of potentials, but also cause productive land to be lost to cultivation through waterlogging and increasing salinity or sodicity. The net result is physical, chemical and biological degradation of land on a very large scale. Salinity is reported to affect one billion hectares mostly located in arid and semiarid regions (Table 1).

Szabolcs (1989) has made quite a different estimate of the world wide salt-affected surface areas (including also non-irrigated land): about 340 million ha (23%) of cultivated lands are saline and another 560 million ha (37%) are sodic. These figures indicate that, approximately, one-third of the developed agricultural lands in arid and semiarid regions reflect some degree of salinity accumulation. In some agricultural systems as much as 50% of the presently irrigated land is salinized (Table 2).

Table 1. Extent for salt-affected soils by continents and sub-continents

Region	Milions of hectares
Africa	80,5
Australia	357,3
Europe	50,8
Mexico and Central America	2,0
North America	15,7
North and Central Asia	211,7
South America	129,2
South Asia	87,6
South East Asia	20,0
Total	954,8

*Source: data Table 19.3 of World resources 1987, a report by the International Institute of Environment Development and the World Resources Institute, published by Basic Books, Inc., New York.

Table 2. Estimates of percentage of irrigated land affected by salinization for selected countries

Country	% affected	Country	% affected
Algeria	10- 15	India	27
Egypt	30 - 40	Iran	< 30
Senegal	10 - 15	Iraq	50
Sudan	< 20	Israel	13
United States	20 -25	Jordan	16
Colombia	20	Pakistan	< 40
Peru	12	Sri Lanka	13
China	15	Syrian Arab Republic	30 - 35

*Source: data Table 19.3 of World resources 1987, a report by the International Istitute of Environment Depelopment and the World Resources Istitute, published by Basic Books, Inc.,New York.

The salt affected soils in the Mediterranean countries amount to some 16 million ha, with Egypt (7.4 m), Algeria (3.2 m) and Turkey (2.5 m) being the most affected.

For irrigation land, Szaboles (1989) estimates that some ten million ha are abandoned yearly as a consequence of salinization, sodification and waterlogging. It is a consensus of specialists that without proper soil and water (irrigation and drainage management), on site effects of salinization will continue to increase (Table 3).

Table 3. On-site and off-site effects of salinity in irrigated agriculture

1- On-site effects:

- 30% of irrigated land in arid and semi-arid areas is salt-affected.
- Mediterranean countries: 16 million ha of salt affected soils.
- 10 million ha of irrigated land are abandoned yearly.
- Without proper soil, irrigation and drainage management on site
- Effects of salinization will continue to increase.

2- Off-site effects:

- Irrigation return flows high in salts, nutrients, sediments,
- Pesticides and trace elements

According to the estimates of UN and affiliated Organizations, more than half of all irrigated territories of the world are more or less salinized, alkalized or water-logged due to the improper methods of water for irrigation and use of saline water also contribute to the process of so-called secondary salinization which is expanding in our days at an accelerated rate. The total territory of secondarily salinized lands increases by more than 10 million hectares yearly and in several countries this result in serious economic problems by devastating the irrigation systems.

DESERTIFICATION AND SALINIZATIONS INTERRELATIONS

Among the adverse processes that leading to the deterioration of land and the impoverishment of many nations, desertification and salinization are quite common. The two processes are different, however, closely interrelated, that progressive salinization induces the development of desertification and vice-versa, the desertification commonly is associated with increasing salinity.

Consequently, when studying or combating either salinization or desertification the other process, too, should be taken into account because increasing salinization in arid areas always furthers desertification and, on the other hand, in desert areas salinization can, as a rule, hardly be neglected.

An increasing awareness of continuing soil salinization and sodication lead the United Nations Conference on Desertification (UNCOD), held in Nairobi in 1978, to adopt the following recommendations:

- it is recommended that urgent measures be taken to combat desertification by preventing and controlling water-logging, salinization and sodication by modifying farming technique to increase productivity in a regular sustained way, by developing new irrigation and drainage schemes where appropriate, always using an integrated approach and, through improvement of the soil, social and economic conditions of people dependent on agriculture.

The actions against, either salinization or desertification should be conduced jointly and reciprocally because salinization had at least the following correlation with desertification:

- salinization promoting desertification
- salinization developing concurrently with desertification
- salinization induced by desertification
- salinization strengthened by desertification.

Table 4. Interrelations between attributes and consequences of desertification and salinization

Salinization	Desertification
	Reduction of water availability
Increase of salt accumulation	Hindering of nutrient uptake
Decrease of leaching	Reduction of biota diversity
Increase of salt concentration in ground and surface waters as well as in soil layers	Limitation of plant cover on the soil surface diminishing of humus content Worsening of thermal and water-physical soil properties
Secondary increase of water soluble compounds	Adverse consequences of irrigation, overgrazing and deforestation

Source: I. Szabolcs, 1991

ASSESSING THE SUITABILITY OF SALINE WATER FOR IRRIGATION

The sustainability of irrigated agriculture with saline water is a real challenge. The concept of improvement and maintenance of the crop productivity at economic level is the core idea of sustainability. In saline environment, the major issues involved are: (1) the effect of saline water irrigation on crop productivity, (2) the economics of the saline water use, and (3) the environmental protection to safe guard the soil crop and human health.

Many problems associated with irrigated agriculture arise from the chemical composition of water applied. The use of various quality for irrigation, as well as the advantage of predicting problems that might develop when different quality of irrigation water is being used, created the need for a system of water quality classification that is completely different from the system in use for geochemical, industrial, aquatic life and sanitation purposes (Frenkel, 1984).

The evaluation and classification of irrigated water depends on its ultimate use. When water is to be used for crop irrigation purposes, five factors should be considered in evaluating water quality:

(1) the total salt content and chemical composition of the water; (2) the climate of the regions; (3) the prevalent soils and drainage conditions; (4) the principal crops to be irrigated; and (5) crop cultural practices, mainly irrigation method. The interaction of these five factors in effect constitutes a water classification. A source of water may be classified as suitable or unsuitable for irrigation after it has been examined in the light of these five factors. Such a classification scheme is essentially a summary of our knowledge concerning the interaction of these five factors. As such, it is always subject to revision and improvement as our knowledge advances.

Obviously the evaluation of a source of saline water is complex and has to be done individually for each region, depending on local conditions. Nevertheless, for simplification some general schemes of water classification have been proposed and used. Most schemes have three basic criteria: total salt content (salinity); sodium, carbonate and bicarbonate ion concentration in relation to calcium and magnesium ion concentration (sodicity); and toxicity of specific ions, e.g. Cl^- and B^-. They have ranged from general schemes designed for average conditions (U.S. Salinity Laboratory Staff, 1954; Doneen, 1967; Rhoades and Bernestein, 1971; Rhoades, 1972; Rhoades and Merille, 1976; Ayers and Westcottt, 1976) to specific water quality rating based on a given crop in a specific region (Thron and Thron, 1954; Doneen, 1959).

Although the several proposed methods of classifying irrigation waters differ somewhat, they agree reasonably well with respect to criteria and limits. However, in all these criteria proposed, much emphasis has been placed on an attempt to answer the question: "How good is the water?" rather than "what can be done with these waters?" (Tables 5, 6, 7 and 8).

Table 5. Laboratory determinations needed to evaluate common irrigation water quality

Water parameter	Symbol	Unit[1]	Usual range in irrigation water
Salinity			
Salt Content			
Electrical Conductivity (or)	Ecw	dS/m	0 – 3 dS/m
Total Dissolved Solids	TDS	mg/l	0 – 2000 mg/l
Cations and Anions			
Calcium	Ca^{++}	me/l	0-20 me/l
Magnesium	Mg^{++}	me/l	0-5 me/l
Sodium	Na^+	me/l	0-40 me/l
Carbonate	CO_3^{--}	me/l	0-1 me/l
Bicarbonate	HCO_3^-	me/l	0-10 me/l
Chloride	Cl^-	me/l	0-30 me/l
Sulphate	SO_4^{--}	me/l	0-20 me/l
Nutrients[2]			
Nitrate-Nitrogen	NO_3-N	mg/l	0-10 mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0-5 mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0-2 mg/l
Potassium	K^+	mg/l	0-2 mg/l
Miscellaneous			
Boron	B	mg/l	0-2 mg/l
Acid/Basicity	PH	1-14	6.0-8.5
Sodium Adsorption Ratio[3]	SAR	(me/l)[1,2]	0-15

Source : FAO, 1985

1. dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/cer metre)
mg/l = milligram per litre ~ parts per million (ppm).
me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, I = 1 millimol/litre adjusted for electron charge.
2. NO_3 – N means the laboratory will analyse for NO_3 but will report the NO_3 in terms chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse nitrogen available to the plant will be the sum of the equivalent elemental nitro. The same reporting method is used for phosphorus.
3. SAR is calculated from the Na, Ca and Mg reported in me/l.

Table 6. Modified US salinity laboratory water classification

Class	Salinity		Evaluations
	m mhos/em	mg/l	
C_1	< 250	< 200	Low – good for most crops.
C_2	250-750	200-500	Medium – some leaching required with sensitive crops.
C_3	750-2250	500-1500	High – tolerant crops and leaching
C_4	2250-4000	1500-2500	High – only with permeable soils and tolerant crops.
	4000-6000	2500-3500	Very High – only with very permeable soils and very-very tolerant crops.
	> 6000	> 3500	Excessive – not usable

Source: Thorne DW and Peterson HB, 1954; irrigated Soils, The Pakistan Co. Inc, New York

The classification of saline water has been proposed by FAO (1992) given in Table 7.

Table 7. Classification of saline water based on salinity hazard

Water class	ECw (dS/m)	Salt concentration (mg/l)	Type of water
Non-saline	< 0.7	< 500	Drinking and irrigation water
Slightly saline	0.7-2	500-1500	Irrigation water
Moderately saline	2-10	1500-7000	Primary drainage water and ground water
Highly saline	10-25	7000-15000	Secondary drainage water and ground water
Very high saline	25-45	15000-35000	Very high saline water
Brine	> 45	> 35000	Sea water

Source: FAO irrigation and Drainage Paper 48, 1992

Table 8. Guidelines for interpretation of water quality for irrigation

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC_W[1]	dS/m	<0.7	0.7-3.0	> 3.0
or				
TDS	mg/l	< 450	450-2000	> 2000
Infiltration				
SAR[2]+ 0-3 and EC_w		> 0.7	0.7-.02	< 0.2
3-6		> 1.2	1.2-0.3	< 0.3
6-12		> 1.9	1.9-0.5	< 0.5
12-20		> 2.9	2.9-1.3	< 1.3
20-40		> 5.0	5.0-2.9	< 2.9
Specific ion toxicity				
Sodium (Na)				
Surface irrigation	SAR	< 3	3 – 9	> 9
Sprinkler irrigation	me/l	< 3	> 3	
Chloride (C1)				
Surface irrigation	me/l	< 4	4 – 10	> 10
Sprinkler irrigation	m^3/l	< 3	> 3	
Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous effects				
Nitrogen (NO_3-N)[3]	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO3)	me/l	< 1.5	1.5 – 8.5	> 8.5
pH		Normal range 6.5 – 8.4		

Source : FAO (1985)

1. EXw means electrical conductivity in deciSiemens per metre at 25ºC
2. SAR means sodium adsorption ratio
3. NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

The disadvantage of such simplified schemes is in their neglect of the other factors influencing water suitability. Consequently a source of water may be rejected where it is usable or accepted where it should not be used because of unfavourable local conditions. Nevertheless, when scheems, based on water chemical composition alone, are used as general guides only in conjunction with other considerations, the classification may become very useful. This illustrates the limitation of generalized water-classification schemes and the need for a more quantitative means of assessing water suitability; one that takes into account the specific conditions of use. The rigid definition of salinity classes as being suitable or not is an oversimplification. The quantitative description of the limitation of use added to each class is generally insufficient.

These guidelines appear to be very conservative in respect of EC_w and SAR of irrigation waters. The limits of HCO_3 apply only for overhead sprinklers and not for flood irrigation. The basic assumptions in the guidelines comprised crop yield potential, soil conditions, methods of timing of irrigation, water uptake pattern of crops and three divisions of the restriction on use. These guidelines do not consider rainfall, better quality water for conjunctive use, and possible use for supplemental irrigation.

A major point that emerges from discussion so far is that it is presently impossible to set precise general standards of wide applicability for judging irrigation water quality as the actual suitability of a given water for irrigation depends very much on the specific conditions of use and on the relative economic benefit that can be derived from irrigation with that water compared to others. In addition, it is difficult to define absolute standards of irrigation water quality as the relationship of the composition and concentration of the soil solution to those of the irrigation water both complex and dynamic, being dependent upon a large number of factors that may be difficult to quantify. Soils and plant responses are not necessarily related to the properties of the soil solution.

In this regard, much work has to be done with much emphasis on how to manage such water and how to manage soils and crops irrigated with such water rather than on how to judge the water quality.

To avoid problems when using these poor quality water, there must be a sound planning to ensure that the quality of water available is put to be the best use.

Therefore, in assessing the suitability of saline water for irrigation it is important to take into considerations:

- cropping system: crop tolerance to salinity must be known on a quantitative basis for all specific ecological conditions of concern;
- prevention of salt accumulation in the soil; the dynamic of salts in the soil must be quantitatively known for all specific soils, climatic and hydrological conditions of concern. Furthermore, the interrelationship of leaching to crop response must also be understood;
- use of advanced irrigation and drainage technology: irrigation methods must be adjusted to the use of brackish water and must be very efficient, technically as well as economically; a drainage system must be provided when necessary.

"Ultimate" method for assessing the suitability of such water for irrigation consists of:

- predicting the composition and matric potential of the soil water, both in time and space resulting from irrigation and cropping;
- interpreting such information in terms of how soil conditions are affected and how any crop would respond to such conditions under any set of climatic variables (Rhoades, 1972).

A computer model for assessing water suitability for irrigated which uses these criteria has been developed (Rhoades and Merill, 1976). A simplified version of it, called "watsuit", has also been developed and used to assess drainage waters for irrigation -a description of "watsuit" and example outputs are given in (Rhoades, 1984a).

Prognoses of suitability are made after the soil water compositions are predicted. A soil salinity problem is deemed likely if the predicted root zone salinity exceeds the tolerance level of the crop to be grown. Use of the water will result in a yield reduction unless there is a change in crop and/or leaching fraction (LF). If yield reduction can be tolerated, then the appropriately higher salinity tolerance level can be used in place of the no yield loss threshold values.

The sustainable use of saline water for irrigation requires that our research programmes should be modified from the individual to the integrated ones where crop rotation, water management and soil amendements are all combined. Thus, many very poor quality water can be sustainability and successfully used.

THE POTENTIAL OF USING SALINE WATER IN IRRIGATION

Although the number of documented reports on successfully using brackish water for irrigation are relatively limited, enough exist to support the premise that water, more saline than conventional water classification schemes allow, can be used for irrigation (Box 1).

Recent research development on plant breeding and selection, soil crop and water management, irrigation and drainage technologies enhance and facilitate the use of saline water for irrigated crop production with minimum adverse impacts on the soil productivity and the environment. Extensive reviews of the world literature conducted on this topic, include those by Bressler (1979), Gupta (1979) and Gupta and Pahwa (1981).

Box 1. The potential of using saline water in irrigation

- In the USA, extensive areas (about 81,000 ha) of alfalfa, grain sorghum, sugarbeet and wheat are irrigated (by gravity flood and furrow methods) in the Arkansas Valley of Colorado, with water salinity not less than 1,500 mgl^{-1} and up to 5,000 mgl^{-1}(Miles, 1977). In the Pecos Valley of Texas, groundwater averaging about 2,500 mgl^{-1} of total dissolved salts, but ranging far higher, has been successfully used to irrigate cotton, small grains, grain sorghum and alfalfa, for three decades (Moor and Hefiner, 1976).
- Cotton is successfully grown commercially in the Nahal Oz area of Israel with saline groundwater (EC of 5 dS/m^{-1} and SAR of 26). The soil is treated annually with gypsum and National Carrier water (non-saline) is used (usually during the winter) to bring the soil to field capacity to a depth of 150 to 180 cm prior to planting (Harden, 1976; Bresster, 1979).
- In Egypt, 3 to 5 thousand million m^3 of saline drainage water are used for irrigating about 405,000ha of land. About 75 percent of the drainage water discharged into the sea has a salinity of less than 3,000 mgl^{-1}. The policy of the Government of Egypt is to use drainage water directly for irrigation if its salinity is less than 700 mgL-1; to mix it 1:1 with Nile water (180 to 250 mgl^{-1}) if the concentration is 700 to 1500 mgl^{-1}; or 1:2 or 1:3 with Nile water if its concentration is 1,500 to 3,000 mgl^{-1}; and to avoid reuse if the salinity of the drainage water exceeds 3,000 mgl^{-1}(Abu-Zeid, 1991).
- The saline Medjerda river water of Tunisia (annual average EC of 3.0 dS/m^{-1}) has been used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichoke. The soils are calcarious (up to 35% $CaCO_3$) heavy clays which crack when dry (Van't Level and Haddat, 1968; Van Hoorn, 1971).
- Salt tolerant cereal crops, vegetables, alfalfa and date palms are being successfully irrigated with water of 2000 mgl^{-1} TDS in Bahrain, 2400 to 6000 mgl^{-1} in Kuwait and 15000 mgl^{-1} in the Tagoru area of the Libyan coastal plain. Forest plantations have been established in the United Arab Emirates using groundwater with up to 10000 mgl^{-1} TDS (Arar, 1975).
- Extensive use of saline groundwater from shallow aquifers (106,000 hectare-meters per year) is being undertaken in nine districts of Haryana State in India. In four of the districts, the brackish water is used directly for irrigation, while in the remaining five it is used after blending with fresh canal water, or by alternating between the two supplies (FAO, 1990).

The assessment of saline water suitability for irrigation, combined with these latter cited worldwide references, give the evidences for the relatively high potentiality for using saline water for irrigation.

MANAGEMENT PRACTICES UNDER SALINE IRRIGATION WATER

With the use of saline waters for irrigation, there is need to undertake appropriate practices to prevent the development of excessive soil salination for crop production. Management need not necessarily attempt to control salinity at the lowest possible level, but rather to keep it within limits commensurate with sustained productivity. Crop, soil and irrigation practices can be modified to help achieve these limits. To maintain the efficacy of the control practices, some system of sensing the status of soil salinity is advisable.

Management practices for the control of salinity include: selection of crops or crop varieties that will produce satisfactory yields under the resulting conditions of salinity, use of land-preparation and planting methods that aid in the control of salinity, irrigation procedures that maintain a relatively high soil-moisture regime and that periodically leach accumulated salts from the soil, and maintenance of water conveyance and drainage systems. The crop type, the water quality and the soil properties determine, to a large degree, the management practices required to optimize production.

There is usually no single way to control salinity, particularly in irrigated land several practices can be combined into an integrated system that functions satisfactorily. Summaries of the hydraulic, physical, chemical and biological practices and human aspects to improve productivity are described in Box 2 and Fig. 2.

Box 2. Management practices using saline water for irrigation

- Hydraulic management:
  - Leaching (requirement, frequency)
  - Irrigation (system, frequency)
  - Drainage (system, depth, spacing)
  - Multiple water resources (alternating, blending)
- Physical management
  - Land levelling
  - Tillage, land preparation, deep ploughing
  - Seedbed shaping (planting resources)
  - Sanding
  - Salt scarping
- Chemical management
  - Amendments
  - Soil conditioning
  - Fertility, mineral fertilization
- Biological management
  - Organic and green manures
  - Crops (rotation, pattern)
  - Mulching
- Human management
  - Farmer
  - Socio-economic aspects
  - Environmental aspects
  - Policy

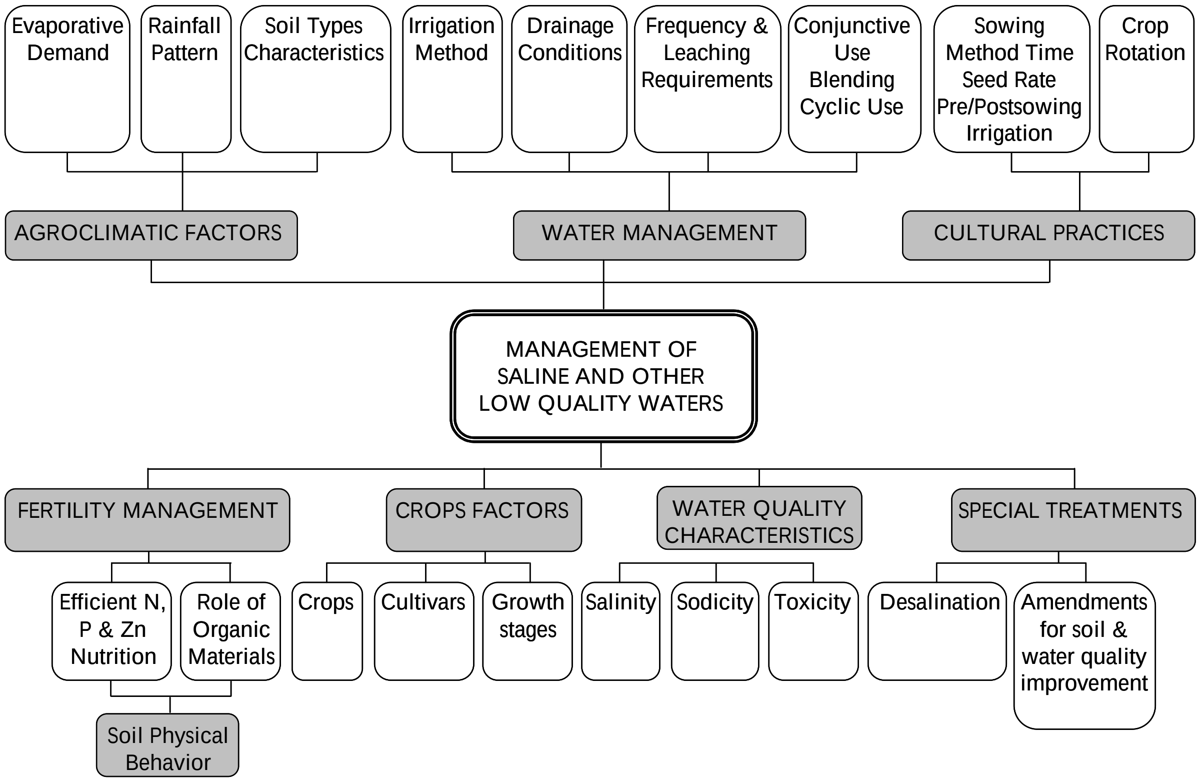


Figure 2. Management of saline water

The sustainability of a viable, permanent irrigated agriculture, especially with the use of saline irrigation waters requires the implementation of appropriate management practices to control soil and water salinity, not only with irrigated soils, but also within entire irrigation projects and even whole geo-hydrologic systems.

Three general management strategies seems practical: (a) control salinity within permissible levels, (b) change conditions to improve crop response, (c) change management to maintain yield at the field level when salinity causes damage at the plant level. All three can be used together, but the first one is the most commonly used.

Irrigation Practices and Management

Irrigation practices which are important in the management of saline water are: irrigation scheduling (amounts and interval); leaching scheduling (amount and timing); irrigation method and management of multi-source irrigation water of different qualities (Shalhevet, 1984).

Irrigation Scheduling

The irrigation scheduling should allow both good crop yields and adequate leaching of the soil when saline irrigation is practiced. Irrigation scheduling is complicated under saline water application mainly due to: i) information of consumptive use of many crops under saline water irrigation is not available and ii) under saline water practices the leaching requirements (LR) of the crops related to the salinity level of water must be calculated and included in the crop water requirements.

Successful saline irrigation requires a new production functions that relates crop yield to water consumption with acceptable irrigation intervals for the various crops.

In general, two approaches to estimate crop-water production functions are apparent in the literature. One approach synthesizes production functions from theoretical and empirical models of individual components of the crop-water process. Parameter values are obtained, in principle, by direct measurement. The second approach estimates production functions by statistical inference from observations on alternate levels of crop yield, water applications, soil salinity and other variables.

Most production functions are estimated based on the assumptions that water applications are uniform and soil conditions are relatively homogeneous. However, in most fields, depths of applied water and conditions of the soil vary in space considerably. Thus, field-level production functions may differ from those estimated from small agronomic plots of theoretical models that assume homogeneous conditions.

Different formulas and equations were proposed describing the production of several crops under saline water (Stewart *et al*., 1974; Shalhevet *et al*., 1983; Hanks *et al*., 1978; Frenkel *et al*., 1982; Para and Romero, 1980; Hoffman and Jobes, 1978; Meiri *et al*., 1980). The field and greenhouse results obtained by those authors offer convincing evidence of the unified relationship between yield and evapotranspiration, independent of changes in the two variables caused by salinity or water stress. These results are empirical and correlative. They do not shed light on the causes and mechanisms involved when osmotic or matric stresses are imposed on growing crops.

Several models to simulate crop-water production functions were developed recently (Feinerman *et al*., 1984; Letey *et al*., 1985; Bressler, 1987). The results of Bressler's model (1987) suggest full compensation between irrigation water amount and salinity for a relatively wide range irrigation water salinities. However, the results of the model of Letey *et al*. (1985) suggest that increasing the amount of irrigation water compensates only partially for the irrigation water salinities.

The dynamic models of Bressler (1987), Van Genuchten (1987), Hanks *et al*. (1977) can be used to stimulate seasonal crop water production functions for various irrigation schedules, if appropriate input data for the given model is available. Solomon (1985) and Letey *et al*. (1985) presented seasonal water-salinity-production functions based on our current understanding of the response of crops to water, the salt tolerance of crops and the leaching process.

Both the dynamic models and the seasonal models of Solomon and Letey *et al*. assume a unique relationship between yield and ET for a given crop and climate that is independent, regardless of whether the water stress leading to the reduced ET is caused by deficit water supply, excess salinity, or both. Beginning with this premise, Solomon (1985) stated the following:

- for any given amount and salinity of irrigation water, there will be some point at which values for field ET, leaching and soil salinity all are consistent with one another. The yield at this point is the yield to be associated with a given irrigation water quantity and salinity.

Letey *et al*. (1985) combined the relationships of yield versus ET, yield versus average root zone salinity and average root zone salinity versus leaching fraction to develop an equation that related yield to the amount of seasonal applied water of a given salinity. The combination of these relationships led to the point that, as Solomon stated, "The value for yield, ET, leaching and soil salinity are all consistent with one another".

The statistical/econometric approach to production function estimation differs from the approachs taken in both dynamic and seasonal production function models. The latter models tend to be formulated on conceptual and theoretical grounds. The statistical models often use *ad hoc* functional forms, although Dinar *et al*. (1986) indicates that this need not always be the case. A more significant difference is the method used to estimate unknown parameter values. The dynamic models presumably rely on actual measurements of the relevant parameters. In the statistical approach, parameter values are inferred from observations on alternate levels of yields and inputs. Statistical models can predict the conditions under which they are estimated reasonably well but will likely be less transferable to other areas as compared with dynamic production function models and the seasonal ones.

There is no doubt that substantial progress has been made in developing empirical models that can be used to relate crop yields and irrigation management under saline conditions. However, further work is needed before these empirical models to be reliably applied under a wide variety of field conditions. Further work also is required on the relation of ET to soil and environmental conditions. In many instances, potential ET or transpiration is determined externally to the model. However, potential ET depends in part on the size of the plant, which depends on irrigation management during the previous part of the irrigation season. Hence, relative and maximum or potential ET should be endogenous variables.

Non-uniform applications of water and spatial variations in soil parameters significantly affect seasonal water production functions. To date, little or no work has been done to estimate transient production functions under non-uniform conditions. Procedures for estimating uniformity distributions on a scale relevant to the plant also are needed. Variations in the environment affect the growth of the plant, so random effects related to the weather need to be included in models of the growth of plants under saline conditions.

Irrigation Intervals

Plant growth is a function of the osmotic and matric potential of soil water; osmotic potential can be controlled by leaching, whereas matric potential is controlled by adequate and timely water application.

The question arises of whether it is necessary to narrow the watering intervals to keep the soil solution concentration low (to diminish harmful effects of the salt) or whether it is possible to lengthen the interval and to apply large amounts of water?

Analysing the process that occurs when evapotranspiration reduces soil water content between waterings shows that as the soil dries, the matric potentials -as well as the soil solute potential- decreases (increases of soil solution concentration). Because of the decreased soil solute potential, beneficial effects from decreasing the irrigation intervals as soil salinity increases could be reasonably expected (Allison, 1964; Ayers and Westcott, 1967). This process is counteracted by the effect of irrigation intervals on the shape of salt distribution in the soil profile and on the overall level of salinity. Under steady state conditions, increased irrigation results in an upward shift of the peak of the salt distribution profile, thereby increasing the mean salt concentration in the upper main root zone. Furthermore, ET increases as irrigation becomes more frequent, leading to additional water applications and an increase in the salt load (Van Schilfgaarde *et al*., 1974).

The effect of irrigation intervals on the final crop yield was studied by several workers (Bernstein and François, 1975; Hoffman *et al*., 1983; Hamdy, 1990a). The data obtained indicated that increasing irrigation frequency did not significantly benefit crop production and may increase, rather than decrease, the effect of salinity.

Irrigation scheduling is a major parameter for assessing an appropriate saline irrigation management. However, this subject did not receive the attention of researchers in this field. A frequent constraint to improving on-farm water use is the lack of information of when an irrigation is needed and what capacity of replenishment is available within the root zone.

Irrigation scheduling requires some method of assessing the water availability to the crop with sufficient lead time to provide for a water application before significant stress occurs. In addition the amounts of water needed for replenishment of the depleted soil moisture from the rootzone and for leaching must be determined. Prevalent methods used to determine the onset of stress include both direct and indirect measurement. Leaf water potential can be measured with a pressure bomb and used to determine stress; however, the method does not give information with which to predict when the stress will occur in advance of its occurrence nor does it provide a measure of the *amount* of water to apply. Infrared thermometry can be used to indirectly measure plant water stress which results in the partial closure of stomata and in reduced transpiration, causing leaf canopy temperature to rise above ambient air temperature. This temperature difference can be interpreted in terms of a crop water stress index with which irrigation need can be assessed (Pinter & Reginato, 1981). It suffers the same limitations as the leaf water potential method. Other scheduling methods can be used which are based on irrigating when depletion of soil water per se or soil water potential, or some associated soil or water property, reaches some predetermined level (set-point). The attainment of this level can be ascertained either by direct measurement of some appropriate soil property or estimated from meteorological data. With the latter method, daily reference evapotranspiration of a full ground-cover crop (usually a well-watered healthy grass) is calculated from measurements of air temperature, humidity, solar radiation and wind. The actual evapotranspiration (ET) of the crop is then estimated from empirically determined crop coefficients (Wright, 1981). The summation of these daily

ET values is a measure of accumulative soil water depletion. A plot of depletion versus time gives a way to project the need for irrigation when the degree of allowable depletion is known. The same approach can be used based on direct measurements of soil water content, or a related parameter, using neutron meters, resistance blocks, time-domain reflectometric (TDR) sensors, four-electrode sensors, or various soil matric potential sensors.

Most of the methods suffer the limitation of needing an empirical determination of the set-point value for irrigation which varies with crop rooting characteristics, stage of plant growth, soil properties and climatic stress. Furthermore, measurements of soil water content or matric potential cannot be used (at least not conveniently) to assess or control the leaching fraction as is required to prevent an excessive build-up of soil salinity. For saline water, irrigations should be scheduled before the total soil water potential (matric plus osmotic) drops below the level which permits the crop to extract sufficient water to sustain its physiologic processes without loss in yield.

According to Rhoades & Merrill (1976), the frequency of irrigations would ideally be determined by the total soil water potential in the upper root zone where the rate of water depletion is greatest. On the other hand, the amount of water to apply depends on stage of plant development and the salt tolerance of the crop and, consequently, should be based on the status of the soil water at deeper depths.

In conclusion, to avoid problems and for a sustainable water saline use in agriculture, further work has to be done and directed to fulfill this gap. The subject is not easy but it is a further complex one, this complexity is due to the fact that under saline water irrigation, the irrigation scheduling is not only governed by the prevailing climatic and pedological conditions but also with the salt content of irrigation water as well as the crop under cropping.

Irrigation Methods

Proper choice of the irrigation method greatly facilitates reduction in drainage volume, uniform leaching and use of poor quality water. Poor selection of irrigation method not only aggravates salinization but may also create drainage problems. Utilization of saline water resources in the long term, calls for scientific knowledge of soil-water-plant relationships and its modifying influence on irrigation techniques.

The method used for saline water irrigation may be guided by:

- the distribution of salt and water under different irrigation methods;
- crop sensitivity to foliar wetting and the extent damage to yield, and
- the ease with which solubility and matric potential can be maintained in the soil.

In the case of border or basin irrigation, salinity will increase in the top layer during the irrigation interval and decrease during watering more or less homogeneously if the land is well graded.

Under saline irrigation, the period of germination and emergence of the seedlings is the most critical stage of crop growth. A failure at this stage leads to a poor stand and a considerable yield decrease. Failures recorded where saline water was used can often be attributed to failures during germination and emergence and not to excessive soil salinity at a later stage (Hamdy, 1990b; Hamdy *et al*., 1993). Salt accumulation can be especially damaging to germination and seedling establishment when raised beds or ridges are used and "wet-up" by furrow irrigation. Seed bed shape and seed location should be managed to minimize high salt effects. For soils irrigated with saline water, slopping beds (Fig.3) are the best where the seedling can be safely established on the slope below the zone of salt accumulation (Bernstein *et al*., 1955; Bernstein and Fireman, 1957).

Under flood or sprinkler irrigation where water and salt transport is downward and away from the seedling, limited pre-planting leaching of the upper soil strata may take care of the germination and establishment inhibition. Under furrow and drip irrigation there is downward component of water and salt transport, but another component is lateral and upward in the spaces between furrows or laterals. With these methods the adjustment of the soil surface contour and seedling or planting position according to the expected salt distribution can limit significantly this damage.

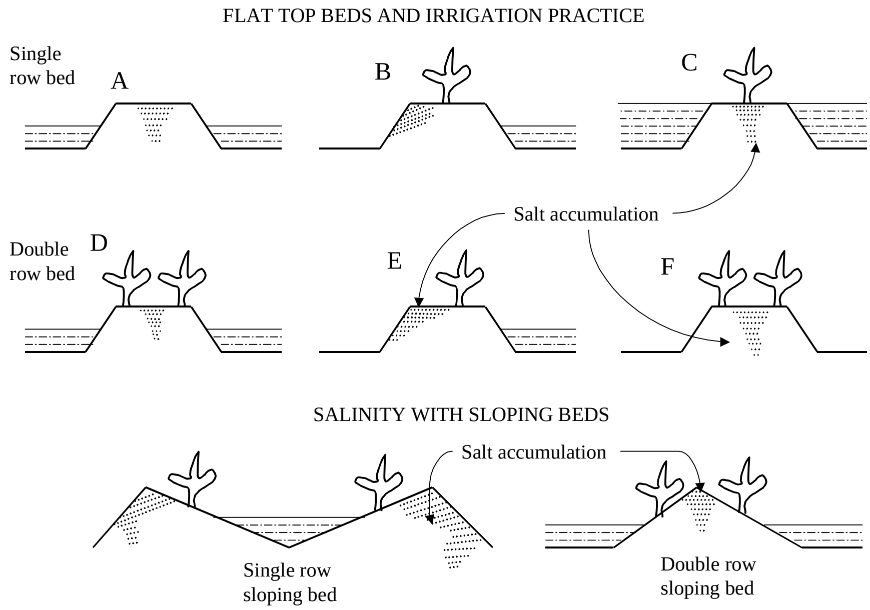


Figure 3. Typical salt accumulation pattern in ridge and bed cross section in soils irrigated by furrows (Bernstein et. al., 1955; Bernstein and Fireman, 1957)

Irrigation by sprinkling allows close control of the amount and distribution and is often used on land where the slope is too great for other methods. In addition, both in soils with a high infiltration rate and those with soil structure problems sprinkling may provide alternative. The principal problem encountered with sprinkler irrigation using saline water is wetting of foliage with consequent tip and marginal burning of the leaves and ultimate defoliation. Provided foliar burn is avoided, sprinkler irrigation has the advantageous that salt-removal efficiency with sprinkler irrigation tends to be substantially higher than with flood or trickle irrigation.

Evaluating the ability of the irrigation method under saline water practice, the prevailing moisture conditions under the drip methods provides the best possible conditions of total soil water potential for a given quality of irrigation, besides avoiding leaf injured. The roots of the growing plants tend to cluster in the leached zone of high moisture near the trickles, avoiding salt that accumulates at the wetting front. Moreover drip irrigation offers the advantage of supplying water on a nearly daily base, in that way keeping the water content of the soil and the salinity of soil solution at a stable level (Ragab, 1998).

Furthermore, under drip irrigation, crop yields are higher with better quality water, reduced weed growth, uniformity of irrigation, water saving as well as better fertilizer application and low operating cost.

The main limitations of drip irrigation lie in the higher initial cost, low root soil aeration, dense root mass, constant power and water supply needs, and higher level of know-how. The development of a salt interface at irrigated and non-irrigated zone may damage the next crop without proper leaching of salts before planting of the next crop. The water distribution uniformity is greatly influenced even when 1 to 5 percent emitters are completely closed with 2 to 8 emitters per plant. The value of uniformity coefficient more than 90 percent is considered excellent and less than 60 percent unacceptable. The discharge rate of emitters having laminar and unstable flow regimes increases with the increase in temperature but the effect is minimum for the turbulent emitter. The ageing or deterioration due to drying, wetting, chemicals in water, exposure to rodent and insect etc. may increase the coefficient of variation.

When high salinity water is used with drip irrigation in arid regions, the salts tend to accumulate at the soil surface and towards the periphery of wetted soil. The space between the parallel drip lines remains dry and escapes salinity processes. The salts that accumulate below the emitters can be flushed down continuously by daily or alternate day irrigation. If the leaching requirement ratio is more than 0.1, the daily irrigation should include enough extra water to maintain a continuous downward movement of water to control salts. The higher the salt content of irrigation water, the higher the leaching requirement. The crops more sensitive to salinity requires more leaching than salt tolerant crops. (Dainel, 1997; ICID, 1998; CSSRI 1998).

Subsurface systems provide no means of leaching the soil above the source. Continuous upward water movement and evaporation cause salt to accumulate near the soil surface. Unless the soil is leached by rainfall or surface irrigation, salt levels will certainly become toxic. Generally, this system, is not suitable over the long-term, especially when salts are high in water supply.

Salt distribution within the root zone is influenced by the water extraction pattern of the crop and the method of water application. Salt distribution under different irrigation systems is illustrated by Fig.4 (Oster *et al*., 1984).

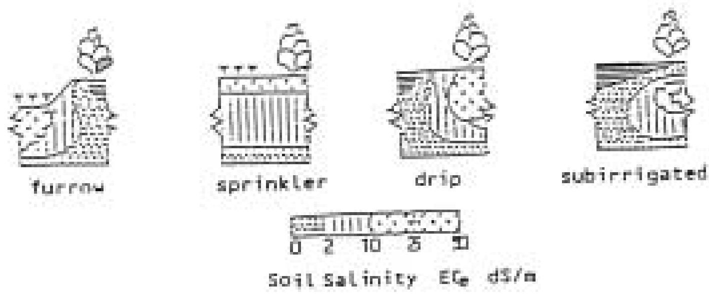


Figure 4. Salt distribution with the root zone (Oster *et al*., 1984)

The irrigation regime greatly influences the moisture and salinity profile and refers to the variables of water supply to the soil: dripper discharge, water quantity applied during one irrigation and the irrigation interval. Increasing the discharge generally enlarges the diameter of the wetted area and increases the water content of the upper soil layer close to the dripper. The lower the hydraulic conductivity of the soil and the longer the duration of the irrigation, the more pronounced will be this effect (Bressler *et al*., 1971). Reducing the irrigation interval without changing the total amount of water will mean smaller amounts of water being applied each time. Wetting will be shallower, but a higher average water content will be produced in the main region of water flow, due to the shorter period available for drainage. There will also be a change in the salt concentration sites (Goldberg *et al.*, 1971).

Leaching Management for Salinity Control

Leaching is the key factor by which soil salinity can be maintained at acceptable levels without undue damage to crops. Thus appropriate natural or installed drainage and disposal systems are essential.

Soil salinity control becomes more difficult as water quality decreases. Greater care must be taken to leach salts out of the root-zone before they reach levels that might affect yields. Alternatively, steps must be taken to plant crops tolerant to the expected root-zone salinity. The frequence and amount of leaching depend on water quality, climate, soil and crop sensitivity to salinity.

The frequency and amount of leaching depend on water quality, climate, soil and crop sensitivity to salinity, the crop seasonal period as well as the accumulated salts in soils.

For efficient leaching management, it is questionably desirable to use extra water to every watering to leach the soil, at the same time increasing the peak requirements of an irrigated area or, on the contrary, to apply less water and to apply less leaching complements when more water is available. This will greatly depend on the salt distribution, which is related to the growing season. Leaching during a period of peak, consumptive use means that not only are greater amounts of water applied but also that greater amounts of salts are brought into the soil. Moreover with permanent leaching there is greater risk of water stagnation and suffocation of the crops. On the other hand, seasonal leaching during a period of low consumptive use can also draw advantage from rainfall, at least in the Mediterranean area and the Middle East where rainfall occurs during the winter.

The findings of Bernstein and François (1973), François (1981) and Hamdy (1990c) support the idea that applying the required leaching when salt accumulation becomes excessive -periodically rather than at every irrigation- is a better strategy for short-season crops.

The adoption of LR as excess water at every irrigation, its indirect benefit is a maintenance of a higher soil water content, in comparison with water application without leaching, for a significant time after each irrigation. The effect is most significant under frequent irrigations. Under such conditions the positive crop response to leaching can be due to both higher soil moisture and reduced soil salinity (Bressler and Hoffman, 1986; Meiri and Plaut, 1985).

The adoption of LR as excess water at every irrigation is most undesirable when saline water is added to a field having a lower salinity level than the acceptable maximum for the crop and salinity build-up occurs. The additional saline water may aggravate the salinity stress as it enhances the salinization for a short season crop it may also result in a higher EC values of extracted soil solution.

Leaching at every irrigation may be accompanied with large unintended errors. Since LR is usually a small fraction of irrigation dose, a small error in the estimate of ET may introduce a considerable error or in the intended L.R and as a result an over leaching practices.

Irrigation tests in Tunisia (Van Hoorn, 1991) have shown that leaching during the period of peak demand can quite well be reduced or postponed. This also follows from salt balance calculations. Leaching during a period of peak consumptive use means that not only are greater amounts of water applied but also that greater amounts of salt are brought into the soil. So, this surplus amount of salt counterbalances to a certain extent the advantage of more leaching water. The author also revealed that, as permanent leaching means greater water applications, there is greater risk of water stagnation and suffocation of the crops. On the other hand, seasonal leaching during a period of low consumptive use can also draw advantage from rainfall, at least in the Mediterranean area and the Middle East where rainfall occurs during the winter.

However, the point still needs to be settled: if leaching should be practiced periodically, at which growing stage should leaching be administrated and what is the appropriate leaching fraction?

Hamdy and Nassar (1991) concluded that for maximum utility and better saving of fresh water, leaching should be carried in accordance with the salinity tolerance of the growing stage and in proper quantities (L.F.). In this regard, the extent to which leaching can be minimized is limited by the salt tolerance of the crops being grown, salt composition of irrigation water and soil characteristics. Increase efficiency or reducing leaching under the proper circumnstances can result in more effective water use in the first instance, a reduction in the salt load needing disposal and a substantial reduction in the volume of drainage water.

A part of the research programme carried out by Bari Institute was developed to leaching practices and management with salty water. In this regard, Hamdy (1989) recommended the followings:

- Two main principles should be carefully considered when leaching with low quality waters; firstly, the EC value of leaching water must be lower than that of the soil EC and, secondly, frequent tests should be performed on soils under leaching bearing in mind that the target to aim at is a soil salinity equivalent to that of the water to avoid the potential danger of reintroducing salts by excessive leaching.
- Under saline irrigation practices, leaching even with saline water played an important role in reducing salt accumulation in soils and improving all the parameters under study (physiological, plant growing and crop field). Such improvements varied according to the variation in the salt content of the leaching water. The lower the salt content in leaching water the greater the improvements. Leaching with waters of EC value around 3 dS/m, particularly, when ECi are relatively high, showed to be advantageous than leaching was practiced with more saline water of 6 and 9 dS/m.
- If leaching is practiced with saline water of the proper leaching fraction, we can bring our soil to an EC value around that of the leaching water. Consequently, the choice in plant selection will be limited and the crop rotations should be rearranged so as to include crops that can tolerate the

prevailing salt conditions. Leaching with the good quality water could completely eliminate such disadvantages and offer a free hand possibilities in the choice of crops. Therefore, under saline irrigation practices, it is always recommended that leaching should be practiced with waters of an EC value lower than the irrigation water.

- Indeed, irrigation with saline water and leaching together with saline water is a complex one. This subject should be regarded more carefully due to its importance, particularly in the arid regions. Further studies are urgently needed under controlled conditions as well as in the fields to have more information to fulfil the knowledge gab in this subject.

Finally, to increase the efficiency of leaching and reduce the amount of water needed, the following practices are suggested (Box 3):

Box 3. Efficient leaching practices

- Leach during the cool season (rather than during the warm season) when ET losses are lower;
- Use sprinklers at lower application rate than the soil infiltration rate to favour unsaturated flow, which is appreciably more efficient for leaching than saturated flow;
- Use more salt-tolerant crops, which require a lower LR and thus a lower water demand;
- Use tillage to slow overland water flow and reduce the number of surface cracks which bypass flow through large pores and decrease leaching efficiency; and
- Where possible, schedule leachings for periods of low crop water use, or postpone leaching until after the cropping season.

CONJUNCTIVE USE OF SALINE AND FRESH WATER

The conjunctive use can be defined as the development and management of multiple water resources in a coordinated manner such that the total yield of the system over a period of years exceeds the sum of the yields of the individual components of the system resulting from an uncoordinated operation. The objective of conjunctive use implies not only the combined use of water resources of more than one type but also their exploitation through efficient management in techno-economic terms by taking advantage of the interaction between them and the impact of one on the others.

It refers to the integrated management of surface water and ground water and it requires: (1) quantification of annual recharge and its spatial distribution to assess potential of conjunctive use, (2) simulation of the ground water basin parameters to analyse the impacts of irrigation and development of the ground water on the changes in water levels in the aquifer, and (3) identification of conjunctive use strategy that is most suitable for the given hydrologic, hydrogeologic, agroeconomic and hydrochemical conditions. The conjunctive use planning methods include: (1) engineering considerations for feasible ground water operations based on simulation of ground water basin, and (2) resource allocations based on both simulation and mathematical programming approach.

In the conjunctive water use process, water balance is estimated considering rainfall, surface runoff, seepage from canals, drains and natural streams and irrigation water recycling. The water table fluctuations and its rise are determined. The optimum water yields that can be drawn from the wells or tubewells with different operation schedules are determined. The available quantity of surface water from canals, lakes or ponds is estimated. The water quality of surface water and ground water is evaluated. A matching cropping plan with the irrigation requirement is developed and the salt tolerances of crops are determined.

The conjunctive use planning must include principles involved in the two water systems considered independently, but must also include principles to guide the optimal development of the complementarity of the two systems. Conjunctive use is planned and practised with the following objectives:

I. mitigating the effect of the shortage in canal water supplies often subject to steep variation in river flow during different periods in the year;
II. increasing the dependability of existing water supplies;
III. alleviating the problems of high water table and salinity resulting from introduction of canal irrigation;

IV. facilitating the use of poor quality water which cannot otherwise be used without appropriate dilution;
V. storing water in ground water basins closer to the users, to ensure water supply to the users in case of interruption of surface water supply;
VI. minimizes drainage water disposal problem.

MANAGEMENT OF THE MULTI-QUALITY WATER RESOURCES

Operation strategies that permit an optimal increase in cropped area and maximize the use of all available water of different qualities can be outlined under the following two major operational techniques:

Blending water (network dilution): different quality waters are mixed in the water supply permitting the predetermination of water quality for every field according to the tolerance of each crop to salinity, thereby either reducing the total salt concentration or changing the composition of the water reducing SAR. This procedure may increase the total quantity of water available for irrigation but at the same time will lower the quality of good water available.

Blending water either to increase the quality of water resource or to improve the relatively poor quality is a common practice. This has shown a good performance under many projects (Australia, Egypt, Israel, Pakistan and India). So far, results of studies show that this practice is not costly, more economic and easier to implement on large farms than other alternatives uses of water. In addition, blending may be more practical and appropriate, providing the drainage or shallow groundwater is not too saline per se for the crop to be grown. Nevertheless, for an extensive reuse of saline water, agronomic trials seems indispensable in order to select salt tolerant cultivars. In addition, specific site allocation of the saline water and the tolerant crops may limit the use of such water. In many cases, there is only a limited choice of tolerant crops with relatively low profit. Furthermore, even the yield of tolerant crops may be influenced by sensitive growth stages.

The suitable blending or mixing ratios of surface and ground water are worked out to plan conjunctive use of surface water and saline ground water. Considerable research efforts dealing with technical aspects of dilution process (mixing different kinds of water into a single distribution system) within the water distribution network have been pursued (Jury *et al.*, 1980; Tyagi and Tanwar, 1986). However, such blending is counter productive (Rhoades, 1983 and 1988).

The following logic is applied. A plant must expend bio-energy (that would otherwise be used in biomass production) to extract water from a saline (low osmotic potential) soil solution. When a water of excessive salinity for crop production is mixed with a low-salinity water and used for irrigation, the plant removes the "good water" fraction from the mix until the fraction of the mix made up of the excessively saline portion is left. This saline fraction is still as unusable (from the the plant energy expenditure point of view) as it was before mixing. But salt-sensitive crops can not concentrate the solution to this point without excessive yield loss. Thus, a fraction of the low-salinity (fully usable) water used to make the blend was made unavailable for transpiration as a consequence of blending. Thus diluting excessively saline water with less saline water does not stretch the water supply for crops of the same or lower salt tolerance. This "saline water" component is only usable by crops that are more salt-tolerant than those grown which produced the drainage.

Conjunctive use of good and poor quality water (recycling-alternation):
i) Soil water dilution through alternate (series/cyclic) use of good and poor quality waters according to water availability and crops needs.
ii) sequential application: the water source is changed during the season according to the specific salt tolerance of the crops at each growth stage.

This technique is centering on the possibility of applying alternatively fresh and brackish water according to the varying tolerance of crops during growth stages. This reuse strategy that avoid blending has been demonstrated in field projects to be viable and advantageous in well-managed irrigation projects (Rhoades, 1984; 1988 and Rhoades *et al*., 1988).

The experimental studies carried out by Bari Institute to evaluate the fore-mentioned two water application strategies favored more the alternate water application than the blending one (Box 4) (Hamdy, 1991 and 1993):

Box 4. Alternating use of good and poor quality water (advantages)

- Avoiding the deterioration of the good water quality. This water could be used at the time it should be most needed, for instance at the germination and seedling stages which are very sensitive to the salinity level of irrigation water as well as to satisfy the leaching requirements which requires water of relatively good quality;
- With the plants which are sensitive to the salinity level in irrigation waters, satisfactory production could only be achieved with water of good quality through alternative application modes. The disadvantages appearing under mixing could be completely eliminated and offer a free-hand possibility in using the different water resources according to the prevailing conditions;
- The cyclic use of water of low and high salinity prevents the soil from becomings too saline while permitting, over a long period, the substitution of brackish water for a substantial fraction of the irrigation needs.
- Cyclic strategy provides a vast choice of the crops to be included in the crop rotation as compared with the blending technique where crop selection is limited to the tolerant ones.

Although cyclic strategy has more potential flexibility than the blending one, there may be difficulty in adopting the cyclic strategy on small farms. In addition, application implies a double distribution system of water -both saline and fresh- to farms.

However, the matter is not simply the alternation of water resources. A suitable cropping pattern is also required that allows the substitution of saline water by normal water to irrigate certain crops in a suitable tolerant growth stage. Indeed, the timing and amount of possible substitution will of course, vary with the quality of the two waters, the cropping pattern, the climate, certain soil properties and the irrigation system.

To overcome the shortage in available fresh water resource in arid and semiarid countries, particularly those of the Mediterranean and for a better reuse of low quality water and for a more fresh water saving through conjunctive water use nationally, it is needed a critical review of the prevailing situation vis-a-vis available water resources and their use in the cropping pattern now being followed. Such an exercise should ideally be focussed on the following requisites:

i) definition and delineation of appropriate agro-climatic irrigation zones for current assessment and future planning of water resources with respect to the use of irrigation;
ii) assessment of the quantum of water available for irrigation in different zones;
iii) estimation of the irrigation requirements on the basis of cropping pattern and recommended irrigation practices;
iv) assessment of the current utilization of irrigation water and ascertaining the magnitude of its over and under use in different zones as in (i) above;
v) determination of alternative pattern of cropping, irrigation practices and supply of irrigation water together with related policy measures such that available water is optimally used to maintain ground water level within safe limits and to keep the short and long-run economic effects in proper balance.

INTEGRATED STRATEGY TO FACILITATE THE USE OF SALINE WATER FOR IRRIGATION AND TO MAXIMIZE THE BENEFICIAL USE OF MULTIPLE WATER SOURCES

In this section, a crop/water management strategy that should increase the practicality of using saline waters for irrigation, is described. Aspects of this strategy have been recently discussed elsewhere (Rhoades, 1983, 1984, 1985; Rhoades *et al.,* 1988a, b). The impetus for the strategy-has its origin in the assumption that typical farmers will not use brackish water for irrigation if access to enough water of lower salinity is available, unless the brackish water can be used without significant losses in yield, cropping flexibility or significant changes of farming practices.

The proposed management strategy, which meets these requirements, is to substitute the saline water (such as drainage or shallow groundwater) for the "good" water when irrigating certain crops in the rotation when they are in a suitably salt-tolerant growth stage; the "good" water is used at the other times. The maximum soil salinity in the rootzone that can result from continuous use of brackish water will not occur when such water is used for only a fraction of the time. The timing and amount of substitution will vary with the quality of the two waters, the cropping pattern, the climate, and the irrigation system. Whatever salt build-up occurs in the soil from irrigating with the brackish water is alleviated in the subsequent cropping period when a more sensitive crop is grown using the low-salinity water for irrigation. (It should be noted that a soil will not generally become unduly saline from use of a saline water for a part of a single irrigation season and often not for several seasons)

Furthermore, the yield of the sensitive crop should not be reduced if proper preplant irrigations and careful management are used during germination and seedling establishment to leach salts out of the seed area and shallow soil depths. Subsequent "in season" irrigations will leach these salts farther down in the profile ahead of the advancing root system and "reclaim" the soil in preparation for the brackish water which will be used again to grow a suitably tolerant crop. This cyclic use of “low” and “high” salinity waters prevents the soil from becoming excessively saline while permitting, over the long period, substitution of the brackish water for a low-salinity water for a large fraction (50%) of the irrigation water need.

In this regard we shall briefly describe two field experiments as examples illustrating a new crop/water management strategy to facilitate the use of saline waters for irrigation (Rhoades, 1988).

- The first concerns a 16 ha experiment in the Imperial Valley of California. Two sources of surface water were available: "good" irrigation water from the Colorado River containing approximately 900 mg/l TDS and water from the Alamo River, which is in essence a drain to dispose of agricultural drainage into the Salton Sea, with 3000 mg/l TDS. The objective was to grow a mixture of salt tolerant and salt sensitive crops in rotation, using that water source for any one irrigation that was suited to the crop and its stage of growth. The results verified that excellent crop yields could be maintained on a field scale with conventional surface irrigation, even if salt sensitive crops followed salt tolerant crops in the rotation, with a substitution of Alamo River water for Colorado River water over 50% of the time. Thus, this experiment demonstrated that the reuse of drainage water could reduce the need for fresh water without impact on crop yield.
- The second experiment, in the lower San Joaquin Valley of California, made use of well water at 8 ds m-1 (and 5.5 mg l-1 boron), California's Aqueduct water (0.6 dS m-1) and a 50-50 mix. In this case, the objective was to grow cotton with a minimum of fresh water. Again, results verified that highly respectable cotton yields could be obtained with saline water, especially if fresh water was used for seedling establishment and plant density was increased from conventional practice. As in the previous experiment, the call on fresh water could be reduced substantially.

The findings of the above-mentioned experiments indicate that the dual-rotation cyclic strategy for management of the multi-quality water resources not only resulted in relatively high freshwater saving, but also facilitated the use of saline water for irrigation. This can be clearly demonstrated by considering the following:

- In both experiments all over the cropping period including the different crop rotations, irrigation with freshwater including the leaching requirements amounted to nearly 50% of the total irrigation volume without any significant yield losses.

The maximum possible soil salinity in the rootzone resulting from continuous use of saline water does not occur when this water is used only for a fraction of the time.

Alleviation of salt build-up resulting from irrigation of salt-tolerant crops with the saline water occurs later when a salt-sensitive crops (s) is irrigated with the low-salinity water supply, or during off season periods of high rainfall.

Proper preplant irrigation and careful irrigation management undertaken during germination and seedling establishment are made using the low-salinity water supply to leach salts accumulated from saline irrigations out of the seed-area and from shallow soil depths.

The 50% saving in freshwater on one hand, keeping the soil at its productivity level maintaining soil salinity and alkalinity level within acceptable limits for seedling establishment and the subsequent growth of the individual crops growth in rotation along with the high crop yields on the other hand, support the credibility of the recommended cyclic, dual-duration (crop and water strategy) to facilitate the use of saline water for irrigation.

However, in order to plan and implement a successful practice involving the use of the cyclic, dual-rotation strategy for irrigating with saline waters, various other considerations must be addressed. The intention here is not to provide a step-by-step process that must be followed nor a rigid set of criteria to address these considerations, since most management decisions are subjective and case specific, but to discuss some of the factors that should be considered and to provide some rough guidelines for selecting appropriate management practices.

Perhaps the most important management decision to make before implementing a reuse practice is crop selection. In most cases, it is recommended that crops of high tolerance to salinity be selected when saline drainage water is to be used for irrigation. However, crops of intermediate tolerance (e.g. alfalfa, melons, tomatoes and wheat) may also be used in some cases, especially if the crop quality is sufficiently benefitted. For example, drainage water (EC 4-8 dS/m) significantly increased the protein content of wheat and alfalfa (Rhoades *et al.,* 1989a), soluble solids in melons and tomatoes (Grattan *et al.,* 1987), total digestible nutrients in alfalfa (Rhoades *et al.,* 1989a), and improved colour and netting of cantaloupe (Rhoades *et al.,* 1989a), and improved peelability in processing tomato (Grattan and Rhoades, 1990). While improved plant quality should not be the major factor in adopting a reuse practice it may be an important factor in crop selection. Use of saline water to irrigate crops of intermediate tolerance to salinity is feasible, of course, only after seedlings have been established by good quality water.

FACILITATING THE USE OF SALINE WATER FOR IRRIGATION: ESSENTIAL PARAMETERS OF PRIORITY CONSIDERATION

Operation Delivery Systems Efficiency

Water delivery and distribution systems must be operated efficiently to facilitate the timely supply of water in the right quantities and to avoid waterlogging and salinity build-up in irrigated lands, especially when saline waters are involved. The amount of water applied should be sufficient to supply the crop and satisfy the leaching requirement but not enough to overload the drainage system. Over-irrigation contributes to the high water table, increases the drainage requirement and is a major cause of salinity build-up in many irrigation projects. Therefore, a proper relation between irrigation, leaching, and drainage must be maintained in order to prevent irrigated lands from becoming excessively waterlogged and salt-affected.

In this regard, it is all important when using saline water for irrigation having reliable data or appropriate methods to predict project water requirements. FAO (1984) has developed methods to determine project water requirements based on actual crop water needs, leaching requirements and irrigation efficiencies, a computer programme (CROPWAT, 1992) and a complementary computerized database programme (CLIMWAT, 1991).

Excessive loss of irrigation water from canals constructed in permeable soil is a major cause of high water tables and secondary salination in many irrigation projects. Such seepage losses should be reduced by lining the canals with impermeable materials or by compacting the soil to achieve a very low permeability.

Furthermore, provision for effective flow measurement should be made. It is generally computed that many delivery systems encourage over-irrigation because water is supplied for fixed periods or fixed amounts, irrespective of seasonal variation in on-farm needs and thereby salinity and water table problems are often the result. In addition, and to achieve high efficiency and to facilitate salinity control, it is of paramount importance that the distribution system to be designed and operated as to provide water on demand and in metered amounts as needed.

Irrigation Efficiency

Improvements in salinity control generally come hand-in-hand with improvements in irrigation efficiency. The key to the effective use of saline irrigation waters and salinity control is to provide the proper amount of water to the plant at the proper time. The ideal irrigation scheme should provide water as nearly continuously as possible, though not in excess, as needed to keep the soil water content in the rootzone within optimum safe limits. However, carefully programmed periods of stress may be needed to obtain maximum economic yield with some crops; cultural practices also may demand occasional periods of dry soil. Thus, the timing and amount of water applied to the rootzone should be carefully controlled to obtain good water use efficiency and good crop yield, especially when irrigating with saline water. As mentioned above, this requires water delivery to the field on demand which, in turn, requires the establishment of close coordination between the farmer and the entity that distributes the water; it calls for the use of feedback devices to measure the water and salt contents and potentials in the soil and devices to measure water flow (rates and volumes) in the conveyance systems.

A frequent constraint in improving on-farm water use of saline water is the lack of knowledge of just when an irrigation is needed and of how much capacity for storage is available in the rootzone. Ways to detect the onset of plant stress and to determine the amount of depleted soil water are prerequisites to supplying water on demand and in the amount needed. Prevalent methods of scheduling irrigation usually do not, but should, incorporate salinity effects on soil-water availability (Rhoades *et al.,* 1981). When irrigating with saline waters, the osmotic component of the soil water potential of the rootzone must be considered in scheduling decisions.

Saline Water Irrigation Planning and Management Models

A couple of models are developed to predict long term behaviour of ground water, rootzone salinity index, desalinization of a tile drained soil profile, quality of ground water and drainage, efficient solute transport, crop water requirement and crop response models to simulate crop production. Some computer models are indicated as follows:

- **SIWATRE Computer Model:** It was developed in ILRI, the Netherlands for simulation of water management system in arid regions (unsaturated flow model) which has the components as sub-model design for water allocation to the intakes of the major irrigation canal, sub-models WDUTY for estimation of water requirement at farm level, sub-mode REUSE for the water losses to the atmosphere, and WATDIS sub-model for water distribution within the command.
- **SGMP Computer Model:** It was developed in ILRI, the Netherlands as a numerical ground water simulation model to quantify the amount of recharge from the top system to the aquifer and its spatial variation and to assess its effects on water table depths.
- **SALTMOD Computer Model:** It was developed in ILRI, the Netherlands to predict long term effects of ground water conditions, water management options, average water table depth, salt concentration in the soil, ground water use, drain and well water yields, dividing the soil-aquifer system into four resources surface reservoir, soil reservoir (root zone), an intermediate soil reservoir (vadose zone), and a deep reservoir (aquifer).
- **UNSATCHEM Computer Model:** It was developed in US Salinity Laboratory in USA and is one dimensional solute transport model, which simulates variably saturated water flow, heat transport, carbon dioxide production and transport, solute transport and multi-component solute transport with major ion equilibrium and kinetic chemistry. UNSATCHEM package may be used to analyse water and solute movement in the unsaturated, partially saturated, or fully saturated porous media. Flow and transport can occur in the vertical, horizontal, or in an inclined direction. This package is a good tool to understand the chemistry of unsaturated zone in case of saline water use and development of analytical model to predict the changes in ground water and soil quality.
- **SWASALT/SWAP Computer Model**: It was a package on an extended version of SWATRE model. The depth and time of irrigation applied, quality of irrigation water used, soil type and initial soil quality can be modified and the effects on crop performance, soil salinization and desalinization process, soil water storage (excess/defecit) can be obtained from the model output.
- **WATSUIT Computer Model:** It was developed in US Salinity Laboratory USA is a transient state model and is used for assessing water suitability for irrigation which can incorporate the specific

influences of the many variables that can influence crop response to salinity, including, climatic, soil properties, water chemistry, irrigation and other management practices.

- **CROPWAT Computer Model:** It was developed to calculate crop water requirement and irrigation water requirement including irrigation schedules for different management conditions and calculation of water supply scheme for different cropping patterns (FAO, 1992). CLIMWAT program is available to obtain the required climatic data for CROPWAT (FAO, 1991).
- **SALTMED Model:** The model runs on a PC under Windows 95/98 operation System. The model's input consists of: Climate data, Soils data, crop data, irrigation data (system, amount, salinity), soil parameters, crop parameters, and other model parameters. The model has default values and includes database for soils and crops. In the model, the Richards Equation and the Convection-Dispersion Equation describe the water and solute movements respectively. The daily potential and actual evapotranspiration were calculated using Penman-Monteith equation according to FAO Irrigation & Drainage paper No. 56. The model runs for a variety of irrigation systems, crops, soils, and water salinity levels. The daily model output (graphs and data files) includes, yield, potential and actual water uptake, salinity, soil matric potential and soil moisture profiles, crop water requirements, leaching requirements, plant growth parameters, Potential and actual evapotranspiration, bare soil evaporation and plant transpiration. The model is friendly and easy to use benefiting from the windows environment (Ragab, 2002) Wallingford, Uk.

CROP MANAGEMENT

The crop management is an important aspect in addition to water management and soil management to obtain optimum crop production by irrigation with saline water. Sustainable use of saline water for irrigation cannot be achieved unless we have an integrated management approach including the three primary production elements: water, soil and plant.

Excess salinity within the plant rootzone has a general deleterious effect on plant growth which is manifested as nearly equivalent reductions in the transpiration and growth rates (including cell enlargement and the synthesis of metabolites and structural compounds). This effect is primarily related to total electrolyte concentration and is largely independent of specific solute composition. The hypothesis that best seems to fit observations is that excessive salinity reduces plant growth primarily because it increases the energy that must be expended to acquire water from the soil of the rootzone and to make the biochemical adjustments necessary to survive under stress. This energy is diverted from the processes which lead to growth and yield.

The plants can extract and use more water from the salt free soil than from the salty soil. Salts have an affinity for water. If water contains salts, more energy per unit of water uptake must be expended by the plants to absorb relatively pure water from a salty soil water regime. The added energy required by plants to absorb water from the salty soil (soil osmotic potential) is additive to the energy required to absorb water from a salt free soil (soil water potential).

Not all growth depression of plants can be ascribed to the effect of osmotic pressure of the soil solution and decrease of moisture availability. Salinity may also affect the plants by the toxicity of specific salt, either through its effect surface membrane to plant roots or in the plant tissues or through its effect on intake or metabolism of essential nutrients.

The soil salinity may be a main limiting factor, but other factors may also limit crop production or modify crop salt tolerance. These factors may include: (1) climate, (2) production potential of soil with level of soil fertility, soil structure, aeration capacity, and intensity of soil moisture regime, (3) crop plant variety and growth stages, (4) crop cultural practices, and (5) application of irrigation methods.

Crop Tolerance to Salinity

Crop plants greatly vary in their ability of germinate, develop and produce yield under saline environment. It is the crop’s sensitivity or tolerance to salinity, which defines the salinity of soil or soil water.

Salt tolerance in plants is a polygenetic trait controlled by the genes that synthesize enzymes responsible for a variety of biochemical and physiological processes. Genetic variation in salt tolerance does exist within and among the plant species. This differential capacity of plants to endure the effects of salinity has been the basis in screening and breeding studies for commercially marketable salt tolerant varieties of crops (Mass, 1977; FAO, 1979; Doorenbos and Kassam, 1979; Gilani and Ghaibah, 1998; Singh, 1998; CSSRI, 1998).

The worldwide efforts have been made towards understanding the mechanism of plant salt tolerance with the eventual goal of improving the performance of crop plants in saline soils, more dealing with the effects of excess NaCl in the media. Plants use different strategies at the cell, tissue and organ level. A widely used approach to unravel plant salt tolerance mechanism has been to identify cellular processes and genes whose activity or expression is regulated by salt stress (Zhu *et al*., 1997).

Plants under saline conditions have to deal with four major overlapping problems in order to become a salt tolerant one: (1) ability to either exclude or take up and compartmentalize Na and Cl using ion channels, porters and AT Passes, (2) ability to maintain internal water status through the increased activities of enzymes, (3) ability to prevent direct or indirect damage by Na and Cl to sensitive cellular structures, and (4) ability to prevent any nutritional deficiency to occur (CSSRI – Salinity Management in Agriculture, 1998).

Growth suppression is typically initiated at some threshold value of salinity, which varies with crop tolerance and external environmental factors which influence the need of the plant for water, especially the evaporative demand of the atmosphere (temperature, relative humidity, windspeed, etc.) and the water-supplying potential of the rootzone, and increases as salinity increases until the plant dies. The salt tolerances of various crops are conventionally expressed (after Maas and Hoffman, 1977), in terms of relative yield (Y_r), threshold salinity value (a), and percentage decrement value per unit increase of salinity in excess of the threshold (b); where soil salinity is expressed in terms of EC_e, in dS/m), as follows:

$$Y_r = 100 - b\,(EC_e - a)$$

where Y_r is the percentage of the yield of the crop grown under saline conditions relative to that obtained under non-saline, but otherwise comparable, conditions. This use of EC_e to express the effect of salinity on yield implies that crops respond primarily to the osmotic potential of the soil solution. Tolerances to specific ions or elements are considered separately, where appropriate.

Mass (1984, 1986 and 1990) presented the information in standard tabular forms on salt tolerance of selected crops and their yield potential as influenced by irrigation water salinity (EC_{iw}) or soil salinity (EC_e) giving the salinity at which crop yield begins to decline (threshold values) and the rate of crop yield decline with increased salinity.

Ayers and Westcot (1989) suggested salinity potential of different crops in relation ECe (Table 9). Rhoades *et al*. (1992) Salt tolerance threshold of different field crops, vegetables and fruit trees (Table 10).

Table 9. Salinity tolerance and yield potential of different crops in relation to EC_e (dS/m)

	Crops	Yield potential (%)			
		100	90	75	50
Field Crops					
1.	Barley	8.0	10.0	13.0	18.0
	(a) Mustard	8.0	9.0	12.0	-
2.	Cotton				
3.	S.beet	7.0	8.7	11.0	15.0
4.	Sorghum	6.8	7.4	8.4	9.9
5.	Wheat	6.0	7.4	9.5	13.0
	Wheat (Durum)	5.7	7.6	10.0	15.0
6.	Soybean	5.0	5.5	6.3	5.7
7.	Cowpea	4.9	5.7	7.0	9.1
8.	Groundnut	3.2	3.5	4.1	4.9
9.	Rice	3.0	3.8	5.1	7.2
10.	Sugarcane	1.7	3.4	5.9	10.0
11.	Maize	1.7	2.5	3.8	5.9
12.	Broad veab	1.5	2.6	4.2	6.8
13.	Bean	1.0	1.5	2.3	3.6

Source: Ayers and Westcot, 1989

Table 10. Salt tolerance threshold of field crops, vegetable and fruit trees

Crop	Electric conductivity of saturated soil extract Threshold dS/m	Tolerance level
Barley	8	T*
Bean	1	S
Broadbean	1.6	MS
Cotton	7.7	T
Maize	1.7	MS
Sorghum	6.8	MT
Soybean	5	MT
Sugarbeet	7	T
Wheat	6	MT
Alfalfa	2	MS
Clover	1.5	MS
Asparagus	4.1	T
Carrot	1	S
Beet, red	4	MT
Broccoli	2.8	MS
Brussels sprouts	1.8	MS
Okra	1.2	S
Onion	1	S
Pea	1.5	S
Spinach	3.2	MS
Strawberry	1.5	S
Tomato	0.9	MS
Almond	1.5	S
Date Plam	4	T
Grape	1.5	MS
Orange	1.7	S
Peach	1.7	S
Guayule	15	T

Source: Rhoades *et al.*, 1992; FAO, 1935

*T: tolerant; S: sensitive; MS: moderately sensitive; MT: moderately tolerant.

Guidelines on Salt Tolerance Limit in some Mediterranean Countries (Syria, Tunisia, Libya)

The Arab Center for Studies of Arid zones and Dry Lands (ACSAD) in League of Arab States, Damascus, Syrian Arab Republic have studied the crop responses and yields to different salinity levels of low quality irrigation water obtained through blending of irrigation water with drainage water and through use of saline ground water at field conditions in Syria, Tunisia and Libya. The EC_{iw} ranged from 1.5 to 11.4 dS/m for Syria; 0.3 to 5.46 dS/m for Tunisia; and 3.9 to 16.7 dS/m for Libya (Addelgawad and Abdelrahman, 1998). Table 11 provides threshold (ECe) values for different crops in Syria. Table 12 includes data of Tunisia. Table 13 provides data for Libya. The data on salt tolerance in these three tables can be considered as guidelines for the use of saline water in irrigation.

Table 11. Relative salt tolerance of crops (Syria) (EC_{iw} range = 1.5, 4.4, 6.4, 8.4, 9.4, 11.4 dS/m)

Crops	Threshold	Slope	Leaching fraction	EC_{iw} of Zero yield
Cotton	4.75	11.0	0.0	13.8
	4.81	9.8	0.15	15.0
	4.72	9.1	0.30	15.7
	4.78	10.2	All	14.7
Maize	3.99	17.5	0.0	9.7
	4.02	16.1	0.15	10.3
	3.87	15.5	0.30	10.3
	3.88	15.9	All	10.2
Vetch	2.90	5.52	0	21.5
	2.99	6.60	15	19.4
	2.98	6.60	30	18.0
	2.95	6.14	All	19.8
Wheat Grain	3.61	10.2	0	13.4
	5.43	8.3	0.15	17.5
	4.36	9.6	0.30	14.8
	4.36	9.51	All	14.9
Wheat Hay	4.6	8.62	0	16.1
	7.89	9.91	0.15	18.0
	6.96	11.6	0.30	15.6
	7.2	10.4	All	16.7
Barley Grain	7.14	7.5	0	20.5
	8.02	6.6	0.15	23.1
	5.72	6.7	0.30	20.5
	6.95	7.0	All	21.4
	6.4	9.9	0.0	16.5
	7.33	9.5	0.15	17.9
Barley Hay	6.4	9.4	0.30	17.0
	7.05	9.3	All	17.8
Alfalfa Dry	6.1	11.7	0.0	14.6
	6.1	11.7	0.15	14.6
Production	4.4	10.2	0.30	14.0
	6.4	12.4	All	14.5

Source: Abdelgawal and Abdelrahman, 1998

Table 12. Relative salt tolerance of crops (Tunisia)

Crops	Threshold	Slope	Leaching fraction	EC_{iw} of zero yield
Tomato	3.27	14.7	0.15	10.1
Melon	1.83	9.1	0.15	12.8
Maize	1.2	8.6	0.15	12.9
Pepper	2.12	8.9	0.15	13.3
Water melon	1.43	8.3	0.15	13.5
Clover	0.33	7.58	0.15	13.5
	1.2	6.9	0.15	15.6
Potato	0.58	5.5	0.15	18.8
Broccoli	2.87	4.5	0.15	25.2

Source: Abdelgawal and Abdelrahman, 1998

Table 13. Relative salt tolerance of crops (Libya) (EC_{iw} : 3.9, 8.0, 11.6, 16.7 dS/m)

Crops	D. Threshold	Slope	Leaching fraction
Barley	6.97	1.72	0.2
Barley hary	6.89	2.49	0.2

The fact that there is ample information on crop tolerance to salinity, but, it is important to recognize that such salt tolerance data cannot provide accurate quantitative crop yield losses from salinity for every situation, since actual response to salinity varies with other conditions of growth including climatic and soil conditions, agronomic and irrigation management, crop variety, stage of growth, etc. While the values are not exact, since they incorporate interactions between salinity and the other factors, they can be used to predict how one crop might fare relative to another under saline conditions.

Climate Variation

Plant tolerance may be strongly affected by climate variables. Climatic factors: temperature, humidity and rainfall may interact with salinity so that tolerance levels reported from one location may not be applicable under other conditions, although these is general agreement as to the relative tolerance of many crops (Framji, 1976).

Most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. Yield is reduced more by salinity when atmospheric humidity is low. Ozone decreases the yield of crops more under non-saline than saline conditions, thus the effects of ozone and humidity increase the apparent salt tolerance of certain crops. Rainfall, though does not have a direct effect on crop tolerance, may indirectly affect by leaching the response of plants to irrigation with saline water.

Crop Growth Stages (Germination, Emergence and Early Seedling Growth)

These stages are the most critical periods for a crop to obtain a good stand. Losses in plant density during this period cannot be compensated for later and will cause an equivalent loss in production. In case of irrigation under saline conditions, either with saline water or in saline soil, the crop generally encounters more problems during germination, emergence and early seedling growth than during later growth stages and may even fail to establish.

The losses in plant density encountered during the first growth stages are not so much due to a lower salt tolerance during this period. The essential difficulty is the high salinity in the top layer of the soil, exposing the germinating seed and the seedlings to a much higher salt concentration than at later growth stages (Hanks *et al*., 1978).

Field studies and laboratory on salt distribution in furrow irrigation and laboratory studies (Rhoades and Merrill, 1976) indicated a very pronounced local salt concentration. To avoid seed germination damage in furrow irrigation various alternatives of bed shaping, placement of seeds and irrigation conditions may be used (Greenway and Munns, 1980).

The delay in germination and emergence of seedlings caused by salinity may be increased or germination prevented under unfavourable soil and weather conditions. High temperature may speed up germination but will at the same time increase evaporation and capillary rise of salts. Low temperature may delay germination so much that the seedlings are caught in the crust formed in the meantime. So it is dangerous to transfer results obtained with saline water irrigation from the laboratory to the field or from one region to another without carefully considering the condition of the soil and weather during germination.

Soil texture has its great impact on seed germination as well as seedling development under saline irrigation practices. In the heavy textured (clay) soil, although salts accumulated relatively more than in the sandy clay, seedlings were better developed than in the sandy clay soil. Moreover, in the sandy soil where salt accumulation was the lowest with respect to the other investigated soils, the seed germination percentage as well as the seedling development were the worst. The selection of the salt concentration level in irrigation leading to good germination percentage as well as to well developed seedlings must be decided not only in view of the salt tolerance degree of the crop but also to other factors such as soil properties and climatic conditions (Hamdy, 1999).

Under irrigation with saline water or in saline soils, good emergence of the seedlings with the shortest delay is of primary importance for the development of the crop. This could be achieved by the use of fresh water during germination, if this water is available, followed by saline water once the seedlings are already established (Hamdy, 2002).

To ensure proper crop management at these sensitive growth stages, the following precautions should be adopted (Van Schilfgaard and Rhoades, 1979; Puntamkar *et al*:, 1972; Hamdy and Ragab, 1999):

- germinating seeds should receive good quality water especially if plants are sensitive and, in the case of lack of fresh water, only for tolerant and semi-tolerant plants, fair seed germination can be obtained by using water of EC values not exceeding 4 dS/m;
- under saline irrigation practices, fresh water at germination efficiently improves the growing parameters of the developed seedlings, especially at the relatively high salt concentration levels in irrigation water;
- fresh water at germination not only improves the seedling growth but also reduces, on an average of 35%, the accumulated salts in the soil with respect to the irrigation treatment with permanent saline water.

In this respect, it is wise to recall the benefit which could be achieved in improving crop production through the alternation of low and good quality water rather than blending (Hamdy, 1993; Oster *et al*., 1984 and Hamdy, 1990b).

Vegetative Growth and Yield

Plant growth is directly affected by the salinity level of the soil rather than the salinity of irrigation water, except where direct contact between foliage and irrigation water results in leaf burn. Decrease of growth due to salinity at the vegetation stage is not necessarily followed by a decline in yield (Rhoades, 1972; Shalhevet and Kamburov, 1976; Allison, 1964 and Agarwal *et al*., 1978).

Many data are available with regard to salt tolerance of crops, but most of this information refers to the total period from the late seedling stage to maturity. For many crops the germinating and early seedling stage is the most sensitive. Much less is known about the sensitivity during later growth stages, e.g. flowering, seed formation. If crops appear to be sensitive during specific periods, it could be beneficial to lower soil salinity in the upper part of root zone with the highest root density by applying fresh water during sensitive periods, if such water is available to the farmer.

Efficient crop management under saline irrigation practices requires that the critical growing stage for the majority of crops be identified. A suitable irrigation method can be selected, based principally on how and when it should be applied to prevent stressing the plant during the sensitive stages of its growing cycle (Hamdy and Ragab, 2002).

Varietal Differences

Varietal difference among crops may cause strong differences regarding salt tolerance among varieties and root stocks of fruit trees and vine crops. Tolerant plants require multiple adaptations to enable them to grow in saline environments. The problem faced by plant scientist wishing to enhance tolerance in crop plants is how to manipulate complex multigenic traits. The research work needs to be aimed at basic information about the genetic of physiological traits and attempts to discover genes regulating salt tolerance following the imposition of salinity stress and understating signaling cascades.

Modern molecular techniques can be used to analyze the genetics of quantitative traits determined by quantitative traits loci (QTLS) developing practical makers and map their positions for positional cloning to discover genes. The use of DNA-based technology is capable of dealing with large number of samples, markers may be a valuable means of assisting in the development of salt tolerance in plants. The molecular biological approaches may be helpful to enhancing salt tolerance (CSSRI, 1993).

Crop Selection

Crop selection is an important management decision. The most desirable characteristics in selecting crop for irrigation with saline water are: (1) high marketability (2) high economics value, (3) ease of management (4) tolerance to salts and specific ions, (5) ability to maintain quality under saline conditions, (6) low potentional to accumulate trace elements, and (7) compatibility in crop rotation (Grattan and Rhoades, 1990; Tanji, 1994).

CULTURAL PRACTICES

Many factors that facilitate the use of saline water are related to management practices for short and long term salinity control. Adequate drainage and leaching to control salinity within the tolerances of the crops are the ones most appropriate management practices for long term salinity control.

Seed treatment, land smoothening and grading, plant population and placement, fertilization, irrigation doses and frequency and methods of irrigation are important short term cultural practices, highly related to crop management. Such cultural practices can have profound effect upon germination, early seedling growth and ultimately on yield and crop.

MANAGING SOIL UNDER SALINE IRRIGATION

Several physical, chemical and biological soil management measures help facilitate the safe use of saline water in crop production. Some important ones in this regard are: tillage, deep ploughing, sanding, use of chemical amendments and soil conditioners, organic and green manuring and mulching.

Tillage

Tillage is a mechanical operation that is usually carried out for seedbed preparation, soil permeability improvement, to break up surface crusts and to improve water infiltration. If tillage is improperly executed, it might form a plough layer or bring a salty layer closer to the surface. Sodic soils are especially subject to pudding and crusting; they should be tilled carefully and wet soil conditions avoided.

Deep Ploughing

It is most beneficial on stratified soils having impermeable layers lying between permeable layers. In sodic soils, deep ploughing should be carried out after removing and reclaiming the sodicity, otherwise it will cause complete disturbances and collapse of the soil structure. Deep ploughing to 60 cm loosens the aggregates, improves the physical condition of these layers, increases soil-water storage capacity and helps control salt accumulation when using saline water for irrigation. Crop yields can be markedly improved by ploughing to this depth every three or four years.

The selection of the right plough types (shape and spacings between shanks), sequence, ploughing depth and moisture content at the time of ploughing should provide good soil tilth and improve soil structure (Mashali, 1989).

Sanding

It is a process aiming to have a fine textured surface soil more permeable. It results in improved root penetration and a better aeration and water permeability which facilitates leaching of salts when surface infiltration limits water penetration.

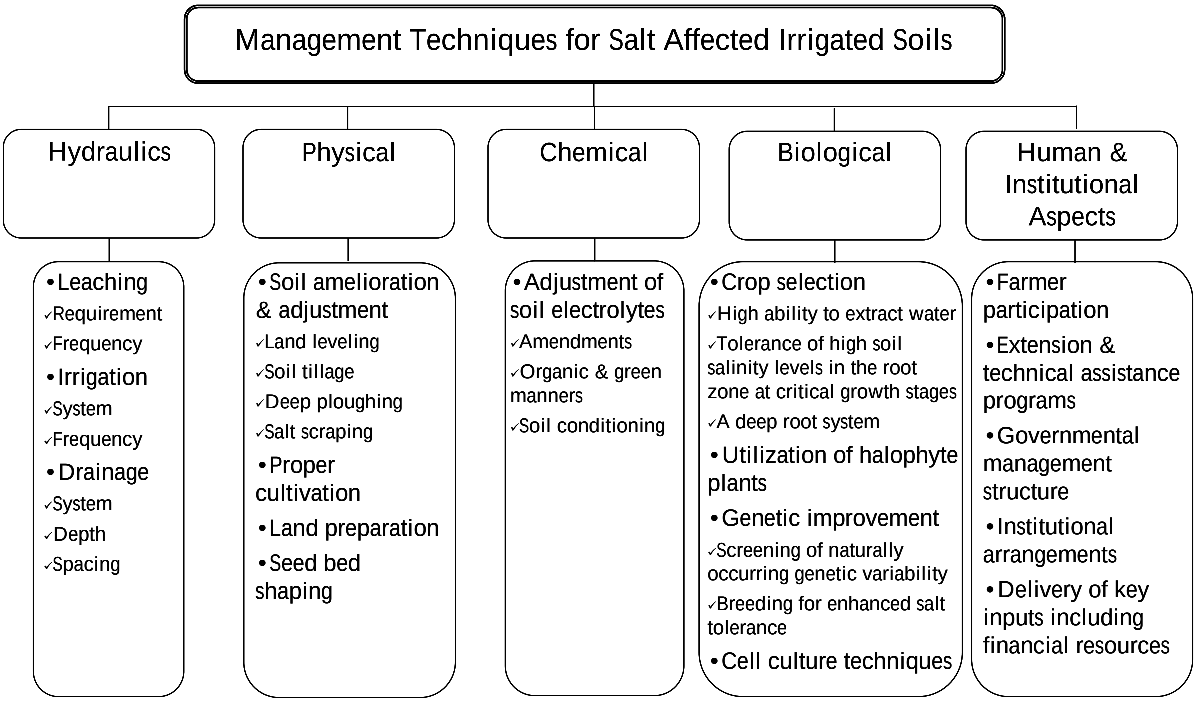


Figure 5. Management techniques for salt affected irrigated soils

Chemical Soil Amendments and Their Quantities

These amendments are used to neutralize soil reaction, to react with calcium carbonate and to replace exchangeable sodium by calcium. This decreases the ESP and should be followed by leaching for removal of salts derived from the reaction of the amendments with sodic soils. They also decrease the SAR of irrigation water if added in the irrigation system.

Unlike saline soil water, alkali soil/water responds to chemical amendments materials that directly supply the soluble calcium for replacement of exchangeable sodium. The choice of amendment and the quantity required for reclamation depends on the physico-chemical properties of the soil, the amount of exchangeable sodium to be replaced, the desired rate of improvement, the quality and quantity of water available for leaching and the cost of the amendment. The common amendments are given in (Box 5). Gypsum by far is the most common amendment for sodic soil reclamation when using saline water with a high SAR value for irrigation.

Box 5. Gypsum equivalent of different amendments

Amendments	Amount equivalent to gypsum
Gypsum ($CaSO_4$. $2H_2O$)	1.00
Sulphur (S)	0.19
Sulphuric Acid (H_2SO_4)	0.57
Lime Sulphur (24%S)	0.77
Calcium Carbonate ($CaCO_3$)	0.58
Calcium Bicarbonate Dehydrate ($CaCl_2.2H_2O$)	0.85
Ferrous Sulphate ($FeSO_4.7H_2O$)	1.61
Aluminium Sulphate ($Al_2(SO_4)_3$;$18H_20$)	1.29
Iron Pyrite (FeS_2.30%S)	0.63

Prather *et al*. (1979) have reported the advantages gained by using the different amendments in combination. The quantity of amendment needed to reclaim an alkali soil is determined as a product of gypsum requirement (the equivalent amount of exchangeable sodium to be replaced in the soil) which is multiplied by a factor (1.2-1.3) to compensate for the inefficiencies. Based on pH value of soil in 1.2 soil water suspension, Abrol *et al*. (1973) have developed a graphical relationship to determine the gypsum requirements of light, medium and heavy alkali soils (Fig. 6). The quantities of gypsum computed by this method are, however, approximate.

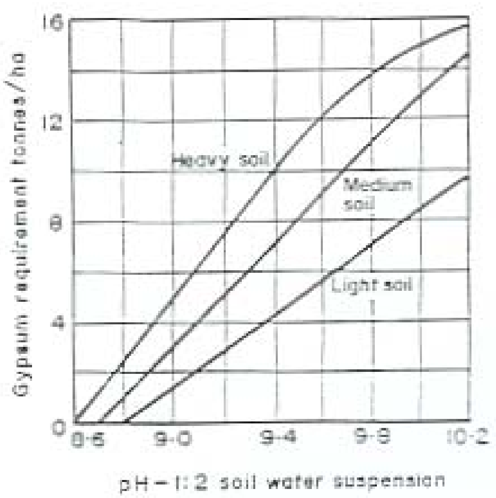


Figure 6. Nomogram for calculating gypsum requirement in alkali soil

The addition of gypsum (either to the soil or water) can often help appreciably in avoiding or alleviating problems of reduced infiltration rate and hydraulic conductivity. For more specific information on the effects of exchangeable sodium, electrolyte concentration and pH, as well as of exchangeable Mg and K, and use of amendments on the permeability and infiltration rate of soils reference should be made to the reviews of Keren and Shainberg (1984); Shainberg (1984); Emerson (1984); Shainberg and Letey (1984); Shainberg and Singer (1990).

ORGANIC AND GREEN MANURES AND MULCHING

Incorporating organic matter into the soil has two principal beneficial effects of soils irrigated with saline water high SAR and on saline sodic soils: improvement of soil permeability and release of carbon dioxide and certain organic acids during decomposition. This will help in lowering soil pH, releasing calcium by solubization of CaCO3, and other minerals, thereby increasing ECe and replacement of exchangeable Na by Ca and Mg which lowers the ESP.

Mulching is effective in reducing evaporation losses lowering the upward flux of soluble salts and thereby decreasing the opportunity for soil salinization.

When using saline water where the concentration of soluble salts in the soil is expected to be high in the surface, mulching can considerably help leach salts, reduce ESP and thus facilitate the production of tolerant crops. Mulching to reduce evaporation losses will also decrease the opportunity for soil salinization.

MINERAL FERTILIZERS

Salt accumulation affects nutrient content and availability for plants in one or more of the following ways: by changing the form in which the nutrients are present in the soil; by enhancing loss of nutrients from the soil through heavy leaching or, as in nitrogen, through denitrification, or by precipitation in soil; through the effects of non-nutrient (complementary) ions on nutrient uptake; and by adverse interactions between the salt present in saline water and fertilizers, decreasing fertilizer use efficiency.

Crop response to fertilizer under saline or sodic conditions is complex since it is influenced by many soil, crop and environmental factors. The benefits expected from using soil management measures to facilitate the safe use of saline water for irrigation will not be realized unless adequate, but not excessive, plant nutrients are applied as fertilizers. The level of salinity may itself be altered by excess fertilizer application as mineral fertilizers are for the most part soluble salts. The type of fertilizer applied, when using saline water for irrigation, should preferably be acid and contain Ca rather than Na taking into consideration the complementary anions present. Timing and placement of mineral fertilizers are important and unless properly applied they may contribute to or cause a salinity problem.

CONCLUDING REMARKS AND RECOMMENDATIONS

Saline water is a potential source of irrigation and freshwater saving in irrigated agriculture. Recent research developments on salt tolerance of various crops, water, soil and crop management, irrigation and drainage methods and the reuse of drainage effluents, will enhance and increase its potential use for irrigation. There is ample evidence to illustrate the widespread availability of saline waters and a wide range of experience exists around the world with respect to using them for irrigation under different conditions. This evidence and experience demonstrates that waters of much higher salinities than those customarily classified as “unsuitable for irrigation” can, in fact, be used effectively for the production of selected crops under the right conditions.

Salinity is not the property of irrigated agriculture but occurs in response to the kind of management imposed on the system. Management of salinity is a multidimensional problem requiring the understanding of the genesis, and the development of appropriate technology which is socially acceptable and economically viable. Irrigation technology developed so far has considerably enhanced our capacity to manage land and water salinity problems. But as the concern for protecting the natural environment grows, the need to refine the technology and shift emphasis on drainage volume reduction and reuse will also increase.

In considering the use of a saline water for irrigation and in selecting appropriate management to protect water quality, it is important to recognize that the total volume of a saline water supply cannot be beneficially consumed for irrigation and crop production; and the greater its salinity, the less it can be consumed before the salt concentration becomes limiting. In the Mediterranean countries, particularly the arid and semiarid ones, focus should be directed towards the setup of new crop/water management strategies that facilitate the use of saline water for irrigation and minimizing the negative drawbacks of its use on soil productivity, yield production and the environment.

Regarding the strategies of saline water use, it is recommended that the practice of blending or diluting excessively saline waters with good quality water supplies should only be undertaken after consideration is given to how this affects the volumes of consumable water in the combined and separate supplies. Blending or diluting saline low quality waters with good quality waters in order to increase water supplies or to meet discharge standards may be inappropriate under certain situations. More crop production can usually be achieved from the total water supply by keeping the water components separated. Serious consideration should be given to keeping saline waters separate from the "good quality" water supplies, especially when the latter waters are to be used for irrigation of salt-sensitive crops. The saline drainage waters can be used more effectively by substituting them for "good quality" water to irrigate certain crops grown in the rotation after seedling establishment.

Sustainable and safe use of saline water for irrigation and to maximize freshwater saving in the agricultural sectors, to achieve these goals, it is needed:

- ✓ An integrated, holistic approach is needed to conserve water and prevent soil salinization and waterlogging while protecting the environment and ecology. Firstly, source control through the implementation of more efficient irrigation systems and practices should be undertaken to minimize water application and reduce deep percolation to promote.
- ✓ To promote conjunctive use of saline groundwater and surface water to aid in lowering water table elevations, hence to reduce the need for drainage and its disposal and to conserve water.
- ✓ New technologies and management practices must be developed and implemented. Efficiency of irrigation must be increased by the adoption of appropriate management strategies, systems and practices and through education and training. Such measures must be chosen with recognition of the natural processes operative in irrigated, geohydrologic systems, not just those on-farm, and with an understanding of how they affect the quality of soil and water resources, not just crop production.
- ✓ To introduce the participatory approach in saline irrigation practices and management. There is a wide gap of knowledge level between the technical staff and the farmers. The use of saline water and its management is a complex process and needs adequate knowledge at farmer's level. Farmers' participation and involvement in planning and management is the key point leading to success and/or failure in saline irrigation projects. Many of the irrigation and drainage projects failed because of the non-cooperation and non-involvement of the local users in their planning, design, construction, operation and maintenance.

There is usually no single way to achieve salinity control in irrigated and associated waters. Some practices can be used to control salinity with the crop root zone, others for larger units of management such as irrigation projects and river basins beside those to protect offsite environment and ecological systems including the associated surface and groundwater resources. Indeed, the approaches are numerous, but, the difficulties exit in selecting the appropriate approach to be followed as it depends upon economic, climatic, social as well as edaphic and hydrogeological situations. Thus, there is no procedure to be given for selecting the appropriate set of control practices that could be adopted in the different countries of the Mediterranean. Every country has to search and decide on the most appropriate control practices in view of the prevailing local conditions and to integrate and combine them into satisfactory control systems.

The future research in land/water salinity management will have to give more attention in the following areas:

- ✓ integrated management of water of different qualities at the level of farm, irrigation system and drainage basins with the explicite goals of increasing agriculture productivity, achieving optimal efficiency of water use, preventing on-site and off-site degradation and pollution, and sustaining long-term production potential of land and water resources;
- ✓ further research is needed in developing and use of mathematical and computer simulation models to relate crop yield and irrigation management under saline conditions so far that those empirical models can be reliably applied under a wide variety of field conditions;
- ✓ at present, there is no clearly defined policies and strategies on the use of saline water and/or the reuse of drainage water for irrigation. To arrive at these policies and strategies, monitoring programs are required on both water quantities and qualities, as well as on soils;
- ✓ low volume and localized water application methods like sprinklers, drip and earthern pitchers can considerably reduce the drainage volumes. Pilot projects need to be established in saline groundwater areas having rising watertable trend to evaluate efficacy of such methods;
- ✓ in the past leaching and drainage were considered the ultimate solution for resolving salinity problems. The growing environmental concerns have put question mark on the sustainability of drainage system itself. There is a need to study the trade-off between provision of full drainage and drainage volume reduction;
- ✓ the groundwater flow models should incorporate salinity component to predict the development of not only waterlogging but also of soil water salinity. Regional agro-hydro-salinity models should be of immense value in planning appropriate water management strategies;
- ✓ the emphasis so far has been on development of technology hardware. The role of policies and institutions in creating demand for technology has not been fully appreciated. There is

need to give adequate attention to this very important aspect if sustainability of irrigated agriculture in saline environment has to be ensured;

- ✓ much important and useful research on potentials and hazards of the use of saline water in irrigation were undertaken in relative isolation and no mechanism existed for coordinating the research work and to utilize effectively the research fingings. In this regard it is needed:
  - ❖ To establish working relationships on national, regional and international institutions dealing with this subject through the formulation of networks; as successful examples in the Mediterranean region, the CIHEAM/MAI-Bari Non-conventional Water Resources practices and Management (NWRM) and WASAMED Networking projects.
  - ❖ To conduct and foster a comprehensive multi-disciplinary basic and applied research programme in coordinating fashion on the sustainable use of saline water in irrigation and related problems and obstacles.
  - ❖ Provide facilities for research workers and to train associated personal in techniques and methods for dealing with saline water practices and related salinity problems.

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HALOPHYTES AND SALT-TOLERANT GLYCOPHYTES A POTENTIAL RESOURCE

V. Sardo
Department of Agricultural Engineering, University of Catania
Via Santa Sofia, 100 – 95123 Catania, Italy - email sardov@unict.it

SUMMARY - Water of good quality for agricultural uses is becoming ever more limited in regions where irrigation is necessary, due to increasing requirements for domestic and industrial uses. This makes exploration of using "non conventional" waters mandatory. Seawater or saline water may be used to irrigate a variety of plants, both halophytes and glycophytes, however their use entails a number of problems. A review is given of the halophytes most commonly grown and of their various uses, of the response of some glycophytes when irrigated with saline water and of the possible levels of production. A brief account is given of researches addressing plant tolerance to various salinity levels; salt balance in the soil as affected by leaching fractions and precipitations; soil physical conditions as affected by irrigation systems.

Keywords: halophytes, seawater, brackish water, non-conventional irrigation

INTRODUCTION

The rapidly increasing world population puts ever more pressure on land and water resources: it becomes therefore imperative to undertake a serious effort not only to train advisers and irrigators to better use available freshwater (thereby reducing the rate of water and land loss) but also to expand agricultural crops in those vast unused areas that are an enormous potential resource. Under those extreme conditions of soil or water salinity where no crop of agricultural interest can be grown it is possible to imagine dedicated halophyte plantations for forage production, soil rehabilitation, bioenergy generation, landscaping, carbon dioxide sequestering, and a number of other useful purposes at no cost in terms of good quality water and soil. Worldwide, there are vast surfaces of barren and abandoned marginal lands that are commonly believed useless: on the contrary a huge research and demonstration activity in the last decades has demonstrated their unsuspected value.

Mankind today is not in a position to overlook such untapped resources.

HALOPHYTES

Various attempts to classify halophytes have been proposed, however the simplest and clearest definition is probably that of Aronson and Le Floc'h (1996), stating that "halophyte species are those occurring in naturally saline conditions only".

It is difficult to precisely define halophytes, as opposed to glycophytes, due to the variability of plant responses in dependence of a number of factors, including climatic conditions and plant phenophases: for instance a plant may be sensitive during, say, the germination or seedling phase while it is tolerant during the other phases or may suffer salinity under dry climatic conditions while easily overcoming it under a moist climate (an interesting new "dynamic" salinity stress index linked also to temperature and solar radiation has been worked out by Dalton, Maggio and Piccinni, 1997, 2000 and 2001). In conclusion there is a wide and uncertain frontier between halophytes and tolerant glycophytes.

Those plants growing best under a certain level of salinity are called "euhalophytes"; a further distinction is that between xerohalophytes, thriving under saline, arid conditions, and hydrohalophytes, thriving under saline, moist conditions.

According to Le Houérou (1996) "there are as many as 6000 species of terrestrial and tidal halophytes in the world" and by far the largest proportion is that belonging to Chenopodiaceae, followed by Poaceae; the Mediterranean flora includes about 700 species of halophytes, some 70% perennials and 30% annuals. In China, Kefu *et al*. (2002) identified 430 halophyte species.

Halophytes can tolerate high salinity levels in irrigation water, in some cases even higher than those in seawater (which typically has an EC, electrical conductivity, of about 45-50 dS/m) by enacting several different mechanisms of defence which include exclusion, compartmentation or excretion of noxious ions.

HALOPHYTES AND SALINE LANDS

The wide variety of halophytes and of their characters permits to envision a profitable use of vast barren extensions of saline lands by selecting the appropriate species best fitting local conditions. Possible actions in dependence of peculiar soil and water conditions are synthetically shown in the following table.

Case	Soil	Main Water Source	Principal possible actions
1	Coastal lands	Seawater	Fixing dunes, landscaping, growing mangroves, fodder production
2	Inland saline areas (irrigated)	Brackish/saline water	Various scopes
3	Inland saline areas (dry)	Rain	Erosion control, fodder production
4	Salinized agricultural lands	Fresh/brackish water	Soil rehabilitation, agricultural production
5	Endangered agricultural lands	Fresh/brackish water	Soil protection, agricultural production

All the possible actions listed in the table can be easily undertaken after an appropriate plant selection but of course also a preliminary analysis assessing their environmental, economic and social feasibility is in all cases required.

The principal experiences on halophyte uses in the various conditions listed in the table are briefly illustrated below.

Case 1 - Coastal lands

One of the main problems in sandy coastal lands is their vulnerability to wind erosion and dunes shifting, possibly combined with sea eroding action. Under such conditions it is obvious to think of a soil cover with halophytes to be irrigated with seawater, without any risk of damage to the soil and the aquifer, since the soil is typically a-structural, with no colloidal fraction to be protected, and the aquifer is the seawater itself.

Experiences conducted within a European Commission-funded Concerted Action have shown the amazing performance of seawater-irrigated Sesuvium portulacastrum, able to rapidly spread to form a thick cover, perfectly tolerant to a wide range of temperatures (- 2°C to 46°C) and drought stresses, apparently free of diseases and natural enemies (Sardo and Merlo, 2002).

Sesuvium grew very well when subsurface irrigated, but tolerated well enough sprinkler irrigation, even when seawater was daily applied in the warmest hours of the day.

The action of sprinkler-applied seawater on the soil was dramatic, since an evident decay was detected in the sprinkled coarse sand, as opposed to a subsurface irrigated plot: in the former case, after two campaigns' daily application at the precipitation rate of about 6 mm/h during two hours, a surface crust was formed in the sand which reduced infiltration rate from the initial 1400 mm/h to only 22 mm/h, whereas in the adjacent subsurface-irrigated plot the infiltration rate showed a limited reduction, to 954 mm/h (Sardo, unpublished work). It has been proposed to plant protective strips of Sesuvium along the sandy shorelines, to be automatically irrigated through the use of solar-powered pumps at the cost of about US $ 2 per square meter (Sardo and Merlo, 2002).

In those coastal areas where tourist development is planned it is also possible to select particular halophytes for embellishment and landscaping, thus saving precious freshwater.

As early as 1985 Gallagher reported the results of his interesting researches on seawater-irrigated plants potentially useful for forage (Spartina alternilflora and S. patens, Distichlis spicata, Sporobolus virginicus), as vegetables (Atriplex triangularis) and as grain producers (Kosteletzkya virginica), with promising results (Gallagher, 1985).

Forage production in seawater-irrigated fields (*Salicornia bigelovii, Batis maritima, Suaeda esteroa, Sesuvium portulacastrum, Atriplex barklayana*) has been obtained in Mexico and the Arabian Gulf, and appropriate irrigation systems have been developed (UNEP, 1993; Glenn *et al*., 1996; ICBA, 2003).

Challenges for restoring vegetation on tidal, hypersaline substrates have been illustrated by Zedler *et al*. (2003), who point out the importance of the many factors affecting plant mortality upon transplanting.

A typical solution for coastal areas protection in the warmest regions is that of mangrove plantations, which create a rich ecosystem in addition to protecting the coast and supplying fodder and wood (Lieth, 1999).

Examples of production with full strength seawater irrigated halophytes

mangroves: in excess of 8 tons/ha (fresh biomass)
Batis: almost 34 tons/ha (dry matter)
Atriplex: 24 tons/ha (dry matter)
Sesuvium: almost 17 tons/ha (dry matter)
Salicornia: 2 tons/ha (oilseeds)
Distichlis: 1 ton/ha (grain)
Aster: 40-80 tons/ha (fresh biomass)

Case 2 - Inland saline areas (irrigated)

The most evident beneficial uses of halophytes in irrigated inland areas are forage production and soil rehabilitation (some other uses will be examined later).

Forage production in saline-sodic or sodic soils, when brackish or saline water is available for irrigation, has been extensively studied, with very encouraging results (e.g. Pasternak and Nerd, 1996; ICBA,2003; Qadir and Oster, 2004), since water availability permits to simultaneously achieve an appreciable forage yield and a significant action in soil rehabilitation.

The reuse of drainage water for irrigation is useful to conveniently dispose of an otherwise dangerous salt load, provided that long-term sustainability is secured. It is recommended to prepare seedbeds ripping the soil to the depth of some 50 cm in case of an existing hardpan, following with a shallow cultivation.

Grieve and Suarez conducted a research on purslane (*Portulaca oleracea* L.) as a candidate crop to be irrigated with selenium-rich, highly saline drainage water in San Joaquin Valley of California, concluding that "Purslane appears ideal as a salt-tolerant crop to be used at the end of a drainage reuse system to reduce drainage water volume" and noting that purslane is "highly tolerant of both chloride- and sulphate- dominated salinities; a moderate selenium accumulator in the sulphate-system, and a valuable, nutritive vegetable crop for human consumption and for livestock forage (Grieve and Suarez, 1997).

Forage production is frequently obtained by adopting appropriate intercroppings or rotations; among the most used species are Kallar grass (*Leptochloa fusca*) and old man saltbush (*Atriplex nummularia*). Kallar grass is a perennial extensively used in Pakistan with excellent results both in forage production and soil reclamation, but it dries up during the winter season (Aslam *et al.*,1991); for this reason it has been suggested to substitute it with saltbush which is more salt tolerant and produces green forage throughout the year (Hanjra and Rasool, 1991). It has also been suggested to integrate it with *Aster tripolium* which is cold-tolerant and able to vegetate during the winter. Aster tripolium is also marketed as an edible delicacy in the Netherlands (Lieth, 1999).

In Australia, saltbush (five species of Atriplex) when irrigated with water containing up to 10.000 ppm dissolved solids averaged a fresh biomass yield of over 20 tons per hectare in the second year of saline irrigation as opposed to a production of 17,4 tons when freshwater-irrigated (Schulz and West, 2002).

A synthesis of experiments conducted in Sicily during several years and covering several aspects of plant tolerance to various abiotic stresses is reported in the table below.

Genus	growth rate & soil cover	"hedge" action	fire resistance	tolerance to		
				drought	cold	salt
Chamaerops	-	+ +	+ +	+++	+++	++
Nicotiana glauca	+ +	-	?	+++	+	+
Arundo	+ + +	+ +	+ +	--	++	++
Portulaca	+ + *	-	+	-	-	++
Lippia	+	-	+	--	+	+
Atriplex	+	-	+	+++	+	++
Cynodon	+ +	-	+	+	++	++
Phragmites	+	+	?	---	+++	++
Typha	+	-	?	---	+++	-
Sesuvium	+ +	-	+	-	+	+++
Spartina	+ +	+	?	-	+	+++

* seasonal cover

Case 3 - Saline drylands

Problems with halophytes growing in saline rainfed areas refer mainly to the germination phase; to the scope special techniques have been devised, including the formation of "niches" where rainfall water is collected and seeds are protected with a mulch to reduce evaporation (Malcolm, 1981; Malcolm *et al*., 2003).

A rather simple mechanical equipment permitting a fast soil preparation (from 2 to 14 ha /day) at the cost of US$ 20 to 60 per hectare has been developed and successfully used on a relatively large scale (over 100.000 ha) by Vallerani (Vallerani, 2002), which combines pit digging to seeding in a single passage. Such a system is particularly useful in rainfed areas during the crop cycle and not only in the establishment phase since it has the advantage of harvesting rainwater conveying it to the plants.

In rainfed areas the soil rehabilitation action is typically slower than in the irrigated ones due to the lower amount of incoming water while fodder production is less, however it can reach appreciable levels provided that the right species are selected. For instance Greig (1994) reported the results of an interesting trial with 72 different halophytic species in an area in Australia receiving an average of 425 mm rainfall and rated their performance according to salt tolerance, palatability, productivity, persistence and ability to spread.

Of a particular interest in arid saline soils is the “old man saltbush” (Atriplex nummularia), reportedly able to grow with only 150-200 mm of rainfall per year, and able to survive for a year with only 50 mm (Aganga *et al*., 2003).

Moselhy and El-Hakeem (2002) report the results of an interesting experiment conducted in Egypt during three years, combining in an “alley cropping system” rows of *Atriplex nummularia* with barley; in a loamy sand under a yearly average precipitation of about 144 mm they obtained the best results when barley was grown in alleys 10 metres wide (i.e. saltbush rows were spaced 10 metres) and saltbush was planted at the distance of 3 metres along the row. Results were less positive when rows were 15 and 20 metres apart: the authors explain this with a less effective wind protection.

An overlooked crop, certainly deserving more attention, is quinoa (*Chenopodium quinoa* Willd). Quinoa, a pseudocereal, is one of the three big staple crops existing in South America at the time of Spanish invasion (the other two being potato and maize), but its use was discouraged by the Spaniards who saw it linked to pagan practices and later by middle classes who considered it a food for the poor. Nowadays it is being explored with ever increasing interest due to its vast nourishing potential (Oelke *et al*., 1992) and its amazing ability to adapt to extreme conditions (it is tolerant to drought, salinity, frost, submersion: Jacobsen and Mujica, 2001) provided that the right cultivar is selected. For instance, from a research conducted in Peru by the CIP, it resulted that the highest yield was obtained with an EC of 15 dS/m in the irrigation water (Jacobsen *et al*., 2000).

Results of experiences with diluted seawater irrigation in glycophytes

PLANT GENUS	COMMENTS	RESULTS
Chamaerops	very good	surviving 40% dilution
Citrus	fair	surviving 16% dilution
Elytrigia	excellent	surviving 60% dilution
Ficus	good	surviving 33% dilution
Olea	very good	surviving 40% dilution
Pistacia	good	surviving 33% dilution
Punica	good	surviving 33% dilution
Vetiveria	excellent	surviving 60% dilution

Case 4 - Salinized agricultural lands and their rehabilitation

This is the case of those barren lands affected by secondary salinization mostly dependent on irrigation mismanagement; the case, recurrent in Australia, of problems due to a shallow saline water table is rather rare in the Mediterranean region (one example in Spain is given by Moreno *et al*, 2001; more examples for Egypt are given by Ghaffer *et al*., 2004 and Kotb *et al*., 2000). Compared to Australian conditions the task of reclaiming soils in the absence of a shallow water table is relatively easier since it is possible to rely on the natural drainage to leach excess salts down, if sufficient rainfall or irrigation water is available for leaching.

One additional difference between Mediterranean and Australian conditions (where problems were originated by forest clearing) is that in the Mediterranean there is a limited interest to explore the potential of tree plants such as Eucalyptus or Casuarina in soil reclamation since there is no need of applying such “biopumps”, which are useful in lowering the water table but certainly do not offer an appreciable income nor permit an intercropping.

The potential of halophytes in bioremediation is well illustrated by Qadir and Oster (2004) who compared the results from 14 experiments with gypsum application versus vegetative reclamation in sodic soils. Results were slightly in favour of chemical treatments (62% sodicity decrease versus 52%) but in the bioremediation treatments sodicity was reduced throughout the whole root zone whereas gypsum was effective only in the layer where it was applied and furthermore the plant action improved soil structure and formed macropores enhancing air and water infiltration. In an earlier work Qadir and Oster (2002) listed advantages and disadvantages of bioremediation as follows:

- advantages: low initial capital input; promotion of soil aggregate stability and creation of macropores; better plant nutrient availability; more uniform and greater zone of reclamation; financial or other benefits from crops grown during reclamation.
- disadvantages: action slower than chemical methods; limited plant tolerance to highly saline-sodic and sodic soils; essential presence of adequate $CaCO_3$ in the soil.

Qadir *et al*. (2001) compared bioremediation (or phytoremediation) to chemical soil or water treatment, concluding that similar results can be achieved at a lower cost with bioremediation; they attributed its action to CO_2 emission from roots, encouraging Ca^{2+} ions release from the calcareous soil.

Kirda and Hera (1997) report encouraging results in bioremediation obtained in the course of a coordinated research with a network including eleven institutions: they refer that several tree and herbaceous plants significantly decreased soil salinity and sodicity.

Other authors (Barrett-Lennard, 2002; Marui *et al*., 2003) however caution against excessive optimism about bioremediation, showing that plant action can be very slow, particularly in low-producing rainfed areas; however vetivergrass (Vetiveria zizanioides) with adequate leaching has proved useful in helping to reduce saline load in lysimeter-contained sandy soils (Hamdy *et al*., 2004).

Yunusa and Newton (2003) remark that salt damage depends not only on chemical degradation but on soil structure degradation as well and suggest the use of plants (which they call “primer plants”) capable of drilling “biopores” in the soil thus helping to restore its structure, conditioning it for the following agricultural crops.

Case 5 - Endangered agricultural lands – Sustainable saline irrigation

An integrated approach to soil, water and crop management is required to achieve irrigation sustainability in the long term and to forestall that the often quoted sentence “in irrigated arid areas salinity build up is not a question of if but of when” comes true.

Thorough reviews of irrigation management under saline conditions aimed at averting the risk of soil salinization are given by Hamdy (1996, 2001), who examines in detail the various practices for a sustainable land and water use, stating that “there is usually no single way to control salinity in irrigated land. Several practices can be combined into systems that function satisfactorily depending upon the economic, climatic, social and hydrogeological situation. Thus, management measures should not be considered in isolation but should be developed in an integrated manner to optimise water use, minimize drainage and increase crop yields within limits of the physical and social environment.”

When embarking in an action of soil rehabilitation it is crucial to take into account the water and salt balance, securing an adequate drainage of salts; a decisive support in the planning stage can be obtained from the adoption of simulation models, permitting to explore various contrasting scenarios and to have “a glimpse into the future”; one of the best known is WATSUIT (Oster and Rhodes, 1990).

A quite useful tool in predicting the evolution of salinity in the soil as affected by soil and water quality, climate, drainage and irrigation management is the recently developed simulation model SALTMED (Flowers *et al*., 2003). It is in fact imperative to monitor salt balance in the soil, controlling rainfall and irrigation water action in order to maintain fertility in the long term (Hamdy and Ragab,

2003) and it is imperative to adopt a holistic strategy considering simultaneously in-farm and off-farm impact of irrigation and drainage, including drainage water reuse (Oster and Wichelns, 2003).

A major support to the maintenance of a favourable salt and water balance can be achieved through the adoption of water harvesting technologies, particularly when plants are grown as isolated trees or bushes, or in rows where water can be collected.

Introducing halophytes or salt tolerant crops in the rotation can significantly help in keeping a low salt level in endangered areas. Vetivergrass hedgerows can be quite useful to reduce overland flow and solid transport (to about 25 - 30% compared to unprotected lands: Hamdy and Sardo, unpublished data), thus encouraging water infiltration and salt leaching. Additionally, vetivergrass can thrive in highly saline soils and contribute to their bioremediation (Hamdy *et al*., 2004).

Mitchell *et al*. (1999) give a very interesting report on the results obtained with 125 winter-growing potential cover crops in the Mediterranean environment of California, on moderately saline soils: the best results in terms of biomass production were achieved with some Brassica species, while with the N-fixing plants outstanding results were given by some species of Hedysarum, Trifolium, Medicago and Vicia.

SELECTING CROPS FOR SALINE ENVIRONMENTS

Frequently in the case of secondary salinization salinity levels do not reach those extreme values which make the adoption of highly salt-tolerant plants mandatory, and as a consequence two opposite courses of action can be planned, namely either selecting or "domesticating" halophytes to be used as an agricultural crop or "training" agricultural crops to thrive in the saline environment.

In all cases the first step is the formation of an extended gene pool, which is a crucial starting point due to the variability of edaphic conditions and the consequent multiplicity of plant traits required to best fit them.

Selection, hybridisation and breeding, to be conducted in the field, under specific pedo-climatic conditions, "hold tremendous promise for domesticating wild species and developing economically useful crops with higher salinity thresholds" (Biosalinity Awareness Project, 2004). The International Center for Biosaline Agriculture is conducting an excellent work in constituting a germplasm bank of halophytes and salt-tolerant species, in selecting the most promising varieties and in trying to fill the gap in the large scale halophyte use existing between Australia and the more conservative Mediterranean region (ICBA, 2003).

Breeding techniques applied to conventional crops include not only screening, selection and hybridisation, but also the more recently developed bioengineering solutions. As Flowers puts it "attempts to enhance tolerance have involved conventional breeding programmes, the use of in vitro selection, pooling physiological traits, interspecific hybridisation, using halophytes as alternative crops, the use of marker-aided selection and the development of transgenic plants. After ten years of research, the value of using transgenic plants to alter salt tolerance has yet to be tested in the field. The use of physiological traits in breeding programmes and the domestication of halophytes currently offer viable alternatives to the development of tolerance through the use of transgenic technologies" (Flowers, 2003). Such cautious statements substantiate the early sceptical previsions of Malcolm (Malcolm, 1991).

Contrary to that, an optimistic view is shared by Sharma *et al*. (2002) who presented in an interesting review the prospects of biotechnology for crop improvement and Wei *et al*. (2001) who illustrated their (only partly successful) efforts to transfer salt tolerance from a halophyte, Aeleuropus littoralis, to wheat via asymmetric somatic hybridisation. Suiyun *et al*. (2004) report some promising results obtained applying asymmetric somatic hybridisation to Triticum aestivum and Thinopyrum ponticum (Agropyron elongatum).

Also López-Bucio *et al*. (2000) are optimistic about the possibility of obtaining transgenic varieties able to elaborate and excrete organic acids permitting plants to thrive in "extreme soils".

Munns *et al*. (2002) illustrate the " avenues " for increasing crop salt tolerance, highlighting the potential of molecular markers to solve the problem of the diffuse rejection of genetic engineering and concluding that "possibly a combination of all approaches, old and new, will be the most productive".

HALOPHYTES AND CO_2 EMISSION MITIGATION

The rapid increase in atmospheric CO_2 content in the last decades has aroused concern about its impact on the greenhouse effect (e.g. Lal, 2000). In principle, agriculture can help to contrast CO_2 increase in two ways: by reducing emissions from fossil fuels through the production of renewable biofuels and/or by sequestering it in the biomass; however, although repeatedly demonstrated technically feasible, such solutions have not been adopted due to economical reasons. It has been in fact suggested (UNEP, 1993; Glenn *et al*., 1993; Lal, 2000) to use halophytes or anyway plants able to thrive in severely degraded soils for capturing and long-term sequestering atmospheric CO_2 in order to alleviate the greenhouse effect. UNEP (1993) estimated in fact that in world dry lands 0.5 to 1.0 gigatons of carbon per year over 100 years can be sequestered at a cost of 10-20 US $/ton of carbon: a significant part of the desert land needed for sequestration could be irrigated with seawater or brackish water to enhance biomass production.

Mean carbon storage in forest biomass (including above ground and below ground parts) in dry areas of low latitudes has been estimated in the range of 33 to 124 tons/ha (Winjum and Schroeder, 1997) but such figures are quite distant from those given by Douglas for seawater- irrigated halophytes in Mexico, of about 4 to 8 metric tons per hectare (Douglas, 1994).

One interesting feature of halophytic biomass behaviour in drylands is its slow decomposition rate, a sort of "salami effect", favouring the long term sequestration of the captured carbon; however such effect has been questioned, at least for specific environmental conditions (Goodfriend *et al*., 1998).

It has also been proposed (e.g.Douglas, 1994) to use halophytes to produce bioenergy, since annual dry biomass yields in the range of 17 to 34 metric tons per hectare have been reported for seawater irrigated plants in an experimental Mexican farm (from researches conducted in Sicily by the authors a biomass yield in the order of 10 to 15 metric tons appears more probable, however). The solution is certainly attractive, since almost no fossil fuel would be used to add CO_2 to the already overburdened atmosphere, but the problem has been overlooked of the high ash and salt content in such biomass, which can be detrimental in the process of bioelectricity production with the current technologies.

ECONOMIC AND SOCIAL CONSIDERATIONS

Until today the possible agricultural utilization of saline lands has been overlooked, in the belief that it would be un-economic. But if worthless, saline lands and waters are used to grow dedicated halophytes, able to produce some useful yield, albeit at a lower level than in good arable lands, then the economic framework can be totally different, particularly if externalities are taken into account.

Externalities can include social benefits depending on soil protection against water or wind erosion (and hence reductions in-site and off-site damages), biodiversity enhancement, the creation of shelters for wildlife, the protection of atmosphere quality through the production of biofuels, the mitigation of the greenhouse effect through the capture of CO_2. The attribution of a monetary value to such items (their "internalisation") would give to the biosaline agriculture the right to claim a financial support to integrate the limited direct farm income; a significant step in this direction has been taken with the approval of the Kyoto protocol fining those nations which exceed the fixed emissions and permitting the trade of CO_2.

The economic and social aspects of salinity management were analysed in some detail by Feinerman, who quite aptly maintained that "the best way to promote effective water management is via collaboration among economists and soil, water and plant scientists" and clearly focused the conflict between the viewpoints of farmers "who may believe that they should be compensated for respecting environmental rules, and environmental activists, who may believe farmers should bear responsibility for on-farm pollution. The latter group adheres to the principle that the Polluter Pays" (Feinerman, appendix to Hillel, 2000). It can be commented that 1) the "Polluter Pays" principle is only acceptable if a reasonable threshold value of pollution is defined (which is not the case at present) and 2) that automatically a reward must be granted to farmers for the positive impact of some activities on the environment, such as CO_2 capturing, wastewater disposal, land protection, landscape embellishment.

The extensive, large-scale adoption of halophyte and salt-tolerant crops in marginal lands, to be irrigated with marginal waters can be determinant in enhancing the production of food, forage and fibres and more in general human well being, contributing also to alleviate the problem of unemployment. As Khan and Duke write, "saline agriculture, however, must fulfil two conditions to be cost-effective" namely, first must produce yields reasonably high and second, must be sustainable (Khan and Duke, 2001).

Furthermore growing crops and achieving significant productions without putting any more pressure on limited good quality land and water resources would contribute to mitigate social strains and litigations, inside and outside national boundaries.

Through such possible pathways agriculture can abandon its present uncomfortable position of defendant as an environmental polluter to assume instead that of the environment defender.

CONCLUSIONS

"The development of mankind has reached the point that a variety of new resources need to be tapped in order to fill our basic needs for food, feed and freshwater": in this statement of Lieth (1999) lies the basic reason for the interest in halophyte research.

A vast, very promising field is now facing the research on halophytes, where only part of the "conventional" knowledge of those previously engaged in research with saline water and soils can be used. Paradoxically, it can be argued that those approaching such researches without the support of the classic background are under some respects in a position of privilege: evidence is in fact accumulating of the need of adopting new agronomic approaches and revising currently accepted guidelines for water quality evaluation and recommendations for irrigation with saline waters.

Undeniably the problems to be overcome for an environmentally safe and economically convenient use of saline lands and waters are still formidable and their solution requires a coordinated effort of a vast number of experts in various domains. However, though challenging the task may appear, it is exciting and stimulating to participate in an undertaking which can lead to enormous strides towards mankind's well being and environmental protection.

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PART TWO

NON-CONVENTIONAL WATER RESOURCES AND ITS POTENTIAL USE

WASTEWATER TREATEMENT AND REUSE AS A POTENTIAL WATER RESOURCE FOR IRRIGATION

R.Choukr-Allah* and A. Hamdy**
* I.A.V Hassan II, Salinity and plant nutrition laboratory BP 773, Agadir, Morocco
E-mail: ch.redouane@wanadoo.net.ma

** Mediterranean Agronomic Institute of Bari (CIHEAM-IAMB), Via Ceglie 9, Valenzano (BA), Italy
E-mail: hamdy@iamb.it

SUMMARY - Water resources scarcity, accessibility, and environmental degradation are the major challenges facing most of the Mediterranean region and especially the southern and eastern Mediterranean countries. An increasing number of countries are now approaching full utilization of their surface and ground freshwater and that most of the economically viable development of these resources has been already implemented.Treated and re-used sewage water is becoming a common source for additional water in some water scarce regions and many countries have included wastewater re-use in their water planning. Policies have been formulated but few have had the capacity to implement them in their water management practices in terms of actions to deal with water pollution control and waste disposal. In arid and semi-arid countries, particularly the developing ones, the full utilization and re-use of sewage water is still far from our final goal, i.e. to be used as a water source, in spite of the vital role it could play in reducing the high pressure imposed on the limited available freshwater. Health and environmental problems are the major obstacles restricting the sustainable and safe re-use and recycle of wastewaters which require concerted efforts supported by regional and international organizations, if real change and beneficial results are to be realized in the near future.

Key words: wastewaters re-use, water management, water saving, irrigation.

INTRODUCTION

Agriculture is the largest single user of water with about 75% of freshwater being currently used for irrigation (Prathapar, 2000). In some cases, it draws as much as 90% of the total water (Allan, 2001).

With increasing pressure on freshwater resources in water-deficit regions, there is a need to conserve and use available freshwater supplies more efficiently because future increases in agricultural production will have to rely heavily on existing water resources. Thus, there is a great potential for improving water-use efficiency in agriculture, particularly in those areas where need is the greatest (Oweis *et al.,* 2000; Wallace, 2000; Hatfield *et al*., 2001). In addition, non-conventional water sources, particularly treated wastewaters represent complementary supply sources that may be substantial in regions affected by extreme scarcity of renewable water resources.

Expansion of urban population and increased coverage of domestic water supplies and sewage network will give rise to greater quantities of municipal wastewater which can become a new water source, particularly for irrigation. The water recycling and re-use provide a unique and a viable opportunity to increase traditional water supply. Water reuse can help to close the loop between water supply and wastewater disposal. The successful development of this reliable water resource depends upon close examination and synthesis of elements from infrastructure and facilities planning, wastewater treatment plant sitting, treatment process reliability, economic and financial analysis, water utility management, and public acceptance.

Consequently, the re-use of municipal wastewater will require more complex management practices and stringent monitoring procedures than when good-quality water is used. Treatment and re-use of sewage waters is becoming a common source for additional water in some water scarce regions. Re-use of sewage waters, when properly managed, has the benefit of reducing environmental degradation.

For many of those arid and semi-arid countries, re-use of wastewater may contribute more future water availability than any other technological means of increasing water supplies. Treated wastewater can be used effectively for irrigation, industrial purposes and groundwater recharge and for protection against salt intrusion in groundwater aquifers. Furthermore, the wastewater treatment and possible use of sewage effluents is a health and environmental necessity to the civil society, especially in urban areas. Therefore, for those countries, the use of appropriate technologies for the development of alternative sources of water is, probably, the single most adequate approach for solving the problem of water shortage, together with the improvements in efficiency of water use and adequate control to reduce water consumption. Our water management policy should be fundamentally directed to support that “no higher quality, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade”. This is what we are challenging for and we have to find the key-recommendations and solutions for action.

APPROPRIATE TECHNOLOGIES

The term «appropriate technology» has been described as a subjective judgment depending on the observer's viewpoint. The primary reason for confusion is the inexact definition of the term. The definition chosen here is that of a technology which is affordable to and operable by the user which reliably provides the degree of purification needed for the wastewater's end use. Note that this definition includes the following key requirements:

- Affordable: both in capital and operation and maintenance (O&M) costs
- Operable: within an affordable O&M cost the user can operate the system with locally available labor and infrastructure
- Reliable: the system can meet effluent quality requirements prescribed by the empowered regulatory agency

Classification of the urban wastewater quality in developing countries

A classification of the urban wastewater quality in Morocco has been carried out for ONEP (1998). The results of this study provide a precise idea about the quality of wastewaters in Morocco, of the evolution of ratios and the restitution rates, on the basis of agglomeration size (Table 1).

Table 1. Classification of wastewaters in Morocco

Parameters	Small Villages (less than 20,000 inhabitant)	Average Cities (Between 20.000 and 100,000 inhabitant)	Large cities (more than 100,000 inhabitant)	National average
BOD_5 (mg/l)	400	350	300	350
COD (mg/l)	1000	950	850	900
TSS (mg/l)	500	400	300	400
Restitution rates (%)	50	75	80	65
Supply x restitution rate(l/inhab)	40	70	80	60

Source: ONEP-GTZ (1998)

The bigger the city is, the more the concentration of polluting elements explained in terms of BOD_5, COD, and MES decreases. In fact, big cities use a more important quantity of water, which leads to a more considerable dilution of wastewaters.

Low cost technologies

The treatment systems which meet the appropriate technology definition for rural application must be chosen based on the needs of the intended use. If surface water discharge is contemplated, there are a number of different systems which may be both affordable and reliable in meeting these standards. In the U.S. surface water discharge requirements start at «Secondary treatment» (BOD_5 and TSS of 30 mg/l) and get more stringent, usually in terms of these two parameters and nutrients (N&P). Sometimes the requirements are seasonal, and sometimes they consider facility size, but they are usually based on the water quality of the receiving water body.

Presently there are a limited number of appropriate treatment processes for small communities which should be considered. These include stabilization ponds or lagoons, slow sand filters, land treatment systems, and constructed wetlands. All of these fit the operability criteria discussed above, and to varying degrees, are affordable to build and reliable in their treatment performance. In order to illustrate the viability of these systems, the following example is provided. In this example, a small sewered community collects its wastewater at the treatment site, and the effluent will be required to meet WHO standards for unrestricted agricultural irrigation.

INFILTRATION PERCOLATION TECHNIQUES

The infiltration percolation technique constitutes an efficient and low technology way to ensure an acceptable disinfection level of wastewaters (Lance et al., 1976 and 1980; Lefever, 1988; Schmitt, 1989; Brissaud et al., 1991). Infiltration percolation consists in infiltrating sewage into calibrated and homogeneous sand beds. This natural filtration process allows removal of suspended solids (SS), chemical oxygen demand (COD), oxidizable nitrogen (NTK) and microorganism.

ARTIFICIAL OR CONSTRUCTED WETLANDS

Artificial or constructed wetlands are increasingly viewed as a viable tertiary treatment alternative for municipal wastewater. In recent years, there have been several major works published on these systems (EPA, 1988; Hammer, 1989; Reed *et al*., 1995). A limited number of previous studies have examined the reduction in indicator bacteria by constructed wetlands (Reed *et al*., 1985).

In the multi-species wetlands, decreases in total nitrogen were particularly in evidence during the summer months (July and August) with lower rates of removal during the fall and early winter. BOD5 concentrations were decreased to the tertiary standard during all the months of this study.

The duckweed system, BOD5 was reduced to a lesser extent and total nitrogen actually increased during some of the study months. Overall decreases were noted in both the duckweed and multi-species systems for total coliforms, fecal coliforms, Giardia, Cryptosporidium and enteric viruses. A higher rate of removal of parasites occurred in the aquatic duckweed system. The multi-species system provided a greater rate of removal for the indicator bacteria. No significant removal of coliphages was observed from the duckweed system. The degree of removal of microorganism in the duckweed pond appeared to be related to their size, with greater removal of the largest organism (i.e., parasites). This suggests that removal is related to the settling of the organism in the pond. Longer retention times could potentially increase the removal of the parasites and viruses.

STABILISATION PONDS

Wastewater stabilization ponds (WSP) are man made large shallow basins enclosed by concrete or earthen embankments in which raw Or Settled sewage is treated by exploiting natural processes, mainly the power of the sum through photosynthesis of algae to produce the oxygen necessary for the bacteria that promote purification. Since the natural process does not need electromechanical equipment, the purification system is not exposed to damage and operational interference is therefore minimal.

The removal efficiency depends on the following factors:

- The absence of toxic and inhibitory substances

- The consistency of volumetric and surface loading

- The temperature of the water (preferably more than 15 C) - Adequate Mixing

- Adequate sludge depth to enhance the performance of the anaerobic bacteria at the bottom of the pond.

Expected BOD_5 removal for different detention times in anaerobic ponds have been given by Mara (1976), as shown in Table 2

Table 2. BOD Removal in anaerobic ponds loaded at 250 kg BOD_5 per m^3 per day

Retention time, Days	BOD5 removal, Percent
1.5	50
2.5	60
5.0	70

EFFICIENCY OF DIFFERENT TECHNOLOGY OPTIONS

In summarizing the options for a small community the choice of treatment for ultimate reuse will hinge on the following:

- Reuse Requirements - If the reused wastewater is to be used for vegetables, citrus or other crops to be eaten raw, the options employing stabilization ponds and intermittent filters can be used, or a recirculation alter may be substituted with subsurface drip irrigation only. This last restriction may be lifted if it can be proven that the RSF effluent is free of nematode eggs, or if disinfection of the effluent is employed.

- Land Availability - If sufficient land is available the other limitations stated above and below will control the options evaluated. If land availability is limited by economies or terrain or surrounding development, one of the filter options should be chosen.

- Operational Capability - If a sufficiently skilled management program with electricity is available, all options are possible. If, as is often the case, only unskilled labor is locally available, only the pond-wetland or anaerobic lagoon-intermittent filter options are viable.

Table 3. Comparison of the two passive alternative technologies

	Lagoon Wetland	Anaerobic Lagoon-ISP
Land requirement, m^2	13,000	2,000
Energy KWH/d	0	0
Capital cost, US$	200,000	150,000
	250,000	200,000
O&M cost, US$/yr.	5,000-7,000	7,000-10,000
Effluent Quality		
BOD5 (in=200), mg/l	10	5
TSS (in=100), mg/l	10	5
TN (in=50), mg/l	10-35	35-40

TP (in=10) mg/l	7-8	7-9
FC (in=l0^{6}), per 100 ml	10^{2}-10^{3}	10^{1}-10^{2}
Virus (in=10^{3}), per L	10^{1}-10^{2}	0-10
Parasite Ova (in=10^{3}), per L	0-10	0

Concerning the treatment of wastewaters, Table 4 sums up the results of the treatment results of some experimental treatment plants in Morocco.

Table 4. Treatment performance (in reduction percentage)

Plant	Ouarzazate		Ben Sergao	Drarga	Ben Slimane	Marrakech	Bouznika
Processing System	Lagoon	High Output Lagoon	Filtration - percolation		Aerated Lagoon	facultative Lagoon	Lagoon
Period of Stay (Days)	25	21.9	-	-	30 – 40	30	-
BOD_5 (mg/l)	81.7	65.3	98	98.5	78	97	75
COD (mg/l)	72	65.4	92	96	79	76	71
TTS (mg/l)	28	-	100	96.6	-	69	76
NTK (mg/l)	31.5	48	85	96.8	75	71	14
Ptot (mg/l)	48.5	54	36	95.9	41	85	-
CF /100ml	99.9	99.9	99.9	99.9	100	99.4	99.9
O. Helminthes/L	100	100	100	100	100	100	100

Source: ONEP-FAO (2001)

Finally, when the viable options which pass the above tests are evaluated against each other, experience in the U.S. bas shown that they are very similar in present worth cost, so local availability or cost of components, climatic and social conditions, and support infrastructure may be the deciding factor between them. For example, the lack of suitable sand or substitute media locally will significantly increase the cost of the filter options. Very close proximity of housing to the treatment site May make odor concerns a key issue, and add costs to certain options to control odors. Therefore, engineering decisions of which method of treatment or sitting of the facility may be skewed to suit local needs. However, in all cases the appropriate technology options presented herein are significantly more sustainable than the use of sophisticated urban wastewater treatment technologies such as activated sludge with tertiary treatment for small communities of North Africa.

ECONOMIC AND FINANCIAL ASPECTS

The financing of the projects concerning the construction of a treatment plant constitutes the main handicap for the realization of these projects. The majority of the projects of wastewater treatment are financed by communes through state credits. Other plants have been built by way of experiment, within the framework of partnership including water reuse and municipalities. The financial contribution of international organizations also helps in the construction of small plants in some cities and small communes of Morocco. Although the communes have proved to be willing to work, the initiation of treatment plant depends first on the establishment of a sewerage network. The cost of financing the latter makes future treatment plants seem illusory.

The investment costs of wastewaters, treatment plant varies considerably according to the adopted technology, the treatment process, and the specificities of the site, the pollutant load, and final disposal of treated wastewaters. For the treated wastewaters directed to reuse, the standards of health and environment protection impose a high quality requirement of the final effluent. Still, it is possible to compare the costs of investment of different projects and the reuse of wastewaters in Morocco per equivalent inhabitant.

Table 5. Costs of different processing plants of wastewaters in Morocco

Plant	Investment cost (millions of dirham)	Functioning cost (dirham / year)	Cost per inhabitant / year (dirham)	Cost / m^3 (dirham)
Ouarzazate	5	108.500	643	1,43
Ben Sergao	5	307.500	250	1,12
Benslimane	96,44	935.000	1.928	1,45
Drarga	20,3	260.000	1.000	1,70

Until now, there is no model for cost estimation of wastewater treatment in the Moroccan context. As mentioned above, these costs vary according to a number of factors. However, leading experiences have shown that the cost of technologies appropriate for Morocco such as lagoon and filtration-percolation vary between 1,12 and 1,70 Dirham per m^3 of treated waters (1 Euro= 10 Dirham).

In the case of Drarga and Benslimane, the treated wastewaters are sold. In Benslimane, the treated wastewaters are sold to the golf course for 2Dh/m^3 while the initial tariff for farmers in Drarga is 0, 50 Dh/m^3. For mere comparison, the agricultural wastewaters distributed by the offices of Agricultural Development are sold for an average tariff of 0.5 Dirhams/m^3, while the price for potable water varies between 2 and 8 Dirhams/m^3. It is worth noting that in many places, farmers resort directly to underground waters and solely pay the fees of pumping. In some regions where the level of the ground water has witnessed a considerable decrease, especially in Souss Massa, the pumping cost have become very expensive and may raise up to 1.5 Dirhams per m^3.

The increase in the price of water has always been subjected to resistance. Nonetheless, due to the scarcity of resources and repetitive droughts, more and more farmers accept the principle of a more rational resource management, especially through a more adequate price setting policy. In the regions with more severe water scarcity, farmers are ready to pay the cost of water, provided they have a perennial source.

Within the framework of the law on water 10-95, the deduction charges are stipulated and the use of raw wastewaters are banned. It is therefore expected that once the application decrees of the law will be enforced, the demand for treated wastewaters, in addition to the willingness to pay for this water, will increase significantly.

The treated wastewaters contain fertilizing elements and allow the farmer to save fertilizes inputs. The Table 10 is based on the performances obtained in Ouarzazate and Ben Sergao projects.

Table 6. Economic gain from treated wastewaters irrigation.

Cultivation	Net gain of water (Dh / year/inhab)	Benefit in fertilizers (Dh / year/inhab.)	Total benefit (Dh / year/inhab)
Tender Wheat	750	1.492	2.242
Unground corn	1.588	3.614	5.202
Fodder corn	1.568	3.572	5.140
Clover (Berseem)	774	1.539	2.313

Courgette	677	1.545	2.222
Marrow	611	1.216	1.827
Tomato	1.553	3.542	5.095
Potato	940	2.140	3.080

(1) Calculated on the basis of pumping water of Sous Massa (0.7 dh/m^3) and of the selling price of treated wastewaters (0.5 dh/m^3).

(2) Calculated on the basis of the total value of fertilizing elements in treated wastewaters.

WASTEWATER REUSE

Owing to the variable availability of water in water scarce countries for human consumption, there are different estimates on per capita generation of wastewater, which may range from 30 to 90 m^3 on an annual basis. Therefore, population of one million would generate wastewater in the range of 30 × 10^6 m^3 to 90 × 10^6 m^3. Considering average use of such water at 10000 m^3 ha^{-1} yr^{-1} would mean irrigation of about 3000-9000 ha. In order to supplement the freshwater needs, a large part of wastewater generated in these countries is reused to grow a variety of crops. The total area irrigated with untreated, partly treated, adequately treated, or diluted wastewater is estimated at 20 × 10^6 ha in 50 countries, somewhat below 10% of total irrigated area in developing countries.

Although all water is recycled through the global hydrologic cycle, adequate local treatment of wastewater and its reuse are crucial for several reasons: (1) The discharge of untreated wastewater into surface water is becoming difficult in the presence of government policies and regulations in several countries to protect the quality of receiving water used for different purposes and to avoid contamination of downstream water. (2) Being a significant water resource, treated wastewater may be used as a reliable source of irrigation of crops in urban and peri-urban areas, urban parks, playgrounds, sports fields, school yards, golf courses, commercial nurseries, and road plantings. Other uses may be industrial (cooling, boiling, and processing), environmental (wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), and non-potable (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge, which has received considerable attention in recent years. (3) Preservation of existing scarce sources of good-quality water for drinking and other household matters. (4) Consequent to reuse of treated wastewater as an irrigation source, a decrease in the demand for freshwater to be used for irrigation. (5) In case of appropriate treatment and management, treated wastewater presents a source of several nutrients essential for plant growth. This is a direct benefit to the farmer because of no or little investment on a significant farm input dealing with fertilizer purchase and application. (6) The benefits of reusing treated wastewater must also be considered against the cost of not doing so at the human health, economic, and environmental levels.

Owing to gradual addition of contaminants into freshwater bodies and the awareness of their possible impacts, wastewater treatment is now receiving greater attention from the governments of several water scarce countries and organizations such as World Bank. Keeping in view the foreseeable scenario of reusing treated wastewater for agricultural, environmental, recreational and industrial purposes, there is a greater scope in the water and environment sector to develop and implement wastewater treatment technologies that (1) need low capital investment on construction, operation and maintenance, (2) maximize the recovery of by-products such as nutrients from the pollution substances, (3) show compatibility with the intended reuse option in terms of appropriate quality and adequate quantity, (4) could be applied from very small to very large scale, and (5) have acceptance from the farming community and local population.

Untreated wastewater is being used by poor farmers in an unregulated manner in many developing countries to irrigate a variety of crops. Most cities of these countries have large number of open and covered channels that are interconnected and distributed within and around urban premises. In general, these channels carry a mixture of wastewater generated by domestic, municipal, and industrial activities. The farmers divert this untreated wastewater for irrigation as and when needed. They prefer to grow high-value vegetables as a market-ready product to generate greater income (Qadir *et al*., 2000). In most cases, there is no check on the part of administrators on such use of wastewater. Rather they regard this farming practice as a viable option for wastewater disposal. The farmers consider untreated wastewater as a source of irrigation, which involves less cost than other sources of irrigation water such as groundwater pumping (Van der Hoek *et al*., 2002). Other benefits to the farmers include no or little investment on fertilizer purchase and application, and greater crop production than freshwater irrigation. Therefore, farmers take health risks and use untreated wastewater when they find an opportunity for additional benefits such as greater income generation, improved nutrition, and education for children (Ensink *et al*., 2002; Matsuno *et al*., 2004). The use of untreated wastewater is intense in areas where there is a lack or little access to other sources of irrigation water. Most farmers are not fully aware of the health and environmental implications of using untreated wastewater for irrigation.

In Morocco, the use of raw wastewaters is a current and old practice. Raw wastewaters are used where they have most value in general. These practices are resorted to on the periphery of some big cities where agricultural lands are located downstream of effluent discharge, and also in small areas around the treatment networks. Climatic constraints push farmers to irrigate cultivations in places where water resources are available.

In recent years, the reuse of wastewaters has also developed around some suburbs recently provided with a treatment network. A total of 7000 ha is directly irrigated with raw wastewater discharged by towns, i.e. about 70 million m^3 of wastewater is used every year in agriculture with no application of health control (WHO standards for example). Many crops are irrigated in this manner (fodder, market gardening, major crops, arboriculture…).

The irrigation of market garden crops with raw wastewaters is forbidden in Morocco, but this ban is not respected. This makes the consumer of agricultural products and the farmer face risks of bacteria or parasite disease.

Table 7. Main areas of raw wastewater reuse in Morocco

Area	Surface (ha)	crops
Marrakech	2000	Cereals, fruit threes
Meknes	1400	Cereals, fruit threes
Oujda	1175	Cereals, fruit threes
Fès	800	Fruit threes
El Jadida	800	Fodder
Khouribga	360	Cereals,
Agadir	310	Fruit threes, soybean, floriculture
Béni-Mellal	225	Cereals, Cotton, beetroot
Ben guérir	95	Fodder, fruit threes
Tétouan	70	Fodder
Total	7235	

Source: CSEC (1994)

In general, the volume of wastewaters reused does not represent more than 0.5% of the water used in agriculture.

This situation tends to occur in all agglomerations that are provided with a treatment system or where wastewaters are discharged. Following an investigation carried out by SNAI (1998), a total of 70 areas where raw wastewaters are used and found in the country. This practice is not free of dangerous consequences for human health and for the environment. For example:

- Spread of water borne diseases (more than 4000 cases of Typhoid and more than 200 case of malaria have been noted in 1994, some cholera sources in the Sbou basin).

- Difficulty and high cost of treatment potable water.
- Many sections of water courses in the country contain low quantities of dissolved oxygen, and even a total deficit in oxygen when discharges are significant, and which causes massive fish mortality, and;
- Many barrage waters are atrophic, as a consequence of the significant phosphorus and nitrogen levels in the waste discharges.

There are several negative impacts of continued and uncontrolled applications of untreated wastewater as an irrigation source, which include: (1) Groundwater contamination through movement of high concentrations of a wide range of chemical pollutants (Ensink *et al*., 2002), particularly in case wastewater contains untreated industrial effluent. Nitrate (NO_3^-) and heavy metals reaching groundwater have the potential to impact human health under conditions of groundwater pumping for direct human consumption, although limited information is available on this aspect (Cooper, 1991). Accumulation of pathogens has also been found in groundwater immediately below the wastewater-irrigated fields. (2) Gradual build-up of deleterious ions such as sodium (Na^+) and a range of metals and metalloids in soil solution and on the cation exchange sites. The concentrations of potentially harmful metals and metalloids may reach to levels that may become phytotoxic to a wide range of species, and in certain cases toxicity may occur in soil faunae and florae, higher animals, and humans (Qadir *et al*., 2004). Accumulation of excess Na^+ in the soil has the potential to cause numerous adverse phenomena, such as changes in exchangeable and soil solution ions and soil pH, destabilization of soil structure, deterioration of soil hydraulic properties, and increased susceptibility to crusting, runoff, erosion and aeration, and osmotic and specific ion effects on plants (Sumner, 1993; Qadir and Schubert, 2002). (3) Accumulation of potentially toxic substances in crops and vegetables that ultimately enter the food chain, impacting human health. There are chances of greater accumulation of metals such as cadmium (Cd) in leafy vegetables than non-leafy species (Qadir *et al*., 2000). Excessive exposure to this metal has been associated with illnesses in human beings including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis (Wagner, 1993). There are numerous illnesses associated with ingestion of excessive levels of other metals and metalloids. Similarly, pathogens may enter and accumulate in the food chain. In most cases, industrial pollution inducing a variety of metals and metalloids could cause greater and long lasting impacts on human health than pathogenic organisms. (4) Extended contact of farmers with untreated wastewater may expose them and their families to health risks such as parasitic worms, and viruses, and bacteria that have the ability to cause diseases. Studies conducted on farmers using untreated wastewater for irrigation have shown higher prevalence of diarrhea through hookworm and roundworm infections than those farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater, penetrate through the skin of farmers working barefoot. In addition, nail problems—koilonychia in the form of spoon-shaped nails—have a more occurrence in wastewater-irrigated farmers (Van der Hoek *et al*., 2002).

Owing to the environmental implications and health risks, the use of untreated wastewater for irrigation cannot be encouraged. However, the poor farmers of many developing countries are expected to continue using untreated wastewater as long as it is accessible, and alternate disposal options are not available. With little allocation of funds for wastewater treatment and disposal, it is extremely difficult for these countries to enforce a ban on agricultural use of untreated wastewater, which supports a large number of livelihoods. In addition, an immediate ban would mean disposal of untreated wastewater into freshwater bodies leading to an increase in pollution of surface-water with negative impacts on downstream water quality and health of its users. In this way, most environmental and health problems will move to downstream areas, which already suffer from water quality problems in many irrigation projects. Therefore, the use of untreated wastewater can only be avoided in case of providing adequate funding for construction and efficient operation of treatment plants. However, the present scenario suggests that economies of most developing countries do not afford to build such treatment plants. Keeping in view these challenges, the studies carried out by researchers at the International Water Management Institute (IWMI) have proposed a number of policy options to maximize the benefits and minimize the risks involved with agricultural use of untreated wastewater (Scott *et al*., 2000; Ensink *et al*., 2002; Van der Hoek *et al*., 2002; Matsuno *et al*., 2004). These policy options include: (1) use of appropriate irrigation techniques and selection of suitable crops that are less likely to transmit contaminants and pathogens to consumers, (2) use of protective measures such as boots and gloves to control exposure of farm workers from pathogens,

(3) implementation of medical care program through the use of preventive therapy such as anti-helminthic drugs, (4) appropriate post-harvest management of vegetables through washing and improved storage, (5) conjunctive use of wastewater and freshwater to dilute the risks and greater benefits through supply of nutrients(Choukr-Allah, 1996a, 1996b) on a larger area, (6) upstream wastewater management and appropriate low-cost treatment, (7) education and awareness among farmers, consumers, and government organizations, and (8) implementation of monitoring programs for key environmental, health, and food safety parameters. While considering the situation that unconditional restriction on wastewater use is not possible in many developing, the World Health Organization has made a commitment to take into account the realities faced by these countries when reviewing its guidelines for wastewater use in agriculture (IWMI, 2003).

The precaution to be taken in reusing treated wastewater

Any project with the aim to treat and reuse wastewaters should have the main objectives directed to:

- Study the effects of using treated wastewaters on land, cultivations, and irrigation systems;
- Define the health criteria required for the use of treated wastewaters.
- Identify the most appropriate techniques for maximum exploitation rising treated wastewaters and the residual sludge.
- Study the efficiency of the wastewater treatment system per basin
- Follow the effects of reuse process on the environment and especially on the quality of underground waters.
- Reinforce national capacities in reusing treated wastewaters for agricultural purposes
- Exploit the results in extending the use of treated wastewaters at the national and regional level.
- Produce dimension standards for future plants
- Calculate the direct or indirect costs that come within a financial and economic analysis.
- Reduce the nuisance impacts on the environment generated by the raw wastewaters, and;
- Conserve the underground water resources.

POTENTIAL OF SAVING BY USING TREATED WASTEWATER

Wastewater treatment provides opportunities to increase the use of wastewater in agriculture (Choukr-Allah, 2004, GWP8Med, 2000). The percentage of population served with water supply and sanitation varies from one country to another. The table 1 below indicate that the annual water use in domestic and industrial sectors could reach 83 BMC. Assuming 80% of wastewater will be collected and treated, the annual collected wastewater could reach 66.7 BMC. The existing wastewater reuse is estimated at 0.75 BMC in the Mediterranean countries (FAO, 1997). The potential treated wastewater for reuse can therefore be estimated at 66 BMC/year in the Mediterranean region. Based on the water demand of year 2025, and assuming that this water could be satisfied, the saving using treated wastewater could reach 70 BMC / year. The cost to achieve this saving is estimated to 55 billions euros which include the need to fill the gap in water supply and sanitation coverage for 25 million people without access to water and to treat the wastewater effluents.

Table 1. Annual domestic and industrial water use and potential treated wastewater for reuse

	Potential Total Irrigation Savings	Potential Total Domestic Savings	Potential Total industrial Savings	Potential Treated Wastewater for use	Total Potential Water Savings
	M m3/year	M m3/year	M m3/year	M m3/year	M m3/year
Syria	1,360.0	174.1	3.5	135.9	1,673.5
Lebanon	95.0	99.7	1.9	286.3	482.9
Jordan	73.8	71.0	0.4	89.7	234.9
Egypt	4,773.0	1,079.4	55.5	5,108.1	11,016.0
Libya	400.2	161.9	1.2	248.0	811.2
Tunisia	270.6	91..5	1.2	201.1	564.3
Algeria	270.0	368.3	8.4	1,138.6	1,785.4
Morocco	1,016.1	186.5	4.1	553.9	1,760.6
Albania	99.4	129.3	0.0	221.4	450.1
Croatia	0.0	121.7	4.8	506.9	633.3
Cyprus	15.6	16.1	0.1	20.1	51.8
France	488.0	1,947.9	371.1	26,776.5	29,583.5
Greece	569.4	359.0	2.6	779.2	1,710.3
Italy	2,537.6	2,136.9	197.5	16,135.3	21,007.4
Malta	0.7	15.5	0.0	25.3	41.4
Spain	2,415.4	1,472.1	79.9	7,567.3	11,534.7
Turkey	2591.5	1,818.8	48.8	6,173.9	10,633.0
Total	16,976	10,250	781	65,968	93,974

WASTEWATER AS AN ADDITIONAL WATER RESOURCE

Benefits

There are several benefits of treated wastewater reuse. First, it preserves the high quality, expensive fresh water for the highest value purposes–primarily for drinking. The cost of secondary-level treatment for domestic wastewater in MENA, an average of $US 0.5/m3, is the cheaper, in most cases much cheaper, than developing new supplies in the region (WB, 2000). Second, collecting and treating wastewater protects existing sources of valuable fresh water, the environment in general, and public health. In fact, wastewater treatment and reuse (WWTR), not only protects valuable fresh water resources, but it can supplement them, through aquifer recharge. If the true, enormous, benefits of environmental and public health protection were correctly factored into economic analyses, wastewater collection, treatment and reuse would be one of the highest priorities for scarce public and development funds. Third, if managed properly, treated wastewater can sometimes be a superior source for agriculture, than some fresh water sources. It is a constant water source, and nitrogen and phosphorus in the wastewater may result in higher yields than freshwater irrigation, without additional fertilizer application (Papadopoulos, 2000). Research projects in Tunisia have demonstrated that treated effluent had superior non-microbiological chemical characteristics than groundwater, for irrigation. Mainly, the treated wastewater has lower salinity levels (WB, 2000, pg.8).

Case-Studies

Countries in the region which practice wastewater treatment and reuse include Spain, France, Cyprus, Malta, Tunisia, Israel, Italy, Greece, Portugal, and Egypt. However, only Israel, Cyprus and Tunisia, and to a certain extent, Jordan, already practice wastewater treatment and reuse as an integral component of their water management and environmental protection strategies.

In Tunisia, treated effluent with a total flow of 250 m3/d is used to irrigate about 4500 ha of orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), fodder, cotton, cereals, golf courses and lawns (Abu-Zeid, 1998).The agricultural sector is the main user of treated wastewater. Mobilisation of treated wastewater, and transfer or discharge are an integral part of the national hydraulic equipment program and are the responsibility of the State, like all related projects. The advantage of this water resource is that it is always available and can meet pressing needs for irrigation water. Indeed use of wastewater saved citrus fruit when the resources dried up (over-exploited groundwater) in the regions of Soukra (600 inhabitants) and Oued Souhil (360 inhabitants) since 1960 and contributed among other things to the improvement of strategic crop production (fodder and cereals) in new areas.

Technical and economic criteria enabled the irrigation of more than 6600 ha mobilising 30% of discharged effluent. The average effective utilisation rate of treated wastewater is 20%. The volume consumed differs greatly from one area to another, according to climatic conditions (11 to 21 Million m^3 per year.) At present, treated wastewater is an available source of water for farmers, but on the one hand, it is not suitable for crops that are economically profitable, and on the other hand it poses some health risks. The best levels of utilisation are found in arboriculture areas, in areas with a tradition of irrigation and in semi arid areas.

With a projected volume of 215 million m^3 by the year 2006, the utilisation potential of this water will be about 20,000 hectares that is 5% of the areas that can be irrigated, if we assume intensive inter-seasonal storage and a massive introduction of water saving systems that would increase the mobilisation rate to 45%. It is expected that additional treatment of treated wastewater will improve the rate of use in irrigated areas (ONAS 2001).

Agricultural reuse however will not see marked improvement, unless restrictions are lifted on pilot wastewater treatment plants with complementary treatment processes. This can only be decided when the stations are functioning with acceptable reliability. This will take a few years of experience. Nonetheless, in all cases, and regardless of the treatment method, technical and organizational measures should be introduced in order to systematically warn those managing the reuse of any breakdowns that may occur in the wastewater treatment plants and to avoid the flow of treated wastewater into the distribution network.

In Jordan, Treated wastewater generated at nineteen existing wastewater treatment plants is an important water resources component. About 72 MCM per year (2000) of treated wastewater are effectively discharged into the watercourses or used for irrigation, 76% is generated from the biggest waste stabilization pond Al-Samra treatment plant serving a population of 2 million (approximately 70% the total served population) in 2000. By the year 2020, when the population is projected to be about 9.9 million, about 240 MCM per year of wastewater are expected to be generated. All of the treated wastewater collected from the As-Samra wastewater treated plant is blended with fresh water from the King Talal reservoir and used for unrestricted irrigation downstream in the Jordan Valley.

In Israel reuse up to 1982 amounted to about 25% of the wastewater generated. Since that time several large projects lead to a large increase in water reuse. In 1987 some 230 reclaimed water projects produced about 0.27 x 10^6 m^3/day of reclaimed water from a population of over 4 million people (Argarnan, 1989). About 92% of the wastewater was collected by municipal sewers and of this 72% was reused for irrigation 42%) or groundwater recharge (30%). Reuse constitutes approximately 10 % of the water in Israel but by 2010 it is projected that reuse will account about 20%, with about 33% of the total water resource allocated to agricultural irrigation. This practice is generally recognized at the moment as an economically feasible strategy for developing a crucial water source for irrigation replacing freshwater to be reallocated for urban/domestic use, while also having public health advantages. About eighty percent of Israel’s treated wastewater is reused in irrigation.

Despite all efforts in practice and research however, the associated health and environmental risks and the implications of the increase in the quantities of wastewater effluents in the human environment are not fully understood. Furthermore, the inclusion of sewage effluents as part of “water irrigation rights” and the associated institutional and pricing adjustments need to be analyzed as well as the modifications in the agricultural production systems. Extensive engineering and academic research is being conducted in an attempt to elaborate the consequences and effects of large scale and expanded use of treated effluents of varying degree of quality on the human and natural environment, in general, and the soil/water/crop relationship, in particular. Subsurface trickle irrigation in large field scale was tried and no yield benefits or deficits were found as compared to surface trickle irrigation. However the E.coli pathogens in the surface soil was the same as background samples suggesting a safer method of irrigation though not always the maximum yields are obtained.

In Cyprus wastewater generated from the main cities is collected and following tertiary treatment is used for irrigation. It is expected that the irrigated agriculture will be expended by 8-10% and an equivalent amount of water will be conserved for other sectors (Papadopoulos. 1995)

In Italy, in the areas near the treatment plants of the towns Castiglione, Cesena, Cesenatico, Cervia and Gatteo an intensive programme of reuse of treated wastewaters has been carried out. Wastewater irrigation now covers an area of over 4000 ha and very interesting results both in terms of the effects on the soil and on the irrigated crops are shown. The first survey of Italian treatment plants estimated the total treated effluent flow at 2 400 Mm3 /yr of usable water. This gives an estimate of the potential resource available for reuse.

The reuse of treated wastewater in Spain is already a reality in several regions of the country for four main applications: golf course irrigation, agriculture irrigation, groundwater recharge and river flow augmentation. In Tenerife, the treated water reused in irrigation amount to 17 00 m^3/day. These waters are stored in two reservoirs of a capacity of 250 00 m^3 and 50 000 m^3 respectively in San Lorenzo and Sen Isidro. The main crops irrigated are banana, vineyards, tomatoes, and cut flowers.

In Portugal, treated wastewater is a valuable potential resource for irrigation and should soon reach 580 Mm3 /yr, which is approximately twice as much as today. Even without storage, this amount could be enough to cover about 10% of the water needs for irrigation in a dry year. Roughly, between 35 000 and 100 000 ha, depending on storage capacity could be irrigated with recycled water.

In Morocco, the reuse of raw wastewaters has become a current and old practice. They are reused in agriculture in several parts the country. These practices are mainly localized to the periphery of some big continental cities where agricultural lands are locate in the downstream of effluent discharge, and also in small parts around the wastes of the treatment networks. The climatic constraints had pushed farmers to irrigate their crops with raw wastewater when water resources are not available.

During the last years, the reuse of wastewaters has also developed around some suburbs recently provided with a treatment network. A total of 7000 ha (Choukr-Allah, 2004) is directly irrigated with raw wastewaters discharged by towns, i.e. about 70 million m^3 of wastewater is used every year in agriculture with no application of the sanitary precaution (HWO standards for example). This second use concerns a diversity of cultivation types (fodder, cereals, fruit threes…).

The irrigation of vegetable crops with raw wastewaters is forbidden in Morocco, but this banning is not respected, which makes the consumer of agricultural products and the farmer face risks of bacteria or parasite contaminations. In general, the volume of wastewaters that have been recycled does not represent more than 0.5% of the water used in Agriculture.

This situation tends to be generalized in all the suburbs that are provided with a treatment system where wastewaters are discharged. Following an investigation carried out within the framework of NSLC (1998), a total of 70 areas using wastewaters are spread out in the territory. This practice is not free of dangerous consequences on human health and on environment. For example:

(i) Spread of water diseases (more than 4000 cases of Typhoid and more than 200 case of malaria have been noted in 1994, some cholera sources in the Sebou basin).

(ii) Difficulty and high cost of processing, and for the production potable water.

(iii) Many section of water courses in the country present a largely weak quantity of dissolved oxygen, and even a deficit in oxygen when these discharges are important, which causes massive fish mortality, and;

(iv) Many dam volumes present marks of eutrophication, as a consequence of the important phosphor and nitrogen wastes.

Since early nineties, many multidisciplinary projects concerning the treatment and reuse of wastewater in irrigation have been launched in Morocco. The aim was to answer the major agronomic, health, and environmental concerns. The results of these researches have made the local collectivities and the regional agriculture services benefit from reliable data necessary to conceive and to size the treatment plants of wastewaters adapted to the local contexts and to disseminate the best practices for reusing treated wastewaters in agriculture.

In Egypt an ambitious programme is running for municipal wastewater treatment that will provide by the year 2010 nearly 3 billions m^3/yr of treated wastewater as an additional water source to be used in agriculture (Abu-Zeid, 1992).

Most nations in the region are already importing virtual water, in the form of food, and will likely have to increase specific imports, such as cereal crops. Despite this, many countries wish to increase fresh water supplies to domestic, and industrial usages, and at the same time, expand irrigated agriculture. For example, Tunisia wishes to increase the area of irrigated agriculture by at least 30,000 hectares (ha), and Egypt, by 880,000 ha. How can these seemingly contradictory objectives be reconciled? The answer is water demand management more efficient water use within all sectors. One specific component is to increasingly reuse domestic wastewater, for industry, for some municipal purposes, such as flushing toilets and irrigating green spaces, but above all, for agriculture, to offset the fresh water being taken out of this sector.

WASTEWATER REUSE CONSIDERATIONS

Wastewater reuse applications

In the planning and implementation of wastewater reclamation and reuse, the reuse application (see Table 2) will usually govern the wastewater treatment needed, and the degree of reliability required for the treatment processes and operations. Because wastewater reclamation entails the provision of a continuous supply of water of consistent quality, the reliability of the existing or proposed treatment processes and operations must be evaluated in the planning stage (Tchobanoglous and Burton, 1991). Specific reuse categories and treatment technologies that may be applicable will depend on the location and type of wastewater management employed (e.g., centralized versus decentralized, as discussed subsequently). Worldwide, the most common use of reclaimed wastewater has been for agricultural irrigation. Recently, groundwater recharge and potable reuse have received considerable attention in the United States. The re-purification project in San Diego, CA, in which it is proposed to blend re-purified wastewater with local runoff and imported water in a local water supply storage reservoir, is an example of such a project (Montgomery and Lowry, 1994.)

Table 2. Categories of municipal wastewater reuse and potential issues/constraints

Wastewater reuse categories	Issues/constraints
Agricultural irrigation	(1) Surface and groundwater Pollution if not managed properly, (2) Marketability of crops and public acceptance, (3) effect of water quality, particularly salts, on soils and crops, (4) public health concerns related to pathogens (bacteria, viruses, and parasites), (5) use for control of area including buffer zone, (6) may result in high user costs.
Crop irrigation	
Commercial nurseries	
Landscape irrigation	
Parks	
School yards	
Freeway medians	
Golf courses	
Cemeteries	
Greenbelts	
Residential	
Industrial recycling and reuse	(1) Constituents in reclaimed wastewater related to scaling, corrosion, biological growth, and fouling, (2) public health concerns, particularly aerosol transmission of pathogens in
Cooling water	

Boiler feed Process water Heavy construction	cooling water.
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	(1) Organic chemicals in reclaimed wastewater and their toxicological effects, (2) total dissolved solids, nitrates, and pathogens in reclaimed wastewater.
Recreational/environmental uses Lakes and ponds Marsh enhancement Stream-flow increase Fisheries Snowmaking	(1) Health concerns of bacteria and viruses, (2) eutrophication due to nitrogen (N) and phosphorus (P) in receiving water, (3) toxicity to aquatic life.
Non-potable urban uses Fire protection Air conditioning Toilet flushing	(1) Public health concerns on pathogens transmitted by aerosols, (2) effects of water quality on scaling, corrosion, biological growth, and fouling, (3) cross-connection.
Potable reuse Blending in water supply Pipe to pipe water supply	(1) Constituents in reclaimed wastewater, especially trace reservoir organic chemicals and their toxicological effects, (2) aesthetics and public acceptance, (3) health concerns about pathogen transmission, particularly viruses

Source: Tchobnoglous and Burton, 1991

Wastewater quality and health issues

Irrigating with untreated wastewater poses serious public health risks, as sewage is a major source of excreted pathogens - the bacteria, viruses, protozoa- and the helminths (worms) that cause gastro-intestinal infections in human beings.

Wastewater may also contain highly poisonous chemical toxins from industrial sources as well as hazardous material from hospital waste. Relevant groups of chemical contaminants are heavy metals, hormone active substances (HAS) and antibiotics. The risks associated with these substances may, in the long run, turn out to constitute a greater threat to public health and be more difficult to deal with than the risks from excreted pathogens. Unregulated and continuous irrigation with sewage water may also lead to problems such as soil structure deterioration (soil clogging), salinization and phytotoxicity.

These risks are not limited to ‘official’ wastewater but often also apply to rivers and other open water sources, as indicated by figures gathered by Westcott: 45% of 110 rivers tested carried faecal coliforms levels higher than the WHO standard for unrestricted irrigation (FAO, unpublished, cited in Birley).

The ideal solution is to ensure full treatment of the wastewater to meet WHO guidelines prior to use, even though the appropriateness of these guidelines are still under discussion. However, in practice most cities in low income countries are not able to treat more than a modest percentage of the wastewater produced in the city, due to low financial, technical and/or managerial capacity. The rapid and unplanned growth of cities with multiple and dispersed wastewater sources makes the management more complex. In many cities a large part of the wastewater is disposed of untreated to rivers and seas, with all related environmental consequences and health risks. The perspectives regarding the increase in wastewater treatment capacity in these cities are bleak. It may safely be assumed that urban and peri-urban farmers increasingly will use wastewater for irrigation, irrespective of the municipal regulations and quality standards for irrigation water.

Only a few large cities in developing countries and newly industrializing countries have adequate sewer systems and treatment plants, which is not the case for the majority of developing countries. In any case, usually, only a small portion of the wastewater is treated and purified even when it is channeled through a sewer system. Existing sewage treatment plants rarely operate satisfactorily and, in most cases, wastewater discharges exceed legal and/or hygienically acceptable maxima.

This does not necessarily lie in the treatment plants themselves, but in the frequent lack of adequately trained technicians capable of technically operating such treatment plants.

The discharge of untreated wastewater and/or minimally treated municipal ones in water sources has resulted in a substantial economic damage and has posed serious health hazards to the inhabitants, particularly in the developing countries. In many countries, various diseases are particularly prevalent and the consequential costs for the health care system are considerable.

Considerable sums have been spent on water and wastewater treatment in both the developing and developed regions of the world to substantially reduce waterborne diseases and meet commonly accepted environmental and ecological objectives. Yet, statistics indicate that in spite of such enormous investments in water quality improvement and protection, in the less developed countries, nearly 2 billion people are suffering from the lack of clean drinking water and sanitation facilities.

This is now the case in many mega-cities where the drinking water supplies from rivers or local groundwater sources are no longer sufficient, mostly because of their poor quality.

As a matter of fact, water quality problems are certainly not restricted to urban areas. The lack of sanitation facilities and the too often associated unsafe drinking waters remain among the principal causes of disease and death, especially in rural areas. Specific measures to counteract water-related threats are often needed, but, lack of investments and inadequate local management often lower their effectiveness.

Institutional manageability

Wastewater reuse is characterised by the involvement of several departments and agencies, either governmental or private or both. In the southern part of the Mediterranean countries, few governmental agencies are adequately equipped for wastewater management. In order to plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This could require the availability of a substantial number of engineers, access to a local network of research for scientific support and problem solving, access to good quality laboratories and monitoring system and experience in management and cost recovery. In addition, all technologies, included the simple ones, require devoted and experienced operators and technicians who must be generated through extensive education and training.

For adequate operation and minimization of administrative conflicts, a tight coordination should be well defined among the Ministries involved such as those of Agriculture, Health, Water Resources, Finance, Economy, Planning, Environmental Protection and Rural Development. The basic responsibilities of such inter-ministerial committees could be outlined in:

- developing a coherent national policy for wastewater use and monitoring of its implementation;
- defining the division of responsibilities between the respective Ministries and agencies involved and the arrangements for collaboration between them;
- appraising proposed re-use schemes, particularly from the point of view of public health and environmental protection;
- overseeing the promotion and enforcement of national legislation and codes of practice;
- developing a national staff development policy for the sector;

Financial considerations

The lower the financial costs, the more attractive is the technology. However, even a low cost option may not be financially sustainable because this is determined by the true availability of funds provided by the polluter. In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses. The ultimate goal should be full cost recovery although, initially, this may need special financing schemes, such as cross subsidization, revolving funds and phased investment programmes.

In this regard, adopting an adequate policy for the pricing of water is of fundamental importance in the sustainability of wastewater re-use systems.

The incremental cost basis, which allocates only the marginal costs associated with re-use, seems to be a fair criteria for adoption in developing countries.

Subsidizing re-use system may be necessary at the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to users arising from the permitted use of the treated wastewater.

However, setting an appropriate mechanism for wastewater tariff is a very complex issue. Direct benefits of wastewater use are relatively easy to evaluate, whereas, the indirect effects are “non monetary issues” and, unfortunately, they are not taken into account when performing economic appraisals of projects involving wastewater use. However, the environmental enhancement provided by wastewater use, particularly in terms of preservation of water resources, improvement of the health status of poor populations in developing countries, the possibilities of providing a substitute for freshwater in water scarce areas, and the incentives provided for the construction of urban sewage works, are extremely relevant. They are also sufficiently important to make the cost benefit analysis purely subsidiary when taking a decision on the implementation of wastewater re-use systems, particularly in developing and rapidly industrializing countries.

Monitoring and Evaluation

Monitoring and evaluation of wastewater use programmes and projects is a very critical issue, hence, both are the fundamental bases for setting the proper wastewater use and management strategies. Ignoring monitoring evaluation parameters and/or performing monitoring not regularly and correctly could result in serious negative impacts on health, water quality and environmental and ecological sustainability.

Unfortunately, in many countries that are already using or start using treated wastewater as an additional water source, the monitoring and evaluation programme aspects are not well developed, are loose and irregular. This is mainly due to the weak institutions, the shortage of trained personnel capable of carrying the job, lack of monitoring equipment and the relatively high cost required for monitoring processes.

In the developing countries, two types of monitoring are needed: the first, process control monitoring to provide data to support the operation and optimization of the system in order to achieve successful project performance; the second, compliance monitoring to meet regulatory requirements and not to be performed by the same agency in charge of process control monitoring.

In the developing countries, to avoid failure in wastewater use and attain the desired success, the monitoring programme should be cost effective, and should provide adequate coverage of the system. Equally so, it must be reliable and timely in order to provide operators and decision making officials with correct and up-to-date information that allows the application of prompt remedial measures during critical situations.

Public awareness and participation

This is the bottleneck governing the wastewater use and its perspective progress. To achieve general acceptance of re-use schemes, it is of fundamental importance to have active public involvement from the planning phase through the full implementation process.

Some observations regarding social acceptance are pertinent. For instance, there may be deep-rooted socio-cultural barriers to wastewater re-use. However, to overcome such an obstacle, major efforts are to be carried out by the responsible agencies.

Responsible agencies have an important role to play in providing the concerned public with a clear understanding of the quality of the treated wastewater and how it is to be used; confidence in the local management of the public utilities and in the application of locally accepted technology, assurance that the re-use application being considered will involve minimal health risks and minimal detrimental effects on the environment.

In this regard, the continuous exchange of information between authorities and public representatives ensures that the adoption of specific water re-use programme will fulfill real user needs and generally recognized community goals for health, safety, ecological concerns programme, cost, etc.

In this way, initial reservations are likely to be overcome over a short period. Simultaneously, some progressive users could be persuaded to re-use wastewater as supplementary source for irrigation. Their success would go a long way in persuading the initial doubters to re-use the wastewater available.

MAJOR NEEDS FOR RECYCLING AND REUSE OF WASTEWATER

Applying realistic standards and regulations

An important element in the sustainable use of wastewater is the formulation of realistic standards and regulations. However, the standards must be achievable and the regulations enforceable.

Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations because they create an attitude of indifference towards rules and regulations in general, both among polluters and administrators. In arid and semi-arid countries where wastewater is recognized additional water source standards, guidelines and regulations in the majority of developing countries do not consider the re-use aspect as an integrated part of the treatment process; they are only intended to control and protect the quality of water bodies where the reclaimed water is discharged. In reality, in the arid regions of the Near-East, North-Africa and Southern-Europe, not all countries have developed guidelines and regulations for reclaimed water use. For those countries, standards and regulations for the re-use should be tailored to match the level of economic and administrative capacity and capability standards should cope with the local prevailing conditions and should be gradually tightened as progress is achieved in general development and in the economic and technical capability of the involved institutions and of the private sector as well.

Formulation of national policies and strategies

It is now widely recognized that wastewater re-use constitutes an important and integral component of the comprehensive water management programs of the majority of countries, more so in the water scarce ones.

This implies that these countries should have national policies and strategies relating to wastewater management in general and wastewater re-use for agriculture, in particular, in order to guide programme, projects and investments relating to wastewater collection, treatment, re-use and disposal in a sustainable manner.

This requires the establishment of a clear policy with regard to wastewater management.

This policy should be compatible with a number of related sectoral or sub-sectoral policies such as national water management and irrigation policy, national health, sanitation and sewage policy, national agricultural policy and national environmental protection policy.

Such policy should give guidance on the following issues:

- the current and future contribution of treated wastewater to the total national water budget;
- criteria required to achieve maximum benefit of wastewater-reuse for the different water sectoral uses;
- modalities for strengthening the national capacity building in this sector.

Such policy should be accompanied by an appropriate national strategy for wastewater reuse characterized by the following features:

- spelling out ways and means of implementing policy directives;
- defining the nature and mechanisms of inter-institutional collaboration, allocation of funds, establishment of pilot wastewater reuse demonstration sites of good management practices and phasing the implementation of wastewater programmes;
- fostering the share of responsibilities between involved ministries, agencies and authorities, and the way to link and integrate the activities among them, individually and in combination;
- identifying an economically feasible, safe and socially acceptable set of standards, regulations and codes of practices for sustainable use.

Ideally, policies of wastewater reuse and strategies for its implementation should be part of water resources planning at the national level. At the local level, individual reuse projects should be part of the overall river basin planning effort.

Institutional, Legal and Political aspects of wastewater reuse

Safe water treatment, disposal and reuse are the responsibility of different organizations such as authorities, cooperatives and communities operating under the jurisdiction of the ministries of agriculture, water resources and others. The responsibilities of these organizations must be considered and reconciled.

To tackle the range of institutional levels involved and to allocate responsibilities in both treatment and reuse stages, several actions are needed, including:

(i) A well-defined policy and strategy for the comprehensive management and reuse of treated wastewater is a precondition to success.

(ii) Many different stakeholders are involved, so roles and responsibilities (who does what) need to be clearly defined, along with mechanism to ensure the active co-ordination of the various institutions.

(iii) Inadequate legislation often hinders the effective reuse of treated wastewater. Integrated legal arrangements can be of great value, along with provisions for active enforcement of all laws and regulations, without exception.

(iv) A comprehensive plan of action for reusing treated wastewater, with clearly assigned roles, needs to be complemented by periodic reviews and follow-up. Adequate funding is essential.

(v) Capacity building is required to analyse staff needs and provide suitable training.

(vi) More participatory approaches are needed, including raising the awareness of the general public (whose cultural and religious perceptions sometimes regard treated wastewater as impure). Irrigators also need to be involved in the planning and utilisation of this resource.

(vii) More co-ordination is needed between donors and national institutions involved in wastewater reuse.

To reinforce and help consolidate improved arrangements in countries with many ministries involved, the possible formation of a « higher council » to create policy and strategies should be considered. This body could oversee implementation and obtain necessary funding.

Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

Awareness raising, education, and best practices

Targeted health education is the most realistic, practical and cost effective measure to reduce health risks associated with wastewater use in agriculture. The following categories should be addressed:

- Policymakers: convince them that the use of wastewater is a reality that has to be accepted; provide them with data on the food security, income generating capacity, health and nutrients aspects of wastewater use in agriculture; show trade-offs of costs and benefits of wastewater treatment and reuse in agriculture, co-management of water provision, sanitation, treatment and reuse, and strategies for handling wastewater from the source to the users.

- Farmers: provide information through interactive learning methods on health risks associated with wastewater use, information and technical assistance on proper crop selection in relation to wastewater quality, irrigation techniques, protective clothing (boots), personal hygiene, washing crops before marketing, group organization for on field sanitation and washing facilities; preventing damage to soils and ground water.

- Consumers: Inform them on proper washing; cooking or blanching of vegetables; and sufficient cooking time for fish raised with wastewater; necessity of paying for treatment of household wastewater as they are the generators.

- Tradesman: use of clean water for freshening products (vegetables) on the market; ways for minimizing contamination risks during transport and processing.

- Local authorities: to help them understand the implications of wastewater use and the role they can play in minimizing the risks.

- The NGO’s and media may have to play a vital role in this exercise, if authorities are slow to take the lead.

Best practices should include:

- Crop selection and certification of produce (labelling);

- Variations in absorption of certain chemicals by crops, makes crop selection a suitable strategy, in the absence of market forces, which discourage crop restriction;

- Offering financial incentives i.e. labelling clean products, which will fetch higher prices, is also a possibility provided customers are willing to pay more and certification programs, which are costly processes, can be set up;

- Suitable irrigation system.

Improving irrigation practices

Irrigation techniques, which wet only the roots and not the leafy part of vegetables, were suggested as good practice for minimizing risk of contamination. Bed and furrow irrigation, drip systems and any other technique applying water close to the root systems was suggested. There is a further advantage in that there will be less infiltration into groundwater. Rotating wastewater application over fields if this is possible is another means to limit over-fertilisation and pollution of groundwater. Avoiding irrigation with wastewater in the two weeks before harvest can minimize the risk from pathogen contamination of leafy vegetables, but this necessitates a fresh water source accessible to farmers, which is rarely possible in these peri-urban situations.

CONCLUDING REMARKS AND RECOMMENDATIONS

Domestic WWTR is one tool to address the food and water insecurity facing many countries in the Mediterranean. In coming years, in most Mediterranean countries, valuable fresh water will have to be preserved solely for drinking, very high value industrial purposes, and for high value fresh vegetables and salad crops consumed raw. Where feasible, most crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, and generate new knowledge, and monitor and enforce standards.

- One of the prerequisites for any cure is an adequate information base. This includes inventorying water stocks, on one hand, and ascertaining the demand at local and regional level, in quantitative and qualitative terms within the framework of national water strategy, on the other one. Economic, social and environmental concerns must all be taken into account in accordance with the goal of sustainability.

- It is important to strengthen the capacity of national and local hydrological research institutes to improve their links to environmental research as well as to institutes in the field of economic and social science, particularly in the field of urban studies and planning. The transfer of knowledge to local government decision-makers must be improved.

- Local governments must focus their policies on treating municipal wastewater to eliminate the rapid degradation in both surface and groundwater quality. In this regard, simple methods of wastewater treatment are to be recommended as realistic solutions; equally so, governments have to operate as well to strengthen the capacity of both institutions and users.

Efforts concerning domestic sewage must center on promoting and further developing low cost, easy-to-handle and, in general, regionally developed technologies with a low degree of complexity. Special weight must be placed on minimizing the energy needs for these technologies.

- The failure of governance at local government level should be counteracted by improving the efficiency of public administration at the local level. The measures required include the building of responsibilities, combining management and financing functions, improving environmental legislation and monitoring, dismounting bureaucratic, decentralizing tasks to the lowest levels possible, increasing the transparency of government activities as well as enhancing the skills of the public administration employees.

- Enhancing and improving cooperation between local governments and the informal sector which is far below the level required. The informal sector should be exploited to a greater extent and integrated with decentralized public administration to find more rapid, appropriate and flexible solutions to the existing and raising problems. In this regard, the involvement of the NGOs has to be strengthened in the management of infrastructural institutions and the mobilization of public participation and individual responsibility within the framework of urban supply and wastewater treatment and use projects.

- Existing water charges must be changed so that they reflect scarcities and increase the reliability of supply. Most of the water tariff systems in both developed and developing countries do not reflect the economic and environmental scarcity of water. To be environmentally and economically viable, water tariff systems should ensure that the costs of collecting, treating and using water are recovered. Low income users should be able to reduce the amount they have to pay through active participation in systems of water collection, water supply and wastewater disposal and treatment.

The demand of major polluters or large consumers should be controlled using the instrument of marginal cost tariffs. Taxing consumption in this way is a financial incentive to water sustainability.

Where many different laws complicate wastewater reuse, consideration could be given to consolidated legislation that would cover all aspects of water resources planning, management and utilisation.

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SALINITY EFFECT ON CROP DEVELOPMENT AND YIELD, ANALYSIS OF SALT TOLERANCE ACCORDING TO SEVERAL CLASSIFICATION METHODS

N. Katerji*, J.W. van Hoorn, A. Hamdy*** and M. Mastrorilli******
* INRA, Unité de Recherche, Environnement et Grandes Cultures, 78850 Thivernal-Grignon, France
** Sub-Department Water Resources, Wageningen University, Wageningen, The Netherlands
*** Istituto Agronomico Mediterraneo, 70010 Valenzano (Bari), Italy
**** Istituto Sperimentale Agronomico, 70125 Bari, Italy

SUMMARY - The publication is a synthesis of previous publications on the results of a long-term lysimètre experiment. From 1989 to 1998, the experimental variables were soil salinity and soil type, from 1999 onwards, soil salinity and crop variety. The plant was studied during the whole growing period by measuring the saline stress and analyzing its effect on leaf area and dry matter development and on crop yield. Salinity affected the pre-dawn leaf water potential, stomatal conductance, evapotranspiration, leaf area and yield. The following criteria were used for crop salt tolerance classification: soil salinity, evapotranspiration deficit, water stress day index. The classification according to soil salinity distinguished the salt tolerant group of sugar beet and wheat, the moderately salt sensitive group comprising broadbean, maize, potato, soybean, sunflower and tomato, and the salt sensitive group of chickpea and lentil. The results for the salt tolerant and the moderately salt sensitive groups correspond with the classification of Maas and Hoffman, excepted for soybean. The evapotranspiration deficit criterion was used, because for certain crops the relation between yield and evapotranspiration remains the same in case of drought and salinity. This criterion, however, did not appear useful for salt tolerance classification. The water stress day index, based on the pre-dawn leaf water potential, distinguished a tolerant group, comprising sugar beet, wheat, maize, sunflower and potato, and a sensitive group, comprising tomato, soybean, broadbean, chickpea and lentil. The classification corresponds with a difference in water use efficiency. The tolerant crops show a more or less constant water use efficiency. The sensitive crops show a decrease of the water use efficiency with increasing salinity, as their yield decreases stronger than the evapotranspiration. No correlation could be found between osmotic adjustment, leaf area and yield reduction. As the flowering period is a sensitive period for grain and fruit formation and the sensitive crops are all of indeterminate flowering, their longer flowering period could be a cause of their greater sensitivity. The tolerant group according to water stress day index can be divided according to soil salinity in a salt tolerant group of sugar beet and wheat and a moderately sensitive group, comprising maize, sunflower and potato. The difference in classification can be attributed to the difference in evaporative demand during the growing period. The sensitive group according to water stress day index can be divided according to soil salinity in a moderately sensitive group, comprising tomato, soybean and broadbean, and a salt sensitive group of chickpea and lentil. The difference in classification can be attributed to the greater salt sensitivity of the symbiosis between rhizobia and grain legume in the case of chickpea and lentil.

Key words: Crop salt tolerance, osmotic adjustment, pre-dawn leaf water potential, soil salinity, water use efficiency

INTRODUCTION

Much research has been done to determine crop response to salinity by measuring crop yields at increasing salinity and relating yield reduction directly to soil salinity. This method permits to distinguish salt tolerant and salt sensitive crops and to choose a cropping pattern corresponding with the expected soil salinity. The method is simple and practical, but it does not, however, explain the behavior of crops under saline conditions, nor why crops differ in salt tolerance.

In 1989, the Mediterranean Agronomic Institute at Bari, southern Italy, started a longterm lysimeter experiment to initiate students in the study of plant growth under saline conditions. In this experiment, the plant was studied during its whole development by measuring the saline stress and analyzing its effect on the growth and yield of the plant to arrive at a better understanding of crop behavior under saline conditions.

The experimental set-up, the laboratory facilities and the manpower put certain restrictions. One crop per year was grown. During the period from 1989 to 1998, the first variable was the soil salinity, at three levels, and the second variable the soil type, loam and clay. From 1998 onwards, the second variable was the variety of the crop. All treatments were irrigated at the same time with surplus water for leaching. Soil dryness was not a variable in this experiment. Since the set-up consisted of lysimeters equipped with porous cups for soil water sampling, it was not possible to study root development. This was only done in a pot experiment with early seedlings. The lysimeter set-up allowed to establish the nitrogen balance of the grain legumes, but a laboratory study of the salinity effect on rhizobia was outside the scope of this experiment.

The results of the experiment have been published from 1992 onwards in Agricultural Water Management. This publication is a summary of previous publications. It starts with a description of the experimental procedure, after which examples are presented of the salinity effect on the water stress of the plant, followed by the effect on growth and yield to arrive finally at a comparison between the crops, their salt tolerance classification and some hypothesis about salt tolerance.

EXPERIMENTAL PROCEDURE

Set-up

The set-up consisted of 30 tanks of reinforced fiber glass with a diameter of 1.20 m and a depth of 1.20 m. A layer of coarse sand and gravel, 0.10 m thick, was overlain by a repacked soil profile of 1 m. At the bottom of the tank, a pipe serving as a drainage outlet connected the tank to a drainage reservoir. The set-up was covered at a height of 4 m by a sheet of transparent plastic to protect the assembly against precipitation.

One series of 15 tanks was filled with loam and a second series of 15 tanks with clay from 1989 to 1998. In summer 1998, the tanks were emptied and refilled with clay. Table 1 presents some properties of the soils after filling the lysimeters.

The tanks were irrigated with water of three different qualities: the control treatment with fresh water containing 3.7 meq. Cl/l and an electrical conductivity (EC) of 0.9 dS/m and two saline treatments, obtained by adding equivalent amounts of NaCl and CaCl2 to fresh water. During the second year wheat was irrigated with waters containing 10 and 20 meq. Cl/l; during the third year potatoes were irrigated with waters containing 15 and 30 meq. Cl/l on loam and 15 and 20 meq. Cl/l on clay; from the fourth year onwards the saline waters contained 15 and 30 meq. Cl/l and an EC of 2.3 and 3.6 dS/m. Table 2 presents the chemical composition of the irrigation waters. To eliminate the salinity effect on germination and emergence 10 l fresh water were applied after sowing.

Table 1. Soil properties

Soil	Particle size in percentage of mineral parts			$CaCO_3$ (%)	%Water (v/v)		Bulk density (kg/dm^3)
	< 2 µm	2-50 µm	> 50 µm		pF2.0	pF4.2	
Loam	19	49	32	25	36.3	20.4	1.45
Clay	47	37	16	05	42.0	24.0	1.45
Clay	49	22	29	11.4	38.5	21.9	1.41

Table 2. Composition of irrigation water (meq./l)

Treatment	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	HCO_3^-	SO_4^{2-}	EC (dS/m)	SAR
Fresh	6.2	3.1	2.3	0.4	3.7	7.3	0.6	1.0	1.1

15 meq. Cl/l	10.8	3.1	8.7	0.4	15.0	6.6	0.8		2.3	3.3
30 meq. Cl/l	16.7	3.4	16.2	0.4	30.0	6.5	0.7		3.6	5.1

At each irrigation surplus water was added to provide a leaching fraction of about 0.2. Irrigation water was applied when the evaporation of the class A pan had attained about 50 mmduring the beginning of the growing season and 80–100 mm during the full growing season, the latter corresponding with an evapotranspiration of about 80 mm, half of the total amount of available water. The evapotranspiration during the irrigation interval was calculated for each tank as the difference between the amounts of irrigation and drainage water. Soil moisture sampling during the first experimental year showed almost the same moisture content after each irrigation, corresponding with field capacity. No infiltration or water logging problems were observed.

For determining the depth average soil salinity, the average chloride concentration of soil water was calculated from the salt balance of irrigation and drainage water and converted into EC of soil water by the equation, established after the first 3 years, 1989–1992, In EC ¼ 0:824 In Cl _ 1.42. This EC-value of soil water was divided by 2 for the conversion into ECe. Owing to leaching at each water application, soil salinity remained almost constant from the start till the end of the growing period. According to measurements with soil water samplers, soil salinity slightly increased with depth. A previous publication (Van Hoorn *et al*., 1997) presents detailed information on development of soil salinity.

Crops

Table 3 presents the crops grown during the past 11 years, their variety and the reference publication with detailed information concerning crop density, fertilization, water stress, growth and yield. Broadbeans, grown during the first year, only succeeded on clay, since the loam was infected with broom rape.

Water stress of the plant

The parameters used to characterize the water stress of the plant were the pre-dawn leaf water potential, the stomatal conductance and the osmotic potential.

Table 3. Crop, variety, growth period and reference

Crop	Variety	Growth period	Reference
Broadbean (*Vicia faba*)	Superguadulce	8/12/1989–28/5/1990	Katerji *et al.* (1992)
Durum wheat (*Triticum durum*)	ISA	22/11/1990–26/6/1991	Van Hoorn *et al.* (1993)
Potato (*Solanum tuberosum*)	Spunta	3/2/1992–7/6/1992	Van Hoorn *et al.* (1993)
Maize (*Zea mays*)	Hybride Asgrow 88	27/7/1993–2/11/1993	Katerji *et al.* (1996)
Sunflower (*Helianthus annuus*)	Hybride ISA	22/4/1994–2/9/1994	Katerji *et al.* (1996)
Sugar beet (*Beta vulgaris*)	Suprema	25/11/1994–2/6/1995	Katerji *et al*. (1997)
Soybean (*Glycine max*)	Talon	18/7/1995–16/9/1995	Katerji *et al.* (1998a)
Tomato (*Lycopersicon esculentum*)	Elko 190	28/6/1996–10/9/1996	Katerji *et al.* (1998b)
Broadbean (*Vicia faba*)	Superguadulce	25/11/1997–20/5/1998	
Lentil (*Lens culinaris*)	Idlib I ICARDA 6796	29/12/1998–13/6/1999	Katerji *et al.* (2001a)
Chickpea (*Cicer arietinum*)	ILC 3279 Filip 87-59C	23/12/1999–24/6/2000	Katerji *et al.* (2001b)

The pre-dawn leaf water potential was determined with a pression chamber (Scholander *et al*., 1965) on the upper leaf surface of 1 leaf per lysimeter (five leaves per treatment), taken from the upper part of the canopy to avoid senescent leaves. The stomatal conductance was measured with a diffusion porometer at midday on the lower leaf surface of two leaves per lysimeter (10 leaves per treatment). The osmotic potential was determined with the pressure volume curve, established from two replicates for all six treatments, following the procedure described in a previous publication (Katerji *et al*., 1997). The measurements were made on five crops: sugar beet, tomato, broadbean, lentil and chickpea.

Growth and yield

The leaf area and the dry matter of leaf and stem were determined at the successive phenological stages on five plants, equally distributed over the five tanks per treatment, first the leaf area and afterwards the dry matter.

At harvest, the commercial yield, the number of fruits, ears and tubers and the average weight of grains, fruits and tubers were determined on each lysimeter.

Nitrogen balance

The nitrogen balance of the grain legumes was established to determine the salinity effect on the biological nitrogen contribution of the soil. The detailed procedure was described in a recent paper (Van Hoorn *et al*., 2001). The biological nitrogen of the soil was calculated as the difference between the nitrogen absorbed by the plant on one hand and the nitrogen input from fertilizer and irrigation water minus the output from drainage water on the other hand.

WATER STRESS OF THE PLANT

Pre-dawn leaf water potential and stomatal conductance

Salinity affects the water stress of the plant through its effect on the osmotic potential of the soil water. With increasing salinity the osmotic potential decreases and so the water availability for the plant, resulting in increasing water stress which in turn affects stomatal conductance, leaf growth and photosynthesis (West *et al*., 1986; Yeo *et al*., 1985).

Several indicators for the water stress can be used. After the first year of experiment, during which the radiation temperature and the pre-dawn leaf water potential were compared, the latter was selected (Katerji *et al*., 1992).

Fig. 1 presents the salinity effect on the pre-dawn leaf water potential of sugar beets, showing an increase after each irrigation and then a decrease during the irrigation interval. The stomatal conductance, presented in Fig. 2, also shows the effect of salinity and irrigation. The largest difference appears after irrigation, whereas the pre-dawn leaf water potential shows the largest difference before irrigation.

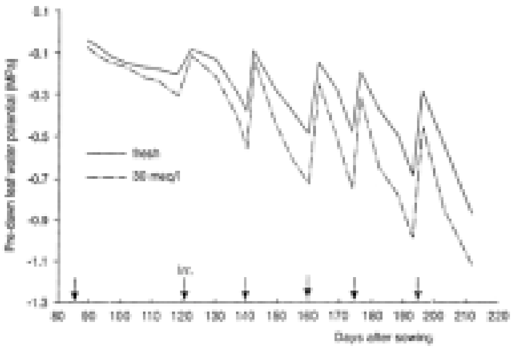

Fig. 1. Pre-dawn leaf water potential of sugar beet vs. days after sowing

The observations of the pre-dawn leaf water potential and the stomatal conductance show a perfect synchronization as the changes after each irrigation are simultaneous. The daily course of the leaf water potential and the stomatal conductance also shows a simultaneous change as presented in Fig. 3.

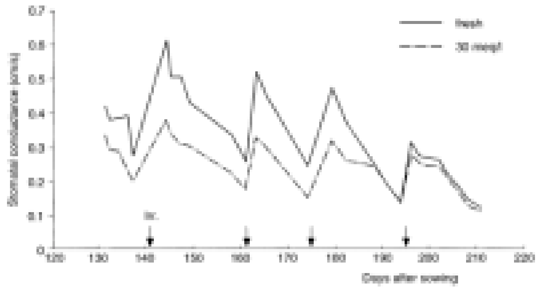

Fig. 2. Stomatal conductance of sugar beet vs. days after sowing

The Figs. 1 and 2, presenting the response of sugar beets, can be considered as general examples for all the crops grown during the experiment. Potatoes show a slight difference: the response of the pre-dawn leaf water potential on irrigation was immediate as for other crops, whereas the response of the stomatal conductance, in contrast to the other crops, showed a delay of 2–3 days before it attained the maximum value. This particular behavior was also observed by other authors (Epstein and Grant, 1973).

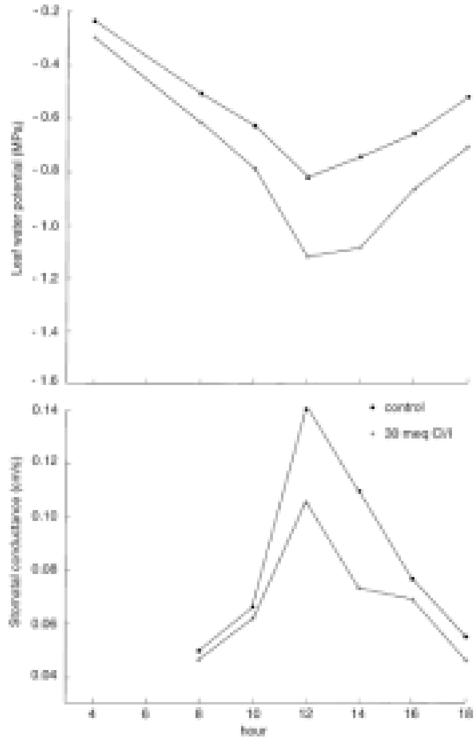

Fig. 3. Daily course of leaf water potential and stomatal conductance of maize

The pre-dawn leaf water potential and the stomatal conductance are also affected by the climatic conditions. According to the Figs. 1 and 2, the maximum values observed after irrigation decrease with time, which means with increasing temperature. This decrease is less pronounced for the pre-dawn leaf water potential, because the temperature and the relative humidity at dawn change less with time than at noon, when the stomatal conductance is measured (Ferreira and Katerji, 1992).

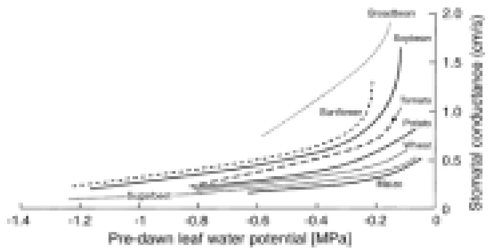

Fig. 4. Stomatal conductance vs. pre-dawn leaf water potential

Since the pre-dawn leaf water potential and the stomatal conductance are changing simultaneously, the relationship between both parameters is presented in Fig. 4 (the stomatal conductance of potato immediately after irrigation was left out). Sunflower, soybean and particularly broadbean are able to maintain the stomatal conductance at a rather high level at decreasing pre-dawn leaf water potential, that means under saline conditions, in comparison with the other crops.

Osmotic adjustment

Crops, when exposed during a long period to water stress caused by salinity or drought, are able to make an osmotic adjustment. This phenomenon consists of decreasing the leaf osmotic potential by accumulation of solutes and in that way increasing the turgor potential to maintain stomatal conductance and leaf growth under saline conditions (Beeg and Turner, 1976). A detailed description of the relationship between osmotic and turgor potential was given in a previous paper (Katerji *et al*., 1997).

Table 4 presents the maximum osmotic potential at three growth stages of sugar beets and shows that:

- the maximum osmotic potential of the control treatments (fresh) decreases with time, which means an osmotic adjustment to the phenological stage;
- the maximum osmotic potential decreases with increasing salinity, indicating an osmotic adjustment to salinity;
- the osmotic adjustment to salinity increases with the time of exposure to salinity, shown by comparing for t + 118, t + 172 and t + 211 the differences between the control and the saline treatments;
- soil texture does not show a clear effect on the maximum osmotic potential.

Table 4. Maximum osmotic potential at three growth stages of sugar beet (MPa)

Time	Loam			Clay		
	Fresh	15 meq./l	30 meq./l	Fresh	15 meq./l	30 meq./l
t + 118	-0.84	-0.89	-1.11	-0.88	-0.91	-1.09
t + 172	-1.13	-1.32	-1.50	-1.03	-1.15	-1.35
t + 211	-1.27	-1.45	-1.67	-1.36	-1.50	-1.73

Tomato, broadbean, lentil and chickpea showed a similar behavior, but the crops differed in the degree of osmotic adjustment. Table 5 presents the osmotic adjustment, expressed as the difference between the osmotic leaf potentials of the most saline treatment and the control treatment, also mentioning soil salinity and days after sowing, since the osmotic adjustment increases with the time of exposure. For detailed information on the osmotic adjustment, the reader is referred to the publications on the crops, mentioned in Table 3.

To analyze the effect of the osmotic adjustment on the stomatal conductance, the relationship between pre-dawn leaf water potential and stomatal conductance was calculated for sugar beet, tomato and broadbean. Owing to the small size of the lentil and chickpea leaves it was not possible to make reliable measurements of their stomatal conductance. Fig. 5 shows that the relationship for sugar beet and tomato can be approximated by straight lines. The higher the salinity, less steep the slope. Osmotic adjustment does not mean maintaining stomatal conductance at a high level, but it contributes to maintaining a low stomatal conductance under saline conditions (low pre-dawn leaf water potential). Broadbean, presented in Fig. 6, did not show an effect of the osmotic adjustment on the relationship between pre-dawn leaf water potential and stomatal conductance. For this crop no reliable difference in the relationship could be distinguished between different salinity levels. Varieties of broadbean, differing in salt tolerance, showed the same relationship between pre-dawn leaf water potential and stomatal conductance, almost similar to the curve for the variety Superaguadulce in Fig. 6.

Table 5. Leaf osmotic adjustment of the most saline treatment in MPa and in percentage of the control treatment at the end of the growing season

Crop	EC_e (dS/m)	Days after sowing	Leaf osmotic adjustment	
			MPa	Percentage of control
Sugar beet	6.1	211	0.39	29
Tomato	5.9	080	0.21	15
Broadbean	6.1	157	0.20	16
Chickpea	3.8	133	0.13	10
Lentil	3.1	146	0.36	28

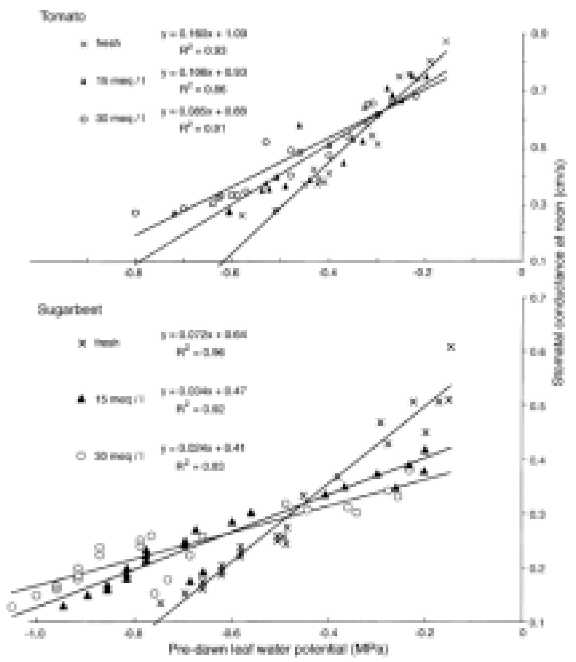

Fig. 5. Stomatal conductance vs. pre-dawn leaf water potential for tomato and sugar beet

Growth and yield

Crop establishment consists of three parts: germination, emergence and early seedling growth. When seeds are put in the soil, germination can only be observed as emergence, which may be affected by the water content and structure of the soil.

As fresh water was applied on the lysimeters after sowing to obtain a good stand, emergence and early seedling growth were studied in a greenhouse experiment, using pots filled with two soils, sandy loam and sandy clay, and two crops, maize and sunflower (Katerji *et al.*, 1994).

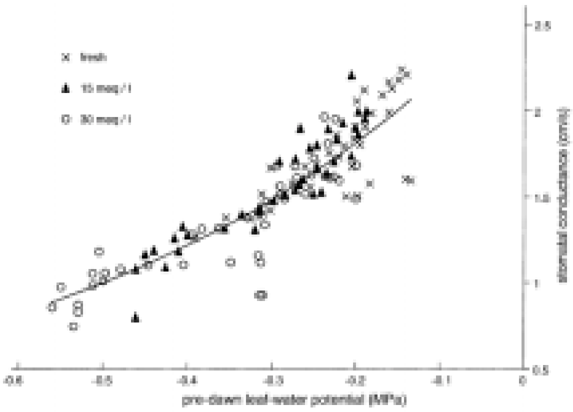

Fig. 6. Stomatal conductance vs. pre-dawn leaf water potential for broadbean

Table 6 presents the development as average values of both soils: at the start a delay with increasing salinity and at the end a lower emergence percentage. The difference between the crops was due to a difference in temperature. In practice, the delay in germination may lead to a failure in emergence and crop establishment, if a hard soil crust is formed under favorable weather conditions. Due to the evaporation of soil water during germination and emergence the salinity increases strongly in the top layer of the soil and seeds are exposed to a higher salinity than during later growth stages (Van Hoorn, 1991). Therefore it is doubtful whether plants during germination and emergence are more sensitive than later on.

A few days after emergence salinity already affected the pre-dawn leaf water potential of both crops. Fig. 7 shows that the dry matter production, calculated as average for both soils about 1 month after sowing, was affected in almost similar way for leaf, stem and root. The growth reduction of 20–30% at an ECe of 4 dS/m is in the same order as the yield reduction at harvest time.

The decrease in root development under saline conditions means that a smaller soil volume is available for crop water uptake. So, the moisture availability is not only reduced by less available water per unit of volume due to the osmotic potential, but also by the available soil volume.

Table 6. Development of emergence of maize and sunflower after sowing

Crop	Time (days)	Cl^- concentration of irrigation water (meq./l)				
		3.7	15	30	45	60
Maize	3	62	64	49	46	41
	4	81	78	67	65	60
	6	95	94	88	86	82
Sunflower	4	60	58	54	51	40
	7	77	74	71	67	61
	10	94	91	86	80	75

The slight difference in dry matter production between maize and sunflower during early seedling growth becomes more pronounced during the later growing period. Fig. 8 presents the leaf area development of both crops. The leaf area of maize is only slightly affected, a reduction of about 10%, whereas the leaf area of sunflower shows a stronger salinity effect. Tomato and soybean showed a similar, moderate effect on leaf area as maize, but the leaf area of the other crops was strongly affected, showing a reduction of 20–50%.

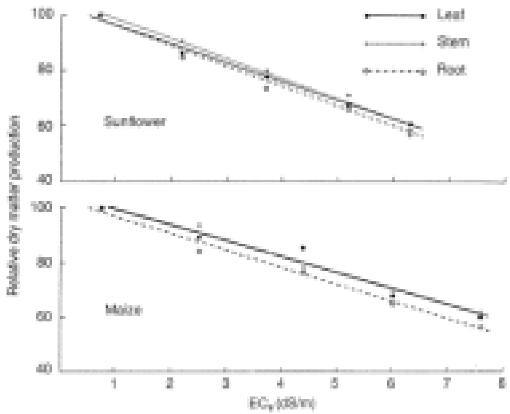

Fig. 7. Relative dry matter production of leaf, stem and root vs. soil salinity

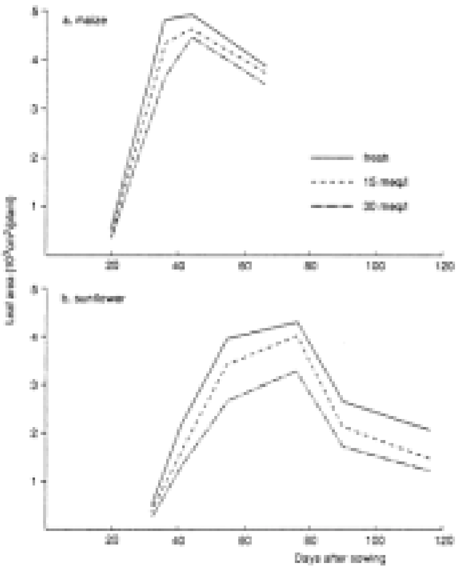

Fig. 8. Leaf area of maize and sunflower vs. days after sowing

Table 7 presents the commercial crop yields and the corresponding evapotranspiration and soil salinity. Table 8 presents the result of the statistical analysis of the salinity and texture effects on yield, evapotranspiration, pre-dawn leaf water potential, stomatal conductance and leaf area.

Salinity always affected yield, evapotranspiration, pre-dawn leaf water potential, stomatal conductance and leaf area. Salinity causes a yield reduction by affecting the number and weight of grains, tubers and fruits.

The yield of all crops, excepted broadbean, was lower on clay than on loam. According to Table 1 the total available moisture content between field capacity and wilting point is almost the same for both soils, but the air content on loam is higher than on clay, permitting probably a better root development and water supply. The statistical analysis did not show an interaction between salinity and texture.

Broadbean, as the only exception among the crops, showed a higher grain yield on clay, but a lower aerial biomass. The crop was harvested shortly after ripening on clay. At that moment broadbean on loam, on which the vegetative growth had continued longer, was still flowering and probably, if harvested later, would have shown an equal or even higher yield.

Table 7. Yield (kg/m^2), ET (mm) and EC_e (dS/m) of the crops growing during the lysimeter experiment

	Loam	Clay
Broadbean, 1990		

	Loam			Clay		
Yield, grain	–	–	–	000.246	000.179	000.175
ET	–	–	–	802	763	750
EC_e	–	–	–	000.8	001.2	001.75
Durum wheat, 1991						
Yield, grain	000.90	000.82	000.80	000.78	000.78	000.64
ET	883	800	721	733	648	563
EC_e	000.8	002.9	006.0	000.8	001.7	003.1
Potato, 1992						
Yield, grain	008.62	006.54	005.40	005.80	005.00	004.84
ET	415	382	328	363	327	304
EC_e	000.8	002.6	005.9	000.8	002.5	003.4
Maize, 1993						
Yield, grain	000.678	000.674	000.533	000.548	000.486	000.414
ET	607	578	494	644	552	505
EC_e	000.8	001.8	003.0	000.8	001.9	003.7
Sunflower, 1994						
Yield, grain	0000.351	0000.291	0000.263	0000.216	0000.193	000.154
ET	1450	1310	1157	1215	1040	994
EC_e	0000.8	0002.7	0003.8	0000.8	0002.0	003.9
Sugar beet, 1995						
Yield, grain	006.56	005.84	005.53	004.47	003.57	003.68
ET	836	753	734	731	642	657
EC_e	000.8	003.5	006.3	000.8	003.4	005.8
Soybean, 1995						
Yield, grain	000.334	000.294	000.180	000.311	000.221	000.106
ET	410	376	306	430	361	300
EC_e	000.8	004.2	007.0	000.8	003.8	006.3
Tomato, 1996						
Yield, grain	006.12	004.46	002.42	005.31	003.85	002.29
ET	708	631	540	667	628	522
EC_e	000.8	004.5	006.4	000.8	004.0	005.4
Broadbean, 1998						
Yield, grain	000.468	000.339	000.236	000.706	000.572	000.337
ET	409	354	322	448	398	345
EC_e	000.8	004.9	006.6	000.8	004.3	005.6
Lentil, 1999		Variety Idlib I			Variety 6796	
Yield, grain	000.683	000.517	000.082	000.411	000.353	000
ET	272	254	225	248	230	198
EC_e	000.7	002.0	003.1	000.7	002.0	003.3
Chickpea, 2000		Variety ILC 3279			Variety 87-59C	
Yield, grain	000.474	000.460	000.134	000.420	000.240	000.130
ET	613	467	290	516	328	239
EC_e	000.8	002.5	003.8	000.8	002.4	003.8

Table 8. Effect of salinity and texture on yield, evapotranspiration, pre-dawn leaf water potential and stomatal resistance

Crop	Yield		Evapotranspiration		Pre-dawn leaf water potential		Stomatal resistance	
	Salinity	Texture	Salinity	Texture	Salinity	Texture	Salinity	Texture
Broadbean 1990	s	–	s	–	s	–	s	–
Durum wheat	s	s	s	s	s	s	s	s
Potato	s	s	s	s	s	s	s	s
Maize	s	s	s	ns	s	s	s	s
Sunflower	s	s	s	s	s	s	s	s
Sugar beet	s	s	s	s	s	ns	s	s
Soubean	s	s	s	ns	s	ns	s	ns
Tomato	s	s	s	ns	s	ns	s	ns

Braodbean 1998	s	s	s	s	s	ns	s	ns
Chickpea	s	–	s	–	s	–	s	–
Lentil	s	–	s	–	s	–	s	–

s: significant; ns: non-significant

The evapotranspiration of durum wheat, potato, sunflower and sugar beet also was lower on clay than on loam, corresponding with the texture effect on pre-dawn leaf water potential, stomatal conductance and leaf area. Maize, soybean and tomato did not show a significant difference in evapotranspiration between both soils, also corresponding with the observations on pre-dawn leaf water potential, stomatal conductance and leaf area, that did not show significant difference or, for maize, only a slight difference. The evapotranspiration of broadbean was higher on clay than on loam, but as mentioned above, the crop on loam was harvested before full maturity.

SALT TOLERANCE CLASSIFICATION

Crop classification according to soil salinity

The method consists of determining the relationship between soil salinity and relative yield, the latter being the ratio between the yields under saline and non-saline conditions, the other growth conditions remaining the same. Maas and Hoffman (1977) proposed the following equation to express the relationship between soil salinity and relative yield:

$$y = 100 - b(EC_e - a) \qquad (1)$$

where y is the relative yield, ECe the electrical conductivity of the saturated paste (dS/m), a the threshold value of ECe (dS/m), and b is the slope, expressing percentage yield depression per dS/m.

The result of the linear regression analysis of the relationship between relative yield and salinity for the crops grown during the experiment is presented in Fig. 9 and Table 9, the latter also presenting the values published by Ayers andWestcot (1985) according to Maas and Hoffman (1977) and the values obtained from the water quality test at the Cherfech experimental station in Tunesia (UNESCO, 1970). The regression analysis is based on the four observations of the saline treatments and did not include the relative yields of 100 with the corresponding ECe of 0.8 dS/m in order to avoid the effect of the non-saline treatments on the threshold value and the slope.

Differences between the three sources can be attributed to variety and weather conditions. Letey and Dinar (1986) mentioned a personal communication of Maas that in more recent studies lower values for the threshold and the slope of sugar beet were found. The large differences in the case of soybean are due to differences in variety. Four varieties were grown on the water quality test, two of which (Flora, Violetta) were moderately salt sensitive and two (Amsoy, Chipewa) sensitive. Several authors (Abel and Mackenzie, 1964; Velagaleti and Schweitzer, 1993) already mentioned the large differences in salt tolerance of soybean.

Fig. 10 shows an example of the effect of weather conditions on the threshold value by comparing the relationship between the yield of broadbean and soil salinity obtained in 1998 and the one obtained in 1990. The spring of 1998 was cold and the evapotranspiration during April and May attained 3–5 mm per day, whereas the spring of 1990 was exceptionally warm and the evapotranspiration in April and May attained 10–11 mm per day. Apparently in a period of high

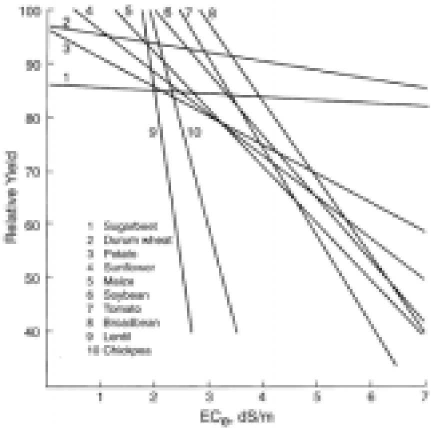

Fig. 9. Relative yield vs. soil salinity

Table 9. Threshold EC_e (dS/m) and slope (percentage yield reduction per dS/m) according to the regression analysis of the saline treatments, the corresponding values published by Mass and Hoffman and those obtained from a water quality test in Tunisia temperature a crop is more sensitive to salinity due to the high evaporative demand. The relationships obtained by Maas and Hoffman and Tunisia correspond more or less with the one obtained in 1998.

Crop	Lysimeter experiment		Mass and Hoffman		Water quality test	
	EC_e	b	EC_e	b	EC_e	b
Sugar beet	0.0	00.4	7.0	05.9	>6.5	–
Durum wheat	0.0	01.9	5.7	03.8	–	–
Potato	0.0	05.6	1.7	12.0	–	–
Sunflower	0.5	08.7	–	–	–	–
Maize	1.3	10.5	1.7	12.0	01.8	11.9
Soybean	2.0	11.4	5.0	20.0	01.7	11.2–23.5
Tomato	2.4	16.4	2.5	09.9	01.8	12.7
Broadbean, 1998	2.8	14.4	1.6	09.6	02.5	08.9
Chickpea	1.9	37	–	–	–	–
Lentil	1.7	62	–	–	–	–

A statistical analysis of the regression lines of the crops grown during the lysimeter experiment distinguished three groups:

- the salt tolerant group: sugar beet, wheat;
- the moderately salt sensitive group: potato, sunflower, maize, soybean, tomato, broadbean;
- the salt sensitive group: chickpea, lentil.

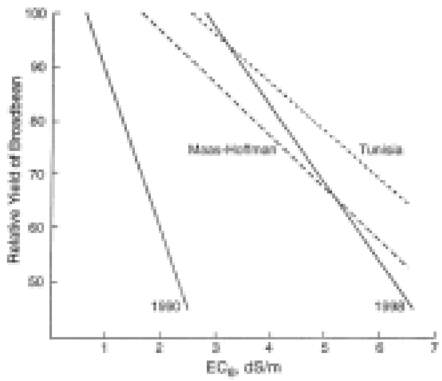

Fig. 10. Relative yield of broadbean vs. soil salinity

The analysis confirms the classification of Maas and Hoffman, excepted for soybean, classified as moderately tolerant, and the not mentioned crops chickpea and lentil.

Crop classification according to evapotranspiration deficit

Stewart *et al*. (1977) showed that the relation between yield and evapotranspiration of maize is the same in case of drought and salinity. Shalhevet (1994) appears to generalize this result for other crops, assuming a common relationship between yield and evapotranspiration, independent of whether changes in the two variables are caused by drought or salinity, but no information on other crops was available to check this hypothesis.

According to the theory of De Wit (1958) crop yield is a linear function of crop transpiration. The equation mostly used for yield prediction from evapotranspiration is the one proposed by Stewart and Hagan (1973):

$$y_a = y_m - y_m K_y \frac{ET_m - ET_a}{ET_m} \quad (2)$$

where ya is the actual crop yield, ym the maximum crop yield under the same growing conditions, Ky the crop coefficient, ETa the actual evapotranspiration, and ETm the maximum evapotranspiration.

Using as crop coefficients for maize, sunflower, potato and soybean, respectively 1.25, 0.95, 1.1 and 0.85, as determined by Doorenbos and Kassam (1979), the yields of the saline treatments of the lysimeter experiment were calculated from the measured yield of the control treatment and the observed evapotranspiration of the control and the saline treatments. Fig. 11a and b shows the comparison between the calculated and measured yields. The statistical analysis (Katerji *et al*., 1998a) showed a good correspondence between the predicted and measured yields for maize, sunflower and potato, but the accuracy of the yield prediction for soybean was not satisfactory. The particular behavior of soybean could be ascribed to:

- the large difference in salt tolerance between soybean varieties, already mentioned in Section 5.1;
- the salinity effect on the nitrogen supply from rhizobium bacteria (Bernstein and Ogata, 1966; Tu, 1981).

The results obtained on maize confirm the conclusions of Stewart *et al*. (1977) and Shalhevet (1994) who admit a common relationship between yield and evapotranspiration, independent of whether changes in the two variables are caused by drought or salinity. The results obtained on soya contradict the results of Shalhevet and Hsiao (1986) on cotton and pepper, who observed that plants under saline conditions present at the same soil water potential a better growth than plants under drought. They attributed this difference to osmotic adjustment.

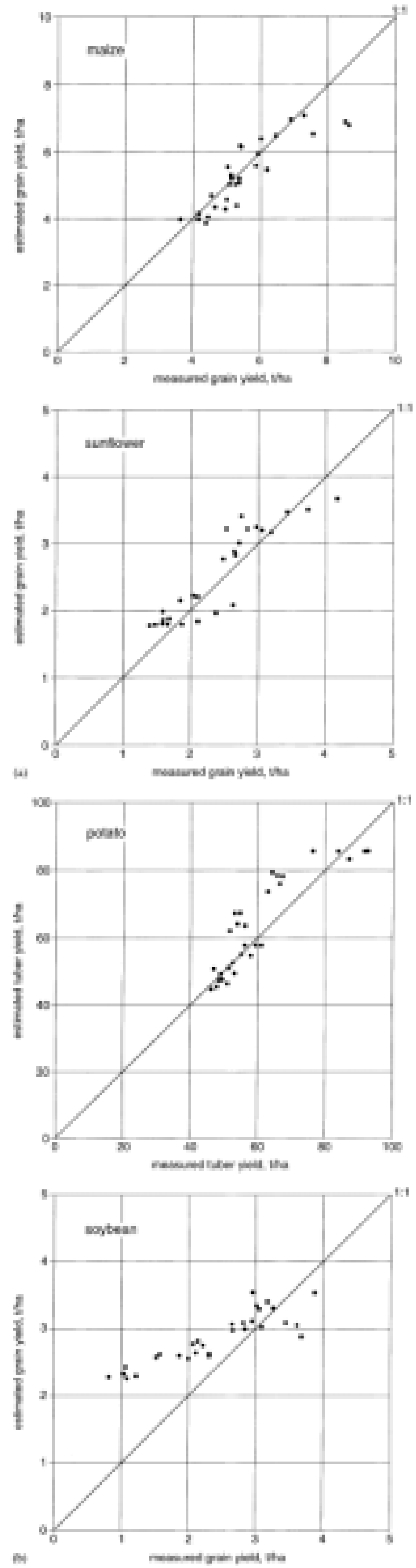

Fig. 11. Measured yield vs. yield estimated with Eq. (2)

Eq. (2) can also be used for crop classification according to evapotranspiration deficit, when written as relation between relative yield decrease and relative evapotranspiration deficit, proposed by Stewart *et al*. (1977):

$$1 - \frac{y_a}{y_m} = b\left(1 - \frac{ET_a}{ET_m}\right) \qquad (3)$$

According to Eq. (3), the higher the slope coefficient b, the stronger the drought effect, the relative yield decrease at equal evapotranspiration deficit. Doorenbos and Kassam (1979) classified in this way crops in four groups from drought tolerant to drought sensitive. Fig. 12 shows the result of the linear regression analysis for the crops of the lysimeter experiment. For lentil, the average values of both varieties were used, whereas for chickpea only the variety FLIP 87-59 was used, the other variety showing a particular behavior (Katerji *et al*., 2001b). Four groups with a different slope can be distinguished:

- durum wheat (slope 0.6);
- maize, chickpea, sunflower, sugar beet, potato (slope 1.3);
- soybean, broadbean, tomato (slope 2.3);
- lentil (slope 4.2).

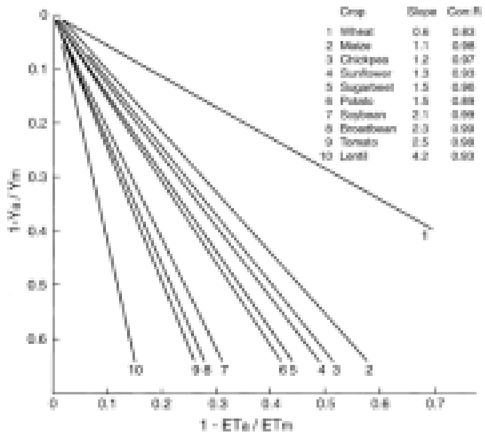

Fig. 12. Relative yield decrease vs. relative evapotranspiration deficit

The slope coefficients of crops of the same group do not differ significantly, but show a significant difference with the slope coefficients of the other crops. In contrast with the classification according to soil salinity, that indicates durum wheat and sugar beet both as salt tolerant and chickpea and lentil as salt sensitive, the classification according to the evapotranspiration deficit puts sugar beet and chickpea together with maize, sunflower and potato, still making a distinction with soybean, broadbean and tomato and indicating lentil as sensitive. Apparently the evapotranspiration deficit does not give a satisfactory classification for salt tolerance. Stegman (1985) mentioned that the slope coefficient is sensitive to climate conditions, e.g. an increase with decreasing air humidity, and the slope coefficient is also sensitive to the leaf area index (Katerji *et al*., 1991).

Crop classification according to water stress day index

Salinity affects the plant through the reduced water availability and increased water stress, which is reflected by the leaf water potential. The concept of the water stress day index (WSDI) provides a quantitative method for determining the stress imposed on a crop during its growing season (Hiler and Clark, 1971). The use of this concept in irrigation scheduling was discussed in detail by Hiler and Howell (1983). Hiler *et al*. (1974) and Katerji (1997) reviewed the methods characterizing the water stress of the plant and their accuracy. In practice, the use of the WSDI concept remains limited, the main reason being the lack of a simple and sufficiently sensitive method to characterize crop water stress.

To compare crop salt tolerance, the crop water stress is determined by measuring simultaneously the pre-dawn leaf water potential of the plant on the saline and non-saline treatments. This choice is justified for the following reasons.

- The pre-dawn leaf water potential expresses the equilibrium between soil water potential and leaf water potential of the plant, when the plant has covered its need for water after the moisture loss of the previous day (Katerji and Hallaire, 1984).
- This parameter is measured at dawn and is not affected by the change in meteorological conditions during the day (radiation etc.) which affect other parameters such as the stomatal conductance and the leaf temperature (Katerji *et al*., 1997).
- The pre-dawn leaf water potential is significantly affected by soil salinity, as was shown in Table 4.
- The difference in pre-dawn leaf water potential, used to calculate WSDI, only depends on soil salinity, excluding the evaporative demand of the environment and the irrigation regime, which are the same for all treatments.

The method is based on the hypothesis that crop salt tolerance is experimentally determined as the fractional yield reduction resulting from water deficit imposed on a crop during its growing season. The relationship between relative yield and water stress is expressed in the following way:

$$Y = a - b \times WSDI \tag{4}$$

with

$$WSDI = \sum_{1}^{n} \frac{\psi_c - \psi_s}{n} \tag{5}$$

in which cc is the daily value of the pre-dawn leaf water potential of the control treatment, irrigated with fresh water, from the start of leaf growth until the start of senescence, cs the equivalent of the saline treatment, n the number of days from the start of leaf growth until the start of senescence, b the yield loss in percentage per unit increase of WSDI, and a the value of the ordinate, which should be around 100. Because c is negative, WSDI positive.

The WSDI, as defined above, only translates a salinity effect and no drought effect, because it is based on a difference in pre-dawn leaf water potential between non-saline and saline treatments under equal environmental conditions of evaporative demand and irrigation regime.

Fig. 13 presents the relationship between relative yield and water stress day index. According to the linear regression analysis two groups can be distinguished: the first group comprising durum wheat, maize, potato, sunflower and sugar beet, of which the slopes do not differ significantly but show a significant or highly significant difference with the second group comprising broadbean, soybean, tomato lentil and chickpea.

In comparison with the classification based on soil salinity, the classification according to the water stress day index also includes maize, sunflower and potato in the tolerant group and does not distinguish between broadbean, soybean and tomato on one hand and chickpea and lentil on the other hand in the sensitive group. So, the first question is why durum wheat and sugar beet are classified in the same group as maize, sunflower and potato. Wheat and sugar beet are grown during a cooler period of the year, when the evaporative demand is lower than during the warmer period when maize and sunflower are grown. The classification based on the water stress day index, indicating maize and sunflower just as salt tolerant as wheat and sugar beet, excludes the effect of the evaporative demand and means that, if these crops could be grown during the same season, they would show the same salt tolerance. The classification based on soil salinity, indicating maize and sunflower as moderately sensitive, includes the reality that these crops are grown during a period of high evaporative demand and are for that reason more salt sensitive.

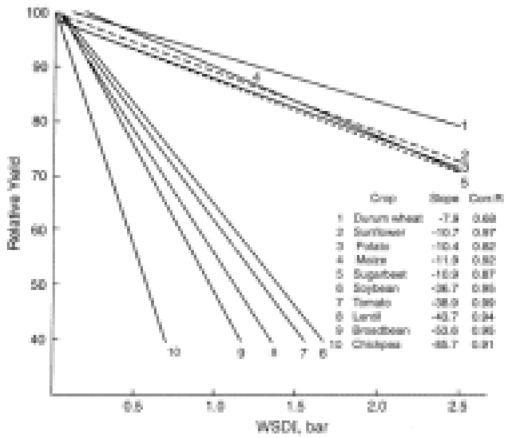

Fig. 13. Relative yield decrease vs. water stress day index

Potato is grown during the same period as sugar beet, but, unlike wheat and sugar beet, it is a shallow rooting crop. The limited capacity of potato to exploit the water-holding capacity of the soil could explain its salt sensitivity.

The second question regards the sensitive group. Broadbean, chickpea and lentil are winter crops, soybean and tomato are summer crops. Their sensitivity does not seem to be linked with the season of the year. All crops of the sensitive group are crops of indeterminate flowering. The flowering period lasts longer in comparison with crops having a determinate flowering. Several studies (Salter and Goode, 1967, Mouhouche *et al*., 1998) indicate a maximum sensitivity during flowering. The effect of water stress during this period can be attributed to several causes.

- The reduction of the number of flowers, caused by a decrease of dry matter growth (Meynard and Sebillotte, 1994) or by a disturbance of the nitrogen uptake (Jeuffroy and Sebillotte, 1997), observed during water stress.
- The disturbance of pollination and fecundation. According to several authors (Sioni and Kramer, 1977; Westgate and Boyer, 1985) the fecundation is particularly affected by water stress.

So, the longer flowering period, a common characteristic of the five crops, could be a cause of their greater sensitivity to water stress.

Water use efficiency, osmotic adjustment and leaf area

Table 10 presents the soil salinity, expressed as ECe, the relative yield, the relative evapotranspiration and the water use efficiency of the crops. For the eight crops grown from 1989 to 1998, the values are the averages obtained on loam and clay, for lentil the average of both varieties, whereas for chickpea only the variety FLIP 87-59 was used. Two groups can be distinguished, corresponding with the classification according to the water stress day index:

- the group of which the water use efficiency is not affected by salinity and remains more or less constant: durum wheat, potato, maize, sunflower, sugar beets;
- the group of which the water use efficiency clearly decreases with increasing salinity: tomato, soybean, broadbean, chickpea and lentil.

Table 10 shows that the decrease of the water use efficiency results from the yield decrease being stronger than the decrease of evapotranspiration. Apparently, the grain and fruit formation of the second group is stronger affected than the evapotranspiration, indicating that the factors affecting the transpiration (stomatal conductance and adaptation by osmotic adjustment, leaf area) are not determining salt tolerance.

Table 10. ECe relatively yield, relative evapotranspiration and water use effeciency of crops grown during the lysimeter experiment

Crop	EC_e (dS/m)	Yield (%)	ET (%)	WUE (kg/m)	WUE (%)
Durum wheat	0.8	100	100	1.04	100
	2.3	095	090	1.10	106
	4.6	086	080	1.12	107
Potato	0.8	100	100	18.5	100
	2.6	081	091	16.3	088
	4.7	073	081	16.2	088
Maize	0.8	100	100	0.98	100
	1.9	094	090	1.03	105
	3.4	077	080	0.95	097
Sunflower	0.8	100	100	0.21	100
	2.4	086	088	0.20	097
	3.9	073	081	0.19	091
Sugar beet	0.8	100	100	7.0	100
	3.5	085	089	6.7	096
	6.1	083	089	6.6	094
Tomato	0.8	100	100	8.3	100
	4.3	073	091	6.6	080
	5.9	041	077	4.4	053
Soybean	0.8	100	100	0.77	100
	4.0	080	088	0.70	091
	6.7	044	072	0.47	061
Broadbean	0.8	100	100	1.37	100
	4.6	077	088	1.21	088
	6.1	049	078	0.86	063
Lentil	0.7	100	100	2.09	100
	2.0	081	091	1.78	085
	3.2	06	081	0.36	17
Chickpea	0.8	100	100	0.81	100
Variety 87-59C	2.4	057	064	0.73	090
	3.8	031	046	0.54	067

In Section 3.2, several examples of osmotic adjustment were presented that showed a different behavior in adjustment to salinity and its effect on stomatal conductance. The osmotic adjustment of sugar beet and lentil are the same (Table 5), whereas chickpea, classified in the same, sensitive group as lentil, shows a much lower value. Tomato and broadbean show the same osmotic adjustment but behave differently with respect to its effect on stomatal conductance, as shown in Figs. 5 and 6. At least for these five crops, it is not possible to use the osmotic adjustment as a criterion for explaining differences in salt tolerance.

Plants show a different salinity effect on leaf area. As already mentioned before, maize, soybean and tomato showed a leaf area reduction of about 10%, whereas the reduction was 20–50% for the other crops. The salinity effect on leaf area does not appear to be correlated with the plant's aptitude for osmotic adjustment. The leaf areas of sugar beet and broadbean, differing considerably in osmotic adjustment, are both strongly affected, whereas this is not the case for tomato. The leaf areas of chickpea and lentil are both strongly affected, whereas the crops differ strongly in their osmotic adjustment. Table 11 compares the salinity effect on leaf area and the crop classifications according to soil salinity and water stress day index. No relation appears between the salinity effects on leaf area and yield. Observations of leaf area of salt affected crops are not reliable for yield prediction.

Salt tolerance of grain legumes

If crops are classified according to the water stress day index, tomato, soybean, broadbean, lentil and chickpea belong to the same, sensitive group. Still these crops show considerable difference among themselves if classified according to soil salinity. Soybean is classified by Maas and Hoffman (1977) as moderately salt tolerant, but did not differ significantly in the lysimeter experiment from broadbean, classified as moderately sensitive by the same authors. This may be attributed to a difference in variety. Both crops, however, differ significantly from chickpea and lentil, as shown in Fig. 9.

Table 11. Salinity effect on leaf area and crop classification according to soil salinity and water stress day index (WSDI)

Crop	Leaf area		Crop classification				
	Slight	Strong	Soil salinity			WSDI	
			Tolerant	Moderate	Sensitive	Tolerant	Sensitive
Durum wheat		x	x			x	
Sugar beet		x	x			x	
Potato		x		x		x	
Maize	x			x		x	
Sunflower		x		x		x	
Tomato	x			x			x
Soybean	x			x			x
Broadbean		x		x			x
Lentil		x			x		x
Chickpea		x			x		x

To determine the salinity effect on the nitrogen uptake of the four grain legumes, the nitrogen concentration of the aerial parts was analyzed and the nitrogen uptake of the crop was calculated. The difference between the nitrogen uptake and the input from fertilizer and irrigation minus drainage water yielded the biological nitrogen contribution of the soil, comprising together the nitrogen fixation and the transformation of organic matter.

Table 12. Effect of soil salinity on relative biological nitrogen contribution of the soil

Soybean		Broadbean		Chickpea		Lentil	
EC_e (dS/m)	N (%)	EC_e (dS/m)	N (%)	EC_e (dS/m)	N (%)	EC_e (dS/m)	N (%)
0.8	100	0.8	100	0.8	100	0.7	100
4.0	077	4.6	056	2.4	045	2.0	045
6.7	028	6.1	015	3.8	024	3.2	000

Salinity did not affect the nitrogen concentration of the shoots and pods of soybean and chickpea, but the shoots and pods of broadbean and lentil showed a decrease of the nitrogen concentration at increasing salinity. Not only the total nitrogen uptake of the crop decreased at increasing salinity—not astonishing in view of the yield decrease—but also the biological nitrogen contribution of the soil. Table 12 shows this decrease and that it already starts at a lower salinity level for chickpea and lentil. At an ECe between 3 and 4 dS/m chickpea and lentil present much lower values for the nitrogen contribution than soybean and broadbean. Apparently, the difference in salt tolerance between the grain legumes is caused by a difference in nitrogen fixation and the symbiosis between rhizobia and plant is more salt sensitive in the case of chickpea and lentil.

APPLICATION IN MODELING CROP RESPONSE TO SALINITY

For simulating the effect of water deficit on plant growth, crop response models generally use stress coefficients that depend on the soil water status and are calculated from the soil water balance. Salinity affects the availability of soil water due to its osmotic potential component. Simply adding the osmotic potential and the soil matrix potential does not give an accurate expression of the water availability for the plant. Since the predawn leaf water potential is a reliable indicator of the plant water status, this parameter can be used for expressing the water stress instead of a soil water based stress coefficient.

This principle was applied in the modification of the CERES- Maize model (Castrignano *et al*., 1998). The pre-dawn leaf water potential was introduced for the calculation of the stress coefficient and the modified model was tested with data obtained from the maize crop grown during the lysimeter experiment. Reasonable agreement was found between model predictions and measured data of evapotranspiration, leaf area index, biomass and grain yield.

Conclusions

The pre-dawn leaf water potential is a useful parameter for indicating plant water stress caused by salinity. Crops show a lower pre-dawn leaf water potential at increasing salinity. When used for salt tolerance classification of crops, the pre-dawn leaf water potential, expressed as water stress day index during the growing period, distinguishes a tolerant group, comprising durum wheat, sugar beet, maize, sunflower and potato, and a sensitive group, comprising tomato, soybean, broadbean, chickpea and lentil. The tolerant crops show a more or less constant water use efficiency at increasing salinity. The sensitive crops show a decrease of the water use efficiency, as their yield decreases stronger than the evapotranspiration. This indicates that the factors affecting the transpiration are not determining salt tolerance. Indeed no correlation could be found between osmotic adjustment, leaf area and yield reduction. As the flowering period is a sensitive period for grain and fruit formation and the sensitive crops are all of indeterminate flowering, their longer flowering period could be a cause of their greater sensitivity.

The tolerant group, when classified according to soil salinity, can still be divided in a salt tolerant group, comprising wheat and sugar beet, and a moderately sensitive group, comprising maize, sunflower and potato. The difference in classification can be attributed to the difference in evaporative demand during the growing period.

The sensitive group, when classified according to soil salinity, can be divided in a moderately sensitive group, comprising tomato, soybean and broadbean, and a salt sensitive group, comprising chickpea and lentil. The difference in classification can be attributed to the salinity effect on the biological nitrogen contribution of the soil, reflecting the greater sensitivity of the symbiosis between rhizobia and grain legume in the case of chickpea and lentil.

The combination of both classifications leads to better understanding of the salinity effect on crops. The salt tolerance classification according to soil salinity is necessary for practical purposes.

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DOMESTIC WASTEWATER TREATMENT AND AGRICULTURAL REUSE IN DRARGA, MOROCCO

R. Choukr-Allah*, A. Thor and P. E. Young
* Salinity and plant nutrition laboratory I.A.V Hassan II Agadir, Morocco BP 773
E-mail: ch.redouane@wanadoo.net.ma

SUMMARY - The Municipality of Drarga is located in a semi-arid region near the coast in southwest Morocco. Although the town is located in the Souss River Valley, the river is dry for much of the year and most water for the area is conveyed from the mountains by a network of dirt canals (seguias). Additional water resources for the area have been exhausted due to the construction of Abdelmoumen Dam, a recent drought, migration into the region following electrification, and excessive use of groundwater. At the initiation of the project, the wastewater generated the town was discharged untreated leading to the development of a large cesspool, where it percolated into the soil or evaporated. As part of he Water Resources Sustainability (WRS) project jointly funded by the United States Agency for International Development (USAID) and the Moroccan Ministry of the Environment, a wastewater treatment facility and water reuse system for the area are being developed. At capacity, the wastewater treatment facility will serve an estimated 17,600 people the Municipality of Drarga. The wastewater treatment facility includes influent screening, grit removal, anaerobic lagoons, denitrification lagoons, and flow holding basins. The effluent from the wastewater treatment facility will be passed through recirculating sand filters and reed beds (man-made constructed wetlands) to further reduce solids, organics, pathogens, and nitrogen to World Health Organization WHO) standards for unrestricted agricultural irrigation water. No chemicals or complex mechanical equipment are required in the process. The effluent from the wastewater treatment facility will be stored on-site in lined basins and pumped to local farms for as irrigation water. Crops grown in the local area include alfalfa, clover, corn, bananas and vegetables. The wastewater treatment facility will receive income from the sale of the irrigation water, the sale of reeds and the sale of composted sludge.

Key words: Morocco, USAID, wastewater treatment, water reclamation, water reuse, agricultural reuse, intermittent sand filters, recirculating sand filters, anaerobic lagoons, biogas utilization, reed beds, biological nitrogen removal, fecal coliform removal

SITE SELECTION AND COMMUNITY INVOLVEMENT

The Municipality of Drarga is a rapidly expanding town with an efficient central planning organization. Two large housi1r developments financed by ERAC-Sud are under construction within district limits. The entire town has been electrified, and a w distribution system serves most of the town. In addition, the town has a sewage collection system that covers about 80% of the town's population. The Al-Amal water users association provides the water and sewage services. This organization is headed by a board of directors elected by the citizens of the town. The organization operates two chlorinated drinking water wells, a 60 m^3 water tower, the water distribution network, and the sewage collection system. The water use at each household connection is metered, and the customers pay the quarterly for the amount of water used, in addition to a flat connection fee. The Al-Amal association was interested in the construction of a wastewater treatment facility and indicated a willingness to operate and maintain the facility.

Current discharges of untreated wastewater in the town of Drarga pollute ground water, emit unpleasant odors, and are a threat to public health . Wastewater from the town of Drarga is drained through four drainage or outfall sewers coming from (1) Iguidar and Ikiou; (2) Drarga Centre, eastern part; (3) Drarga Centre, western part; and (4) Talat Izem. Those outfall sewers take the wastewater directly to undeveloped areas, which in some cases are only a few meters from residential areas (outfall 3 and 4). The wastewater accumulates in ponds (particularly for discharge points 1 and 2), and a part of it infiltrates into the ground. These ponds promote the development of parasites and insects and give off unpleasant odors. In addition, nitrogen in the wastewater was identified as a contributor to the high nitrate concentrations in the local groundwater (although agriculture is the primary contributor).

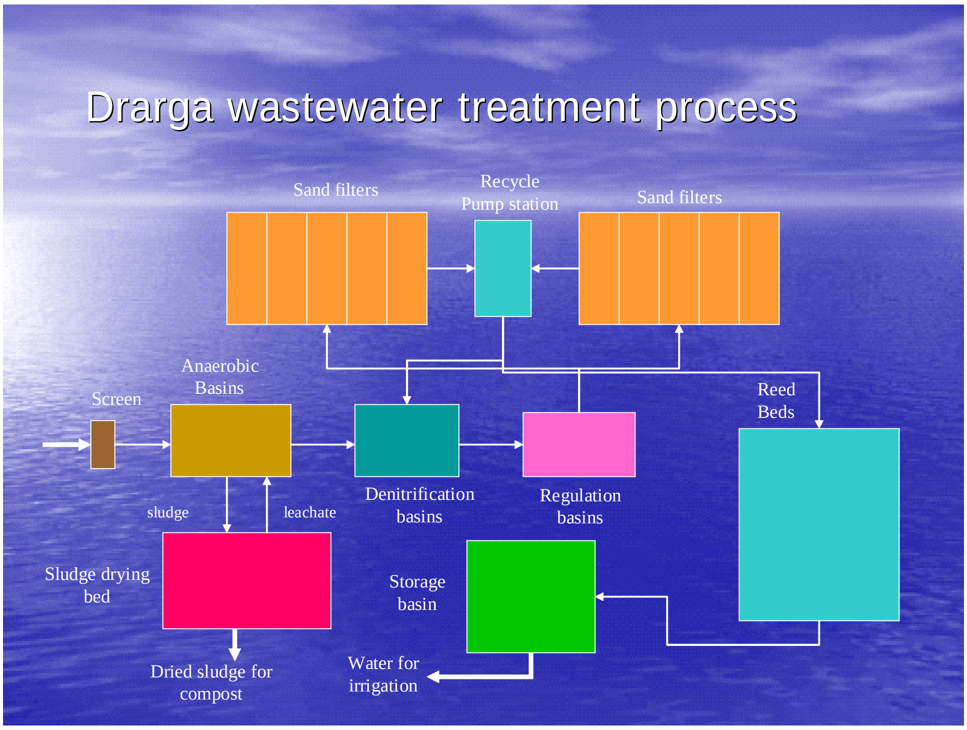
As the first step in the project development, potential sites for the treatment plant were identified and compared. The main evaluation criteria for the selection of the site were as follows:

1. Distance between the site and the population center (impact of odors)
2. Ownership of the site (private or public land)
3. Access to the site
4. Conveyance to the site of untreated wastewater
5. Topography and geology of the site
6. Risks of flooding
7. Risks of polluting groundwater
8. Proximity to users of treated wastewater
9. Room for future expansion

Based on these criteria, four potential sites were established and evaluated. The most favorable site was selected and acquired by the municipality.

WASTEWATER TREATMENT PROCESS DESCRIPTION

Although the treatment plant, designed to meet the year 2020 wastewater flow, during the initial stage of the project, only the facilities necessary to meet the year 2010 design flow are being constructed. Two supplementary projects were also required to implement the wastewater treatment process; construction of flood protection improvements along the Oued Irhzer El Arba (which is subject to seasonal flooding) and extension of the existing sewer system from the four current outfall points to the treatment plant site. A step-by-step description of the treatment plant components follows.



Bypass Chamber: The bypass chamber is the first structure in the wastewater treatment plant. Normally, all of the wastewater flow generated by the Municipality will be treated at the plant. However, during heavy rain events, a large quantity of rainwater May enter the collection sewer system through inflow and infiltration. This rainwater will dilute the strength of the sewage, but it will also increase the quantity of sewage above what the treatment plant is capable of handling. During such periods, the treatment plant will continue to function at full hydraulic capacity, while any additional flow will bypass to the intermediate pump station from where the combined raw sewage and recirculating sand filter effluent will be pumped into the Oued Irhzer El Arba. It is anticipated that this situation will occur very infrequently, and when it does the Oued Irhzer El Arba will be flowing with water which will further dilute the bypassed sewage.

Screening: The first step of the treatment process is to remove large floating and suspended solids, rags, rocks, debris, and other large objects from the influent wastewater. These objects will be captured in the manually cleaned influent bar screen located immediately downstream of the bypass chamber. Influent screening is important because large solids and rags could potentially clog downstream pumps, pipes, and valves if not removed at this time.

Grit Removal: The next step of the treatment process is grit removal, which occurs in two parallel grit removal chambers. Dense solids such as sand or bone fragments will settle to the bottom of this chamber, from which they must be shovelled out by hand. A proportional weir at the end of each chamber maintains a constant flow velocity through the chamber. This constant velocity ensures that biodegradable organic solids, which are typically less dense than grit, will not settle inadvertently in the grit removal chamber.

Flow Distribution: There are three flow distribution boxes in the plant: Flow Distribution Box No.1, Flow Distribution Box No.2, and the Nitrate Recycle Flow Distribution Box. These boxes are used to spilt the wastewater flow evenly between all process tanks on line by flow over equal length sharp-crested weirs set at the same height.

In addition, the Nitrate Recycle Flow Distribution Box allows the RSF effluent pumped from the intermediate pump station to be distributed proportionally between the denitrification lagoons and the reed beds. By using stop plates to cover some of these weirs, the operators can achieve a 3:1, 2.4:1, 1.8:1, 1.2:1, or 0.6:1 ratio of nitrate recycle to plant influent. The design nitrate recycle ratio is 2.4 for the year 2010 design and 1.8 for the year 2020 design. The ratio is lower for the future design condition because the nitrogen concentration in the plant influent is expected to decrease with modernization of the area (see Development of Design Criteria, above) .

Anaerobic Lagoons: The purpose of the anaerobic lagoons is to remove COD present in the influent wastewater through anaerobic biological decomposition. At the same time, suspended solids presenting the influent wastewater and the bacteria that grow as a result of the anaerobic activity will settle to the bottom of the lagoon. There are two anaerobic lagoons in the year 2010 design. A third lagoon will be added in the future expansion to the year 2020 design flow. Each lagoon has a volume of 918 m^3 and the units combine to provide a 3.0 day hydraulic detention time (HRT) for the year 2010 design flow, and a 2.3 day HRT for the year 2020 design flow. The anaerobic biological decomposition process generates methane gas and carbon dioxide as a by-product. Floating covers over the lagoon capture this gas. Collection piping carries the gas to a 16 kW engine generator, which converts the energy in the methane gas into electricity .The electricity, can be used to power the operator's house, laboratory, and selected pumps. Submersible sludge pumps in the bottom of the lagoon can be used to pump the sludge out of the lagoon onto the sludge drying beds for dewatering.

Denitrification Lagoons: The purpose of the denitrification lagoons is to remove oxidized nitrogen (nitrate and nitrite) by the biological process of denitrification. Heterotrophic bacteria operating in an anoxic environment carry out this process. The bacteria require a carbon source to carry out the denitrification process. The carbon source in this application is the COD present in the anaerobic lagoon effluent wastewater. Additional COD can be supplied by directly bypassing a portion of the influent wastewater from Flow Distribution Box No.1 around the anaerobic lagoons. The effluent from the anaerobic lagoons contains most of the nitrogen present in the form of TKN. Therefore, a portion of the effluent from the RSFs (in which the nitrification process has converted ammonia into oxidized nitrogen) must be recycled back to the denitrification lagoons. The Nitrate Recycle Flow Distribution Box accomplishes this. Like the anaerobic lagoons, the denitrification lagoons contain submersible sludge pumps that can be used to pump settled solids out of the lagoons and onto a sludge drying bed for dewatering. There are two denitrification lagoons in the year 2010 design. A third lagoon will be added in the future expansion to the year 2020 design flow. Each lagoon has a volume of 736 m^3

and the units combine to provide a 2.4 day nominal HRT for the year 2010 design flow, and a 1.9 day nominal HRT for the year 2020 design flow.

Flow Holding Basin: The purpose of the flow-holding basin is to store the effluent from the denitrification lagoons until it is time to dose the next sand filter. The sand filters are dosed three time per day, so the combined volume of the flow holding basins are equal to one-third of the total volume of influent flow and nitrate recycle flow for one day. At pre-set intervals during the day, the operators will manually open the sluice gate at the end of the flow holding basin, releasing the contents of the basin to the RSFs. There will be relatively few solids present in the flow leaving the denitrification lagoons, but some additional solids may settle out in the flow holding basins and can be removed periodically by draining the foot of the basin into the recycle pump station. There are two flow-holding basins in the year 2010 design. A third basin wi11 added in the future expansion to the year 2020 design flow. Bach basin has a volume of 360 m^3.

Recirculating Sand Filters: The primary purpose of the recirculating sand filters (RSFs) is nitrification (the biological process by which ammonia is converted to nitrate by autotrophic bacteria under aerobic conditions). Additional reduction of BOD and some degree of denitrification will also take place in the RSFs. The denitrification is possible in portions of the RSF, which do not receive adequate oxygen.

The primary source of oxygen in the RSFs is diffusion of oxygen into the upper layers of the sand from the air. Frequent "tilling" of the sand on the surface enhances this effect. The tilling process involves turning the top few centimeters of sand to expose the bacteria growing on the sand grains to the surface air. The tilling process also breaks up the hard pan of solids and algae that tends to build up on the RSF surface over time. Some oxygen will also enter the bottom of the RSF through the open underdrains. There are ten RSFs built for the Year 2010 design flow. An addition four RSFs will be constructed for the year 2020 design flow. Two RSFs will be dosed at a time for the Year 2010 design, and three at time for the year 2020 design. Each RSF has a surface area of 1560 m^2 and at the design dosing rate of 360 m^3 per sand filter, the hydraulic loading will be 230 mm per dose. Each RSF is dosed once every five dosing period. There are three dosing periods each day. In each dosing period, the slide gate at the end of both flow holding basins is opened, sending a rush of stored wastewater onto the surface of two of the RSFs. The flow of wastewater onto the RSF surface is faster than the liquid can percolate through the sand, so the liquid ponds on top of the sand surface. The ponding results in an even depth of wastewater over the entire RSF surface., which in turn, ensures an even distribution of flow across all parts of the RSF. Over the next several hours , the ponded water percolates through the sand particles, where attached bacteria carry out the nitrification process.

INTERMEDIATE PUMP STATION

The effluent from the RSFs drains into the intermediate pump station. The maximum water level in the intermediate pump station must be kept below the bottom of the RSFs to allow the RSFs to drain completely. Due to the great depth below the ground water surface at this point, submersible wastewater pumps are used to lift the wastewater back up to the surface level. These pumps serve a dual purpose as they also return a portion of the RSF effluent back to the front end of the denetrification lagoons to serve as a source of nitrates for the denitrification process. The intermediate pump station has a large volume so that it can act as a flow equalization point. Even through liquid exits the RSFs at an inconsistent rate (due to the periodic loading method), the RSF effluent flow will be equalized in the intermediate pump station and (when properly adjusted) the pumps will operate at a constant rate throughout the 24-hour period.

Reed Beds: There are two reed beds, each about 2,900 m2 in area. These membrane-lined beds, which are subsurface irrigated with a constant water depth of 1.0 m, wil1 be planted with local varieties of fast. growing giant reeds (qchqlich and aghanim) in alternating rows. The primary purpose of the reed beds is to grow reeds that wil1 be harvested periodically and sold as a source of income for the plant. The reed beds wil1 also remove some nitrogen and other nutrients from the wastewater by uptake into the plants and by biological nutrient removal. This nitrogen removal, however, will be partially offset during many parts of the year by the loss of water through the basins due to evapotranspiration. Thus, although the nitrogen load (in kg/d) will decrease across the reed beds, the change of nitrogen concentration across the reed beds is highly dependent on the percentage of water loss across the reed beds. The concentration can increase or decrease.

Effluent Storage Ponds and Pump Station: There are two effluent storage ponds, each with a volume of 1,014 m3. The effluent flow storage ponds store treated effluent from the plant until the local farmers need it. The effluent pump station pumps treated plant effluent from the effluent flow storage ponds to the farmer' s fields for use as irrigation water. A flowmeter is used to measure the quantity of irrigation water delivered to the farmers. Irrigation water will be distributed among the eligible farmers through a piping distribution network. Valves will be installed at each farm parcel and controlled under the authority of a "gouadier" (according to the traditional rules of the region). Major crops to be developed include alfalfa, clover, corn, bananas, zucchini, pumpkin, cabbage, potato, and onion. Water may be allocated for cereal crops, such as wheat, during certain crucial growing periods (such as the ripening period). The reuse water wil1 provide a significant source of nutrients (nitrogen, phosphorus, and potassium) to the irrigated crops without excessive contribution of nitrates to the groundwater. Excess water which is not required by the farmers will overflow the storage ponds and into the adjacent Oued Irhzer El Arba.

Table1. P lant performance

Indicator	BOD5 (mg/l)	COD (mg/l)	TSS (mg/l)	NTK (mg/l)	Fecal Coliforms (mg/l)
Entrance	625	1825	651	319	6.3x106
Standard	<30	N/A	<30	N/A	103

Exit	10	75	3.9	10.2	<500

Sludge Drying Beds: The purpose of the sludge drying beds is to dewater sludge produced in the anaerobic lagoons and the denitrification lagoons. The liquid sludge is pumped from the bottom of the lagoons by submersible pumps and onto the surface of the sludge drying beds. The liquid portion of the sludge will evaporate into the atmosphere or drain through the sand in the drying beds into the underdrain below. The underdrain is piped back to the anaerobic lagoon effluent channel. The dried sludge must be removed with a small loader and disposed of or used for co-composting with municipal solid waste. The on-site municipal solid waste/wastewater sludge co-composting project is currently under design through a separately funded project.

There are five sources of nitrogen removal in this treatment system.

- Nitrogen contained in sludge removed from the anaerobic lagoons. .
- Nitrogen contained in sludge removed from the denitrification lagoons.
- Nitrates (from the RSF effluent) recycled in the nitrate recycle flow and denitrified in the denitrification lagoon.
- Ammonia nitrified (converted to nitrates) in the RSFs and immediately denitrified in anoxic regions of the same filter.
- Nitrogen contained in the harvested reeds.

At the same time, the nitrogen concentration through the treatment system is increased by water losses from the system through evaporation, transpiration, and plant uptake. The overal1 result is an antidpated reduction in the total nitrogen across the facility of 70% (in the year 2010) and 63% (in the year 2020).

Impacts of the project

Reduced water pollution

Tests conducted at the plant in 2000 show that the facility was , meeting the targets set for reducing water pollution in Drarga. Table 5 below shows the characteristics of raw wastewater generated by Drarga and the levels after the establishment of the treatment plant. The quantity of treated wastewater generated from the plant is around 400 m^3/day.

Increased Water savings

The treated wastewater fulfills the requirements of World Health Organisation category A, and therefore is suitable for reuse in agriculture without restriction. The WRS project increased farmers awareness on the use of treated wastewater for crop irrigation by developing demonstration plots using drip irrigation. The results of the demonstration plots convinced the farmers of the benefits of using treated water for irrigation. Crops that are irrigated with treated effluents in the demonstrations plots include cereals (wheat and maize), vegetables (tomatoes and zucchini), and forage crops (alfalfa and ray-grasses).

The farmers irrigating with treated water are benefiting in two ways. First, they have access to a guaranteed amount of low-priced water. In addition, they can economize on buying fertilizer since the treated wastewater already contains fertilizer elements needed by the crops. Table 2 summarizes the economic savings of water and
fertilizer for each crop. The total economic savings range from DH 2,222 per hectare for zucchini to DH 5,140 per hectare for maize.

Table 2 Economic saving from irrigating with treated wastewater

Cultivation	Neat Benefit on water	Benefit on fertilizers (2)	Total benefit

	(1) (Dh / year/inhab)	(Dh / year/inhab.)	(Dh / year/inhab)
Tender Wheat	750	1.492	2.242
Corn	1.588	3.614	5.202
Fodder corn	1.568	3.572	5.140
Clover)	774	1.539	2.313
Zucchini	677	1.545	2.222
Squash	611	1.216	1.827
Tomato	1.553	3.542	5.095

PUBLIC PARTICIPATION, INSTITUTIONAL PARTNERSHIP, AND COST RECOVERY

Public participation

The use of a participatory approach has been one of the r cornerstones of the implementation of the Drarga project. At the f beginning of the project, we did a survey on the attitudes of local people with respect to different types of water (bottled water, tap water, well water, and wastewater.) With town eiders, we retraced the history of the community and its relationship to water. We have worked closely with a local water users association that had provided potable water and a sewage network to the town. We have also helped create an association of users of treated water that distributes the treated water from the plant to local farmers.

We have consulted with the population of Drarga at each step of project development. We presented the results of the feasibility study at a stakeholder' s workshop to receive feedback on the technological options presented. We changed the location of the plant site after receiving objections from some inhabitants on the sites proposed in the feasibility study. We also consulted project partners during the environmental assessment and prior to the start of construction. This process of consultation has enabled the project to gain the support of beneficiaries for the project and to have their participation in implementation.

INSTITUTIONAL PARTNERSHIP

Another key element of the Drarga pilot project was the establishment of an institutional partnership. At the outset of the project, we created a local steering committee made up of all institutions involved with various aspects of water management at the local level (Wilaya of Agadir, RAMSA (Water Utility), ORMVA/SM (Irrigated Perimeter Authority), Regional Hydraulics Department, Commune of Drarga, Ministry of Environment, ONEP (Regional Potable Water Agency), Ministry of Health). The role of the steering committee was to follow each step in the implementation of the pilot project and to provide assistance, when necessary, based on their specific area of expertise. For example, the Department of Hydraulics conducted the hydrogeologic study of the site, the Ministry of Environment assisted with the environmental impact assessment, the Irrigated Perimeter Authority helped with the creation of the water users association.

In December 1998, a collective agreement was signed between the project partners that contribute directly to the pilot project. The purpose of the collective agreement is to clearly spell out the roles and responsibilities of each partner. The partners and their respective contributions are listed below:

- Wilaya of Agadir : Mobilizes local institutions and facilitates administrative procedures;
- WRS project : finances the building of the wastewater treatment plant, the reuse network, undertakes all technical studies, and provides technical assistance to the Commune of Drarga;
- Ministry of Environment supports WRS with the involvement of its staff in the studies conducted by WRS;
- ERAC-Sud : a local government housing development agency that ,has a large new development in Drarga finances the main collector to transport Drarga' s wastewater to the plant, the widening of Oued Laarba to provide flood control for the site, and compensation for non-titled farmers that were using the site; and

- The Commune of Drarga that manages the wastewater treatment plant and provides technical and financial reports to a technical oversight committee.

After the completion of construction, we set up the technical, oversight committee that acts as a watchdog over plant operations. The Commune of Drarga will provide quarterly technical and financial reports to the committee. The technical reports include results from sampling and analysis data collected at the site to ensure that the plants performance meets specific pollution abatement targets and that the water provided for reuse meets WHO standards. The financial reports include statements of expenses and revenues.

COST RECOVERY

The Drarga wastewater treatment and reuse project was conceived with cost recovery features in mind. In Morocco, nearly seventy percent of wastewater treatment plants are not functioning due to lack of spare parts and poor cost recovery .The Drarga project includes several cost recovery features. The plant itself generates a number of products that have a market value:

- Treated wastewater is sold to farmers for irrigation;
- Reeds from the reed beds are harvested and sold twice a year;
- Residual sludges from the anaerobic basins are pumped, dried, and combined with organic wastes from Drarga to produce compost;
- The methane gas from the anaerobic basins is recovered and converted to energy to run pumps at the plant, thereby reducing electricity costs.

In addition to the products from the plant, the Commune is committed to raise revenues to pay for the operations, maintenance, and replacement costs of the plant. These revenues include:

- An increase of 1 Dirham ($0.10) per cubic meter to the water and sewage tariff;
- An increase of 2,000 Dirhams ($150) to the one time sewage connection charge for new connections.

These revenues, combined with revenues from the plant are deposited into a special account that is independent of the Commune's general budget and is dedicated to the wastewater treatment plant. This account is further divided into two sub-accounts : (1) an operations account for current expenses, and (2) an extension and renewal account in which money is saved to pay for the replacement of equipment and the future expansion of the wastewater treatment plant.

The project provided the Commune of Drarga with a spreadsheet model to manage all financial aspects of the plant.

The WRS team assisted the Commune in the implementation of the cost recovery mechanisms for the Drarga plant. Activities implemented include the following:

- Opened a special account to manage the costs and revenues of the Drarga wastewater plant;
- Installed a new billing system for water and sewage at the plant, using a computer equipment and software package that wil1 enable the Commune of Drarga to track expenses and revenues of the wastewater treatment plant;
- Organized an association of treated wastewater users, who wi11 purchase the treated water from the Commune and therefore contribute to the payment of part of the operation and maintenance expenses of the plant.

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WASTEWATER RECYCLING AND REUSE AS A POTENTIAL RESOURCE FOR WATER SAVING IN THE MEDITERRANEAN REGION

R.Choukr-Allah
Salinity and plant nutrition laboratory I.A.V Hassan II Agadir, Morocco BP 773
E-mail: ch.redouane@wanadoo.net.ma

INTRODUCTION

Given current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025. The water-use efficiency techniques used with conventional resources have been improved. However, water-scarce countries will have to rely more on the use of non-conventional water resources to partly alleviate water scarcity. Such water resources are harnessed for agricultural and other uses through specialized processes such as desalination of seawater and highly brackish water; harvest of rainwater; collection, treatment, and use of wastewater; capture and reuse of agricultural drainage water; extraction of groundwater containing a variety of salts. Appropriate strategies for managing soil, water and crops may also beneededwhenthese resources areusedfor irrigation.

Marginal-quality water resources

Marginal-quality waters consist of: (1) wastewater generated by domestic, commercial and industrial uses; (2) drainage water generated by irrigated agriculture and surface runoff that has passed through the soil profile and entered the drainage system; (3) groundwater from different sources, such as underlying saline formations, seawater intrusion in coastal areas, recharge of agricultural drainage, storm water runoff from urban areas, and/or infiltration from wastewaterirrigated areas. Marginal-quality waters contain one or more impurities at levels higher than in freshwater, including salts, metals, metalloids, residual drugs, organic compounds, endocrine-disrupting compounds, and the active residues of personal care products and/or pathogens. These constituents may have undesirable effects on soils, crops, water bodies, or human and animal health.

Wastewater from domestic, municipal, and industrial activities

Population growth coupled with the provision of goods and services that allow higher living standards have increased the demand for good-quality water to provide for the needs of the domestic, municipal, and industrial sectors in water-scarce countries. Consequently, greater amounts of wastewater are being generated. After treatment, and in conjunction with suitable management practices, this could be reused for a variety of purposes. Urban wastewater consist of a combination of some or all of the domestic effluent produced (black water and grey water), water produced by commercial establishments and institutions (including hospitals), industrial effluent and storm water which has not infiltrated the soil, as well as other forms of urban runoff (Van der Hoek, 2004).

Estimates of the extent to which wastewater is used for agriculture worldwide reveal that at least 2 _ 106 ha are irrigated with treated, diluted, partly treated or untreated wastewater (Jimenez and Asano, 2004). The use of untreated wastewater is intense in areas where there is no or little access to other sources of irrigationwater. Fewdatabases are available that describe the extent to which wastewater is used for agriculture at thenationalor regional levels (MinhasandSamra, 2003; Van der Hoek, 2004). Owing to the variable quantities of water available for human consumption in water-scarce countries, estimates of the per capita generation of wastewater vary, ranging from 30 to 90m3 yr_1. The volumes of wastewater generatedinsomecountries of Central and WestAsiaand North Africa (CWANA) are presented in Table 3. A significant part of the wastewater generated in these countries is used to supplement the freshwater needs of a variety of crops.

Table 3 – Volume of wastewater generated annually in some countries of Central and West Asia and North Africa		
Country	Reporting year	Wastewater volume ($\times 10^6$ m^3 yr^{-1})
Algeria	2004	600
Bahrain	1990	45
Egypt	1998	10012
Iran	2001	3075
Jordan	2004	76
Kuwait	1994	119
Kyrgyzstan	1995	380
Lebanon	1990	165
Libya	1999	546
Morocco	2002	650
Oman	2000	78
Saudi Arabia	2000	730
Syria	2002	825
Tunisia	2001	240
Turkey	1995	2400
United Arab Emirates	2000	881
Uzbekistan	2004	170
Yemen	2000	74

Except for Algeria, Jordan and Uzbekistan; data derived from the wastewater databases of the Food and Agriculture Organization, available at http://www.fao.org/landandwater/aglw/waterquality/waterusedb.jsp.

The rate at which populations are increasing means that wastewater treatment and its sustainable use is an issue that requires more attention and investment. Most developing countries have not been able to build wastewater treatment plants on a large enough scale and, in many cases, they were unable to develop sewer systems fast enough to meet the needs of their growing urban populations. As a result, in several countries, particularly in Sub-Saharan Africa (SSA), the sanitation infrastructure in major cities has been outpaced by population increases, making the collection and management of urban wastewater ineffective. In many large cities (for example, Accra in Ghana), only a small part of the wastewater produced (_10%) is collected in piped sewerage systems for treatment (Drechsel et al., 2002). Owing to the gradual addition of contaminants into freshwater bodies, and the awareness of their possible impacts, wastewater treatment is now receiving greater attention from the governments of several water-scarce countries and organizations such as World Bank, the Food and Agriculture organization of the United Nations (FAO), and the United Nations Development Programme (UNDP), among others. There is now more scope in the water and environment sector to develop and implement wastewater treatment technologies that: (1) need low levels of capital investment for construction, operation and maintenance; (2) maximize the separation and recovery of by-products (such as nutrients) from polluted substances; (3) are compatible with the intended reuse option in that they yield a product of an appropriate quality in adequate quantities; (4) can be applied at both very small and very large scales; (5) are accepted by farming communities and the local population. Bearing in mind that treated wastewater could be used for agricultural, environmental, recreational and industrial purposes, it is important to realize that such wastewater must be adequately treated and used appropriately. This is important for several reasons:

1. The discharge of untreated wastewater into surface water bodies affects the quality of both the water it enters and thewater further downstream.

2. Treated wastewater could be used to provide a reliable source of irrigation water in urban and peri-urban areas, providing water for parks, play and sports grounds, and roadside greenery. Its other uses may be environmental (providing water for wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), or industrial (used in cooling, boiling, and the processing of materials). It could also be used as a source of non-potable water to provide for many needs (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge, a

use, which has received considerable attention in recent years as it needs proper legislation and periodic monitoring of the aquifer quality.

3. The treatment of wastewater before discharging it into surface water bodies helps to safeguard existing (scarce) sources of good-quality drinking water and protects the environment.

4. Using treated wastewater for irrigation decreases the demand for freshwater in agriculture.

5. If it is treated and managed appropriately, treated wastewater can be used to provide several nutrients essential for plant growth. This directly benefits farmers because they have to make little or no investment in fertilizer (a significant farm input) or its application. The benefits of using treated wastewater must also be considered against the human health, economic, and environmental costs of not using it. For example, treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families.

Table 4 – Guidelines for microbiological qualities of treated wastewater for irrigation[a]

Category	Wastewater reuse conditions	Exposed group of communities	Irrigation method	Intestinal nematodes[b] (arithmetic mean; no. per 1000 mL)[c]	Faecal coliforms (geometric mean; no. per 100 mL)[d]
A	Unrestricted irrigation (all crops, including vegetable and salad crops eaten uncooked, sports fields, public parks[e])	Workers, consumers, public	Any	≤0.1[f]	$\leq 10^3$
B	Restricted irrigation (cereal crops, industrial crops, fodder crops, pastures, and trees[g])	B1 workers, children > 15 years, nearby communities	Spray or Sprinkler	≤1	$\leq 10^5$
		B2 same as B1	Flood or furrow	≤1	$\leq 10^3$
		B3 workers, children of all ages, nearby communities	Any	≤0.1	$\leq 10^5$
C	Localized irrigation (crops in category B, but without exposure of workers and communities)	None	Trickle or drip	Not applicable	Not applicable

Modified from Blumenthal et al. (2000) and Carr et al. (2004).

[a] In specific situations, these guidelines may be modified according to local epidemiological, socio-cultural, and hydrogeological factors.

[b] *Ascaris* and *Trichuris* species and hookworms. The guideline values are also intended to protect against risks from parasitic protozoa.

[c] During the irrigation period; routine monitoring is not required if wastewater is treated in waste stabilization ponds (WSP) or wastewater storage and treatment reservoirs (WSTR).

[d] During the irrigation period; the faecal coliform counts should preferably be done weekly, but at least monthly.

[e] Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas. A guideline of ≤200 faecal coliforms $100\ mL^{-1}$ is appropriate for the lawns.

[f] This guideline value can be increased to ≤1 if conditions are hot and dry and surface irrigation is not used, or if wastewater treatment is supplemented with anti-helminthic chemotherapy campaigns in areas of wastewater use.

[g] In the case of fruit trees, irrigation should stop 2 weeks before fruit is picked, and no fruit should be picked up from the ground. In addition, sprinkler irrigation should not be used.

Based on different parameters, various guidelines (Ayers and Westcot, 1985; WHO, 1989; Blumenthal et al., 2000; Carr *et* al., 2004; WHO, 2006) are available for wastewater use in agriculture (Tables 4 and 5). However, in many developing countries these guidelines are not followed and most farmers use untreated wastewater in an unplanned manner to irrigate a variety of crops. Most cities in these countries have networks of open and covered interconnected channels located within and around urban premises. In general, these channels carry a mixture of wastewater generated by domestic, municipal, and industrial activities. The farmers divert untreated wastewater from these channels to provide irrigation water as and when it is needed. Although farmers irrigate a range of crops with wastewater, they often prefer to grow high-value vegetables as a market-ready product, which will generate a higher income (Qadir *et al*., 2000).

In some cases, the authorities implementing government regulations periodically expel these farmers from their fields (Keraita and Drechsel, 2004) or uproot wastewater-irrigated vegetables.
In other cases, however, the administrators do not make any efforts to check the use of wastewater in this way. Rather they regard this farming practice as a viable option for wastewater disposal. The

farmers consider such untreated wastewater to be a reliable source of irrigation, which involves less cost than other sources of irrigation water such as groundwater pumping (Van der Hoek *et al*., 2002).

Table 5 – Recommended maximum concentrations (RMCs) of selected metals and metalloids in irrigation water[a]

Element	RMC (mg L^{-1})	Remarks
Aluminum	5.00	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg L^{-1} for Sudan grass to less than 0.05 mg L^{-1} for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg L^{-1} for kale to 0.5 mg L^{-1} for bush beans
Cadmium	0.01	Toxic at concentrations as low as 0.1 mg L^{-1} in nutrient solution for beans, beets and turnips. Conservative limits recommended
Chromium	0.10	Not generally recognized as an essential plant growth element. Conservative limits recommended
Cobalt	0.05	Toxic to tomato plants at 0.1 mg L^{-1} in nutrient solution. It tends to be inactivated by neutral and alkaline soils
Copper	0.20	Toxic to a number of plants at 0.1–1.0 mg L^{-1} in nutrient solution
Iron	5.00	Non-toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of phosphorus and molybdenum
Lithium	2.50	Tolerated by most crops up to 5 mg L^{-1}. Mobile in soil. Toxic to citrus at low concentrations with recommended limit of <0.075 mg L^{-1}
Manganese	0.20	Toxic to a number of crops at a few-tenths to a few mg L^{-1} in acidic soils
Molybdenum	0.01	Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel	0.20	Toxic to a number of plants at 0.5 to 1.0 mg L^{-1}; reduced toxicity at neutral or alkaline pH
Lead	5.00	Can inhibit plant cell growth at very high concentrations
Selenium	0.02	Toxic to plants at low concentrations and toxic to livestock if forage is grown in soils with relatively high levels of selenium
Zinc	2.00	Toxic to many plants at widely varying concentrations; reduced toxicity at pH ≥ 6.0 and in fine textured or organic soils

Modified from Ayers and Westcot (1985).

[a] The maximum concentration is based on a water application rate, which is consistent with good irrigation practices (10,000 m^3 ha^{-1} yr^{-1}). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m^3 ha^{-1} yr^{-1}. The values given are for water used on a long-term basis at one site.

Other benefits to the farmers include the fact that farmers have to invest nothing, or very little, in fertilizer purchase and application, while benefiting from greater levels of crop production than are obtained via freshwater irrigation. In addition, they enjoy higher incomes as a result of cultivating and marketing high-value crops. These benefits help the farmers to ensure that their families receive better levels of nutrition and that their children benefit from better educational opportunities. For all these reasons, farmers take health risks and use untreated wastewater when the opportunity presents itself (Ensink *et al.,* 2002; Matsuno *et al*., 2004).

Surveys and research studies carried out in different countries revealed that fields irrigated with untreated wastewater yielded more than those irrigated with freshwater (Shende, 1985; Minhas and Samra, 2004; Table 6). In addition, economic analyses based on the cost of production of different crops have shown attractive economic returns from wastewater-irrigated fields in Syria (Qadir et al., unpublished data). The analyses revealed that each US$ invested in the production process gave a return of US$ 5.31 in the case of wheat (*Triticum aestivum* L.) irrigated with wastewater and US$ 2.34 in the case of wheat irrigated by groundwater. In addition to the higher wheat yields provided by wastewater-irrigated plots, there were savings with regard to fertilizer use. In comparison with those growing groundwater-irrigated wheat, the farmers using wastewater to irrigate wheat saved US$ 95 ha_1. Similar economic return trends were obtained for faba bean (*Vicia faba* L.). However, in the case of cotton (*Gossypium hirsutum* L.), there was little difference between the returns from wastewater irrigation (US$ 5.17) and groundwater irrigation (US$ 5.23) for each US$ invested. This is because wastewater resources in the area during the long summer growing season of cotton are not sufficient to provide the crop with its needs. Therefore, the wastewater-irrigating farmers also use fertilizers and pump groundwater as and when needed. The cultivation of vegetables – which are grown on only 7% of the wastewater-irrigated area because of government restrictions –produced the highest economic returns from wastewater irrigation: US$ 7.48 for each US$ invested. This was much greater than in the case of vegetables irrigated with groundwater, where the return was US$ 3.29 per US$ investment (Qadir et al., unpublished data). Although these crop yield and economic analyses indicate that communities who use untreated or partly treated wastewater clearly benefit financially, there is a need to carry out comprehensive analyses of the potential environmental and health implications and their costs. These must be weighed against both the short- and long-term benefits of wastewater use.

Owing to the low literacy rate found amongst farmers in developing countries, limited and inappropriate information gathering and reporting, insufficient public pressure, most farmers using polluted water in low-income countries remain uninformed about the health and environmental consequences (Hussain *et al*., 2002). Moreover, farmers and authorities have insufficient knowledge about the technical and management options available for reducing the environmental and health risks associated with wastewater use. Depending upon the levels of contaminants present, the continued and uncontrolled use of untreated wastewater as an irrigation source could have a variety of implications. These include the following:

1. Groundwater contamination through the movement of high concentrations of a wide range of chemical pollutants (Ensink *et al*., 2002). This is particularly true in the case of wastewater that contains untreated industrial effluent. The pollutants reaching groundwater in this way have the potential to impact upon human health when groundwater is pumped for direct human consumption. Pathogens have also been found to accumulate in the groundwater found immediately beneath wastewater-irrigated fields (Ensink *et al*., 2002).

2. The gradual buildup, in the soil solution and on the cation exchange sites of soil particles, of ions such as $Na+$ and a range of metals and metalloids which are deleterious to the soil. In this way, potentially harmful metals and metalloids may reach phytotoxic levels (Qadir et al., 2005). The accumulation of excess $Na+$ in the soil can have numerous adverse effects, including changes in exchangeable and soil solution ions and soil pH, the destabilization of the soil structure, the deterioration of the soil's hydraulic properties, and an increased likelihood of crusting, runoff, erosion and aeration. It can also have osmotic effects and specific ion effects in plants (Sumner, 1993; Qadir and Schubert, 2002).

3. The accumulation of potentially toxic substances in crops and vegetables which will, ultimately, enter the food chain, so damaging human and animal health. For example, leafy vegetables irrigated with untreated wastewater containing metals and metalloids can accumulate higher levels of certain metals, such as cadmium (Cd), than non-leafy species (Qadir et al., 2000). Excessive exposure to this metal has been associated with various illnesses in people, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis (Wagner, 1993). Numerous illnesses are also associated with the ingestion of excessive levels of other metals and metalloids. Similarly, pathogens may enter the food chain via the same pathway. However, in most cases, industrial pollutants in the form of a variety of metals and metalloids can cause greater and longer lasting health effects in people than pathogenic organisms.

4. The health risks associated with the presence of parasitic worms, and viruses and bacteria. These have the potential to cause disease in farming families exposed to untreated wastewater for extended periods. Such diseases also raise the issue of the financial consequences associated with treatment. Farmers using untreated wastewater for irrigation demonstrate a higher prevalence of hookworm and roundworm infections than farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater use, penetrate the skin of farmers working barefoot (Van der Hoek *et al.,* 2002).

Bearing in mind the challenges associated with the use of wastewater for irrigation, studies carried out by the researchers at the International Water Management Institute (IWMI), Sri Lanka have proposed a number of options to maximize the benefits and minimize the risks involved in the use of untreated wastewater for agriculture (Scott *et al*., 2000; Ensink *et al.,* 2002; Van der Hoek *et a*l., 2002; IWMI, 2003; Matsuno *et al*., 2004; Scott *et al.,* 2004;). These options include: (1) the use of suitable irrigation techniques and the selection of appropriate crops that are less likely to transmit contaminants and pathogens to consumers; (2) the use of protective measures such as boots and gloves to control farm workers' exposure to pathogens; (3) the implementation of a medical care program through the use of preventive therapy such as anti-helminthic drugs; (4) the post-harvest management of vegetables, through washing and improved storage; (5) the conjunctive use of wastewater and freshwater to dilute the risks and increase the benefits by supplying nutrients to a larger area; (6) upstream wastewater management and appropriate low-cost treatment; (7) education and increased awareness among farmers, consumers, and government organizations; (8) the implementation of monitoring programs for key environmental, health, and food safety parameters.

The Hyderabad Declaration on Wastewater Use in Agriculturemade on 14 November 2002 (available at http:// www.iwmi.cgiar.org/health/wastew/hyderabad_declaration. htm) – which resulted from a workshop organized by IWMI and the International Development Research Center, Canada – stressed the need to ‘‘safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation’’. The management options used should include raising public awareness, using safer irrigation methods, minimizing human exposure, restricting the types of crops irrigated with wastewater, disinfecting produce, ensuring institutional coordination, increasing land tenure, and increasing funding (Scott *et a*l., 2004). In view of the fact that it is not possible to simply ban wastewater use in many developing countries, the World Health Organization (WHO) is considering the realities faced by these countries while revising guidelines for wastewater use in agriculture (WHO, 2006).

Wastewater treatment technology

Technology, particularly in terms of performance and available wastewater treatment options, cannot be expected to find a solution to each problem. Wastewater systems are generally capital-intensive and require expensive, specialized operators. Therefore, before selecting and investing in wastewater treatment technology, an analysis of cost effectiveness needs to be made and compared with all conceivable alternatives.

The selection of technologies should be environmentally sustainable, appropriate to the local conditions, acceptable to the users, and affordable to those who have to pay for them. In developing countries, western technology can be a more expensive and less reliable way to control pollution from human domestic and industrial wastes. Simple solutions that are easily replicated, that allow further up-grading with subsequent development and that can be operated and maintained by the local community are often considered the most appropriate and cost effective. The choice of a technology will depend to the type of reuse. The selection of reuse option should be made on a rational basis. Reclaimed water is a valuable but a limited water resource; so investment costs should be proportionnnel to the value of the resource. Also, reuse site must be located as close as possible to the wastewater treatment and storage facilities.

In the developing countries usually characterized by high population density and notable shortfall in available water resources, the proper waste water technology to be adopted under the prevailing local conditions is one of the critical issues which should be well defined. Technologies available are many and well known, but any choice should rely on those not entailing excessive costs and providing the best environmental practice and option.

Indeed, the selection of the best available technology is not an easy process: it requires comparative technical assessment of the different treatment processes which have been recently and successfully applied for prolonged periods of time, at full scale. However, this is not sufficient, the selection should be carried out in view of well-established criteria comprising: average, or typical efficiency and performance of the technology; reliability of the technology; institutional manageability, financial sustainability; application in re-use scheme and regulation determinants. Furthermore, for technology selection, other parameters have to be carefully considered: wastewater characteristics, the treatment objectives as translated into desired effluent quality which is mainly related to the expected use of the receiving water-bodies.

Benefits impact

Bearing in mind that treated wastewater could be used for agricultural, recreational and industrial purposes, it is important to realize that such wastewater must be adequately treated and used appropriately. This is important for several reasons:

1. The discharge of untreated wastewater into surface water bodies affects the quality of both the water it enters and the water further downstream.

2. Treated wastewater could be used to provide a reliable source of irrigation water in urban and peri-urban areas, providing water for parks, play and sports grounds, and roadside greenery. Its other uses may be environmental (providing water for wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), or industrial (used in cooling, boiling, and the processing of materials). It could also be used as a source of non-potable water to provide for many needs (fire fighting, air conditioning, dust control, and toilet flushing). It may also be used for aquaculture and groundwater recharge - a use which has received considerable attention in recent years.

3. Using treated wastewater for irrigation decreases the demand for freshwater for agriculture.

4. If it is treated and managed appropriately, treated wastewater can be used to provide several nutrients essential for plant growth. This directly benefits farmers because they have to make little or no investment in fertilizer (a significant farm input) or its application.

The benefits of using treated wastewater must also be considered against the human health, economic, and environmental costs of not using it. For example, treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families.

CONCLUDING REMARKS AND RECOMMENDATIONS

Domestic WWTR is one tool to address the food and water insecurity facing many Developing countries. In coming years, in most Middle East and North Africa countries, valuable fresh water will have to be preserved solely for drinking, very high value industrial purposes, and for high value fresh vegetables and salad crops consumed raw. Where feasible, most crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, and generate new knowledge, and monitor and enforce standards.

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IMPACT DE L'IRRIGATION PAR LES EAUX USÉES ÉPURÉES SUR LA PRODUCTIVITÉ D'UNE CULTURE DE TOMATE DE PLEIN CHAMP, LA SALINITÉ DU SOL ET LE BILAN D'AZOTE

R. Choukr-Allah, A. and Aghai, O
* Salinity and plant nutrition laboratory I.A.V Hassan II Agadir, Morocco BP 773
E-mail: ch.redouane@wanadoo.net.ma

RÉSUMÉ - Le présent travail vise à évaluer l'impact de l'irrigation par les eaux usées épurées sur la croissance et la production d'une culture de tomate (*Lycopersicum esculentum*) conduite en plein champ ainsi que sur les caractéristiques chimiques du sol et sur le bilan azoté. L'essai a été mené à la station d'épuration des eaux usées de Drarga. Nous avons utilisé deux régimes hydriques à savoir 100% ETM et 120% ETM. Les résultats obtenus montrent que la consommation hydrique de la tomate a été évaluée à 1937,7 m^3/ha . La croissance a été similaire pour les deux traitements mais les composantes du rendement ont été meilleures pour le traitement 120% ETM ; en effet le rendement exportable est de 1,83 kg/plant pour le traitement 120% ETM contre 1,5 kg/plant pour le traitement 100% ETM. La conductivité électrique initial du sol était 2,32 dS/m et a atteint en fin de cycle 5,24 dS/m et 4,30 dS/m respectivement pour le traitement 100% ETM et 120% ETM ; cette différence entre les deux traitements est le résultat de la fraction de lessivage de 20 % appliquée au deuxième traitement et qui a permis la lixiviation des sels en profondeur. Le sol a été appauvri en azote, phosphore et potassium; cet appauvrissement est de 9,5 kg/ha d'azote nitrique, 6,8 kg/ha d'azote ammoniacal, 41,7 kg/ha de phosphore et 176,2 kg/ha de potassium. Les pertes en azote nitrique sont évaluées à 11,9 kg/ha, elles représentent 31,2% des apports et 28,3% des quantités lessivées dans une exploitation moyenne de la région. L'utilisation de ces eaux usées engendre un gain sur le coût de l'eau et des engrais qui s'élève à 109,29 Euro/ha et 131,12 Euro/ha respectivement pour le traitement 100% et 120% ETM.

Mots clés : Eaux usées épurées, tomate, traitements 100%ETM et 120%ETM, rendement, sol, bilan azoté, conductivité électrique, lixiviation, nitrates, gain.

Introduction

En raison de la rareté croissante des ressources naturelles en eau conventionnelle et étant donné la concurrence entre les secteurs du développement économique de point de vue demande en eau, la valorisation des eaux usées traitées est considérée comme une composante essentielle dans la politique de gestion intégrée des ressources hydriques. Cependant, pour qu'elle soit inscrite dans un cadre de développement durable, la mise en valeur de la réutilisation de ces eaux exige une étude prudente et intégrée qui tienne compte surtout des aspects environnementaux.

En effet, la charge importante de ces eaux usées en sels et en nitrates nous confronte à un dilemme: appliquer juste la quantité d'eau nécessaire à la culture et donc augmenter la salinité du sol, ou bien appliquer une fraction de lessivage et donc faire percoler les nitrates en profondeur provoquant ainsi le risque de contamination de la nappe souterraine.

Le défi sera alors de concevoir et d'opérer une nouvelle génération de systèmes de gestion de l'eau qui soient en mesure de satisfaire la demande alimentaire dans un contexte de rareté de l'eau, tout en respectant les exigences de l'environnement.

Dans ce cadre, on a mené cette étude à la station d'épuration de Drarga afin d'évaluer l'impact de l'irrigation par les eaux usées épurées selon deux régimes hydriques (100% ETM et 120% ETM) sur le rendement d'une culture de tomate en plein champ ainsi que l'évaluation des risques environnementaux qui sont liés à cette irrigation, à savoir la salinité du sol et la pollution de la nappe phréatique par les nitrates.

Matériel et méthodes

L'essai s'est déroulé sur la parcelle de démonstration de la station d'épuration des eaux usées de Drarga, près de la ville d'Agadir, où nous avons comparé l'effet de deux régimes hydriques, à savoir 100% ETM et 120% ETM, sur :

- la croissance et la production de la culture de tomate,
- La salinité du sol,
- Le bilan d'azote,

Le risque de contamination de la nappe souterraine par les nitrates.

Le sol de notre parcelle est un sol calcaire, lourd, à texture limoneuse et à pH alcalin (pH=8,7). Il ne présente ni problème de salinité, ni de problème de perméabilité.

L'eau usée brute passe par trois traitements principaux: la décantation par des bassins anaérobiques, l'infiltration-pércolation par des filtres à sable et le traitement tertiaire par une roselière.

L'eau d'irrigation, ainsi traitée, répond aux normes de la FAO et de l'OMS et présente les caractéristiques suivantes.

Tableau 1: composition physico-chimique de l'eau d'irrigation

Caractéristiques	Valeurs*
CE dS/m	2,61
pH	7,6
NO_3^- ppm	49
NH_4^+ ppm	1,8
K^+ ppm	46,8
PO_4^{3-} ppm	2,4
Cl- ppm	515
Ca^{++} ppm	219,7
Na^+ ppm	176,2
Mg^{++} ppm	62,28
CO_3^{--} ppm	8,5
HCO_3^- ppm	662
SAR	2,69
MES mg/l	10
Coliformes fécaux (/100ml)	<1000
Streptocoques fécaux (/100ml)	<1000
Œufs d'helminthes	0

*. Valeurs moyennes de l'années 2001-2002

Le pH de l'eau d'irrigation se situe dans l'intervalle (6,5-8,4) des normes de la FAO concernant la qualité des eaux. La conductivité électrique comprise entre 0 et 3 dS/m qui est l'intervalle de tolérance de la tomate sans que son rendement ne soit affecté (Bernstein, 1964). Le SAR (taux d'absorption de sodium) est inférieur à 3 donc il n'y a pas de risque de problème de perméabilité pour le sol (Ayers et Westcot, 1985).

On a opté pour une culture de tomate de plein champ avec une densité de plantation de 25000 plants/ha. Les banquettes sont couvertes par un paillage en plastic au-dessous duquel sont installés les rampes de goutte à goutte.

Le matériel végétal utilisé est la variété « Cornelia » à croissance indéterminée, elle a été conduite sur un seul bras avec un système de palissage à roseaux. Cette variété est sensible à la salinité et aux nématodes mais elle est tolérante au virus TYLC.

On a adopté 2 régimes hydriques et 4 répétitions pour avoir 8 unités expérimentales distribuées selon un Dispositif Complètement Aléatoire. Dans chaque unité du traitement 120% ETM était installé un lysimètre de 2m de longueur, 1m de largeur et 0,60m de profondeur. Ces lysimètres nous permettent le pilotage des irrigations et le suivi des teneurs des drainas en nitrates et en sels.

RÉSULTATS ET DISCUSSIONS

Consommation en eau

La consommation globale en eau était de 1937,7 m3/ha pour un cycle de 170 jours. La répartition de cette consommation par stade de développement de la culture est résumé dans le tableau suivant :

Tableau 2 : Evolution des apports en eau pour le traitement 120% ETM selon les stades (en m^3/ha)

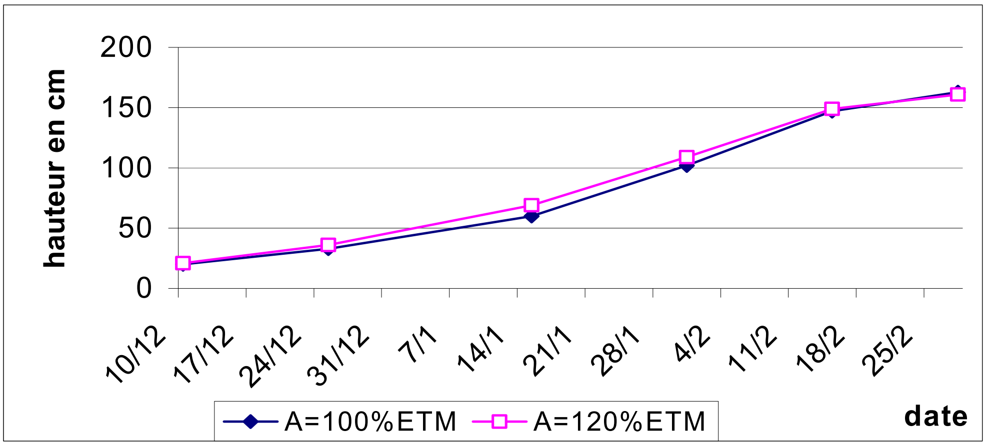
	1^{er} stade	2ème stade	3ème stade	4ème stade	Total
Apports en eau	541,2	303,3	566,2	914,4	2325,1
Drainats	90,05	50,55	94,35	152,4	392,35
consommation	451,15	252,75	471,85	762,00	1937,75

1er stade : floraison
2ème stade : floraison 4ème bouquet
3ème stade : récolte 2ème bouquet
4ème stade : fin récolte

Evolution de la croissance

La croissance des plants en hauteur suit une allure sigmoïde comme l'illustre la figure 1.

Figure 5. L'évolution de la hauteur des plants de tomate pour les deux traitements durant la phase de croissance



La salinité n'a pas eu d'impact négatif sur la croissance des plants puisque le seuil de tolérance de la tomate n'a été atteint que lors du 3ème stade.

En effet la concentration en sels solubles (en particulier Na^+ et Cl^-) réduit modérément la hauteur des plants aux premiers stades de développement car le degré de sensibilité de la tomate au sel diminue avec l'age. (Bernstein, 1975)

Rendement

Notre culture était conduite jusqu'au 6ème bouquet avant d'effectuer l'étêtage. Le nombre de fruits par bouquet varie entre 4 et 6 fruits.

Au début des récoltes la majorité des fruits étaient de calibre 3 mais au fur et à mesure que l'on récoltait, la taille des fruits diminuait pour arriver à la fin du cycle avec des fruits de calibre 5. Ceci est sans doute du à la salinité du sol qui s'est accentuée lors du dernier stade.

Tableau 3: Rendements moyens d'un plant de tomate pour les deux traitements

	Rendement total en Kg/plant	Rendement exportable en Kg/plant	Taux des écarts en %
A=100% ETM	1,98	1,50	24,26
A=120% ETM	2,15	1,82	15,36

On remarque que le rendement exportable du traitement 120%ETM est plus important que celui du traitement 100%ETM. Cette différence est de 22%, et elle est due au taux des écarts de triages qui est plus élevé pour le traitement 100% ETM puisque la variété Cornelia est sensible à la salinité qui se manifeste par des nécroses apicales au niveau du fruit.

Salinité du sol

La conductivité électrique mesurée au cours du cycle de la culture, dans la couche du sol (0-40cm) est représentée dans la figure 2.

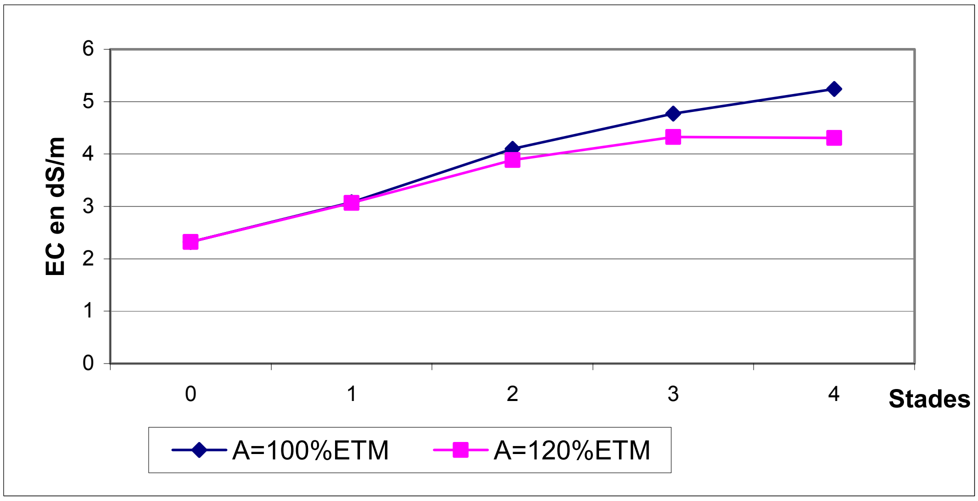


Figure 6: Evolution de la conductivité électrique du sol au cours du cycle de la culture

On remarque que les deux régimes hydriques (100% et 120% ETM) ont contribué à l'augmentation de la CE. Ceci revient à la charge élevée des eaux usées épurées en sels qui pourraient par la suite saliniser le sol.

On note aussi que le traitement 100%ETM a connu une augmentation de la CE plus importante que celle enregistrée pour le traitement 120%ETM. En effet, elle a évolué de 2,3 dS/m à 5,2 dS/m et 4,3 dS/m respectivement pour 100% et 120% ETM. Ceci est attribué à la fraction de lessivage (20%) que l'on a adopté pour le régime 120%ETM et qui a permis le lessivage des sels en profondeur, minimisant ainsi le risque de la salinisation de la couche exploitée par les racines.

On signale aussi qu'environ 84% de l'augmentation de la conductivité électrique a eu lieu durant les trois premiers stades.

Cette augmentation de salinité du sol affecte le rendement de la tomate, en effet Van Hoorn (2001) a démontré qu'il y a une diminution du rendement de 25% quand la conductivité électrique du sol de l'ordre de 5 dS/m.

Lessivage des nitrates

Les quantités totales d'azote nitrique lixiviées durant tout le cycle de la culture s'élèvent à 11,9 kg/ha. La répartition de ces quantités par stade de développement de la plante sont résumé dans le tableau 4.

Tableau 4 : Quantités d'azote nitrique lessivées par stade (kg/ha)

	Stade 1	Stade 2	Stade 3	Stade 4	Total
$N\text{-}NO_3^-$	2,56	1,41	2,66	5,16	11,87

Les pertes en nitrates sont évaluées à 11,9 kg/ha, elles représentent 31,2% des apports. Ces pertes sont faibles par rapport aux pertes trouvées par Benhoummane.B (2001) et qui représentent 60% des apports avec une quantité de 126,8 kg/ha. Aussi Mojtahid.A (2001) s'est retrouvé avec 66,9% de pertes soient 74,4 kg/ha. Ceci prouve que la qualité de notre eau est moins polluante relativement à celle issue du traitement par infiltration percolation seulement.

Aussi, les quantités drainées de nitrates pour la tomate en plein champ pour une exploitation de taille moyenne de la région est de l'ordre de 42 kg/ha soit plus de trois fois les quantités lessivés durant notre essai.

On signale aussi que le 4ème stade a connu environ la moitié des pertes totales en nitrates. ceci est expliqué par le fait que les irrigations étaient plus intenses pour répondre à la demande de la plante en eau.

Fertilité du sol

Comme les apports de l'eau d'irrigation en éléments fertilisants est faible et ne parvient pas à satisfaire les besoins de la culture, cette dernière a puisé des réserves du sol. En effet, on a enregistré une diminution de la teneur du sol en azote, phosphore et potassium. Les résultats obtenus sont présentés dans le tableau suivant.

Tableau 5. Variation de la teneur du sol en éléments fertilisants (kg/ha)

	$N\text{-}NO_3^-$		$N\text{-}NH_4^+$		P		K	
	T1	T2	T1	T2	T1	T2	T1	T2
sol initial	70,56	70,56	25,92	25,92	84,38	84,38	403,78	403,78
Stade4	67,10	61,06	20,30	19,09	45,50	42,62	253,44	227,52
Variation du stock	-3,46	-9,50	-5,62	-6,83	-38,88	-41,76	-150,34	-176,26

*.T1 : traitement 100% ETM
*.T2 : traitement 120% ETM

On remarque que la diminution de la teneur du sol en phosphore et en potassium est plus accentué, elle est d'environ 50%, alors que pour l'azote, cette réduction est plus faible puisqu'elle est de 26% pour l'ammonium et seulement 13% pour les nitrates.

Cette faible variation d'azote assimilable dans le sol est le résultat du fait que l'azote est très dynamique et a plusieurs sources (matière organique…).

En effet Morot-Gaudry (1997) a démontré que les plantes ne peuvent pas bénéficier des réserves importantes en éléments contenus dans le sol (2 à 20 tonnes d'azote par hectare) car une partie seulement de ces réserves est libérée, sous la forme assimilable, à la suite de l'activité biologique des sols et de ses processus chimiques à savoir l'ammonification et la nitrification.

ANALYSE ÉCONOMIQUE

Gain sur le coût de l'eau d'irrigation

Pour les agriculteurs de la région de Drarga, deux sources d'eau d'irrigation sont disponibles : l'eau de pompage, avec un prix moyen d'environ 0,07 Euro/m^3, et l'eau de la station d'épuration des eaux usées, avec un prix de 0,05 Euro/m^3.

On a effectué une brève comparaison entre le coût total pour notre essai en terme de consommation en eau avec les deux sources précitées, et on a résumé les résultats dans le tableau 6.

Tableau 6 : Comparaison entre le coût d'irrigation par l'eau usée et l'eau du puits

Traitement	Consommation en m^3/ha	Coût de l'eau usée épurée en Euro/ha	Coût de pompage en Euro/ha	Gain en Euro/ha
A=100%ETM	1937,7	96,89	135,64	38,75
A=120%ETM	2325,2	116,26	162,77	46,51

On peut donc économiser 28,6% sur le coût de l'irrigation si on utilise l'eau usée épurée au lieu de l'eau de pompage.

Gain sur le coût des engrais

Les eaux usées épurée ne sont pas seulement appréciées en tant que ressources en eau, mais aussi comme source de fertilisation vu leurs teneurs en éléments nutritifs.

Le tableau ci-dessous résume les quantités d'engrais nécessaires ainsi que leur coût d'acquisition qui représente, dans notre cas, le gain engendré par l'application des eaux usées épurées.

Tableau 7: Le gain économique en engrais en Euro/ha

	Acide nitrique		Sulfate d'ammonium		Acide phosphorique		Sulfate de potasse		
Traitement	Quantité	Gain	Quantité	Gain	Quantité	Gain	Quantité	Gain	Gain total
A=100%ETM	34,2	15,37	12,9	2,84	8,7	5,06	189,1	47,27	70,54
A=120%ETM	40,9	18,42	15,7	3,46	10,4	6,05	226,7	56,68	

Le gain global pour notre cas s'élève à 109,29 Euro/ha et 131,12 Euro/ha respectivement pour le traitement 100% et 120% ETM.

CONCLUSION

L'irrigation par ces eaux usées épurées sans amendements en engrais a provoqué un épuisement de la réserve du sol en éléments fertilisants, surtout en phosphore et potassium. L'apport d'un supplément de fertilisants s'avère donc essentielle, à savoir 96 kg/ha-N, 47 kg/ha-P et 252 kg/ha-K.

Le régime 120% ETM a permis une augmentation du rendement exportable de 22%, par rapport à 100% ETM, suite à la faible accumulation des sels dans le sol qui est le résultat de la fraction de lessivage appliquée à ce traitement.

Cependant cette fraction a permis la lixiviation de 11,9 kg/ha d'azote nitrique qui risque de contaminer la nappe souterraine. Cette quantité représente 31,2% des apports de l'eau d'irrigation en nitrates et seulement 28,3% des quantités totales de nitrates lessivées par une exploitation moyenne de la région.

Une bonne gestion des irrigations peut remédier à notre dilemme ; en effet en optant pour le régime 120% ETM durant les trois premiers stades où il y a 84% de l'accumulation des sels et puis après appliquer le régime 100% ETM au dernier stade où il y a près de 50% des pertes en nitrates, on aura réussi à trouver un compris entre les deux grands problèmes liés à l'irrigation par ces eaux usées épurées.

Une autre alternative peut être entreprise pour remédier au risque de pollution de la nappe par les nitrates, en adoptant une culture à grande consommation azoté en rotation culturale avec la tomate. Ceci dit, la luzerne comme culture qui, d'une part tolère à la salinité, et d'autre part exporte de grandes quantités d'azote (1361 kg/ha/an), peut être alterner avec la tomate lors d'une rotation culturale.

Sur le plan économique, l'utilisation de ces eaux usées épurées permet aux agriculteurs de réaliser une économie sur le coût de l'eau et sur le coût des engrais qui remonte à 109,29 Euro/ha et 131,12 Euro/ha respectivement pour le traitement 100% et 120% ETM.

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PART THREE

NON CONVENTIONAL WATER RESOURCES : NORMS FOR REUSE

ASSESSING AND CONTROLLING LABORATORY APPROACH FOR SAMPLE CONTAMINATION

T. Tawfik*
* Director CLEQM-NWRC, Cairo (Egypt) E-mail: tawfic06@yahoo.com

INTRODUCTION

Contamination is a common source of error in all types of environmental measurements. Most sampling and analytical schemes present numerous opportunities for sample contamination from a variety of sources. This paper addresses the problem of assessing and controlling sample contamination and the resulting measurement error. The first part of the discussion examines the different points in the sample collection and analysis process at which contamination for various measurement applications. The next portion deals with the different possible effects of contamination. The last part of the discussion examines the use of blanks to assess and control contamination. Different types of blanks and their respective uses are described. The applicability of control charts to blank measurements is also discussed.

From an environmental sampling and analytical standpoint, contamination is generally understood to mean something that is inadvertently added to the sample during the sampling and analytical process. Although subsequent measurements may accurately reflect what was in the sample at the time the measurements were made, they do not give an accurate representation of the measured characteristic of the media from which the sample was taken.

To minimize error due to contamination, the potential sources of contamination must be identified and eliminated wherever possible. Once a measurement system is established, appropriate types of blanks should be used to define background levels of contamination for the different parts of the sampling and analytical process. Group of recent Ammonia analysis results for years 2000 to 2002 handled by CLEQM will be used as a typical example of the applied approach.

SOURCES OF CONTAMINATION

Contamination may be introduced in the field during sample collection, handling storage, or transport to the analytical laboratory. After arrival at the laboratory, additional opportunities for contamination arise during storage, in the preparation and handing process, and in the analytical process itself. Contamination and cross- contamination from sampling equipment is equally a problem in other types of environmental sampling (Ross, 1986).

Sample handling in the field is another potential sources of sample contamination. Acids and other chemical preservatives that may become contamination after a period of use in the field offer another route of sample contamination during field handling (USEPA, 1999). Sample containers represent another major source of sample contamination. Plastic sample containers, for example, are widely recognized as a potential source of sample contamination in trace metal analyses (Moody and Lindstorm, 1987). Glassware and reagents are common sources of laboratory contamination in all types of analyses. Carry-over and memory effects from consecutive analyses of high- and low-level samples are also common to many types of instrumental methods, including gas chromatography, liquid chromatography, and many spectroscopic methods (Bagchi, 1986). Common sources of sample contamination are summarized in Table (1).

Table 1. Potential Sources of Sample Contamination (Fetter, 1983)

Critical Steps in the Sampling and Analytical Process	Contamination Sources
Sample Collection	Equipment and apparatus Handling Preservatives Ambient contamination Sample containers
Sample transport and storage	Sample containers Cross- contamination from other samples or reagents Sample handling
Sample preparation	Glassware Reagents Ambient contamination Sample handling
Sample analysis	Syringes used for sample injections Carry-over and memory effects Glassware, equipment, and apparatus Reagents (e.g., carrier gases and eluents)

EFFECTS OF CONTAMINATION

Chemical of physical properties of samples that cause errors in the measurement process are commonly known as interference. Generally, two types of interferences are recognized: additive interference and multiplicative interferences (Shacklette and Borngen, 1984). Additive interferences are caused by sample constituents, generate a signal, that adds to the analyte signal. Because they cause a change in the intercept but not the slope of the calibration curve, additive interferences have the most pronounced effect at low analyte contaminations. Multiplicative interferences, on the other hand, are caused by sample constituents the either increase or decrease the analyte signal by some factor without generating a signal of their own. Multiplicative interferences change the slope of the calibration curve not but the intercept.

Multiplicative interferences are a common source of analytical error in many spectroscopic techniques, although matrix effects are a more common source of such error than contamination. Contaminants may, however, cause multiplicative interferences through adsorptive losses of the analyte of interest. These contaminants dive erroneously low results. Adsorption acts as a multiplicative interference when a constant fraction of the analyte is adsorbed, regardless of analyte contamination (i.e., when relative bias is constant). When the amount of analyte is large compared to the available sites for adsorption to occur, the amount of analyte lost to adsorption tends to be constant, and relative bias decreases with increasing contamination. In such cases, adsorption causes a negative interference, opposite in effect to an additive interference.

Regardless of the source of sources of sample contamination, the net effect is added inaccuracy in the measurement process. Like other types of measurement error, error due to contamination may be sporadic and represent special causes, or systematic and affect all measurements. Cross-contamination, such as that which often occurs during analysis when carry-over from high-level samples contaminates subsequent low-level samples, is a common source of sporadic contamination. Similarly, careless sample handling and dirty sampling equipment are often sources of sporadic contamination. Sporadic contamination, most often, affects the measurement process by introducing false positive results. A false positive in the error of concluding that an analyte is present in the media sampled when it is not. In the case of sporadic contamination where the contaminant acts as a negative interference, as in dilution or adsorption, false negatives may result a false negative is the error or concluding that an analyte is not present when it is.

Contamination is a source of systematic error when the level of contamination is stable for all samples. Strictly speaking, however, stable, systematic error due to sample contamination is rare. Almost always, some element of sporadic error is associated with any source of contamination. In some cases through, the effect of this sporadic error component is small in comparison to the systematic error, or bias component. Thus, some types of contamination behave in a fashion that is primarily systematic. Systematic contamination increases the "background contamination" of the analyte of interest and thus affects the lower limit of the measurement process. Contaminated reagents are a common source of systematic contamination in many types of environmental measurements. Contaminated sample containers are another source of contamination that is often primarily systematic.

USE BLANKS TO ASSESS AND CONTROL CONTAMINATION

The most commonly used analytical tools for assessing and controlling sample contamination are blanks. By conventional nomenclature, blanks are samples that do not intentionally contain the analyte of interest but in other respects have, as far as possible, the same composition as the actual samples. Additional descriptors, such as internal, reagent, field, solvent, and others, are used to indicate which of the various stages of the sampling and analytical process the blanks are considered to represent. Because blanks, by definition, do not intentionally contain the analyte of interest, their utility in assessing and controlling sample contamination is limited to contaminants causing additive interferences. In this regard, results for blanks are taken as a direct measure of the non-analyze, or contaminant, signal for the corresponding samples.

Types of Blanks

Blanks play various roles in environmental measurements, depending on the analytical technique used and the goal of the blank measurements. Table (2) summarizes the types of blanks typically used in environmental measurements. The simplest blank, often called a system blank or instrument blank, is really not a blank at all the sense of simulating a sample. Rather, a system blank is a measure of the instrument background, or baseline, response in the absence of a sample. System blanks are often used in gas and liquid chromatographic methods to identify memory effects, or carry-over from high-concentration samples, or as a preliminary check for system concentration.

Table (2): Summary of Blank Types (Shacklette and Borngen, 1984)

Common Name	Other Names	Uses	Description
		Laboratory blanks	
System blank	Instrument blank	To establish baseline response of an analytical system in the absence of a sample	Not a simulated sample but a measure of instrument or system background response
Solvent blank	Calibration blank	To detect and quantitate solvent impurities; the calibration standard corresponds to zero analyte concentration	Consists only of the solvent used to dilute the sample
Reagent blank	Method blank	To detect and quantitate contamination introduced during sample preparation and analysis	Contains all reagents used in sample preparation and analysis and is carried through the complete analytical procedure
		Field blanks	
Matched-matrix blank		To detect and quantitate contamination introduced during sample collection, handling, storage, transport, preparation, and analysis	Made to simulate the sample matrix and carried through the entire sample collection, handling, and analysis process
Sampling media blank	Trip blank	To detect contamination associated with sampling media such as filters, traps, and sample bottles	Consists of the sampling media used for sample collection
Equipment blank		To determine types of contaminants that may have been introduced through contact with sampling equipment; also to verify the effectiveness of cleaning procedures	

Use of Blank Results

When properly used, blanks can be extremely effective tools in assessing and controlling sample contamination and in adjusting measurement results to compensate for the effects of contamination. Used improperly, blank results can increase the variability of analytical data or be very misleading. An important part of using blanks effectively is understanding and recognizing their limitations. As mentioned previously, blanks are ineffective in identifying interferences such as dilution or adsorption. Similarly, blanks cannot be used to spot non-contaminant error sources such as analyte losses due to volatilization or decomposition. Beyond these inherent limitations, the utility of blanks is determined largely by the manner in which they are used and the manner in which the results are interpreted. Blanks serve both control and assessment functions in environmental measurements. In their control function, blanks are used to initiate corrective action when blank values above prestablished levels indicate the presence of contamination. Blanks are most often used in this control mode in laboratory operations where feedback is more nearly real-time. At the first sign of unusual contamination, analyses may be stopped until the source is identified and the contamination eliminated. If possible, affected samples may then be reanalyzed. When field blanks indicate possible contamination, resampling is usually more difficult and often impossible. Therefore, field blank data are generally used primarily for assessment rather than control. If field blank data are used for control, this control is generally accomplished only over relatively long periods of time. In their assessment role, both field and laboratory blank data may be used to define qualitative and quantitative limitations of the associated measurement data. Where appropriate, these blank data may also be used as a basis for adjustments, however, should be made with caution, and the average of multiple blank measurements should be used for a stable, “in control” measurement system.

Control Charts for Blanks

Whether blank data are used primarily for ongoing control or for retrospective assessment, Shewhart control charts (Shewhart, 1984) provide the most effective mechanism for interpreting blank results. In the control mode, control charts can be used to detect changes in the average background contamination of a stable system. This detection is done by providing definitive limits, based on past performance, that signal when the level of contamination is greater than that which is attributable to chance causes. This signal allows corrective action to be initiated to identify and correct new or additional sources of contamination as they appear, before large numbers of samples are affected. In the assessment mode, control charts allow out-of-control periods to be easily identified so that corresponding sample data may be flagged or interpreted separately from the other data (Grant and Leavenworth, 1980). By identifying out-of-control periods, control charts also allow more reliable estimates to be made of the average background contamination level under normal in-control periods.

Control Charts for Individual Measurements

The problem of blanks not usually being run in replicate can be overcome by using a control chart for individual measurements. This special type of control chart is useful when no rational sub-grouping scheme arises, when performance measures can only be obtained infrequently, or when the variation at any one time (within a subgroup) is insignificant relative to variation over time (between subgroups).

Although they share the same statistical basis, control charts for individuals (X charts) are different from control charts for means (X charts) and ranges (R charts) in the way the range is calculated and in the sub-grouping scheme. For these reasons, individual control charts are interpreted somewhat differently than usual. In X charts, the chart reflects variability between subgroups (i.e., between means); in R charts, the chart is used to monitor variability within subgroups. In control charts for individuals, however, the range within a subgroup cannot be calculated because the subgroup size is one. Also, because individual measurements are plotted, a single chart combines all sources of variation.

The first step in preparation of an X chart for blanks is to tabulate historical data for blank measurements. This tabulation will consist of at least 20 individual results for the particular type of blank to be charted. After arranging the K results in chronological order, K-1 moving ranges are calculated, where the first moving range is the range between the second and third values, etc. next, the average of the values, etc. next, the average of the X measurements (X avg). Before calculating the control limits for the individual values, the moving ranges are screened by first calculating the upper control limit for the moving ranges as 3.27MR [The value 3.27 is the D4 value for calculating control limits for ranges having n=2, where n is the number of measurements in each subgroup] . Any moving ranges larger than the calculated control limits are removed, and then the average moving range is recalculated. Finally, the upper and lower control limits (UCL and LCL, respectively) for the individual values are calculated as

$$UCL = X + 2.66\ MR \tag{1}$$
$$LCL = X - 2.66\ MR \tag{2}$$

Although not tabulated in many tables of control chart factors, the value 2.66 used to calculated the control limits is the A_2 factor of calculating control limits for X, where n-1. Unless the average blank value is substantially greater than zero, the LCL may be negative and thus will not be meaningful. Only the UCL can be used in these cases.

In traditional X charts, the underlying assumption is that variability within a subgroup is representative of the system variability. Control limits for X are, thus, derived by using the within-subgroup range to estimate the standard deviation from which the control limits are calculated. In individual control charts, the moving range between subgroups (i.e., between the individual points) is used to estimate the standard deviation. Because pairs of consecutive measurements are more likely to be affected by similar special causes than are results from different points in time, screening the moving ranges prior to calculating the control limits minimize the contribution of these special causes. This screening prevents the control limits from being inflated by these special causes, as would be the case if the standard deviation was calculated by using all the original data points.

In using this approach, the problem still arises of dealing with zero and not detected values in the blank data from which the control limits are to be calculated. In this case, the average moving range must be estimated by using alternate data. Results for low-concentration standard solutions provide the best substitute. Obviously, if the blanks of interest are, for example, matched-matrix field blanks, standards should be prepared in a similar manner by spiking the appropriate matrix with the analyte of interest. In either case, the concentration of the standard should be in the same range as the estimated detection limit (i.e., between 1 and 5 times the estimated detection limit). At this level, imprecision should be of approximately the same magnitude as that for blanks. The actual control limits are calculated by using the average moving range for the standards and the mean blank value for similar blanks.

One limitation that should be considered in using an X chart is the increased sensitivity of the limits to the distribution of the measurements. X charts are less sensitive than X charts to the distribution of individual measurements because mean values are used. Means tens to be normally distributed. Because contamination tends to induce positive errors in blank measurements, the resulting distribution is likely to be skewed toward positive values. If inspection of the results indicates positively skewed values, the measurement data should be transformed prior to developing the control chart, and the transformed data should be charted. A logarithmic transformation is generally most appropriate for environmental data.

ASSESSMENT OF SAMPLE CONTAMINATION

Example of an X Chart for Blanks

As an example of the development and application of an X chart for blanks, consider the Ammonia data for years 2000 to 2002 analyzed by CLEQM. Assume that the results for blanks 1-24 represent historical data used to develop the example control chart, and the results for blanks 21-65 represent subsequent blank measurements. The completed control chart is shown in Figure (1).

The first step in developing the example control chart was to examine the distribution of the historical data. The raw results are significantly skewed as is often the case for blank data. Therefore, before proceeding further, the raw data were transformed by taking the natural logarithm of each value. This produced the transformed results A frequency histogram of the transformed data that shows significant improvement in the skewness of the distribution.

The next step in developing the example control chart was to calculate 23 moving ranges for the 24 chronologically ordered transformed results. The UCL for the moving range, 5.24, was obtained by multiplying the average moving range, 1.24 by 4.22. This moving range control limit was then used to screen the moving ranges prior to calculating the control limits for the blank measurements. Screening the moving ranges and removing any values exceeding the control limit prevent the control limits for the blank measurements from being inflated by values representing special causes. The 7th moving range (blank number 8), 4.80, exceeds the moving range control limit. Therefore, this value was removed, and the average moving range was recalculated to yield a value of 1.21. Finally, upper and lower control limits for the blank measurements were calculated as the average of the transformed results (-4.03) plus and minus 2.46 times the average of the screened moving ranges (1.21).

The completed control chart for this example, shown in Figure (1), illustrates how control charts for blanks are effective tools both for ongoing control and for retrospective assessment of blank results. In the blank indicate unusual contamination from an assignable cause and should initiate corrective action to identify and eliminate the source of additional contamination. In the case of field blanks, analyzing the samples and plotting the results may not be possible until after all of the samples are collected. In such cases, control charts are still useful in assessing the blank data by indicating both sporadic and systematic contamination problems and allowing the corresponding measurement data to be interpreted accordingly. The example control chart in Figure (1), for instance, shows shift in background contamination during the course of the hypothetical sampling and analytical effort. Such a shift might be the result of a change in sampling or analytical procedures, a change in personnel, a new lot of sample bottles, or any one of a number of other possibilities. Identification of these types of changes in background contamination allows field sample data to be ground and interpreted separately even if it is already too late eliminate the new source of contamination.

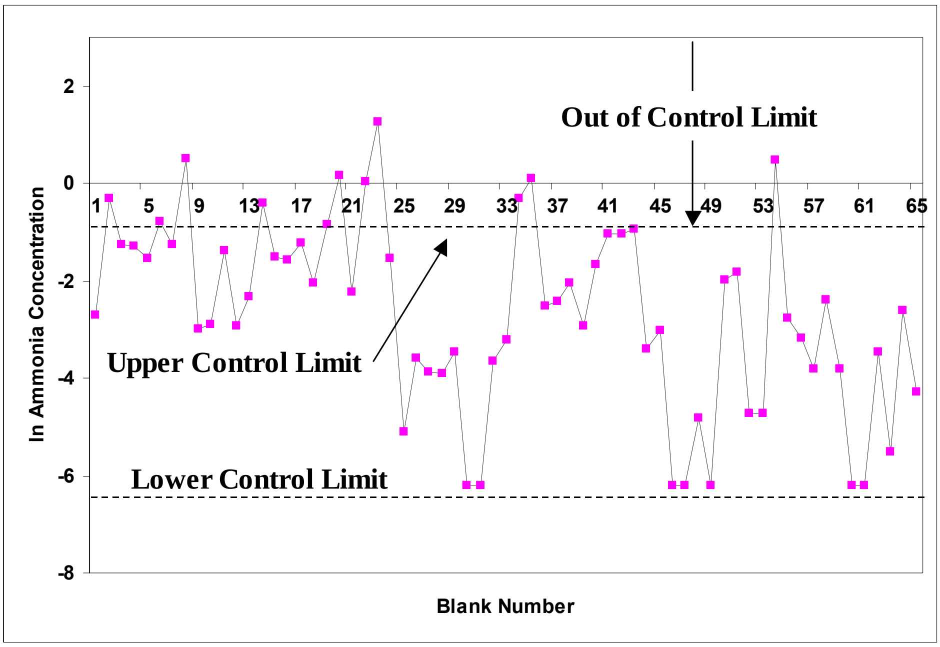

Fig. 1. X chart for Ammonia blank measurements

Assessing the Effectiveness of control Charts for Blanks

The key role of control charts in controlling contamination is in detecting out-of-control points in an otherwise stable measurement process. Although results inside control limits do not indicate the absence of contamination, they are an indication that the effect of contamination is stable. In such a case, systematic adjustment of the measurement data using the average blank value to correct for the background contamination may be appropriate. Blank results that fall outside control limits provide a signal that some new source of contamination has entered the measurement system. Just as establishing the absence of any given analyte in a sample is analytically impossible, establishing the absence of contamination in a measurement process by analyses of blanks is also impossible. The best that can be achieved is to reduce the risk of not detecting contamination to an acceptable level.

In assessing this level of risk in using blanks to detect changes in contamination, the frequency of the blank measurements, the magnitude of change in the level of contamination that one desires to detect, and the amount of variability in the measurement system must be considered. Using three-sigma limits on the average of n measurements, the probability, P, of not detecting a bias (Burr, 1976)

$$P = \Phi\left\{\left[\frac{(n)^{\frac{1}{2}} b}{\sigma}\right]\right\} - \Phi\left\{-3-\left[\frac{(n)^{\frac{1}{2}} b}{\sigma}\right]\right\}$$

of size b when the measurements are normally distributed and have a standard deviation of σ is

Where Φ is the cumulative distribution function of the standard normal distribution. The probability of detecting a bias of size b in m independent tests (each based on the average of n measurements), or P_D, is (Provost and Elder, 1985)

$$P_D = 1 - P^m \quad (3)$$

Where m denotes any power of P.

Consider, for example, a case in which an X chart is used monitor blank results for a particular analyte. In this case, historical data indicate that the average blank concentration of this analyte is 3 ppb, and the standard deviation is 4 ppb. What is the probability of detecting contamination greater than 10 ppb in a single blank? Because 10 ppb represents an increase of 7 ppb above background, b = 6. The subgroup size for X charts is one, so n= 1. In this case, m= 1 also because a single point on the control chart. Therefore,

$$= \Phi(1.25) - \Phi(-4.75)$$
$$= 0.894 - 0.000$$
$$= 0.894$$

and

$$P = \Phi\left\{3-\left[\frac{(1)^{\frac{1}{2}}(7)}{4}\right]\right\} - \Phi\left\{-3-\left[\frac{(1)^{\frac{1}{2}}(7)}{4}\right]\right\}$$

$$P_D = 1 - (0.894)$$
$$= 0.106$$

Thus, the probability if detecting in additional 7 ppb pf contamination is than 11% for a single blank analysis. If the additional contamination is from a constant source, the probability if detection improves somewhat with repeated measurements. However, because the standard deviation is relatively large compared to the added contamination, 24 measurements are required to attain a greater than 90% probability of detection. On the other hand, a shift if 20 ppb for the same measurement system would have a greater than 97% probability of being detected in a single measurement. Figure (2) illustrates the relationship by showing probabilities of detecting unusual contamination in a single blank analysis for measurement systems having standard deviations of 3,5 and 7 ppb. Contamination levels as high as 40 ppb are illustrated.

Control charts are most effective tool for detecting contamination when measurement variability is small relative to the level of contamination to be detected. Many measurements may be required to detect small shifts in background contamination. Also, in order for such shifts to be reliably detected even through repeated measurements, the additional contamination must be persistent. An assumption in equations 3 and 4 is that the problem persists at the same level until corrected. Although reasonable for many sources of contamination, this model is not applicable in all cases. If contamination occurs sporadically at low levels, then detecting the changes in contamination levels is much more difficult. In such cases, the only reasonable approach is to work on identifying eliminating the source or sources of contamination.

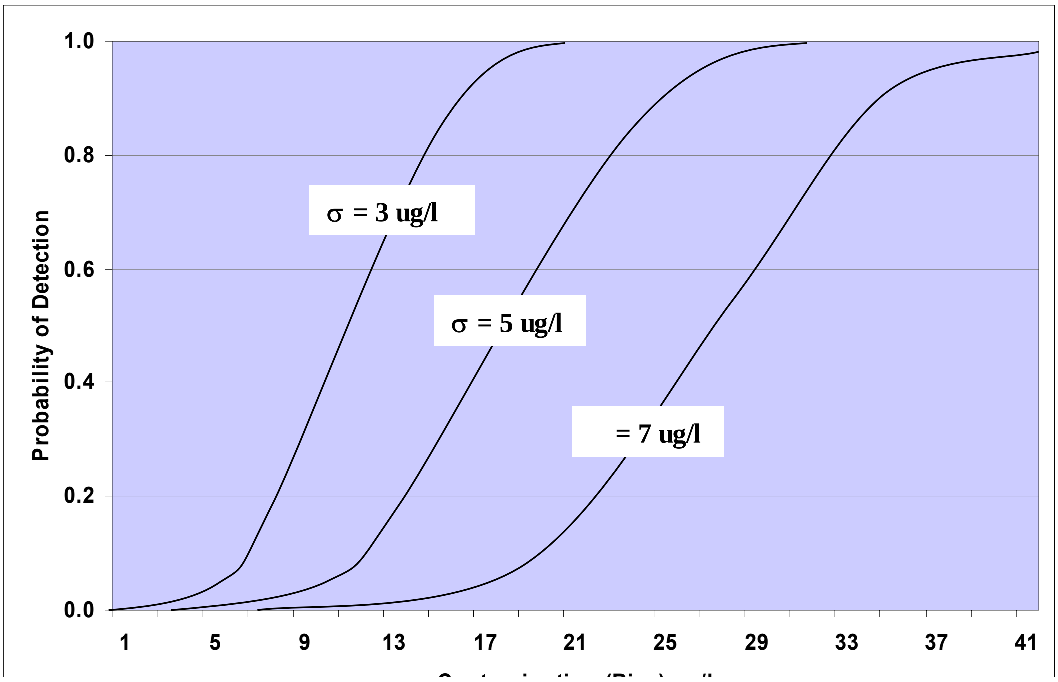

Fig. 2. Relationship between measurement variability and probability of detecting unusual contamination in a single blank measurement

CONCLUSIONS

Environmental sampling and analytical efforts numerous opportunities for sample contamination from a wide variety of different sources. Regardless of the source of contamination, the accuracy of the measurement process is affected. Because environmental measurements often address very low concentrations of analytes, contamination is an especially important source of potential error. To minimize error due to contamination, the potential sources of contamination must be identified and eliminated wherever possible.

Once a measurement system is established, appropriate types of blanks should be used to define background levels of contamination for the different parts of the sampling and analytical process. Blanks should also be used on an ongoing basis to assess and control contamination. In the assessment mode, the information provided by blanks may be qualitative or quantitative; blanks may be used as qualitative indicators of possible sample contamination or to derive quantitative estimates of background contamination levels. In the control mode, blanks are used to initiate corrective action when results above prestablished levels indicate unusual contamination.

Whether used primarily for assessment or for control, control charts should be used to maximize the effectiveness of blank measurements. Control charts for individual measurements, or X charts, are usually more appropriate for blanks than the more common X and R charts. Other types of control charts may be applicable or preferable under certain circumstances. Regardless of the type of control chart used, the risk of not detecting new sources of contamination in a measurement system depends upon the number of blank measurements, the magnitude of the effect of the new contamination, and the variability of the measurement system. This risk should be a primary consideration in developing the overall quality control strategy. By recognizing potential sources of contamination and using blanks to detect changes in background levels, reducing or correcting for contamination is generally possible, and the associated measurement biases can thus be reduced to acceptable levels.

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CHEMICAL SPECIATION OF SELECTED METALS IN GROUNDWATER USING GEOCHEMICAL MODEL

T. Tawfik*
* Director CLEQM-NWRC, Cairo (Egypt) E-mail: tawfic06@yahoo.com

INTRODUCTION

Groundwater contains a wide variety of dissolved inorganic species in various concentrations, as a result of chemical and biochemical interactions between groundwater and the geological materials through which it flows, and to a lesser extent because of contributions from the atmosphere and surface water bodies.

The availability of various inorganic constituents in groundwater is controlled by the reaction mechanism such as dissolution- precipitation reactions and adsorption in addition to the rates (kinetics) of the geochemical process.

Analytical techniques such as spectrometry and chromatography provide important information about the total metals concentration available in water, but ions in groundwater can form unlimited number of species due to the hydrolysis, complexation, and redox reactions.

The purpose of this study is to estimate the activities of various ionic species of manganese, copper, lead and Zinc in groundwater using geochemical models from the measured total metals concentrations.

The selected four metals are of great importance to water chemistry. Manganese is an essential element in plant metabolism, and its organic compounds may influence its occurrence in natural waters. Copper is used extensively in Modern industry, and consequently disposed in the environment. Zinc is widely used in metallurgy, principally as a constituent of brass and bronze or for galvanizing. Such applications tend to increase its level in the environment. Lead is also produced from various activities specially car emissions and is extensively deposited in the environment.

The Visual MINTEQ speciation model was used to calculate ion activities. The model is a geochemical speciation model that is capable of computing specific equilibrium ion activities among the dissolved and adsorbed species and their equilibrium solid phase. The model is able to consider the interaction of metals with major anions (Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-}) as a function of temperature and ionic strength and pH.

MATERIALS AND METHODS

Water Quality Data

The investigation of groundwater chemistry in the study area started with the chemical analysis of samples collected from 30 deep groundwater wells (more than 100 m depth) in El-Sadat City; Fig (1). Collected samples were analyzed for major cations; Na^+, K^+, $Ca^{2+}$and Mg^{2+} and four trace metals; Pb, Cu, Mn and Zn according to standard procedures for the Inductively Coupled Plasma Optical Emission Spectrometric (ICP-OES). Major anions (Cl-, SO_4^{2-}, and NO_3^-) were also analyzed according to standard procedures for ion chromatography, the CO_3^{2-} and HCO_3^- were determined by titration and solution pH values were measured using a microprocessor pH meter.

Geochemical modeling

Geochemical modeling of the water composition was conducted with the Visual MINTEQ Model developed for the USEPA. The model is used to perform the calculations necessary to simulate the contact of waste solutions with heterogeneous sediments or the interaction of groundwater with solidified wastes. The computer equilibrium model contains thermodynamic database which contains equilibrium constants for aqueous simple and complex species as well as solubility product and redox potential, in addition to other equilibrium parameters. Visual MINTEQ can calculate ion species/solubility, adsorption, oxidation-reduction, gas phase equilibrium, and precipitation/dissolution of solid phases.

The following parameters were used to formulate the input files for Visual MINTEQ

1. Equilibrium solution pH values.
2. Total concentration of cations and anions
3. Room temperature

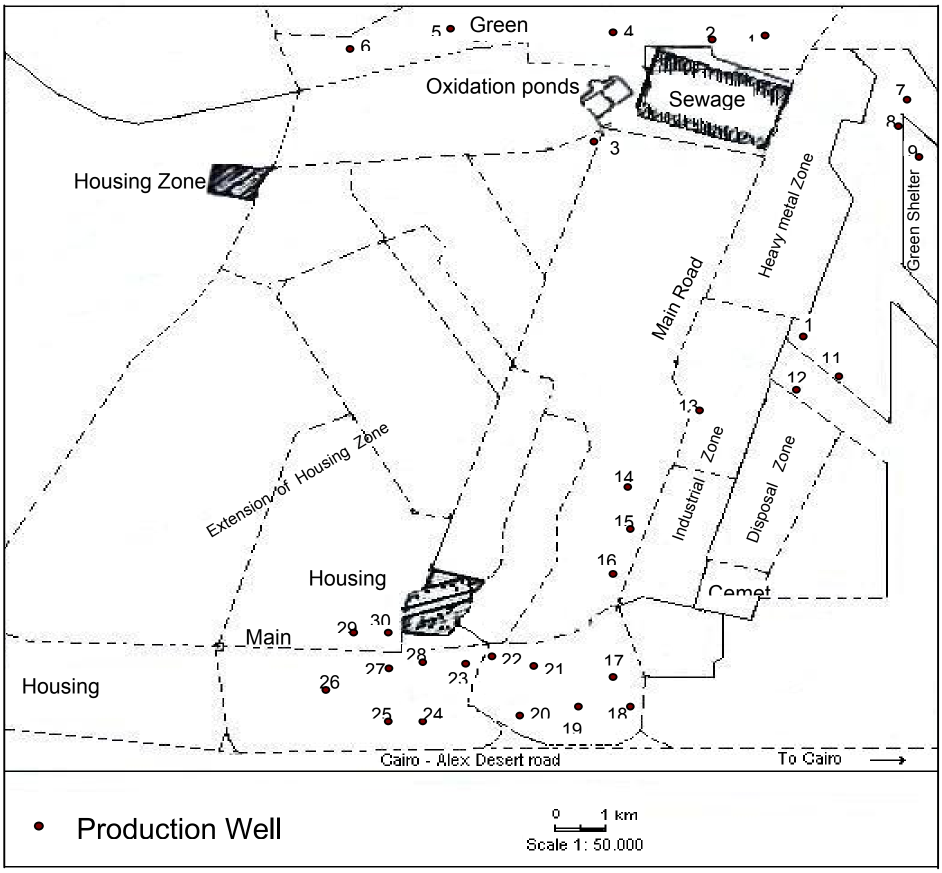

Fig. 1. The distribution of the tested wells in El-Sadat City

RESULTS AND DISCUSSION

Analytical data are provided in Table (I). The pH values for tested samples varied between 7.26 and 8.55. Manganese concentrations range was between 0.011 mg/l and 2 mg/l with an overall average of 0.093 mg/l. Copper was detected in only 13 samples with values less than 0.2 mg/l, and Zinc was detected in 22 samples with values less than 0.5 mg/l while lead was detected in 6 samples only out of the tested 30 well.

Tabulated analytical values of major cations, anions, trace metals and pH were used to create the input data file. Generated output by the model included the calculated ionic strength in analyzed samples and Activities of various metal ionic species whether free or complexed ions (Table 2).

Table 1. Results of chemical analyses for the groundwater wells in the study area

Serial		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
pH	-----	8.33	7.57	7.79	7.70	7.58	8.55	7.78	7.39	7.53	7.49	7.34	8.22	7.4	7.61	7.3
Major Cations																
Calcium	mg/l	58.3	42	63.5	88.7	22.3	19.5	35.6	65.5	31.3	41.2	27	39.4	33.5	37	52.5
Potassium	mg/l	6.2	4.92	8.8	7.1	5.55	2.84	4.43	6.28	8.57	7.51	3.96	4.28	13.5	4.18	4.8
Magnesium	mg/l	20.9	26.5	17.2	30.7	18.5	18.5	23.8	18.2	20.3	26.0	15.9	20.7	26.4	29.6	17.8
Sodium	mg/l	55.4	110	118	119	58.5	80.6	61.3	130	87.9	76.2	50.5	75.5	94.3	55.4	52.5
Major Anions																
Chloride	mg/l	58.4	85.7	110	203	61.7	75.5	59.1	116	80.9	63.4	38.1	74.3	72.5	50.2	39.4
Sulfate	mg/l	44.4	168	160	121	13.1	12	25.4	131	50.3	89.1	24.1	54.6	147	43.7	95.5
Bicarbonate	mg/l	281	190	200	223	190	224	261	265	223	250	204	238	186	262	210
Carbonate	mg/l	14.4	0.0	0	0	0.00	16.0	0.0	0.0	0.0	0.0	0.0	7.20	0.00	0	0.0
Nitrate	mg/l	0.75	5.5	5.1	7.0	5.56	6.47	0.99	4.75	10.7	0.82	0.98	1.1	3.78	5.08	1.62
Trace metals																
Copper	mg/l	n.d	0.04	0.01	0.05	0.12	0.05	n.d	n.d	0.19	n.d	0.12	n.d	0.04	0.08	n.d
Manganese	mg/l	0.13	0.09	0.03	0.2	0.02	0.01	n.d	0.08	0.13	0.12	0.08	0.1	0.06	0.06	0.01
Lead	mg/l	n.d	0.01	0.02	n.d	n.d	n.d	n.d	n.d	0.01	0.11	0.01	n.d	n.d	0.01	n.d
Zinc	mg/l	n.d	0.13	0.19	0.38	0.16	0.05	n.d	n.d	0.04	0.04	0.06	n.d	0.02	0.05	0.25
Serial		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
pH	-----	7.47	7.52	7.53	7.48	8.28	7.59	7.36	8.14	7.62	7.36	7.26	8.12	8.25	7.38	7.44
Major Cations																
Calcium	mg/l	31.5	37.7	29.6	40.6	34.4	35.8	38.2	36.5	45	27.5	29.5	42.5	38.3	23.9	53.5
Potassium	mg/l	3.9	4.20	5.63	5.87	5.40	3.19	4.30	5.98	4.23	2.41	4.07	3.11	2.33	6.23	4.30
Magnesium	mg/l	20.2	14.4	17.5	18.7	20.2	18.6	19.2	10.2	13.6	17.1	14.3	17.7	15.8	27.1	10.2
Sodium	mg/l	42.5	69.8	89.0	77.4	75	60.9	65	48.7	64.6	70.5	55.5	14.2	89.6	34.3	28.7
Major Anions																
Chloride	mg/l	38.6	48.4	69.5	68.9	58.6	60.3	32.6	39.7	72.5	59.6	42.2	12.6	95.7	35.5	39.6
Sulfate	mg/l	22.8	52.5	62.2	35.5	54.6	21	58.8	13	58.5	12.6	45.2	21.6	23.5	10.3	28.3
Bicarbonate	mg/l	210	230	220	260	245	240	251	221	186	235	180	213	239	229	184
Carbonate	mg/l	0.0	0.0	0.0	0.0	9.60	0.00	0.00	12.4	0.00	0.00	0.00	18.4	12.0	13.2	0.00
Nitrate	mg/l	4.6	3.94	5.7	3.83	3.93	0.98	5.06	1.17	3.51	3.92	4.32	3.19	2.23	2.21	3.12
Trace metals																
Copper	mg/l	0.02	0.02	0.11	n.d	n.d	n.d	n.d	n.d	n.d	n.d	0.15	n.d	n.d	n.d	n.d
Manganese	mg/l	0.1	0.05	0.03	0.14	0.04	0.09	0.02	0.03	0.01	0.09	0.03	0.05	0.02	0.03	0.05
Lead	mg/l	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Zinc	mg/l	0.01	0.01	0.11	0.11	0.01	0.04	0.15	0.44	n.d	0.1	0.06	n.d	n.d	0.31	n.d

n.d= not detected

Table 2. Summary of Visual MINTEQ output file containing activities and concentrations of metals ionic species

species	Conc. mol/l	Activity mol/l	species	Conc. mol/l	Activity mol/l	species	Conc. mol/l	Activity mol/l
Cu(CO3)2-2	1.323E-07	7.464E-08	Zn+2	1.356E-05	0.0000076 51	MnOH+	1.423E-09	1.233E-09
Cu(NO3)2(aq)	3.23E-16	3.247E-16	ZnCl+	1.636E-07	1.418E-07	MnSO4 (aq)	1.394E-07	1.401E-07
Cu(OH)2 (aq)	7.74E-09	7.778E-09	ZnCl2 (aq)	1.553E-09	1.561E-09	Pb(CO3)2-2	5.29E-08	2.984E-08
Cu(OH)3-	1.342E-11	1.163E-11	ZnCl3-	1.062E-11	9.201E-12	Pb(NO3)2(aq)	1.513E-14	1.52E-14
Cu(OH)4-2	1.183E-16	6.675E-17	ZnCO3 (aq)	6.243E-06	0.0000062 74	Pb(OH)2 (aq)	7.122E-10	7.157E-10
Cu+2	4.111E-08	2.319E-08	ZnHCO3+	1.171E-06	0.0000010 15	Pb(OH)3-	6.021E-13	5.218E-13
Cu2(OH)2+2	1.066E-10	6.015E-11	ZnNO3+	4.203E-09	3.642E-09	Pb(OH)4-2	1.652E-16	9.318E-17
CuCl+	3.109E-10	2.694E-10	ZnOH+	5.657E-07	4.903E-07	Pb(SO4)2-2	9.769E-11	5.512E-11
CuCl2 (aq)	6.392E-13	6.424E-13	ZnOHCl (aq)	1.364E-07	1.371E-07	Pb+2	3.005E-08	1.695E-08
CuCl3-	5.015E-17	4.346E-17	ZnSO4 (aq)	1.723E-06	0.0000017 32	Pb2OH+3	3.023E-14	8.34E-15
CuCl4-2	3.055E-21	1.723E-21	Mn(NO3)2(aq)	1.071E-13	1.076E-13	Pb3(OH)4+2	2.352E-16	1.327E-16
CuCO3 (aq)	1.936E-06	1.946E-06	Mn(OH)3-	5.318E-18	4.609E-18	Pb4(OH)4+4	1.878E-19	1.902E-20
CuHCO3+	7.084E-09	6.14E-09	Mn(OH)4-2	1.923E-23	1.085E-23	PbCl+	5.082E-09	4.404E-09
CuNO3+	1.602E-11	1.388E-11	Mn+2	1.358E-06	0.0000007 66	PbCl2 (aq)	1.452E-10	1.459E-10
CuOH+	5.679E-08	4.922E-08	MnCl+	8.314E-09	7.205E-09	PbCl3-	5.101E-13	4.421E-13
CuSO4 (aq)	5.438E-09	5.465E-09	MnCl2 (aq)	7.567E-11	7.605E-11	PbCl4-2	2.61E-15	1.473E-15
Zn(NO3)2(aq)	1.342E-13	1.348E-13	MnCl3-	1.806E-13	1.565E-13	PbCO3 (aq)	7.225E-07	7.261E-07
Zn(OH)2 (aq)	6.414E-08	6.446E-08	MnHCO3+	7.583E-08	6.572E-08	PbHCO3+	6.098E-08	5.285E-08
Zn(OH)3-	2.718E-10	2.355E-10	MnNO3+	2.627E-10	2.276E-10	PbNO3+	5.4E-11	4.68E-11
Zn(OH)4-2	1.212E-14	6.837E-15	MnO4-	1.788E-16	1.55E-16	PbOH+	3.582E-08	3.104E-08
Zn(SO4)2-2	2.847E-08	1.606E-08	MnO4-2	5.177E-18	2.921E-18	PbSO4 (aq)	8.671E-09	8.714E-09

Chemical speciation of Manganese

In natural water system dissolved manganese will be often in +2 oxidation state. The results indicate that Mn^{+2} is predominate in most situations and it is often the most soluble Chemical species of manganese and represented about 91.3 % of the manganese. Complexed species were 4.46 % as carbonates, 3.96 % as sulfates, and less than 0.3 % with other anions Fig. 2.

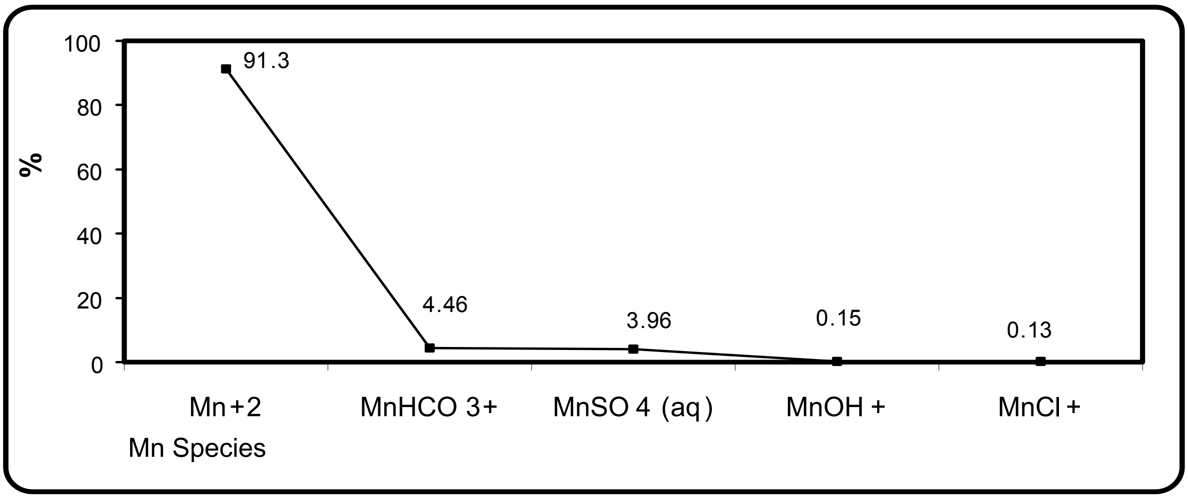

Fig. 2. Percent distribution of manganese ionic species

Chemical speciation of Copper

Copper may occur in solution either as Cu^{+2} or Cu^{+} based on the oxidation state. The redox conditions in oxygenated water favors the more oxidized form (Cu^{+2}). Cupric ions (Cu^{+2}) form complexes with a number of ligands, a strong $CuCO_3$ (aq) appears likely to be the major form in natural water containing dissolved CO_2. Chemical speciation of copper in groundwater samples estimated that 4.8 % of copper is in the free ionic form (Cu^{+2}) and the predominated copper form in groundwater is carbonate (87.9 %), Fig (3).

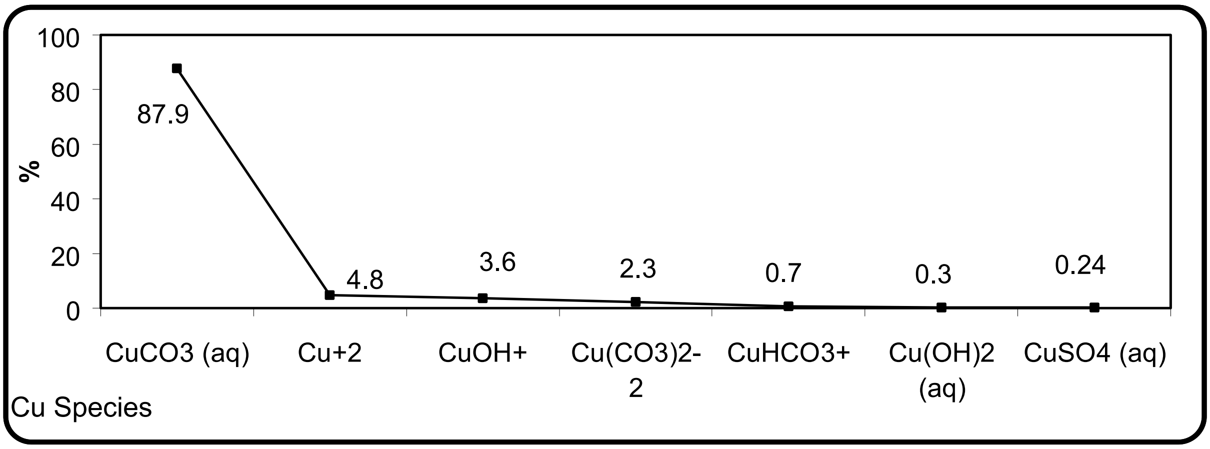

Fig. 3. Percent distribution of copper ionic species

Chemical speciation of Zinc

Zinc has only one significant oxidation state Zn^{+2} and it tends to be soluble in most types of natural waters than copper. Chemical speciation of zinc with different anions is shown in Fig. (4), about 60 %

of zinc exists as free ion (Zn^{+2}), about 31 % as carbonates and bicarbonate, 4.9 % as hydroxides 3.4 % as sulfates, and less than 0.5 % with other anions.

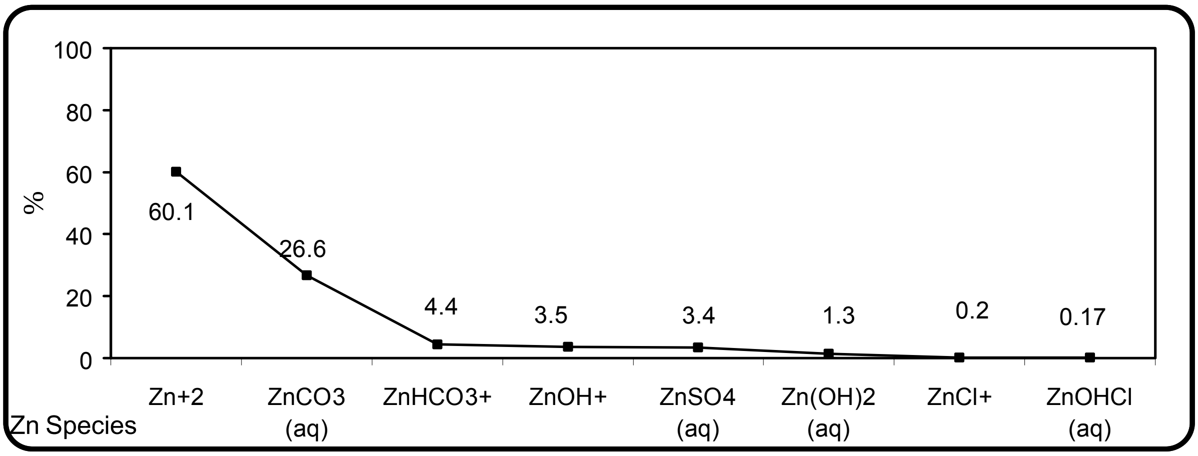

Fig. 4. Percent distribution of zinc ionic species.

Chemical speciation of lead

Chemical speciation of lead with various anions is shown in Fig. 5. About 6.7 % of lead exist in the free ionic form (Pb^{+2}) and the predominate form of lead in groundwater is the carbonate form (73%).

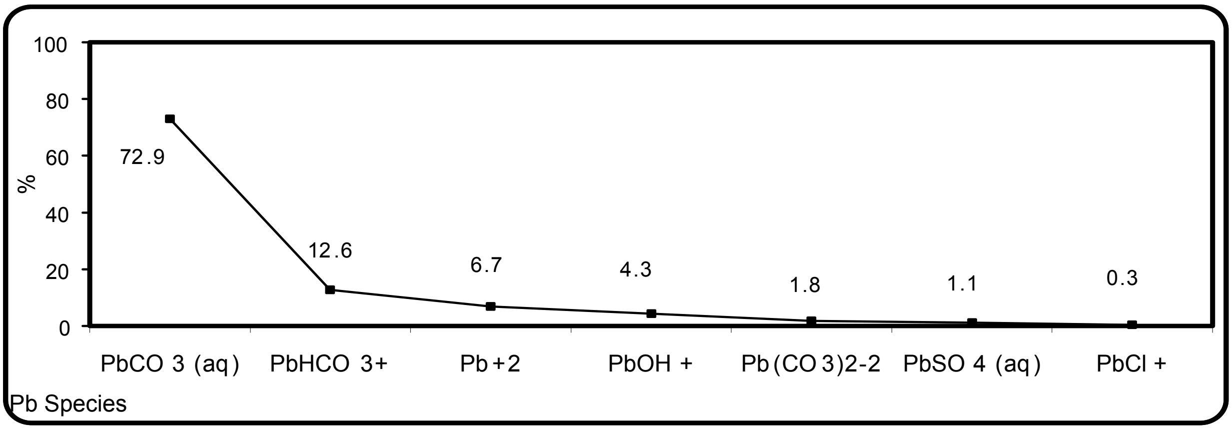

Fig. 5. Percent distribution of lead ionic species

CONCLUSION

The study findings based on model calculations indicated that Mn^{+2} is highly soluble and consequently will be bioavailable at the pH range of tested wells. Zinc is also expected tp be bioavailable as 60% of the total zinc is presented as Zn^{+2}. The law values of Cu^{+2} and Pb^{+2} are highly related to the alkaline pH values and organic complexation of the two ions.

Identifying ionic distributions is of particular importance as pollutants affect the groundwater environment by the chemical behavior of the ionic species and transformation of species than by total concentrations. The adverse effects of highly soluble free Mn^{+2} and Zn^{+2} are important in groundwater chemistry because their inherent toxicities `are related to the bioavailability.

The results suggest that Mn^{+2} and Zn^{+2} at such level would be available for uptake by plants, animals and humans. It is highly possible that such conditions may constitute a negative health impact. The model findings also suggest that Cu^{2+} and Pb^{2+} levels do not represent a health risk.

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PART FOUR

NON CONVENTIONAL WATER RESOURCES MANAGEMENT

EFFECTIVE NATURAL WASTEWATER TREATMENT SYSTEMS IN RURAL AREAS OF EGYPT

T. Tawfik*
* Director CLEMQ/NWRC, Cairo, Egypt. E-mail: tawfic06@yahoo.com

INTRODUCTION

In Egypt, drainage water is actually a combination of agricultural drainage water, industrial effluents, and sewage water with different ratios. Agricultural land drainage is and will continue to be a vital and necessary component of agricultural production systems. Due to scarcity of water resources, drainage water is being reused. Currently about 5.5 Billion Cubic Meters (BCM) of drainage water are being reused after mixing with fresh water. This amount is expected to increase up to 9.6 BCM by the year 2017.

Another form of reuse is being carried out where drainage water is reused without mixing with irrigation water. A major concern when considering drainage water reuse is whether the drainage water quality is within the allowable limits for different uses as outlined by the national and international water quality standards and guidelines.

Identifying appropriate treatment options for improving drainage water quality has a high priority since villages without sanitation facilities can be expected to continue discharging their sewage to near by agricultural drains. Contamination of drainage water by untreated domestic sewage negatively impacts human health of downstream users and limits drainage water reuse.

The objective of this paper is to investigate the potentiality of the in-stream wetland treatment system as the most appropriate natural treatment systems that can be used in rural areas of Egypt. The treatment process and governing equations simulating the treatment process and design criteria is presented as well.

Conventional treatment versus natural treatment system

The ideal system should satisfy the following criteria as indicated USEPA, 1992:

- Health criteria: Pathogenic organisms should not be spread either by direct contact with sewage or indirectly via soil water or food. The treatment chosen should achieve a high degree of pathogen destruction.
- Reuse criteria: the treatment process should yield a safe product for reuse, preferably in aquaculture and agriculture.
- Ecological criteria: in those cases when the wastewater cannot be reused, the discharge of effluent into surface water should not exceed the self-purification capacity of the recipient water.
- Nuisance criteria: the degree of odor release must be below the nuisance threshold. No part of the system should become aesthetically offence.
- Cultural criteria: the methods chosen for wastewater collection, treatment and reuse should be compatible with local habits and social practice.
- Operational criteria: The skills required for the routine operation and maintenance of the system components must be available locally or are such that they can be acquired with only minimum training.
- Cost Criteria: Capital and running costs must not exceed the community's ability to pay. The financial return from reuse schemes is an important factor in this regard.

Feature of conventional treatment

The conventional treatment system is good for urban areas and big cities since it does not need large space to put the wastewater treatment units. The detention time needed to implement the treatment processes is short if compared with other non-conventional treatment systems. The main disadvantage of the conventional treatment is the design and construction high cost plus the following items:

- Operation and maintenance of conventional wastewater treatment relies heavily on electrical machinery pumps, sludge scrapers, aerators that require considerable skills in installation, operation and maintenance.
- Odor in hot climate sewage can quickly become smelly if sufficient oxygen is not made available to prevent the onset of anaerobic conditions.
- Fecal coliform reduction is relatively low comparing with natural systems because of the short detention time.

Features of the natural treatment systems

Using the Natural Treatment Systems for Wastewater has several advantages, among them:

- Treatment efficiency is high, especially biological load treatment.
- Required relatively low capital investment if flat land is available at reasonable price.
- Easy operation and maintenance
- Suitability for hot climate.

If land is not available, especially if the site located inside an attraction area or administration zone inside large cities, the natural treatment system would be very expensive and infeasible. In addition, the detention time needed for complete treatment in natural system is relatively long if compared with the conventional treatment systems.

In-stream wetland system performance expectation

Wetland system can reduce high levels of BOD, suspended solids and nitrogen as well as significant levels of metals; trace organic and pathogens (Wetzel, 1993). The removal of settable organic is very rapid in all wetland systems and is due to the quiescent conditions in the free water surface types and to deposition and filtration in the vegetated submerged bed VSB systems. Similar results have been observed with the over flow of systems where close to 50% of the applied BOD is removed in the first few meters of travel down the treatment slope, see Table 1 (Mitsch, 1993).

Table 1. The expected performance of the wetland systems (Mitsch, 1988)

Parameter	Inflow	Outflow	%Removal
TSS mg/l	130	21	84
BOD mg/l	40	17	57
COD mg/l	200	92	54
Total P mg/l	5	2.5	50
Total N mg/l	12	5	58
NH4-N mg/l	10	5	50
FC MPN/100ml	$3*10^5$	$3*10^4$	One order

Main elements of a typical in-stream wetland treatment system

Figure (2) illustrates a typical in-stream wetland treatment system which consists of the following elements (Harza, 2000):

- Sedimentation zone to reduce suspended matter load
- Two aquatic plant zones to enhance biological treatment process
- Number of submerged berms (two to three) to mange the detention time required for treatment
- Floating vegetation barriers (two to three) to avoid weed and vegetation spreading

- Control weir to manage the treated effluent discharge

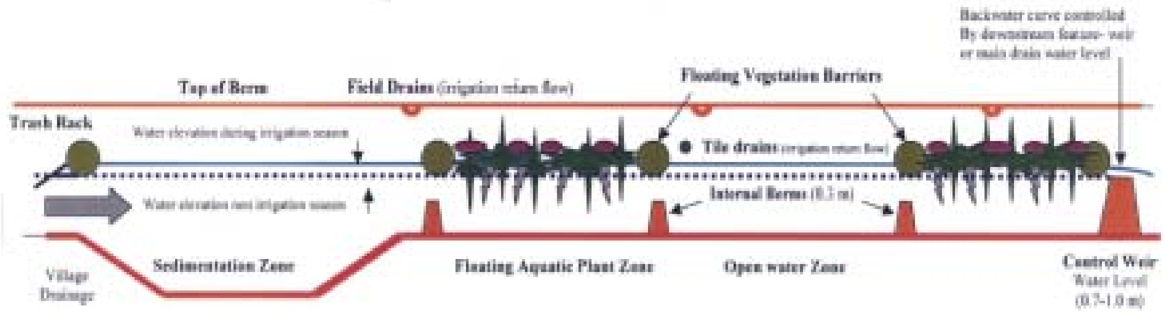

Figure 1. Profile view of an in-stream wetland treatment system

IN-STREAM WETLAND DESIGN CRITERIA

Organic waste removal and land requirement

The design equation of wetland systems considers the environmental conditions especially the evapo-transpiration losses since it affects on the large surface area of the basin. Also, filter media condition is taken into consideration. Therefore, the equations would be as mentioned in (Reed *et al.*, 1988) as follows

$$\frac{C_e}{C_i} = 0.52 \exp\left[-\frac{0.7\, K_t\, (A_v)^{1.75}\, L\, W\, d\, n}{Q}\right] \qquad (1)$$

$$K_t = 0.0057\,(1.1)^{T-20} \qquad (2)$$

Where:
C_e = effluent BOD (mg/l)
C_i = influent BOD (mg/l)
K_t = the rate constant at water temperature (day^{-1})
A_v = specific surface area for for microbial activity (m^2/m^3)
n = porosity of system (decimal fraction)
L = length of pond at surface water (m)
W = width of pond at surface water (m)
d = Depth of the pond (m)

When the bed slope or hydraulic gradient is equal to 1 percent or greater it is necessary to adjust the equation to (Bingham, 1994)

$$\frac{C_e}{C_i} = 0.52 \exp\left[-\frac{0.7\, K_t\, (A_v)^{1.75}\, L\, W\, d\, n}{4.63\, s^{1/3}\, Q}\right] \qquad (3)$$

The next assumptions will be used as design criteria for the free water surface wetlands:

- The specific surface area (A_v) for attached microbial growth = 15.7 m^2/m^3
- Porosity (n) of wetland flow path = 0.75
- Aspect ratio (L/W) > 10:1
- Water depth in warm months < 10 Cm and in cool months < 45 Cm

Then the hydraulic residence time will be as follows:

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{65\, K_t} \qquad (4)$$

If the bed slope or hydraulic gradient is equal to 1 percent then

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{301\, s^{1/3}\, K_t} \qquad (5)$$

The surface area of the wetland is given by

$$A = \frac{Q(\ln C_i - \ln C_e - 0.6539)}{65\, K_t\, d} \qquad (6)$$

And if the bed slope or hydraulic gradient is equal to 1 percent then

$$A = \frac{Q(\ln C_i - \ln C_e - 0.6539)}{301\, s^{1/3}\, K_t\, d} \qquad (7)$$

Pathogen removal

Pathogen removal in many wetland systems is due to essentially the same factors as in facultative pond systems. Equation (7) can be used to estimate the removal of bacteria and virus in wetland systems where the water path is above the surface. Although the detention time is less in constructed wetlands as compared with ponds, the opportunities for adsorption and filtration will be greater. (Johnston, 1993)

Suspended solids removal

Suspended solids removal is very effective in both types of constructed wetlands. Most of the removal occurs with in the few meters beyond the inlet, owing to the quiescent conditions and the shallow depth of liquid in the system (Reed *et al*., 1988)

Nitrogen removal

Nitrogen removal is very effective in both the free water surfaces, submerged flow constructed wetlands, and the major removal mechanisms are similar for both. Although plant uptake of nitrogen does occur, only a minor fraction of the total nitrogen can be removed in this system. (Reed *et al*., 1988). The major contribution to nitrogen removal, as with the hyacinth systems, is believed to result from nitrification/denitrification. (Hammer, 1990). In constructed wetlands, nitrogen removal ranges between 25-85 percent. Reed stated that the total nitrogen removal is up to 79 percent at nitrogen loading rates up to 44Kg/(ha. day) in a variety of wetland systems.

PILOT STUDY IN THE NILE DELTA OF EGYPT

Study outline

One of the key elements impacting the in-stream wetland biological treatment efficiency is the used vegetation type. Pilot study in the Nile Delta drain system was conducted to:

- demonstrate the technical feasibility of the in-stream study
- define the most appropriate vegetation type for the Egyptian environment to be used in the in-stream treatment system

Further, certain performance and design attributes can be evaluated and enhanced in the proposed demonstration study to be incorporated into a full-scale implementation. A preliminary survey was done on three plant species, which are:

- Emerged plant : Cyperus Rotundus and Phragnites Australis
- Floating plant : Eichhornia Crassipes (Water Hyacinth)

Three polluted tributary drains by domestic wastes were selected where they have mostly the same physical, hydraulic and water quality characteristics and each of them were covered by one of the concerned vegetation (dominant). The following table illustrates the characteristics of the studied drains.

Table 2. Physical and hydraulic characteristics of the studied drains

Drain	Studied Reach Length (Km)	Average width (m)	Flow m^3/day	Detention time (Day)	Dominant Species
D1	4.5	3.2	4,320	0.67	Cyperus Rotundus
D2	3.75	3.0	5,120	0.61	Phragnites Australis
D3	4.2	3.5	4,890	0.59	Eichhornia Crassipes

Short term monitoring scheme

Short term monitoring scheme was conducted covering three months of April to June 2003. Water sampling frequency was adopted to be three time a month and in total nine samples were collected for each monitor sites. For each monitor drain, two sampling sites were defined; one site upstream the concerned reach and the other site downstream the reach.

Biological Oxygen Demand (BOD_5) was used as an indicator for removal performance assessment for the three selected species. BOD was analyzed using ORION BOD fast respirometry system model 890 with a measuring range 0 to 4000 mg/l at 20 ^oC incubation in a thermostatic incubator chamber model WTW.

Species performance analysis and assessment

The overall in-stream wetland treatment efficiency varies between 60% to 85% based on the designed detention time and the sedimentation zone. Normally, the minimum detention time can be define as four days and the sedimentation zone can contribute to about 25% to 30% of the overall treatment efficiency. So, it is expected that the performance of the concerned species can varied between 25% to 35% where in nature the detention time in drain almost below a day and no sedimentation zone was constructed. Following is the performance assessment of the concerned vegetation species.

Cyperus Rotundus

The average BOD influent and effluent concentrations are 86 mg/l and 58 mg/l respectively as shown in Figure (2) with an average BOD removal of Cyperus Rotundus is about 32%.

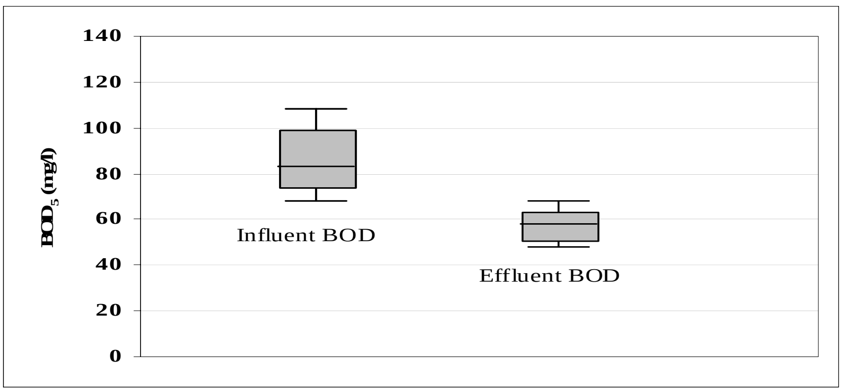

Fig. 2. Box Whisker Plot for BOD concentrations of Cyperus Rotundus case Phragnites Australis

The average BOD influent and effluent concentrations are 88 mg/l and 55 mg/l respectively as shown in Figure (3) with an average BOD removal of Phragnites Australis is about 37%

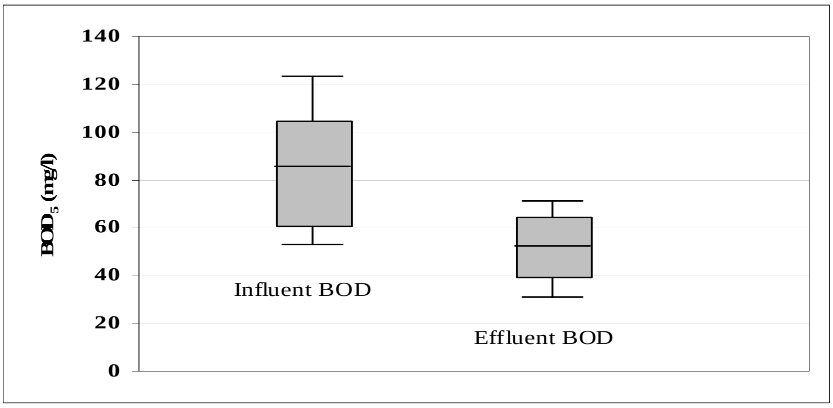

Fig. 3. Box Whisker Plot for BOD concentrations of Phragnites Australis case

Eichhornia Crassipes

The average BOD influent and effluent concentrations are 102 mg/l and 71 mg/l respectively as shown in Figure (4) with an average BOD removal of Eichhornia Crassipes is about 29%.

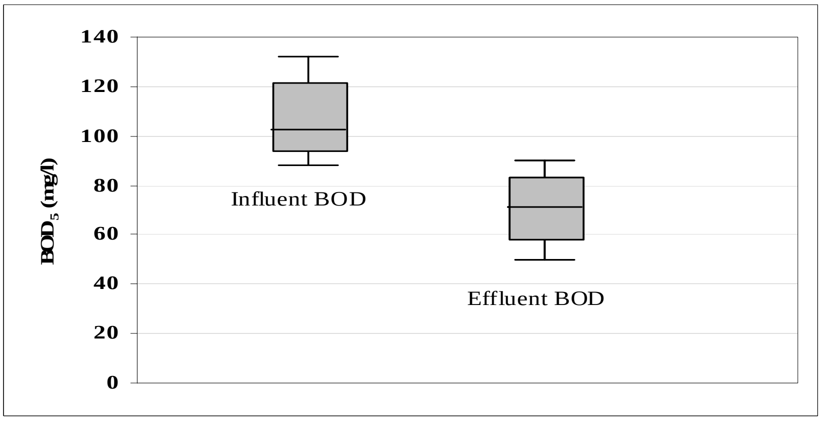

Fig. 4. Box Whisker Plot for BOD concentrations of Eichhornia Crassipes case

It can be concluded from the above analysis that the performance of the studied aquatic species varies in narrow range as presented in the following Table.

Table 3. Summary of aquatic species removal efficiency for BOD

Dominant Species	Detention time (Day)	Removal Efficiency %
Phragnites Australis	0.61	37
Cyperus Rotundus	0.67	32
Eichhornia Crassipes	0.59	29
Average	0.62	33

Expected performance for a full scale study

The following figure illustrates the expected performance of the in-steam wetland treatment system for a full-scale system considering the three studied aquatic species, which requires the following:

- a sedimentation zone with detention time of half day
- floating aquatic zones with detention time varies between one to four days

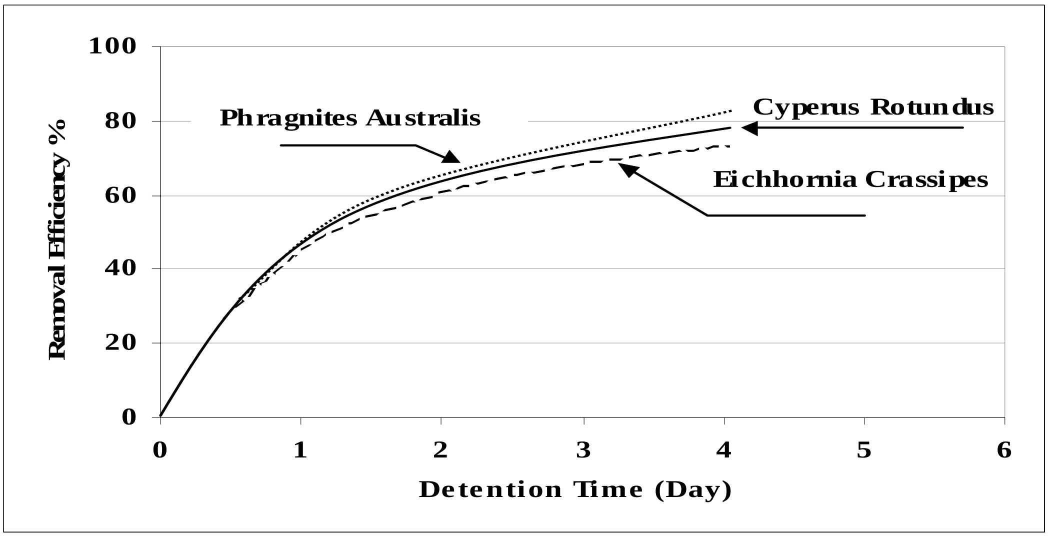

Fig. 5. The expected efficiency of the in-stream wetland for studied species

Figure (5) shows that, in case of detention time one day, the overall efficiency of the in-stream wetland can reach up to 40%, 45% and 50% for Eichhornia Crassipes, Cyperus Rotundus and Phragnites Australis respectively. Those values can reach 75%, 80% and 85% for four days detention time.

The performance of the in-steam wetland treatment system under Egyptian condition is equivalent to the primary to secondary conventional treatment and based on the designed detention time and aquatic species used.

CONCLUSIONS AND RECOMMENDATIONS

The sanitation facilities of Egyptian rural areas are facing lags far behind potable water supply. Economics of scale make conventional wastewater treatment cost prohibitive in smaller more dispersed rural settlements. Domestic wastewater is typically discharged directly or indirectly to drainage canals. This practice has contributed to widespread degradation of drainage water quality and, so, the reuse of drainage water plans in Egypt.

Identifying appropriate treatment options for improving drainage water quality has a high priority since villages without sanitation facilities can be expected to continue discharging their sewage to near by agricultural drains and contamination of drainage water by untreated domestic sewage negatively impacts human health of downstream users and limits drainage water reuse.

Several treatment alternatives that vary in efficiency and cost are available. In general, the advantages of using natural biological processes relate to their "low-tech/no-tech" nature, which means that these systems are relatively easy to construct and operate, and to their low cost, which makes them attractive to communities with limited budgets. However, their simplicity and low cost may be deceptive in that the systems require frequent inspections and constant maintenance to ensure smooth operation. Concerns include hydraulic overloading, excessive plant growth, and loss of exotic plants to natural watercourses. In-stream wetland treatment system has additional advantage that it requires limited land where the treatment process takes place inside the drain.

One of the key elements impacting the in-stream wetland biological treatment efficiency is the used vegetation type. Pilot studies in the Nile Delta drain system were conducted to demonstrate the technical feasibility of the in-stream study and to define the most appropriate vegetation type for the Egyptian environment. Three vegetation species were tested including Emerged plant Cyperus Rotundus, Phragnites Australis and Eichhornia Crassipes (Water Hyacinth). Short-term intensive monitoring scheme was conducted covering three months of April to June 2003.

It study shows that the performance of the studied aquatic species varies in narrow range from 29% to 37% and within the expected treatment efficiency for hydraulic detention below one day. The overall efficiency of the in-stream wetland including sedimentation zone can reach up to 40%, 45% and 50% for Eichhornia Crassipes, Cyperus Rotundus and Phragnites Australis respectively. Those values can reach 75%, 80% and 85% for four days detention time.

The performance of the in-steam wetland treatment system under Egyptian condition is expected to be equivalent to the primary to secondary conventional treatment and based on the designed detention time and aquatic species used.

It is recommended to conduct a full pilot scale in-stream wetland treatment system to be able to design the system under the Egyptian conditions. To minimize the failure risk, three elements should be considered; public acceptance and participation, dredging management of sediments and vegetation control.

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GESTION DE L'IRRIGATION AVEC LES EAUX NON CONVENTIONNELLES

M. Kessira *
* Republique Algerienne Democratique et Populaire, Ministere de L'agriculture et du Developpement Rural, Direction de Développement Agricole dans les Zones Arides et Semi-arides

INTRODUCTION

Il est reconnu que l'irrigation apporte aux agriculteurs la possibilité de lever un certain nombre de contraintes dont celles liées aux aléas climatiques. Tout en permettant la diversification, l'irrigation joue un rôle important dans les domaines techniques et socio-économiques.

A l'échelle de l'exploitation, l'irrigation permet de diversifier les cultures, elle améliore la productivité des exploitations et facilite la stabilisation des productions.

L'irrigation qui constitue, en volume, un des plus importants consommateurs d'eau a, par le potentiel agricole qu'elle permet de valoriser, un effet très marquant sur l'aménagement de l'espace rural.

A l'échelle régionale et nationale l'irrigation contribue à l'amélioration du PIB ainsi que la structuration de l'espace en apportant des changements significatifs à l'aménagement d'un territoire (espaces humidifiés, espaces couverts de réseaux d'irrigation,…) et en contribuant à la mise en place et le développement de microclimats favorables.

En terme d'économie, la maîtrise des stress hydriques permet, tout en ouvrant l'éventail des spéculations, d'agir sur les doses à apporter et donc d'économiser de façon significative la consommation en eau d'irrigation. En contribuant à l'augmentation de la production agricole elle permet d'éviter, au maximum, les risques liés aux aléas climatiques et économiques. .

L'irrigation permet également de modifier l'assolement afin de mieux maîtriser les effets de la monoculture ou les techniques culturales, ou des problèmes phytosanitaires et de rentabiliser les charges inhérentes à cette technique.

Par un système de production à revenu plus élevé, l'irrigation sert aussi à améliorer la rémunération de la main d'œuvre et assurer son maintien, en particulier celui des jeunes, dans les exploitations de type familial sur de petites superficies.

L'irrigation joue un rôle essentiel dans l'entraînement des autres activités. Les effets liés à l'utilisation des techniques d'irrigation moderne se traduisent sur le terrain par l'installation et le développement d'un certain nombre d'activités et d'entreprises prolongeant ou accompagnant la mise en place des équipements et infrastructures d'irrigation et de drainage.

Ressources en eau en Algérie

Depuis un certain nombre d'années, il est observé le développement de plusieurs phénomènes de dégradation qui affectent gravement l'écosystème en général et le potentiel agricole en particulier, risquant par-là d'entraver l'activité et la production agricole.

En Algérie, la plupart des périmètres irrigués sont confrontés aux problèmes de la rareté de l'eau d'irrigation qui différent selon les régions bioclimatiques et agro-pédologiques ; la dégradation avancée du sol suite à l'action conjuguée de l'irrigation non maîtrisée, la salinité des eaux, l'insuffisance et/ou l'absence de drainage et la rareté des amendements organiques est remarquable.

La dimension de ce problème qui touche pratiquement une grande partie des terres agricoles constitue une contrainte majeure au développement agricole ; qui tend par ailleurs, à prendre plus d'importance avec les diverses extensions. Le problème de salinité est rencontré pratiquement au niveau de la quasi-totalité des terres agricoles.

Cette situation a conduit à un appauvrissement des sols qui se traduit par une régression de la productivité et limite très sérieusement la pratique des cultures, ainsi que l'accentuation de la salinisation et le problème d'évacuation des eaux excédentaires, ce qui fait courir un grand risque au développement de l'agriculture.

1) Les eaux conventionnelles :
Les potentialités en eau de l'Algérie sont estimées à 19 milliards de m^3 répartit comme suit :

- Dans les régions du Nord : 14,2 milliards de m^3.
- Dans les régions sahariennes (aquifères profonds) : 5 milliards de m^3

Mobilisation de la ressource
Les volumes mobilisables sont évalués à 12 milliards de m^3 :

- 7 milliards de m^3 au Nord
- 5 milliards de m^3 au Sud

L'agriculture vient en tête dans l'usage d'eau utilisée en moyenne 70% des ressources disponibles la consommation humaine représente 23% et l'usage industriel 7%.

2) Les eaux non conventionnelles :
Le volume global des eaux usées rejetées au niveaux national : 660 millions de m^3

L'utilisation de 50%seulement de cette eau épurée permettra l'irrigation d'une superficie de prés de 40.000 ha/an

Le nombre de station d'épurations (STEP) domestiques réalisées en Algérie est de 45 stations :

- 10 STEP à réhabiliter : dont les études de diagnostics sont achevées

- 11 STEP à réhabiliter (2ème tranche à lancer en étude)

- 03 STEP en cours de réalisations

- 18 STEP en exploitations.

Le volume global des eaux usées traitées ne dépasse pas 75 millions de m^3 par an.

Une réutilisation de cette eau est initiée au niveau des wilayas suivantes :

Sétif : 1592 ha, Constantine : 300 ha, Souk Ahras : 1500 ha, Mila : 150 ha, Boumerdes : 50 ha.

- Les eaux non conventionnelles (salées, médiocres, etc.…) sont utilisées dans de nombreux pays. Elles nécessitent une gestion soignée pour prévenir ou faire face aux problèmes liés à leur utilisation.
- Elles constituent souvent la seule ressource disponible et permettent d'obtenir une rentabilité économique bien qu'un rendement maximum ne puisse être assuré aux cultures.
- Dans certains cas, l'irrigation doit réutiliser des eaux usées à la fois urbaine et industrielles. On prend de plus en plus conscience de la nécessité de traiter ces eaux et de les recycler pour compléter les ressources disponibles.
- La plupart d'entre elles, quoique médiocres, peuvent encore servir et leur utilisation réduit souvent le volume total à évacuer dans l'exutoire final.

Dans le bassin méditerranéen (*Extrait de Claude PUIL : PUIL C. (1998) - La réutilisation des eaux usées urbaines après épuration. Mém. D.U.E.S.S. "Eau et Environnement", D.E.P., univ. Picardie, Amiens, 62 p., http://www.u-picardie.fr/beauchamp/duee/puil.htm)

La réutilisation agricole des eaux usées a toujours existé et est aujourd'hui une pratique largement répandue dans le pourtour sud de la Méditerranée, de l'Espagne à la Syrie. En effet, le bassin méditerranéen est une région où la pénurie en eau est particulièrement ressentie. C'est aussi l'une des régions où la réutilisation des eaux usée urbaines pour l'irrigation est la plus pratiquée.

En Tunisie, si la demande en eau ne devrait théoriquement rejoindre les disponibilités qu'en 2015, on constate déjà que certains endroits souffrent d'une pénurie. De plus, les ressources en eau témoignent souvent d'un degré notable de salinité. Dans ce pays, la réutilisation entre dans le cadre d'une politique nationale. Les eaux usées de Tunis sont utilisées depuis le début des années 60 pour l'irrigation à la Soukra de culture de citrons. En effet, les eaux du sous-sol contaminées par des intrusions d'eau salée n'étaient plus de qualité suffisante pour l'irrigation de ces cultures. Ainsi, la réutilisation avait permis de sauver 600 hectares de cultures. Basé sur l'expérience de La Soukra, une ambitieuse politique de réutilisation des eaux usées est mise en place depuis les années 80. La Tunisie est le premier pays de l'Ouest Méditerranéen à avoir adopté des réglementations en 1989 pour la réutilisation de l'eau. Ce sont le Ministère de l'Agriculture et l'autorité sanitaire (ONAS) qui ont en charge la recherche de moyens pour améliorer l'efficacité de la politique nationale de réutilisation de l'eau. Des 6400 hectares répertoriés pour l'irrigation des eaux usées traitées en 1993, 68 % sont situés autour de Tunis. Les réalisations les plus importantes sont Cebela, La Soukra, Mornag, Nabeul, Sousse, Monastir, Sfax et Kairouan. Une analyse technico-économique a conclu qu'à la vue des conditions locales, les bassins de maturation devraient être préférés aux rayonnements ultraviolets, à la chloration et à la filtration comme traitement de désinfection.

La réglementation de 1989 spécifie que l'utilisation des effluents secondaires traités est autorisée pour irriguer tous les types de cultures mis à part les légumes, qu'ils soient consommés cuits ou crus. Les eaux usées traitées sont donc utilisées pour irriguer les arbres fruitiers (citrons, olives, pêche, pommes, poires...), les vignobles, les fourrages (sorgho, luzerne), le coton, le tabac, les céréales, les terrains de golf (Tunis, Monastir, Hammanet, Sousse) et des jardins d'hôtel à Jerba et Zarzis. Le contrôle de la qualité des eaux réutilisées concerne les paramètres physico-chimiques une fois par mois, les éléments traces tous les six mois et les œufs d'helminthes toutes les deux semaines. En 1992, le taux d'utilisation des eaux usées traitées en Tunisie est relativement bas. En effet, seulement 40 % de l'espace susceptible de concerner le réutilisation est irrigué. De plus, l'irrigation n'a lieu que pendant six mois par an et le stockage de l'eau est extrêmement peu utilisé. On peut citer l'exemple de Nabeul où les effluents secondaires qui ne sont pas utilisés pour l'irrigation en hiver sont infiltrés et stockés dans l'aquifère. De cette façon, les volumes utilisables en irrigation par les agriculteurs sont plus importants en été. Selon Bahri et Brissaud, le stockage saisonnier des eaux usées traitées dans des réservoirs profonds serait la méthode la moins coûteuse pour augmenter les ressources en eau. C'est pourquoi, cette pratique est envisagée comme une perspective à long terme. Les mesures techniques, les investissements et les réglementations devraient développer davantage la réutilisation des eaux usées traitées. Mais l'efficacité de la politique tunisienne dépend du développement du secteur agricole. Celui-ci se met progressivement à jour, ce qui augmente la demande en eau.

En Grèce, la ville d'Athènes a développé en 1996 une stratégie de réutilisation des eaux usées traitées. La réutilisation est une solution particulièrement attractive vu les difficultés d'approvisionnement en eau rencontrées ces dernières années. Les différentes alternatives étudiées sont celles les plus fréquemment appliquées dans les programmes de réutilisation des eaux usées urbaines à travers le monde. Les bassins Thriassio, Megarida et Salamis sont situés autour d'Athènes et font partie intégrante de l'étude de réutilisation.

Parmi les réutilisations favorisées, l'irrigation des cultures est largement prédominante (71%). L'estimation de l'usage des eaux usées urbaines dans les industries est particulièrement basse par rapport aux niveaux de réutilisation dans les autres centres urbains industrialisés (5.2%). Ceci est localement dû à la dispersion géographique des industries fortement consommatrices d'eau. L'estimation de l'utilisation des eaux usées traitées pour l'alimentation des chasses d'eau ne devrait pas voir sa part progresser (6.2%), étant donné les coûts pour la réalisation d'un réseau parallèle de distribution et la réticence des populations. Enfin, on peut noter que le nettoyage systématique prévu de toutes les routes a pour but l'amélioration globale de l'environnement local. La qualité de l'eau suggérée est de 12 coliformes fécaux par 100 ml dans 80 % des échantillons. Les méthodes de traitement recommandées après la filière biologique sont la filtration sur sable et la désinfection au chlore gazeux. Le but de cette réutilisation est d'induire une réduction de la pollution dans le Golfe Saronique en rapport avec la diminution des rejets des effluents riches en nutrients. De plus, la qualité des eaux souterraines devrait s'améliorer. En effet, en bord de mer, le pompage excessif des eaux souterraines conduit à des intrusions salines dans la nappe. Enfin, cela devrait permettre une promotion des espaces verts à Athènes car les ressources existantes ne sont généralement pas suffisantes pour de tels usages.

Les autres pays du pourtour sud de la Méditerranée, de l'Espagne à la Syrie, réutilisent le plus souvent leurs eaux usées urbaines sans traitement. L'arrosage de cultures maraîchères n'y est pas exceptionnel. L'Espagne se dote néanmoins progressivement, région par région, d'une réglementation et améliore la qualité des eaux réutilisées. Les réutilisations sont alors l'occasion d'un effort pour répondre à des standards sanitaires existants ou en cours d'élaboration. C'est le cas pour l'arrosage des parcours de golf ou d'espaces verts aux Canaries, à Majorque, en Catalogne espagnole. Ainsi, furent publiés en 1991 les résultats et les conclusions d'un suivi d'une réutilisation d'eaux usées urbaines épurées et traitées par le chlore dans le cadre de l'irrigation d'un parcours de golf à Castell Platja d'Aro sur la Costa Brava.

Parmi les exemples de réutilisation indirecte des eaux usées urbaines non traitées, on peut citer les Marcites milanaise qui sont des prairies arrosées avec les eaux du canal Vettabia recevant une part importante des eaux usées brutes de Milan . La réglementation italienne est pourtant très stricte en matière d'irrigation. En 1996, les seules références législatives sont une loi de 1976 nommée " Normes pour la protection des eaux contre la pollution "et un texte réglementaire ministériel en découlant. Ce dernier établit les normes pour une réutilisation agricole (coliformes < 20/100ml sur une moyenne de sept jours pour les produits consommés cuits, coliformes < 2/100 ml sur une moyenne de sept jours pour les produits susceptibles d'être consommés crus). Selon Legnani, les limites établies par la législation italienne pour l'irrigation agricole sont trop restrictives comparées aux recommandations internationales et même pratiquement inapplicables dans le cadre de la réutilisation. Ceci n'a d'ailleurs pas empêché certains débordements. En effet, dans les journaux, on a accusé les horticulteurs des Pouilles d'avoir utilisé des eaux prélevées dans des fossés où circulaient des eaux usées brutes. Ces eaux ont servi pour arroser des légumes qui, vendus au marché et consommés crus, ont contribué à une forme de choléra au mois d'octobre 1994 dans la ville de Bari ».

L'irrigation

L'irrigation n'est pas uniquement un apport d'eau sur une terre cultivée en vue de compenser l'insuffisance des précipitations et de permettre le plein développement des cultures.

Elle est considérée plutôt comme un ensemble d'actions de développement intégré des milieux agricole et rural qui doit se traduire non seulement par l'augmentation de la production et l'amélioration du niveau de vie de l'agriculteur, mais doit se traduire également par la préservation du milieu, notamment des terres agricoles, et par une économie de l'eau d'irrigation qui elle-même se traduit par une économie dans l'utilisation de l'énergie (électricité, fuel, etc.…).

Le développement de l'irrigation (particulièrement celle qui économise le maximum d'eau) est une option incontournable qu'il faut privilégier, même si elle induit des coûts d'investissement importants.

Tenir compte des besoins réels des cultures devient à ce moment impératif. Il s'agit donc de faire en sorte pour pouvoir estimer sur quelle culture l'eau serait la plus efficace et à quelle dose l'employer.

Des études menées sur les différentes cultures irriguées montrent qu'il est possible de moduler sensiblement les doses à apporter en fonction des espèces, des objectifs d'économie d'eau et de rendements recherchés.

La réserve en eau utile dans le sol est considérée comme une possibilité d'apport d'eau permettant de réduire les arrosages. Sa connaissance précise et son utilisation raisonnée permettent d'économiser parfois plusieurs tours d'eau.

Le suivi rigoureux des évolutions de l'état hydrique des sols est indispensable si l'on veut atteindre des économies appréciables.

Il est reconnu que l'irrigation apporte aux agriculteurs la possibilité de lever un certain nombre de contraintes dont celles liées aux aléas climatiques. Tout en permettant la diversification, l'irrigation joue un rôle important dans les domaines techniques et socio-économiques.

A l'échelle de l'exploitation, l'irrigation permet de diversifier les cultures, elle améliore la productivité des exploitations et facilite la stabilisation des productions.

L'irrigation qui constitue, en volume, un des plus importants consommateurs d'eau a, par le potentiel agricole qu'elle permet de valoriser, un effet très marquant sur l'aménagement de l'espace rural.

Au Nord de l'Algérie et dans certaines régions du Sud (cas de Abadla) où l'irrigation se fait à partir des eaux superficielles (barrage), les superficies irriguées sont en diminution à cause de la réduction du volume alloué à l'irrigation (volume stocké limité). Par contre, au Sud, la ressource hydrique existe. Seulement l'utilisation irrationnelle de ce patrimoine hydrique par sa mauvaise répartition spatiale ainsi que les techniques d'irrigation utilisées (submersion) ont provoqué dans certains cas une suralimentation de la nappe superficielle d'où le problème d'hydromorphie (cas de la vallée de Oued Righ).

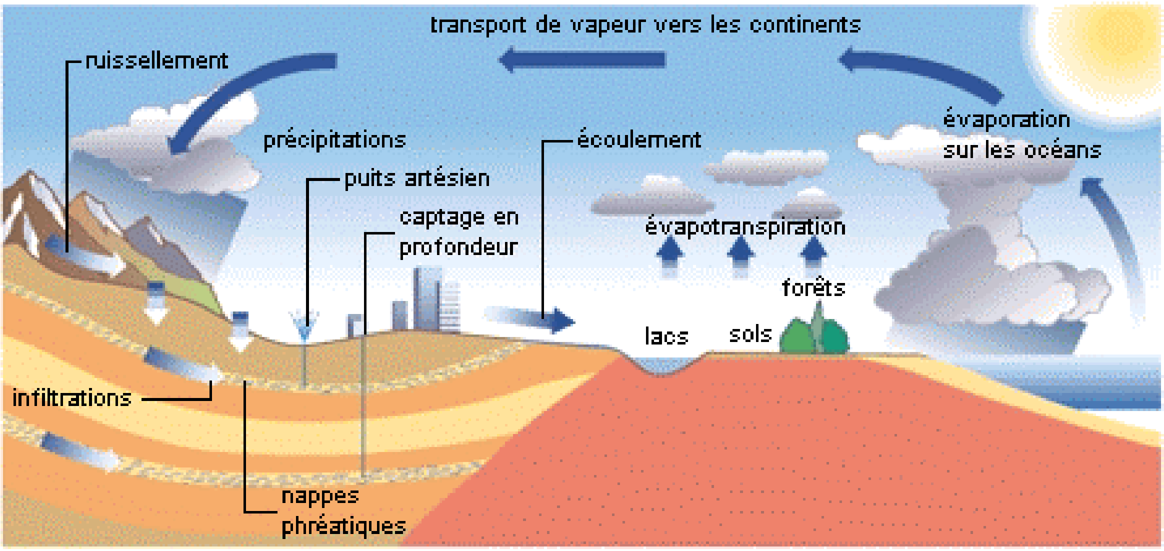
Le recours donc de l'Algérie à l'irrigation par l'utilisation des eaux non conventionnelles s'avère primordial afin que dans les régions où la ressource est superficielle, combler le déficit hydrique, et au Sud où l'irrigation se fait à partir des eaux souterraines, protéger les deux nappes non renouvelables contre leur surexploitation par la création d'autre forages en utilisant les eaux de drainage et surtout que le débit à évacuer est non négligeable (5m3/s dans le cas de la vallée de Oued Righ). À titre d'exemple, le débit évacué équivaut à la réalisation d'une quarantaine de forages, dans le CT (120 l/s par forage) de plus que le problème d'hypotrophie sera atténué. Ceci peut se concrétiser dans la mesure où les résultats obtenus des analyses physico-chimiques de l'eau de drainage à réutiliser s'avèrent sans un danger quelconque sur l'environnement (pollution de la nappe), sur la dégradation de la structure du sol ou sur le rendement et la qualité de la récolte.

L'absence de données techniques locales (référentiels) relatives à:

- la qualité des eaux non conventionnelles;
- Leurs différents usages probables;
- Les différents prélèvements et analyses nécessaires, leur périodicité et le type d'analyses;
- La connaissance de la gamme des principales espèces à cultiver, leur sensibilité, leurs tolérances et leurs besoins en eaux dans ces conditions. Le choix d'espèces adaptées constitue une approche technique et économique à mettre en œuvre dans le développement agricole des exploitations;
- Les équipements d'irrigation et de contrôle adaptés à l'usage des eaux non conventionnelles.

L'irrigation joue un rôle essentiel dans l'entraînement des autres activités, telles que:

- l'investissement et la mise en place des stations d'épuration;
- les laboratoires d'analyse des eaux (création et plan de charge);
- La formation de la ressource humaine spécialisée;
- Les activités de vulgarisation, communication et transfert;
- Les équipements et matériels spécifiques à assurer.
- Autres.



cycle de l'eau

Comment accepter?

L'eau d'irrigation traitée « non conventionnelle » doit être considérée comme source d'eau admissible selon les critères scientifiques et réglementaires (selon sa nature, sa quantité et sa qualité). Elle peut être exploitée à partir des stations d'épuration par des canalisations adéquates ou dans d'autres cas par des lachées au niveau des oueds ou d'autres écoulements.

A ce propos, l'agriculteur doit s'assurer de sa disponibilité au moment voulu pour irriguer, car la connaissance de la quantité d'eau disponible en période de pointe permet de déterminer la superficie à irriguer ;

Il faut « *exiger* » la qualité (bonne, médiocre ou mauvaise) pour savoir le niveau de traitement et/ou de filtration nécessaires à son utilisation (Tableaux 1 et 2).

Tableau 1: Mesures à effectuer pour évaluer la qualité de l'eau d'irrigation.

Paramètres de l'eau	Symbole	Unité	Teneur habituelle dans l'eau d'irrigation	
Salinité				
Teneur en sel				
Conductivité électrique (ou)	ECw	dS/m	0 - 3	dS/m
Total des matières solides dissoutes	TDS	mg/l	0 - 2000	mg/l
Cations et Anions				
Calcium	Ca++	me/l	0 - 20	me/l
Magnésium	Mg++	me/l	0 - 5	me/l
Sodium	Na+	me/l	0 - 40	me/l
Carbonate	CO--	me/l	0 – 0.1	me/l
Bicarbonate	HCO3-	me/l	0 - 10	me/l

Chlorure	Cl-	me/l	0 - 30	me/l
Sulfate	SO4--	me/l	0 - 20	me/l
Eléments nutritifs				
Azote nitrique	NO3-N	mg/l	0 - 10	mg/l
Azote ammoniacal	NH4-N	mg/l	0 - 5	mg/l
Phosphate phosphoreux	PO4-P	mg/l	0 - 2	mg/l
Potassium	K+	mg/l	0 - 2	mg/l
Divers				
Bore	B	mg/l	0 - 2	mg/l
Acidité	pH	1 - 14	6,0 – 8,5	
Coefficient d'adsorption du Sodium	SAR	(me/l) 1,2	0 - 15	

Tableau 2 : Directives pour l'interprétation de la qualité d'une eau d'irrigation

Nature du problème	**Unité**	Restriction pour l'irrigation		
		Aucune	**Légère à modérée**	**Forte**
Salinité (influe sur l'eau disponible pour la plante)				
Conductivité électrique ECw **(ou)**	dS/m	< 0.7	**0.7 – 3.0**	> 3.0
Total des matières solides dissoutes TDS	mg/l	< 450	**450 - 2000**	> 2000
Infiltration (influe sur la vitesse d'infiltration de l'eau dans le sol : utiliser à la fois ECw et SAR)				
SAR = 0 – 3 et ECw =		> 0.7	**0.7 – 0.2**	< 0.2
SAR = 3 – 6 et ECw =		> 1.2	**1.2 – 0.3**	< 0.3
SAR = 6 – 12 et ECw =		> 1.9	**1.9 – 0.5**	< 0.5
SAR = 12 – 20 et ECw =		> 2.9	**2.9 – 1.3**	< 1.3
SAR = 20 – 40 et ECw =		> 5.0	**5.0 – 2.9**	< 2.9
Toxicité de certains ions (affecte les cultures sensibles)				
Sodium (Na)4				
Irrigation de surface	SAR	< 3	**3 - 9**	> 9
Irrigation par aspersion	me/l	< 3	> 3	
Chlore (Cl)4				
Irrigation de surface	me/l	< 4	**4 - 10**	> 10
Irrigation par aspersion	me/l	< 3	> 3	
Bore (B)5	mg/l	< 0.7	**0.7 – 3.0**	> 3.0
Effets divers (affecte les cultures sensibles)				
Azote (NO3-N)6	mg/l	< 5	**5 - 30**	> 30
Bicarbonate (HCO3)(seulement pour l'aspersion sur frondaison)	me/l	< 1.5	**1.5 – 8.5**	> 8.5
pH		Zone normale 6.5 – 8.4		

Un projet d'irrigation avec des eaux non conventionnelles:

En plus de l'approche classique et la diversité des paramètres (sol, climat, plante), il devient primordial de considérer la qualité de l'eau à utiliser dans la conception d'un projet d'irrigation, En général, on doit procéder comme suit :

1. Connaissance du cadre réglementaire régissant l'usage des eaux non conventionnelles (loi portant code des eaux, normes, etc.…);
2. Connaître l'origine, la nature, la qualité (analyses et observations) et la disponibilité de l'eau non conventionnelle à utiliser dans son « état brut »;
3. L'existence d'une station d'épuration et de traitement, sa capacité, la disponibilité et la qualité de l'eau épurée à la sortie;
4. Connaître les modes, types et périodicité des analyses (de l'eau, du sol, du végétal et du fruit), les laboratoires existants et les normes de référence;
5. Connaissance de la gamme des cultures à introduire dans ces conditions;
6. Faire le choix de la technique et le système d'irrigation à utiliser ;
7. Dimensionnement du réseau d'irrigation « adopté » ;
8. Connaissance de des toutes les mesures préventives (laver les fruits, les mains, etc...)

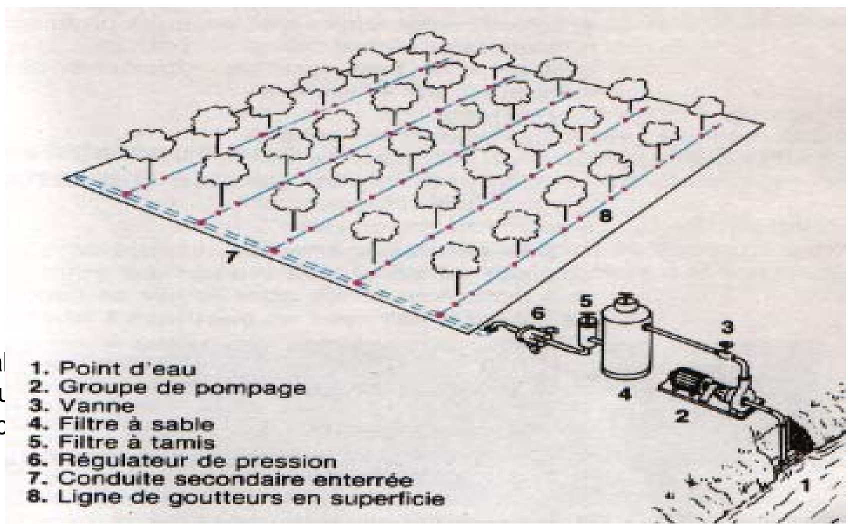
Choix de la technique et du système d'irrigation :
il y a trois systèmes les plus répandus, qui sont : l'irrigation gravitaire, l'irrigation par aspersion et l'irrigation localisée.

1/ <u>Irrigation gravitaire</u> : est l'application de l'eau aux champs à partir de canaux ouverts se situant au niveau du sol. La totalité du champ peut être submergée, ou bien l'eau peut être dirigée vers des raies ou des planches d'irrigation.

2/ <u>Irrigation par aspersion :</u>
Le but d'une irrigation par aspersion est l'application uniforme de l'eau sur l'aire occupée par la culture. Le système d'irrigation doit être conçu pour appliquer l'eau à un taux inférieur à la capacité d'infiltration du sol et éviter ainsi les pertes par ruissellement.

Ensemble d'équipement permettant une irrigation sous forme de pluie artificielle, et constitué d'une pompe et de son dispositif d'entraînement et des tuyaux spécifiques, d'asperseurs et d'accessoires de raccordement pour alimenter un système d'irrigation.

<u>3/ Irrigation localisée :</u>
Cette méthode d'irrigation sous pression est appelée ainsi du fait que l'eau est appliquée en des endroits où l'on désire la voir s'infiltrer. Cette application est donc localisée. L'irrigation localisée regroupe tous les systèmes caractérisés par un réseau de distribution à la parcelle, fixe sous pression, permettant des apports d'eau continus ou fréquents en des endroits déterminés par apport au dispositif cultural et de façon telle que l'infiltration ne se produise que sur une fraction réduite de la surface du sol, en l'occurrence la zone racinaire.



L'irrigation local
Les caractéristiq
– c

– n'arrose qu'une fraction du sol ;
– utilise de faibles débits avec de faibles pressions, d'où une économie d'énergie ;
– met en œuvre des équipements fixes et légers ;
– ne mouille pas le feuillage ;
– convient bien à l'irrigation fertilisante ;
– difficilement modifiable si cela n'a pas été prévu au départ ;
– qui ne peut être réalisée sans calculs techniques et économiques préalables, pour être adaptée aux besoins de l'exploitation : un devis doit forcément résulter d'une étude.
– Qui peut être adéquat dans l'usage d'une eau non conventionnelle (saumâtre, salée, traitée et épurée;

Selon les expériences enregistrées dans certains pays; C'est un système d'irrigation qui peut être adapté à différentes « *qualités* » des eaux, sur le plan performances sur le terrain, il permettra la diffusion de l'eau uniquement en localisé « bulbe de la zone racinaires » ce qui diminuera tout risque quelconque de contamination des nappes, foliaires et humaine, etc….
Ceci, n'exclut pas l'usage des autres techniques d'irrigation s'ils atteignent ces degrés de performances.

— Les valeurs sont en augmentation, soit brusque, soit progressive de jour en jour, ce qui signifie que la zone humidifiée tend à se réduire : il faut donc **augmenter le temps d'apport**.

— Les valeurs sont en réduction, soit brusque, soit progressive de jour en jour, ce qui signifie que la zone humidifiée tend à s'accroître : il faut donc **réduire le temps d'irrigation.**

N.B. : La modification du temps d'arrosage doit être progressive, les réglages se faisant par paliers de 20 % au maximum.

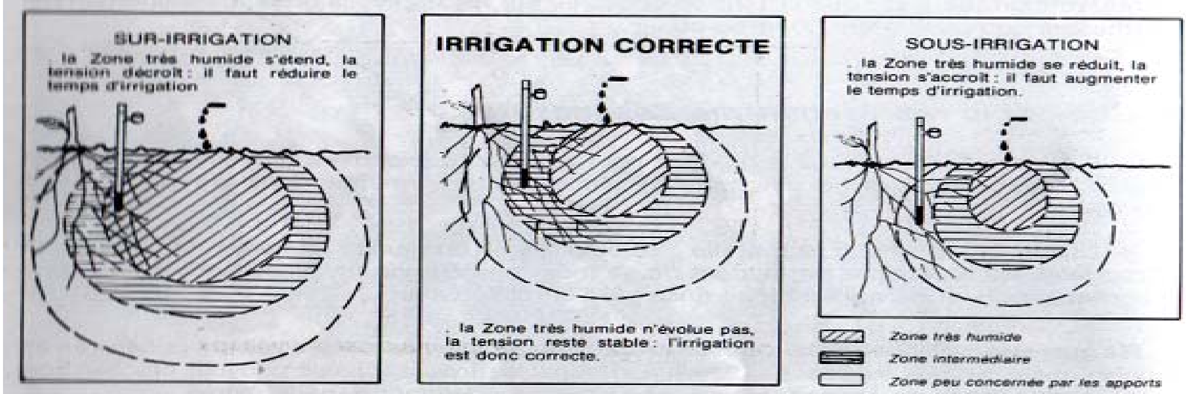


Fig. 21 — ***Principes et stratégie de la méthode de pilotage d'irrigation « goutte à goutte »***
(Source SCP)

L'installation « goutte à goutte » peut être renforcée par une double filtration et même un traitement additif si nécessaire au niveau de la tête de station.

En irrigation localisée, la qualité de l'eau est un élément essentiel dont dépendent les risques de colmatage des distributeurs. La qualité de l'eau est d'autant moins bonne qu'elle contient des éléments susceptibles de boucher les distributeurs. Ces éléments sont de nature chimique, physique ou biologique. Si l'on doit utiliser des distributeurs auto-régulants ou à chicane (plus grande longueur de cheminement de l'eau) on choisira ceux qui sont facilement nettoyable et résistant à l'agressivité de l'eau.

Malheureusement, dans l'état actuel il n'existe pas dans le marché une gamme de matériels étendue, qui a des performances variables, qui permet un choix raisonné et selon la qualité de l'eau dont dispose l'agriculteur.

Ce qu'il faut faire : Bien étudier le projet et faire le bon choix des équipements.

Le coût de l'installation ne doit pas être le critère du choix, s'il s'inscrit dans un plan de développement de l'exploitation.

Une installation qui n'assure pas le service attendu n'est pas rentable à l'usage.

Photo 15 a

Photo 15 b

Photos 15 a et 15 b — *Goutteurs montés en dérivation*

• *Les goutteurs en ligne*

Constitués de deux éléments assemblés en usine, ils s'insèrent dans la rampe par l'intermédiaire de deux embouts cannelés.
Ce montage est effectué, après tronçonnage du tuyau, à des intervalles différents selon les cultures auxquelles sont destinées les installations (écartements de 0,30m à 2,5m).

Photo 16 — *Goutteur en ligne à cheminement long*

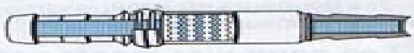


Fig. 118 a — *Montage d'un goutteur en ligne sur la rampe*

Fig. 118 b — *Schéma du circuit de l'eau dans un goutteur en ligne*

LES GAINES

Les gaines sont constituées de tuyaux en plastique qui assurent à la fois les fonctions de transport et de distribution de l'eau.
Elles sont fabriquées par soudure ou par extrusion.
Les constructeurs proposent différentes épaisseurs, de durée de vie variable.
Aplaties au repos, elles se gonflent sous l'effet de la pression, la section prend alors une forme plus ou moins elliptique.
Le débit des gaines est généralement compris entre 1 et 8 l/h par mètre linéaire, suivant l'écartement des sorties (20 à 120 cm) et la pression (0,15 à 1 bar).

• *Gaine perforée à double paroi*

Exemple : la gaine Bi-Wall. Les gaines à double paroi sont constituées de 2 gaines accolées : une, de section plus importante, sert au transport de l'eau et alimente par des orifices internes la gaine secondaire qui laisse s'écouler l'eau par des orifices de petit diamètre.

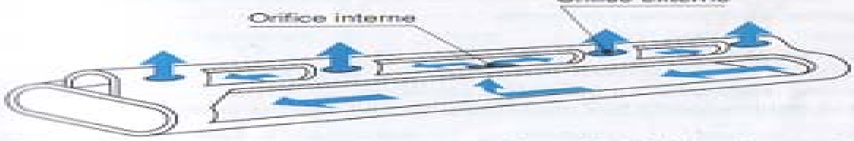


Fig. 125 — *Trajet de l'eau dans une gaine perforée à double paroi : exemple : la gaine Bi-Wall*

• *Gaine à cheminement long*

L'eau sort après avoir suivi un cheminement plus ou moins long et plus ou moins uniforme.

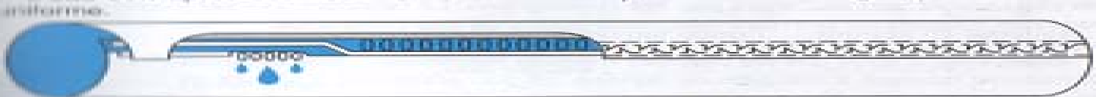
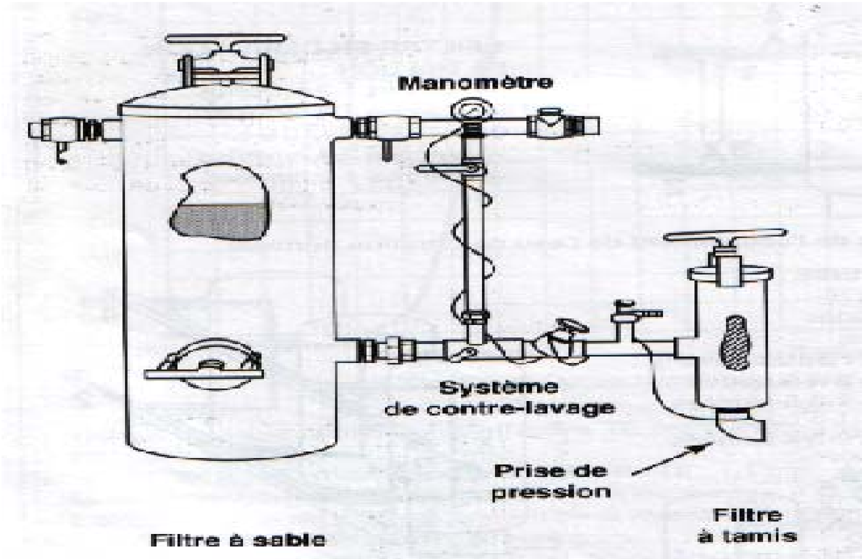


Fig. 126a — *Trajet de l'eau dans une gaine à cheminement long*

La station de tête:
On ne peut concevoir une irrigation localisée sans filtration. Celle-ci a pour but d'arrêter les éléments solides, susceptibles d'obstruer les distributeurs.



Le poste de filtration doit être conçu avec le plus grand soin, afin de fournir à la parcelle une eau la plus propre possible, compte tenu de l'origine de l'eau et du type de distributeur.
Choix des filtres en fonction des conditions locales

Origine de l'eau		Nature des impuretés	Filtration	Option
Eau de surface	**Rivières Canaux Lâchées Retenues collinaires**	**Argiles Limons Algues Bactéries Particules grossières**	**Filtre à sable + Filtre à tamis**	**Filtre flottant**
Eau souterraine	**Puits Forages**	**Limons Sables Fer**	**Filtre à sable + Filtre à tamis Où Filtre à tamis seul (si peu de limons)**	**Séparateur (si particules denses) Déferrisation (coût élevé)**

Pour une capacité de filtration donnée, on a intérêt à prévoir plusieurs petits filtres en parallèle plutôt qu'un seul gros filtre.
En effet, le lavage est d'autant plus difficile et long que le filtre est gros. Il est préférable de le laver avec de l'eau propre provenant des autres filtres.

Le filtre à sable

Le filtre à sable est une cuve à pression remplie d'une épaisse couche de sable calibré, qui arrête les éléments solides en suspension dans l'eau. Il est indispensable pour arrêter les éléments organiques.

Le sable peut être roulé ou concassé. Le sable roulé, d'une seule granulométrie, permet une filtration plus homogène. L'emploi de couches de sable de granulométries différentes, entraîne une variation de la porosité à la suite des lavages du filtre.

Le nettoyage d'un filtre à sable, se fait par contre lavage, en faisant passer de l'eau filtrée en sens inverse de la filtration, par un jeu de vannes. Les impuretés sont évacuées à l'extérieur par le courant d'eau.

Un filtre à sable est toujours suivi d'un filtre à tamis

Le filtre à tamis

C'est une cuve à pression contenant une paroi filtrante ou tamis, en plastique ou en acier inox, dont les mailles varient de 80 à 150 microns. Les particules de dimensions supérieures à cette maille sont arrêtées par le tamis.

On obtient une bonne filtration pour une vitesse de passage de l'eau à travers le tamis du même ordre qu'à travers un filtre à sable soit 2.8 cm/s.

Évaluation technico-économique

Afin d'atteindre les meilleures performances de ce système d'irrigation, le réseau de la parcelle à irriguée, doit avoir une station de tête adéquate et répondant à certaines normes pour la filtration de l'eau, pour le bon fonctionnement des goutteurs et l'uniformité de l'irrigation.

Selon le débit et la qualité d'eau à la source, il peut être déterminé la superficie à irriguer. Ceci permettra de connaître le type de filtration et le nombre de filtres (à sable et à tamis) adaptés.

Par contre, la nature du sol et sa topographie, ainsi que le type de culture, permettront de connaître les types de distributeurs, et les longueurs maximales des conduites à ne pas dépasser.

Le gain économique peut être apprécié à travers plusieurs facteurs techniques et économiques, tels que la rotation des cultures, l'assolement, etc.…

Tableau 22 FACTEURS PHYSIQUES, CHIMIQUES ET BIOLOGIQUES, LIES A LA QUALITE DE L'EAU, CONTRIBUANT AU COLMATAGE DES RESEAUX D'IRRIGATION LOCALISEE (GOUTTE A GOUTTE)[1]

PHYSIQUE (solides en suspension)	CHIMIQUE (Précipitation)	BIOLOGIQUE (Bactéries et algues)
1. Sable	1. Carbonates de calcium ou de magnésium	1. Algues filamenteuses
2. Limon	2. Sulfate de calcium	2. Boues bactériennes
3. Argile	3. Hydroxydes de métaux lourds, oxydes, carbonates, silicates et sulfures	3. Dépôts microbiens : (a) Fer (b) Soufre (c) Manganèse
4. Matières organiques	4. Engrais (a) Phosphate (b) Ammoniaque (c) Fer, zinc, cuivre, manganèse	4. Bactéries
		5. Petits organismes aquatiques : (a) oeufs d'escargot (b) Larves

[1] Source : Bucks et al. (1979).

Tableau 23 TESTS TYPES SUR LA QUALITE DE L'EAU NECESSAIRES POUR CONCEVOIR ET GERER LES RESEAUX D'IRRIGATION LOCALISEE (GOUTTE A GOUTTE)

1. Principaux sels minéraux (voir tableau 2)	8. Micro-organismes
2. Dureté	9. Fer
3. Solides en suspension	10. Oxygène dissous
4. Total des solides dissous (TDS)[1]	11. Hydrogène sulfuré
5. DBO (demande biologique en oxygène)	12. Bactéries du fer
6. DCO (demande chimique en oxygène)	13. Bactéries réductrices des sulfates
7. Composants organiques et matière organique	

[1] Une valeur calculée à partir des analyses présentées dans le tableau 2.

CONCLUSION

Les ressources hydriques diminuent constamment alors que les demandes augmentent sans cesse (AEP, irrigation, industrie). Le déficit pluviométrique enregistré durant la décennie écoulée se répercute sur les réserves disponibles.

À cela s'ajoute le phénomène d'érosion des bassins versants, qui favorise et accélère l'envasement des ouvrages de mobilisation entraînant une réduction des volumes stockés, limitant ainsi l'offre en eau pour les besoins de l'irrigation.

L'extension de l'agriculture en irriguée et l'utilisation intense des ressources en eau dans un pays soumis à un climat chaud et sec entraînent inévitablement l'apparition du problème de salinité des sols et des eaux. L'Algérie, qui offre toutes les variantes du climat méditerranéen, n'échappe pas à cette règle.

Souvent, la perte des terres à haut potentiel risque de compromettre les aptitudes et les capacités de production d'une région

L'investissement en irrigation est considéré beaucoup plus rentable que si la ressource en eau est disponible à n'importe quel moment, dans le cas de l'usage d'une eau non conventionnelle, surtout épurée, cela peut s'avérer possible en tenant compte de la capacité de la station d'épuration existante.

Il reste aux agriculteurs de se soumettre à cette nouvelle réalité de l'usage réglementé des eaux non conventionnelles, car ceci peut leur procurer une régularité en matière de disponibilité, à même d'avoir à gérer des stations d'épuration par le biais de la concession et surtout de procéder périodiquement au suivi et aux analyses nécessaires.

Contrôle de la qualité de l'eau

L'eau indispensable aux besoins des plantes doit obéir à certaines normes de qualité minimales. L'excès d'éléments indésirables peut être nuisible :

• Aux cultures, d'où baisse des rendements et même risque d'intoxication du consommateur ;

- Aux sols, risque d'appauvrissement d'où baisse des rendements, mais aussi risque de contamination des cultures et des nappes souterraines ;
- Aux nappes d'eau souterraines d'où risque de contamination des consommateurs ;
- Aux consommateurs, qui peuvent ingérer directement des polluants fixés aux feuilles, fruits, …

En Algérie, les eaux utilisées en irrigation sont en général de qualité assez moyenne, voire médiocre, mais les dangers les plus craints sont actuellement les ingestions de très faibles traces (ordre de microgramme) qui deviendraient nuisibles à des concentrations plus significatives (cas du bore)

Le développement de l'agriculture entraîne lui-même des dégradations fâcheuses de la qualité de l'eau pour d'autres usages (pollution des nappes d'eau douce utilisées pour la consommation par les nitrates). Ce sujet est à l'ordre du jour de toutes les instances internationales concernées.

À son tour, l'usage de l'eau par les populations agglomérées entraîne une pollution biologique, mais aussi de plus en plus physico-chimique des réserves utilisées pour les usages.

Les réseaux de surveillance de la qualité deviennent donc d'une nécessité impérieuse pour contrôler l'évolution des paramètres de qualité et prendre à temps les mesures correctives indispensables au redressement. Cela implique des progrès dans nos possibilités d'analyses avec, à l'amont, la formation nécessaire, l'industrie des équipements et consommables de laboratoires, celle des équipements de traitement et d'épuration des eaux.

Le plus urgent, c'est de monter un véritable programme d'économie de l'eau au niveau des industries, incluant toute la batterie de procédés peu consommateurs, recyclage, récupération, traitement à l'amont, épuration des rejets à l'aval.

Options Méditerranéennes

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INTERNATIONAL CENTRE FOR ADVANCED MEDITERRANEAN AGRONOMIC STUDIES

Water in the Mediterranean region is rare, fragile and unevenly distributed. The population increase at relatively high rate, the fast urbanization, on one hand, and the rapid development, on the other one, are resulting in a notable increase in water demands in all sectorial water use.

In numerous Mediterranean countries, water use is approaching the limit level of available resources. Pressure on water resources will increase significantly in the South and East and it is expected by the year 2025 that 63 million people in the Mediterranean will have less than 500 m3/per capita defined as the "shortage" threshold.

The dilemma most of the developing countries are nowadays facing is: *how to respond to the increasingly water demand in the presence of a fragile limited water supply?* The sustainable answer to this question is to improve the water productivity in all sectors and, particularly, in irrigation, the one receiving more than 70% of the available water resources and, in the meantime, with major water losses exceeding the 50%.

However, this will not be sufficient to meet the future water demands. We have to search for another water resources rather than the freshwater: *the non-conventional water resources "the treated wastewater and the artesian saline water"* as an additional water resource for irrigation.

The use of such low quality water resources is a win-win game resulting in not only freshwater saving to meet the water requirements in the different sectorial water uses but, also, in increasing the water supply allocated for the development of irrigated agriculture. However, to achieve such gains is a matter mainly depending on the way we are using and managing the non-conventional water resources. The management of such water resources is rather complex in comparison with the freshwater. The know-how in this field has to be developed.

In the Mediterranean region, the use of such water is now a must to meet the severe water shortages. What is needed is to set new strategies for the sustainable use of the non-conventional water resources to avoid any degradation in natural resources quality, health hazard as well as any deterioration in the food quality. Those issues, as well as others constraining the full use of the non-conventional water resources were presented and fully discussed in this Symposium.

The conclusions and the recommendations of this scientific event could be taken as guidelines helping the researchers and water managers to formulate appropriate policies and strategies to achieve the maximum benefit of such water resources.

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