HALOPHYTES, BETWEEN THE FALL OF CIVILIZATIONS AND BIOSALINE AGRICULTURE. ECOLOGICAL DISTURBANCES OVER TIME

GRIGORE Marius-Nicuşor, TOMA Constantin

Abstract. This review is focused on some interesting and less studied effects of salinity on human civilization. Still being perhaps an abstract concept, the salinity was one factor involved in the fall of famous ancient civilizations, but represents also the main threat for agricultural productivity. Despite it is a very old problem, dealing with salinity is a very difficult work to be done. The progressive increase of salinity levels in arable lands drew into attention the necessity to use the saline water - sea or brackish water for irrigations of salt-tolerant species, in order to obtain crops able to grow in saline conditions. In this complicate equation, halophytes play, without any doubts, a crucial role.

Keywords: halophytes, salinity, biosaline, agriculture, future.

Rezumat. Halofitele, între declinul unor civilizaţii şi agricultura biosalină. Dezechilibre ecologice de-a lungul timpului. Lucrarea de faţă pune accentul pe unele aspecte interesante şi mai puţin studiate, referitoare la efectele salinităţii asupra civilizaţiei umane. Fiind, poate, un concept încă abstract, salinitatea a fost unul din factorii implicaţi în decăderea unor mari şi străvechi civilizaţii, reprezentând în egală măsură principala ameninţare pentru producţia agricolă. Deşi reprezintă o problemă destul de veche, gestionarea salinităţii este o misiune foarte dificilă. Creşterea progresivă a nivelului salinităţii pe suprafeţele agricole a adus în prim plan necesitatea utilizării apei sărate (fie marine, fie sălcii) pentru irigarea speciilor tolerante la salinitate, în vederea obţinerii unor specii cultivabile în condiţii saline. În această ecuaţie complicată, halofitele joacă, fără îndoială, un rol de prim ordin.

Cuvinte cheie: halofite, salinitate, biosalin, agricultură, viitor.

INTRODUCTION

The Earth's total surface area covers about 13.2 billion ha, but no more than 7 billion ha are arable and 1.5 billion are cultivated (MASSOUD, 1981). Of the cultivated lands, about 340 million ha (23%) are saline (salt-affected) and another 560 million ha (37%) are sodic (sodium-affected) (TANJI, 2002). Here are many different projections, suggesting that human population will increase over 8 billion by the year 2020 that will worsen the current scenario about food insecurity (ATHAR & ASHRAF, 2009). There are often not sufficient reservoirs of freshwater available (Table 1) and most of the agronomical used irrigation systems are leading to a permanent increase in the soil-salinity and slowly to growth conditions in-acceptable for most of the common crops (KOYRO et al., 2009). A global study of land use over 45 years found that 6% had become saline (GHASSEMI et al., 1995). This area is growing and some studies suggest that the salinization process is almost irreversible and difficult to control. In Australia alone, 2 million ha have become saline since clearing began a century ago, and another 15 million ha are at risk of becoming saline in the next 50 years. Irrigation systems are especially prone to salinization (Table 2); about half of the existing irrigation systems of the world are under the influence of salinization, alkalization or waterlogging (SZABOLCS, 1994). Irrigation schemes cover only 15% of the cultivated land of the world (227 million ha in 1987), but as irrigated land has at least twice the productivity of rain-fed land. On the other hand, it is well known that the actual population of the world has about 6.7 billion people, but according to some calculations, in 2050 this could reach 9.5 billion. According to a FAO Report (2007), despite unprecedented global economic growth, 1.1 billion people continue to live in extreme poverty and more than 850 million people suffer from chronic hunger while ecosystems are being threatened as never before. Not accidentally the first goal of *The Millennium Development Goals Report* (ONU Published, 2008) is to eradicate extreme poverty and hunger.

So, salinity is one of the most severe environmental factors limiting the productivity of agricultural crops, because most crops are sensitive to salinity induced by high concentrations of salts in the soil (PITMAN & LÄUCHLI, 2002). The cost of salinity to agriculture was estimated to be about 12 billions USD per year (GHASSEMI et al., 1995), but perhaps this value will be greater, since it is expected that soil salinity to increase continuously (Table 3).

History of salinity and evolution of ecological disturbances

Salinity is not a precise concept, restricted to a single science language; it covers many interdisciplinary fields of life sciences. We have already discussed this issue in relation to the difficulty of using a unique halophyte definition (GRIGORE & TOMA 2010). Beyond the biological implications of salinity on plant life and agriculture, it is very important to take into account the significance of salt in human history and culture. Many data suggest that salinity played a major role in evolution of some civilizations being a factor related to agricultural practices.

Perhaps one of the earliest allusions of salinity effects on plants growth and productivity is that stipulated in the *Bible*: "*The whole land will be a burning waste of* ***salt*** *and sulfur—nothing planted, nothing sprouting, no vegetation growing on it* […]" (Deuteronomy 29: 23). This is a precocious, best and simple explanation of salinity effects on germination, growth and development of crops.

Table 1. Global water reserves (after GHASSEMI et al., 1995).
Tabel 1. Rezervele globale de apă (după GHASSEMI et al., 1995).

Source	Volume (Mkm^3)	% of total
Global water	**1,386**	**100**
Seawater	1,338	96.5
Saline groundwater	12.9	0.93
Total saline water	**1,350.9**	**97.43**
Ice	24.4	1.76
Fresh groundwater	10.6	0.77
Rainfall	0.108	0.008
Total fresh water	**35.101**	**2.538**

Table 2. Secondary salinization of the world's irrigated lands (after GHASSEMI et al., 1995).
Tabel 2. Salinizarea secundară a terenurilor irigate (după GHASSEMI et al., 1995).

Country	Cultivated land (Million hectares)	Irrigated (%)	Secondary salinized (%)
Argentina	35.8	4.8	33.7
Australia	47.1	3.9	
China	97.0	46.2	15.0
Egypt	2.7	100	33.0
India	169	24.9	16.6
Iran	14.8	38.7	30
Pakistan	20.8	77.5	26.2
USA	190	9.5	23.0
World	1,473	15.4	20

Table 3. Selected examples of estimated crop and income losses caused by secondary salinization (after PITMAN & LÄUCHLI, 2002).
Tabel 3. Exemple selectate de pierderi estimate de recolte şi venituri cauzate de salinitatea secundară.

Country	Region	Secondary salinization (% of irrigated area)	Crop loss (%)	Income loss (%)	Million US $ per year
Australia	Murray-Darling Basin	33			~200
Egypt		33	30		
Israel	Negev			5-45	~300
Pakistan	Punjab				
USA	San Joaquin Valley	39	10		~30
	Colorado River Basin	41-66			~750
Uzbekistan		60	30		
Turkmenistan		80	40		
World					~11,400

For some civilizations, salinity has a cosmological deep value, as in the case of Assyro-Babylonian mythology. As it is well known, from the beginning of the third millennium B.C., a flourishing civilization existed on the lower banks of the Tigris and the Euphrates, due to the neighboring peoples: the Akkadians and the Sumerians (GUIRAND, 1987). These people of Babylonia may have given a cosmological significance to saline water, a "cosmic principal of salinity" (ARONSON, 1987). In many cultures, water is the primordial element. In the Sumerian mythology, from the fusion of sweet water (Apsu) and salt water (Tiamat) arose all beings. Tiamat was a personification of the sea and represented the feminine element giving birth to the world. Here is an interesting coincidence between the "mythology of salt" and agricultural and irrigation practices during the time. The flood plain of ancient Mesopotamia was first irrigated more than 6000 years ago (CORDY & BOUWER, 1999). The resulting agricultural surplus provided the foundation upon which the civilization was built. But canals constructed in 4000 B.C. did not sufficiently drain excess water from the agricultural areas, and salts accumulated in water and soils. Therefore, we could record the first step in secondary salinization in the agricultural history. Progressive waterlogging and salinization were evident from the historical succession of crops. Around 3500 B.C., the proportion of cultivated wheat and barley was 50/50 percent. By 2500 B.C., the more salt-tolerant barely represented 80 percent of the all crops, and finally by 1700 B.C., wheat could not be grown anymore because of the high amount of salts accumulated in the ground water and soil. Centuries of irrigating poorly drained soil with highly mineralized water in an arid climate offered the worst scenario for the agriculture and subsequently for the future of such important civilizations. It is a subtle, but stronger correlation between the high salinity level, as a result of bad irrigation management, and the implications in agriculture and finally in collapse of the civilizations.

WHYTE (1961) stated that the evidence shows that, after some 1000 to 1500 years of the successful irrigation agriculture which produced the brilliant Sumerian civilization, a very serious salinity problem developed. When the country thus became progressively weakened economically, the long political and cultural supremacy of the south could not be not be maintained and the last Sumerian Empire, the third Dynasty of Ur, finally fell.

As we can simply recognize, the secondary salinization of arable lands and water resources is a 6000 year-old problem.

The Sumerian civilization is not the single whose history is close to salinity problems. The Indus basin civilization (3000-1500 BC) is thought to have collapsed due to the Indus River shifting its course, and unchecked salinization of the irrigated land (ALAM et al., 2007). Pakistan has a good and long tradition in salinity issue, facing in the past with irrigation agriculture system and in the present and future with biosaline agriculture, as we will extensively describe in the follow paragraphs.

In Pakistan, the Indus basin today houses over 140 million people and contains about two million farms. It also contains the largest contiguous irrigation system in the world with 16 million ha receiving approximately 172 km^3 of high quality river water annually (PRATHAPAR et al., 2005). It seems that it is one of the oldest agricultural production systems in the Indian subcontinent and annual floods have shaped agricultural development for more than 4000 years. Indus civilization had two main centers that are located in today's Pakistan: Harappa and Mohenjodaro. Excavations done in this region and other data indicate that these civilizations had strong economies, therefore being powerful and advanced (WHEELER, 1976). But in time, nearing the end of the Indus civilization, the cities began to wither and their strong economies slowly deteriorated. It is still obscure the precise reasons for the fall of these civilizations, but is clearly that agricultural practices were implicated in this context. It was suggested that intermittent floods would have wiped out the irrigation system, destroying many of the buildings. In addition, the society would have been affected by a series of floods and droughts. This kind of alternation, dealing with water dynamic in the soil is very dangerous to agriculture, being susceptible to produce progressive salinization. Anyway, since the irrigation system deteriorated over time, thus affecting crops productivity is possible that all society order to have been negatively affected, becoming more vulnerable to final collapse.

The following history of Pakistan, referring on salinity continued to be placed in the same context of the negative impact of increasing salt level on agriculture. It is clear that irrigation technology was used without anticipating its ecological impact; the irrigation strategy in agriculture was considered a great human innovation in agriculture, but the implicit ambivalence of this must be also recognized. Regarding the Indus civilization, as early as 1859, waterlogging and salinization were apparent close to the Western Jumna Canal in the Ganges basin. However, by 1925 the problem was given wider recognition with the Waterlogging Enquiry Committee's establishment. Yet, rather than attributing the problem to irrigation, other infrastructure with surface runoff was seen as responsible for the situation. So, in some instances, the bureaucracy and an insufficient understanding of ecological correlations between factors involved in agriculture could worsen the scenario-salinity.

Pakistan covers an area of about 796,100 million ha (KHAN, 2007), being primarily arid and semiarid. As we already pointed, surface and ground water in agricultural areas in Pakistan became rapidly saline. Today, about 6.2 out 23 million ha of cultivable lands are affected by salinization where 2.8 million ha have some kind of cultivation while 3.4 million ha could not sustain any conventional crops. In Pakistan, mainly the secondary salinization induced by modern irrigation system affects the agriculture.

Salinity management and biosaline agriculture

Despite many centuries of irrigation experience in agricultural practices, the salinization of arable land remains the main problem for the present and future of humanity. Taking a long term historical perspective we could assert that after a long irrigation activity, the only ecological solution to face with salinity is either to use the saline or brackish water for irrigation, either to use halophytes as non-conventional cash-crops. In fact, any direction of these would be choosing, there are advantages and disadvantages in the same time.

Basically, the saline water is an inexhaustible water-source. Our global water reserves consist primarily of saline waters, i.e., 96.5% is seawater and almost 1% is saline groundwater. This leaves only 2.5% of the global water reserves as fresh, non-saline water, of which two-thirds occurs as ice and only about one-third is fluid fresh-water (PITMAN & LÄUCHLI, 2002).

The idea of using seawater for irrigation and developing biosaline agriculture – by using salt tolerant plants - is not such a new approach. Since 1966, Boyko drew attention to the possibility of crop production using seawater irrigation and highly salt-resistant plants (halophytes). After Boyko paper, some monographs dealing with use of saline water for irrigations occurred (HOLLAENDER, 1979; SAN PIETRO, 1982; STAPLES & TOENNIESSEN, 1984; PASTERNAK & SAN PIETRO, 1985; ABROL et al., 1988; JAIWAL et al., 1997), but the number of papers published in different journals is too greater to be summarized here.

In any cases, efforts for developing biosaline agriculture and subsequent technique were carried in the countries facing with salinization and aridization also having basically seawater or brackish resources for sustain such a practice. Therefore, Israel (PASTERNAK & NERD, 1996), Egypt (EL-SHAER & EL-MORSY, 2008), Pakistan (AHMAD & ISMAIL, 1996; KHAN & ANSARI, 2008), U.S.A (TEAS et al., 1996), Australia (MALCOLM, 1996), Iran (KOOCHEKI, 1996), India, and Tunisia (ABDELLY et al., 1996) are actually the main centers where biosaline agriculture concept was introduced and implemented; in addition, attempts to use halophytes for bioreclamation of salt-affected soils were recorded.

Since 1985, an experimental work has been carried out at Ben-Gurion University of the Negev (Israel), in order to develop a seawater agriculture based on salt-resistant halophytes (PASTERNAK et al., 1985). The aim of this experiment has been well described: "we want to develop, from wild halophytic plants, a range of new crop species that will give economically worthwhile yields with seawater irrigation or in other words, a seawater-based agriculture".However, despite research and projects since decades to use seawater for agriculture, only few organisms have been found, which can be grown with seawater: some mangrove trees and shrimps (BRECKLE, 2009). Some halophytes can at least fulfill their lifecycle with seawater, but they also grow better on half seawater concentration. In many other developed projects with cash crops the use of only 10-20% seawater concentration has been in some extent economically feasible. Often, the use of brackish water of 20% seawater has been reported a big success, but 20% instead of 10% or 15% is still no seawater agriculture, many crops suffering from damages under saline conditions.

There are several promising attempts for sustainable agriculture in drylands, as in Siwa Oasis, Egypt. This region has the largest naturally flowing springs in the New Valley. Siwa once contained a thousand springs, with a salinity ranging from EC (Electrical Conductivity) from 2 to 4 dS/m, which were used successfully to irrigate olive and date-palm orchards, with some scattered forage areas. But due to excessive irrigation without appropriate drainage facilities, salinity and waterlogging have developed in some areas of the oasis. For solving this problem, a new strategy management is being developed by the local authorities (RADY, 1990).

Biosaline agriculture – a realistic assay or a simple utopy?

First of all, we think that here might be some confusing interpretations of reported results concerning plants which could be cultivated under saline/brackish water. It is still difficult to define precisely halophytes, salinity and even glycophytes (GRIGORE, 2008; GRIGORE & TOMA, 2010). Despite the fact that biosaline agriculture refers mainly to possibility to use seawater for irrigation (see above mentioned definition of PASTERNAK et al., 1985), we must focused more on brackish water, since the number of plant species having some salt-tolerance mechanisms is more greater than those of "true" halophytes (euhalophytes). In many checked publications, we found that authors are using sometimes the terms "halophyte" and sometimes, "salt-tolerant" species referring in fact, to the same group of plants. This way of approaching may be ambiguous since all the halophytes are salt-tolerant species, being "salt-love" plants, but there are many non-halophytes species having more or less restricted tolerance capacity. In addition, the border between halophytes and glycophytes is still arbitrary (GRIGORE & TOMA, 2010).

Beyond it, opinions regarding the sustainability of biosaline agriculture are still contradictory: some authors think that an agriculture based on seawater irrigation is a utopic illusion, while others regard salt-tolerant species as a solution for the future of agriculture. But what is for sure is the fact that populations in developing countries are growing so quickly that the land and water are unable to sustain them. In most of these countries, prime farmland and fresh water are already completely utilized. Irrigation could be introduced to bring land in arid areas into production, but this often leads to salinization. Salt-tolerant plants (not only halophytes, *stricto sensu!!*) may provide a true alternative for many developing countries. In some cases, salinized farmlands could be used without costly remedial measures, and successful rehabilitation of degraded land is usually preferable, in terms of resource conservation. The salinized groundwater can be used to grow salt-tolerant plants. In a well documented published report (*Saline Agriculture: Salt-Tolerant plants for developing countries* 1990) here are summarized many salt-tolerant species cultivated or with a susceptible potential for growing in saline conditions. This report suggests three possible domains for the use of salt-tolerant plants in developing countries: farmlands salinized by poor irrigation practices, arid areas that overlie reservoirs of brackish water and coastal deserts.

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Grigore Marius-Nicuşor, Toma Constantin
"Al. I. Cuza" University of Iaşi,
Faculty of Biology, Department of Plant Biology,
20 A "Carol I" Bd. 700505, Iaşi, Romania,
E-mail: mariusgrigorepsyche@yahoo.com; ctoma@uaic.ro

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