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Crops for a Salinized World

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Cultivation of salt-tolerant crops can help address the threats of irreversible global salinization of fresh water and soils.

Currently, humans use about half of the fresh water readily available to them to support a growing world population [expected to be 9.3 billion by 2050 (*1*)]. Agriculture has to compete with domestic and industrial uses for this fresh water. Good-quality water is rapidly becoming a limited and expensive resource. However, although only about 1% of the water on Earth is fresh, there is an equivalent supply of brackish water (1%) and a vast quantity of seawater (98%). It is time to explore the agronomic use of these resources.

Adding to the increasing competition for fresh water is the gradual and irreversible spread of salinization. Salinity is affecting fresh water and soil, particularly in arid and semiarid climatic zones. Ironically, irrigation has resulted in the accumulation of salt to above normal concentrations in the rooting zone of arable land, as high rates of evaporation and transpiration draw soluble salts from deep layers of the soil profile. The water and salt balance has also changed in regions where dryland agriculture—growing crops without

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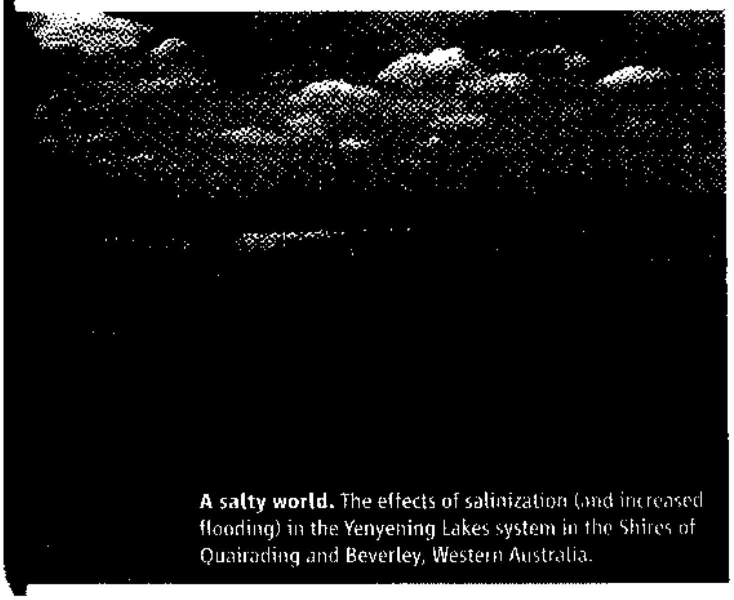
irrigation in areas that receive an annual rainfall of 200 to 300 mm or less—is practiced following forest clearance [this allows salts present in the groundwater to reach the surface (*2*)]. In addition, continuous sea-level rise in a warming world threatens increased salinity in coastal lowlands. As fertile soils become salinized (*3*), the yield of conventional crops decreases. For example, a survey conducted between 1993 and 1995 in the Sacramento Valley in California (*4*) revealed a loss of 10% as the salinity rose by 1 dS m^{-1} (soil salinity is measured by its electrical conductivity in solution). The United Nations Food and Agriculture Organization estimates that there are currently 4 million square kilometers of salinized land, and a similar area that is affected by sodicity, a condition in which Na^+ ions represent more than 15% of the exchangeable cations (*5*). Of the 230 million ha of irrigated land, 45 million are affected by an increase in salt content [figures based on data collected more than 15 years ago (*6*)]. Soil salinization particularly affects economically less-developed countries with large and growing populations that are located in arid climatic zones (including Pakistan, India, Egypt, Tunisia, Morocco, Peru, and Bolivia), whereas more-developed regions are much less threatened by, but not immune from, salinity (*7*). Soil salinization in arid regions is practically irreversible because fresh water is not available to leach any accumulated salts. Even such leaching efforts are questionable because the saltwater created has to be evaporated if it is not to cause further damage.



A salty world. The effects of salinization (and increased flooding) in the Yenyening Lakes system in the Shires of Quairading and Beverley, Western Australia.

PHOTO CREDIT: TIM FLOWERS

The evolution of plant life on Earth started 3 billion years ago in saline ocean water. With the advance of land plants about 450 million years ago, primary adaptations of plants to the high concentrations of Na^+ and Cl^- (about 500 mmol per liter of seawater) were effectively lost (*8*). Today, only about 1% of the species of land plants can grow and reproduce in coastal or inland saline sites. Among these salt-adapted halophytes are annuals and perennials, monocotyledonous and dicotyledonous species, shrubs, and some trees. There is a wide range of morphological, physiological, and biochemical adaptations in such plants, which vary widely in their degree of salt tolerance (*9*). Only some are tolerant to seawater salinity; more halophytes resist lower salinity concentrations. Potentially, many of these salt-adapted plants could become salt-tolerant crops in a saline agriculture in which soil salinity is less than (perhaps half) that of seawater.

Halophytes can grow at rates comparable to those of conventional forage crops (*10, 11*) and under saline conditions, biomass of the former is comparatively greater than that of all our major crops. For example, *Salicornia bigelovii*, a potential oil-seed crop, produces about 18.0 tons/ha of biomass and 2.00 tons/ha of seeds over a 200-day growing cycle (*10*); by comparison, the average yield of sunflower across the world in 2007 was 1.2 tons/ha. Although the physiological adaptations required to tolerate salinity require energy and therefore might be predicted to reduce plant growth and yield, any decline in halophyte biomass production occurs at much higher salt concentrations than for conventional crops.

Modern agrobiotechnology might speed up the process of achieving conventional crops that are resistant to the high concentrations of Na^+ and Cl^- in saline agriculture. Indeed, biotechnology has generated traditional crops that are resistant to plant pests and diseases, such as genetically modified corn and cotton. However, over the past 15 years, the bioengineering approach has not delivered salt-tolerant cultivars of conventional crops such as wheat or rice for release to farmers. So, although between 1996 and 2006 there were more than 30 reports of transformation of rice with different genes aimed at increasing salt tolerance, transgenic salt-tolerant rice is not close to release. The likely explanation is that salt tolerance is a complex trait determined by many different genes, so that transformation of multiple genes into a plant is required (*12, 13*).

Because salt resistance has already evolved in halophytes, domestication of these plants is an approach that should be considered (*12, 13*). However, as occurred with traditional crops such as rice, wheat, corn, and potatoes, domestication of wild halophytic plant species is needed to convert them into viable crops with high yields. Such a process can begin by screening collections for the most productive genotypes. There are many uncertainties and risks: variable germination, propagation, plant diseases, scaling up, processing halophyte biomass, market demand, and economic competition with conventional bulk-produced raw materials such as potato, sugar beet, and sugar cane. The development of halophytic crops would also have to be undertaken with studies of hydrological and soil management of saline agriculture systems.

The use of saline water for irrigation is in its infancy, although experimental trials using seawater (*14*) and mixed saline and fresh water (*15*) have been conducted. A huge benefit of using saline water in agriculture is that seawater contains many of the macro- and micronutrients that are essential for plant growth and function. Seawater is a vast resource that is further supplemented by massive volumes of brackish groundwater (salt concentrations ranging from 1 to 50% of that of seawater) and waste water; all could be available for saline agriculture. Moreover, the number of halophytic crops that would produce an economically viable yield if irrigated with brackish water would be much larger than if seawater were to be used for irrigation, because there are many more halophytes and coastal plants that grow well with brackish water than grow well in seawater.

The benefits of saline agriculture encompass not only food products for human consumption and fodder crops for animals, but also renewable energy (biofuel and biodiesel) and raw materials for industrial use (*16*). This is particularly relevant because the traditional raw materials for energy production—oil, gas, and coal—are being depleted and are expensive. However, the relative costs of growing halophytes for bioenergy and biofuel—a process that would not compete with the growth of conventional crops and therefore not threaten the world food supply requires evaluation. A further advantage of saline agriculture is that growing halophytes may be combined with aquaculture of sea

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fish and shrimp. In such sustainable marine agrosystems, inorganic nutrients from fish or shrimp ponds can be used to promote the growth of halophytes (*17*).

Worldwide, initiatives are being undertaken to develop saline vegetable crops, as well as crops for fuel and fiber (*18*). And in various countries, private companies and research groups are collaborating to develop technologies that combine saline agriculture with aquaculture. The concept of a saline agriculture has been long discussed (*19*), but the increasing demand for agricultural products and the spread of salinity now make this concept worth serious consideration and investment.

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