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# Haloculture and Haloengineering in the Context of Water-Energy-Food Nexus †

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**Abstract:** The utilization of saline soil and water resources by Saline Agriculture systems is an economical and viable strategy for meeting the rising demand for global food. However, despite vast experiences in research and commercial accomplishments, Saline Agriculture have still not played a key role in the extension of sustainable agriculture in saline areas. This could be due to an insufficient devotion to the holistic needs (food, water and energy) of local societies in salt-affected regions. Consequently, Haloculture was developed as a new Saline Agriculture technology, which is defined as the sustainable production of biological and non-biological products in saline environments. The main objective of this paper is to describe and discuss Haloculture in the context of the Water-Energy-Food Nexus (WEFN). This technology integrates engineering tools and sciences referred to as Haloengineering with agricultural sciences to meet the holistic needs of human societies in salt-affected areas. Haloengineering attempts to produce water and energy by exploitation the inherent potentials of saline ecosystems. Haloculture tries to sustainably exploit the services and potentials of saline environments for the production of food, water and energy. It conforms to the contexts of WEFN, and promotes water and energy securities along with food security. Therefore, Haloculture can be a viable strategy for sustainable rural development in saline regions.

**Keywords:** Biosaline agriculture; ecosystem services; Saline agriculture; sustainable agriculture



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## 1. Introduction

The alarming rise in the world population has imposed excessive pressure on soil, water and natural resources to provide the growing demands for food, water and energy. However, most of the productive soils are already being cultivated for agronomic purposes. In addition, the competition between agriculture and other economic sectors for water is escalating due to limitations on available global freshwater resources. Consequently, using salt-affected lands and saline waters for agricultural production through various Saline Agriculture systems (such as Haloculture) is essential for achieving rising human needs in the near future.

Saline Agriculture systems have adequate potentials for the development of sustainable agriculture in salt-affected ecosystems. However, despite rich research and commercial experiences, they have not yet had a significant impact on strengthening the food security in salt-affected regions, especially in less developed countries. This can be due to paying more attention to production aspects and to not paying enough attention to the extension and institutionalizing phases. The holistic needs of human societies and potentials of salt-affected ecosystems to meet those needs (water, energy and food), have not been addressed properly. Suitable measures for the enactment of saline production systems like Haloculture are necessary at regional and national levels. Haloculture is trying to follow the goals and objectives of the Water-Energy-Food Nexus (WEFN) concept. For this purpose, Haloengineering was proposed as a viable solution for the successful development

and expansion of Haloculture in salt-affected regions [1]. Consequently, the objective of this paper is to discuss Haloculture and Haloengineering in the context of WEFN for the sustainable development of salt-affected areas.

## 2. Saline Agriculture Systems, Haloculture and Food Security

The common objective of Saline Agriculture systems is the utilization of saline resources for the improvement of food security. However, with the advancement of the technologies and experiences gained, some instructive differences between their concepts and views have evolved. Haloculture is a production system with emphasis on environmental stewardship and protection, as well as the sustainable and economic exploitation of saline soil and water resources. It started with the successful completion of an international Biosaline Agriculture project in several countries, including Iran [2]. After the end of the project, by considering the strengths and limitations of Biosaline Agriculture and the local and national capacities of the country, Haloculture was introduced [3].

*Haloculture* is the sustainable, economic production of agricultural (biologic) and industrial (non-biologic) products in saline environments [4]. The cutting edge between Haloculture and Biosaline agriculture is its emphasis on the holistic needs of human societies (i.e., water, energy and food). Thus, Haloculture considers the whole salt-affected ecosystem, rather than merely the saline soil and water resources, as a production resource.

Haloculture promotes integrated production systems (Figure 1). For example, saline aquaculture wastewater can be used to irrigate halophyte forage farms. In turn, the halophyte forages may be used as forages for animals such as cattle and sheep. The higher salinity drainage waters from halophyte farms can be utilized for higher halo-tolerant aquatics, such as microalga and Artemia. Therefore, both biologic (various halophytes and animals), and non-biologic or industrial, products (salts and minerals, drinking water and energy) are produced in the integrated system of Haloculture (Figure 1). Saline environments, which possess various natural capacities, are considered as a medium of production in Haloculture, which will be explained thoroughly later on. Haloculture thereby puts an emphasis on covering the holistic needs of rural communities in salt-affected environments (i.e., food, water and energy), which is more in agreement with the WEFN concept.

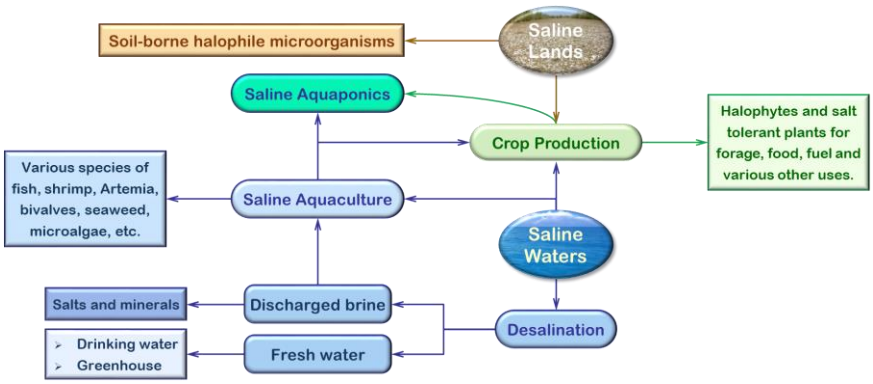


**Figure 1.** Haloculture concept for the sustainable and integrated use of saline resources [1].

Saline Agriculture systems (Seawater Agriculture, Biosaline Agriculture and Haloculture) have over six decades of national and international research and commercial experiences combined. It seems that research organizations have been fairly successful in raising the awareness of scientists and, to some extent, farmers and decision makers on the economic exploitation of saline soil and water resources. Private companies and organizations have validated the viability and profitability of saline agro-complexes. It seems that both research institutes and the private sector have not yet been successful in the widespread expansion of Saline Agriculture and enhancement of food security in arid, salt-affected regions [1]. Therefore, they have so far not played a significant role in

the world food production, reduction of poverty and improvement of living conditions in less developed countries. It is evident that Saline Agriculture systems need to adopt new technical and/or social strategies to help more effectively in the actual implementation of sustainable development in salt-affected areas. This will in turn contribute much more effectively to global food security. Haloengineering is proposed as an effective contribution of Haloculture to the sustainable rural development of saline ecosystems, especially in less developed areas.

## 3. Haloengineering and Water-Energy-Food Nexus

Water, energy and food are essential needs for human health, poverty reduction and the sustainable development of societies. Consequently, the Water-Energy-Food Nexus (WEFN) has been presented as a framework for sustainable development [5]. The WEFN states that water security, energy security and food security are intricately linked to each other and that the actions taken in each one of them affect the other two [5,6]. According to WEFN, the future growth in world population will increase the need for food, water and energy simultaneously. Hence, systems that tackle these three basic human needs concurrently would promote their sustainable security more efficiently. Considering the definition and objectives of Haloculture, it is evident that Haloculture has tried to adhere to the views and objectives of WEFN by addressing the three basic human needs simultaneously.

Saline soil and water resources are usually abundant in salt-affected regions. However, a lack of vital infrastructures (such as road, electricity and drinking water), as well as harsh environmental and climatic conditions (such as excessive heat and cold, sand storms, windstorms and/or high humidity), are also apparent in such regions. These factors may discourage the large-scale acceptance and application of Haloculture by local farmers. Thus, along with the production of economic bio-products, the production of non-biologic commodities (i.e., energy and drinking water) is also emphasized in Haloculture.

Salt-affected ecosystems, depending on their geographic location, possess diverse capacities and features. These potentials may be managed for the production of water and energy. For example, coastal ecosystems have the potential to exploit their high humidity for freshwater harvesting. However, the appropriate technologies needed to achieve this goal are made possible by engineers, not agriculturalists. Consequently, cooperation between agriculturalists and engineering scientists is needed to fully utilize the natural capacities of saline environments. The applications of engineering concepts and technologies in Haloculture are called Haloengineering.

*Haloengineering* or *Haloculture engineering* is defined as the harmonic, interdisciplinary application of concepts, methods and tools from the engineering sciences for the sustainable development and enhancement of the living standards of mankind in salt-affected regions, by using locally available basic resources for the cost-effective and efficient production and management of energy and water [1]. Air, water, soil and biodiversity are the basic resources. The concepts and sustainability objectives of Haloengineering are illustrated in Figure 2. All saline ecosystems possess natural and inherent potentials and capabilities. These ecosystem services may include soil and water resources of different quality and quantity, genetic biodiversity, and climatic characteristics such as rainfall, sunshine hours, wind frequency and speed, and humidity. The tools and technologies developed by engineers may be used and/or developed specifically to exploit these inherent potentials, in order to produce the much needed drinking water and energy for human societies in the region (Figure 2). Thus, with the assistance of Haloengineering, Haloculture can contribute much more effectively to sustainable development programs in salt-affected ecosystems.

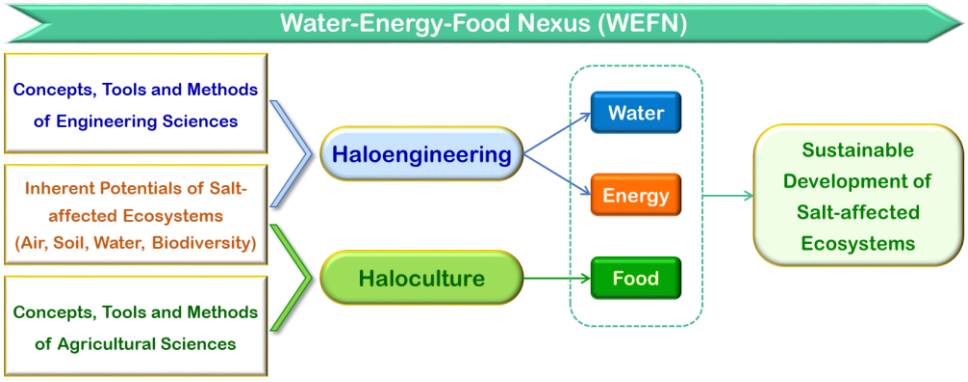


**Figure 2.** The principles of Haloengineering and Haloculture under the concept of WEFN.

## 4. Conclusions

Haloculture, and Haloengineering as its complementary component, were discussed under the framework of WEFN. Haloculture, by adopting and applying the idea of Haloengineering, ensures the concurrent production of water, energy and food; therefore, it may contribute much more proficiently to sustainable rural development in saline areas. Hence, a more comprehensive definition of Haloculture is given as the sustainable use of the potentials and capacities of salt-affected ecosystems for the production of biologic and non-biologic products.

Through Haloculture, significant portions of saline lands and waters are capable of having an economically viable food production. The production of all or some of the needed water and energy can be achieved through Haloengineering as the complementary component of Haloculture. These features of Haloculture are in accordance with the concepts of WEFN. Haloengineering will play a dynamic role in the expansion of Haloculture in saline regions.

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