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Membrane technology for water production in agriculture: Desalination and wastewater reuse

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HIGHLIGHTS

- Water shortage influences also an adequate and sustainable food production.
- Water quality in agriculture does not have the same requirements as for drinking water.
- Seawaters and wastewaters properly treated can be used for irrigation.
- Membrane operations usually used in agriculture are discussed.
- Novel membrane technologies such as fertilizer draw FO and MD are also described.

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ABSTRACT

The problem of water shortage affects not only human and industrial activities but also an adequate and sustainable food production. Water quality in agriculture does not have the same requirements as that of drinking water and also properly treated wastewaters can be used for irrigation. The two possible alternative sources of water for agriculture are: desalinated water and wastewater. In this paper membrane operations usually utilized for water production in agriculture are discussed. Their main advantages are: (i) their mutual compatibility which offers the possibility of combining different membrane operations to achieve the desired water qualities and (ii) their flexibility and easy scale-up which allow passing from small to large scale, from centralized to decentralized systems. The membrane technology mostly used in desalination is reverse osmosis (RO) whereas membrane bioreactors (MBRs) deal with fresh water reclamation from wastewater streams. Novel membrane technologies are described, such as forward osmosis (FO) and membrane distillation (MD), a promising prospect for agricultural water production, and the possible recovery of nutrients from saline waters and wastewaters. Nevertheless, the development of some novel technologies needs to be accelerated to reduce the costs associated with treatment and to avoid further impacts of water scarcity on food production.

Contents

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1. Introduction

Worldwide, food and water availability are vital for the survival of humanity and to ensure adequate living standards. Population increase, climate changes and ongoing industrialization are putting pressure on the existing water resources. Fresh water resources are sufficient only in limited parts of the world (such as in Scandinavia). It is estimated that 50% of the world population will live in water stressed regions in 2025, which highlights the importance of adequate water management and treatment [1]. When water resources are limited, irrigation is penalized. Of the agricultural, municipal and industrial sectors, agriculture uses 70% of the total amount of water withdrawn [2]. In Europe the average usage is 33% with an increase in the southern part of Europe where the consumption can be as high as 80% [3]. In these regions the greater part of the water used in agriculture goes to irrigated crops. In other parts of Europe, irrigation is mainly used to optimize the crop yield by limiting the seasonal differences [3]. Crops like rice, wheat and maize are being produced in huge quantities around the world, thus also accounting for greater water consumption with respect to the total water usage in crop production (Table 1) [4]. Rice accounts for the largest share followed by wheat, despite rice and wheat being produced in almost similar quantities [5]. Maize production also involves a relatively high consumption of water. Similarly huge amounts of water are being used to produce soya for cattle fulfilling the growing demand for meat around the world. Regardless of the high water use in crop production, livestock in general consume more since they need a lot of feed (crops), drinking water and service water in their lifetime. Thus water scarcity will affect not only irrigation for the human food, but also livestock production (where water is essential for both watering and food).

As illustrated in Fig. 1 and in Fig. 2, irrigation with groundwater is not a common practice worldwide whereas the tendency to utilize surface waters is widespread (Fig. 3).

Another important problem is water loss. It has been estimated that around 70% of irrigation water is not returned to the surrounding water bodies and the risk that the remaining 30% contaminate them is high [3]. Indeed, a serious drawback of irrigation is the contamination of the existing natural resources. The failed attempts to irrigate the crops with fossil water due to its nonrenewable nature further highlights the need to find innovative ways of arranging water for agricultural uses and to ensure a better management of water resources for various purposes. In order to improve the agricultural output and minimize depletion of natural water resources, targeted water quality at low cost is needed.

Table 1
Global water consumption for the production of a particular crop with respect to the total global water consumption for crop production in general.
From [4].

Crop	Share in global water consumptions for crop production [%]
Rice	21.3
Wheat	12.4
Maize	8.6
Soybeans	4.6

2. Quality requirements for agricultural water

Water to be utilized in the agricultural sector has to address specific quality requirements in order to obtain an optimal production rate of irrigated crops. At the same time, taking into account the huge amount of water necessary in agriculture, a proper and sustainable management of water resources together with an efficient water distribution network is necessary to minimize losses, leaching and drainage (phenomena that can cause elevated concentrations of salts and nutrients in nearby soils and water bodies).

On the other hand, when using poor quality irrigation water, it is necessary to apply extra water to prevent salt accumulation in the soil which can have a negative effect on the crops [7]. Natural water resource degradation owing to a high concentration of nitrogen and phosphorus is mainly caused by agricultural practices, sewage and industrial effluents. The increase in nutrients in water resources entails an increase in algal blooms which has a severe negative effect on the aquatic environment [8].

Therefore, water quality for agriculture, and in particular for irrigation, is determined by several parameters such as crop selection, soil properties, leaching and drainage. Practically, irrigation water should meet the standards of the Food and Agriculture Organization (FAO) (Table 2).

In particular, sodium and chloride salts are undesirable as salinity level and sodium adsorption ratio (SAR) (Eq. (1) [9]) are the parameters often utilized to check the suitability of irrigation water.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}. \qquad (1)$$

The salinity level and SAR indicate different *water classes* according to their appropriateness for agricultural purposes (Table 3). SAR values are influenced by calcium and magnesium contents. According to FAO, calcium is not toxic, however, scale formation such as calcium carbonate and calcium sulfate can create problems in the irrigation system together with a reduced acceptance by the market when the salts precipitate on fresh fruits and vegetables [9]. Magnesium is essential for field crops, which when its composition is too low, should be added to the irrigation water (even though, in reality, this is not done because of the high cost). Nevertheless, magnesium can also have the same negative impact as sodium when applied in extensive amounts, in particular if the magnesium to calcium ratio is higher than 1 [10]. In fact, Severino et al. [11] found that high concentrations of magnesium and calcium reduce the SAR ratio but, at the same time, increase electrical conductivity thus giving origin to a water with quality not completely appropriate for irrigation. Specific guidelines for calcium and magnesium have to be stipulated with respect to the amount already present in the soil and irrigation water. However, FAO provides values usually in the range of 0–400 mg/l and 0–61 mg/l for calcium and magnesium, respectively [9].

SAR, salinity, trace elements, etc. are the parameters usually used to identify whether water from a source can be utilized or not for irrigation. However, these parameters do not take into account all the components that have to be present (such as nutrients, etc.) in order to maximize crop yields by using less water resources [13]. Therefore