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Attenuating the negative effects of irrigation with saline water on cucumber (*Cucumis sativus* L.) by application of straw biological-reactor

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ABSTRACT

The shortage of high-quality water resources has become a major limiting factor for agricultural development in China, leading to the use of low-quality water resources (e.g., saline water) for crop irrigation. However, irrigation with low-quality water often results in negative effects on plant growth. We conducted an experiment under greenhouse conditions carried out over two growing seasons to investigate the effects of straw biological-reactor (SBR) application on soil properties, cucumber growth, and fruit yield and quality under saline (NaCl) water irrigation. Soils were treated with/without SBR, saline water and their combination. In general, under non-SBR conditions, soils irrigated with saline water showed significantly higher salinity, Na^+ concentration and pH in the main root zone (0–40 cm) of cucumber, but significantly lower plant biomass and cucumber fruit yield, when compared to soils irrigated with non-saline water. However, under saline water irrigation conditions, soils treated with SBR showed significantly lower salinity, Na^+ concentration and pH in the main root zone of cucumber, and significantly higher plant biomass and cucumber fruit yield, when compared to untreated soils. Additionally, saline water irrigation decreased total soluble sugars, titratable acidity and vitamin C in cucumber fruit. In contrast, the negative effects of saline water on fruit quality were significantly reduced by SBR application. Our results suggested that the application of SBR could not only enhance plant growth, but also improve fruit quality under saline water irrigation.

1. Introduction

In Northwestern China (NC), most areas are characterized by scarce water resources (Ma et al., 2005), mainly due to human population growth (Shen et al., 2013). Thus, high-quality water resources are allocated with priority to urban water supply and those available for use in agriculture are decreasing. Since the NC is an important food-producing region in China, and agricultural irrigation consumes most water resources in this region, the shortage of high-quality water resources has become a major limiting factor for agricultural development. Therefore, it is important to look for alternatives to high-quality water resources and improve water management.

Water shortage led to the use of low-quality water resources (e.g., saline water) for crop irrigation (Chen et al., 2010). However, irrigation with low-quality water often results in negative effects on plant growth and decreasing agricultural productivity (Carmassi et al., 2013; Valdez-Aguilar et al., 2013). For example, under saline water irrigation, sodium ions (Na^+) will accumulate in plant tissues, and then disturb water absorption and restrict the uptake of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K) and Calcium (Ca) (Lakhdar et al., 2008). Moreover, the accumulation of Na^+ in soils may decrease soil quality, which may result in the reduction of plant growth. Therefore, irrigation with low-quality water may cause secondary salinization, progressively compromise soil resources and decrease plant productivity (Beltran, 1999; Tejada et al., 2006; Chen et al., 2010). Thus, it is of

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the utmost importance to find methods for reducing the negative effects of low-quality water if used for irrigation.

Input of organic matter conditioner (OMC) is a common practice in salt-affected areas to reduce the negative effects of saline water. The OMC application has three main beneficial effects on the plant–soil system: enhancing salt leaching through improving soil structure and permeability (Walker and Bernal, 2008; Lakhdar et al., 2011), providing essential nutrients for plants (Lakhdar et al., 2008), and re-establishing microbial activities and populations (Lakhdar et al., 2009). Among OMC, straw compost, made of plant straws and animal manure, has been demonstrated to be effective in reclamation of salt-affected soils (Walker and Bernal, 2008; Lakhdar et al., 2011). The application of compost on salt-affected soils can increase water infiltration and aggregate stability, accelerate NaCl leaching, and decrease exchangeable sodium percentage and electrical conductivity (Lakhdar et al., 2009). Furthermore, animal manure has been confirmed to be effective in improving plant growth in salt-affected soils. Animal manure represents a source of nutrients that can improve soil fertility, and thereby contribute to restoring the productivity of salt-affected soils (Tejada et al., 2006; Walker and Bernal, 2008).

Recently, in China, a new technique, named straw biological-reactor (SBR), has been applied to recover degraded soils that show secondary salinity (salting that results from human activities) in greenhouse vegetable production systems (Sun et al., 2014). Although SBR is a new technology, it may be used to improve salt-affected soils or cultivate crops with saline water because the main materials used in SBR are plant straws and animal manure (Sun et al., 2014), which are the main feedstocks used in straw compost (Lakhdar et al., 2009). However, unlike straw compost, which is decomposed plant straws and animal manure mix, the SBR is composed of 2 layers of un-crushed maize straws and 2 layers of well decomposed animal manure. In addition, the C/N ratio is higher in SBR (30–35) than in straw compost (<20; Bernal et al., 2009). Therefore, the effects of SBR on soil properties and plant growth in salt-affected soils (under saline water irrigation) may be different from those of straw compost.

The SBR is recommended for improving plant growth in areas with soils characterized by low organic matter (Cao et al., 2010). It is often buried under 20-cm soil layer 20 days before transplanting (Sun et al., 2014). The main limiting factors of SBR application are related to the organic and/or inorganic pollutants (e.g., heavy metals) and microbial contaminants (e.g., fungal pathogens) in feedstocks (Peng et al., 2011; Sun et al., 2014). Thus, feedstocks with high quality should be used during SBR application. Otherwise, for feedstocks containing microbial contaminants, treatments such as fungicide application should also be used when SBR is applied in soils (Sun et al., 2014).

Evidence from previous studies indicates that the advantages of SBR application are related to the improvement of the soil physical, chemical and microbial properties (Cao et al., 2010; Peng et al., 2011; Sun et al., 2014). To our knowledge, however, a low number of studies have been conducted to investigate the influence of SBR on effects of saline water on crop growth. Since the SBR could be used to improve soils that showed secondary salinity (Sun et al., 2014), we hypothesize that this technique might be beneficial for reducing the negative effects of irrigation with saline water on crop growth and quality.

Cucumber (*Cucumis sativus* L.) is one of the most economically relevant vegetable crops in China (Tian et al., 2011, 2013). In Northwestern China, cucumber is a common vegetable crop in agricultural production systems, especially in protected vegetable production systems. However, the shortage of high-quality water resources has limited cucumber production in Northwestern China (Ma et al., 2005; Shen et al., 2013). In this study we assessed the effects of SBR application on soil

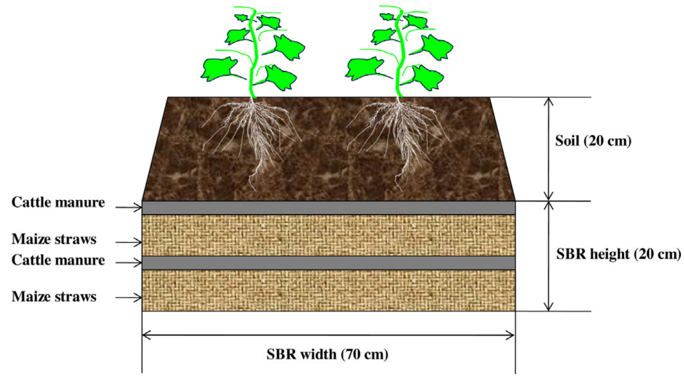

Fig. 1. The structural diagram of straw biological reactor (SBR) used in this study. The SBR was composed of 2 layers of un-crushed maize straws (6.0 t ha^{-1}, 3.0 t ha^{-1} per layer) and 2 layers of well decomposed cattle manure (0.78 t ha^{-1}, 0.39 t ha^{-1} per layer). It is buried in the soil below the 20-cm soil depth.

properties, plant growth and cucumber fruit yield and quality under irrigation with saline water from an experiment under greenhouse conditions carried out over two growing seasons. The objective of this study was to test whether the negative effects of irrigation with saline water on cucumber growth and quality can be reduced by the SBR application. If the negative effects of irrigation with saline water on plant growth could be attenuated by application of straw biological-reactor, our study would provide data for a better management of low-quality water resources (e.g., saline water) in agricultural production.

2. Materials and methods

2.1. Site description and experiment design

The trial was conducted in a three-year-old commercial greenhouse which was randomly selected for the greenhouse field experiment from 12 greenhouses in Zhenbeibao county, Ningxia, China. The greenhouse was covered with polyethylene film (ground area 7.6 m × 66 m) without supplementary lighting or heating. The greenhouse soil was previously used to produce cucumber in the winter–spring (from January to June) and autumn–winter (from July to November) cropping seasons. The experiment was conducted from early January to early November in 2013. All plants were irrigated with half-strength Hoagland nutrient (HSHN) solutions (Hoagland and Arnon, 1950). The treatments considered were (i) the untreated soils irrigated with nutrient solution without NaCl (control, C), (ii) soils irrigated with nutrient solution containing 3 g L^{-1} NaCl (saline water, SW), (iii) soils amended with straw biological reactor (SBR) and irrigated with nutrient solution without NaCl (C + SBR), and (iv) soils amended with straw biological reactor and irrigated with nutrient solution containing 3 g L^{-1} NaCl (SW + SBR). The structural diagram of straw biological reactor (SBR) used in this study is shown in Fig. 1. The steps regarding how SBR has been established in the field are the following:

Step 1. *Digging ditches in the field.* The length, width and depth for each ditch were 7.2 m, 70 cm and 20 cm, respectively. The soils dug out were carefully placed near the border of the ditch.

Step 2. *Filling ditches with SBR feedstocks.* The SBR was composed of 2 layers un-crushed maize straws (60 t ha^{-1}, 30 t ha^{-1} per layer) and 2 layers of well decomposed cattle manure (0.86 t ha^{-1}, 0.43 t ha^{-1} per layer) (Fig. 1). Such rates for establishing SBR were used based on our preliminary experiments (Peng et al., 2011; Sun et al., 2014). The initial C/N ratio of such SBR was 30.5. Selected