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RESEARCH ARTICLE

Applying a salinity response function and zoning saline land for three field crops: a case study in the Hetao Irrigation District, Inner Mongolia, China

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Abstract

Salinity is one of the major abiotic factors affecting the growth and productivity of crops in Hetao Irrigation District, China. In this study, the salinity tolerances of three local crops, wheat (*Triticum aestinum* L.), maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.), growing in 76 farm fields are evaluated with modified discount function. Salinity ecological zones appropriate for these local crops are characterized and a case study is presented for crop salinity ecological zoning. The results show that the yield reductions of wheat, maize and sunflower when grown in saline soils are attributed primarily to a reduction in spikelet number, 1 000-grain weight and seed number per head, respectively. Sunflower is the most tolerant crop among the three which had a salinity tolerance index (ST-index) of 12.24, followed by spring maize and spring wheat with ST-Indices of 9.00 and 7.43, respectively. According to the crop salinity tolerance results, the arable land in the Heping Village of this district was subdivided into four salinity ecological zones: the most suitable, suitable, sub-suitable and unsuitable zones. The area proportion of the most suitable zone for wheat, maize and sunflower within the Heping Village was 27.5, 46.5 and 77.5%, respectively. Most of the most suitable zone occurred in the western part of the village. The results of this study provide the scientific basis for optimizing the local major crop distribution and improving cultural practices management in Hetao Irrigation District.

Keywords: salinity tolerance, modified discount function, ecological zoning, Hetao Irrigation District

1. Introduction

Salinity is one of the major factors reducing plant growth and productivity worldwide. About one-fifth of the irrigated agriculture in the world is adversely affected by salinity (Rodríguez and Maiti 2010). The phenomenon is more prevalent in arid and semi-arid regions, where evaporation

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is intense and rainfall is insufficient for substantial leaching (Deifel *et al.* 2006; Dai *et al.* 2011). In these areas, salinity has been considered as the most serious factor that limits the productivity and distribution of agricultural crops in natural habitats (Apse *et al.* 1999). Plants have evolved a complex adaptive capacity to respond to salinity stress (Rus *et al.* 2005). A crop's salinity tolerance relates to its inherent ability to yield economic product as root zone salinity increases (Steppuhn *et al.* 2005c). In fact, crop salinity tolerance research is the basic gist of agro-ecological zoning, crop allocation and regional planting structure optimization in saline land.

Numerous greenhouse and plot experiments in sand, water or soil culture have been carried out to identify the reduction in crop yield in response to increasing root zone salinity (Tanji and Kielen 2002). After reviewing the yield responses measured in a large number of root zone salinity experiments conducted worldwide, Maas and Hoffman (1977) concluded that crop yield as a function of the average root zone salinity could be described with a piecewise linear response function characterized by a salinity "threshold" value below which the yield was unaffected by soil salinity, and above which yield decreased linearly with salinity. But in fact, careful measurements of crop yields grown under slightly saline conditions almost always result in segments of continuous reductions with increasing salinity prior to reaching threshold concentrations. van Genuchten and Gupta (1993) indicated that the salinity threshold-slope model had no biological rationale and did not describe well in some cases which had no data points at the lower salinities. In order to improve the accuracy, van Genuchten (1983) proposed two alternative formulations, the general discount and the bi-exponential functions, to simulate the crop yield response to increasing levels of root zone salinity. Steppuhn *et al.* (2005a) showed that the modified compound-discount function recorded the lowest root mean square error and the highest coefficient of determination among all of the functions compared to describe test data from a spring-wheat (*cv*. Biggar) experiment conducted in Canada's Salt Tolerance Testing Laboratory, Swift Current, Canada. In addition, van Genuchten (1983) developed software named "SALT 1.0" to obtain the unknown parameters in different salinity tolerance response functions with the method of non-linear least squares inversion.

Sensitivity of crops to soil salinity continually changes during the growing season (Hoffman 2010; Tabatabaei and Anagholi 2012). For most crops the early seedling period of growth is the most salinity sensitive (Maas *et al.* 1986; Maas and Poss 1989; Francois and Maas 1994). As during this period of cereal crop, development leaf and spikelet primordia are initiated and tiller buds are formed (Maas and Grieve 1994). Consequently, soil salinity during this period can significantly affect final seed yield. More than 60, 79 and 90% of the root dry weight was distributed in the top 0–20 cm soil layer when measured during the seedling grown period for the wheat, corn and sunflower plants, respectively (Chassot *et al.* 2001; Hu *et al.* 2006; Yang and Zhang 2011). Therefore, salinity of 0–20 cm soil layer can be considered as indicative of root zone salinity. Salinity tolerance studies on crops have often been conducted in laboratories or in pots. However, the results from such costly and time-consuming experiments are needed for field verification. Salinity tolerance study in farmers' fields with different salinity levels ranging from very low to very high can help generate more research data for modeling and the results are more convincing. It is pertinent to study crop salinity tolerance in farmers' fields and characterize salinity ecological zones for ecological zoning.

The purpose of ecological zoning is to separate areas with similar constraints for agricultural developmental planning, land use optimization and cultural practices management. There are large numbers of studies devoted to characterize ecological zones for crop production, using the data of climate, soil, landform and land cover conditions (Alves *et al.* 2011; Neamatollahi *et al.* 2012; Liu *et al.* 2013). As in these references, crop land was divided into several ecological zones such as the most suitable, suitable, sub-suitable and unsuitable zones for more effective land-use planning and management (Store and Jokimäki 2003; Chen *et al.* 2010; Su *et al.* 2011). Spatial salinity variability of farmers' fields influenced by natural and anthropogenic factors is one of the most striking characteristics (Yao and Yang 2010). This makes the saline land-use planning more complex than any other farm land. Rational and sustainable use of saline land requires sound agricultural developmental planning based on knowledge of local crop salinity tolerance. However, there is little or no information on the ecological zoning in saline land according to crop salinity tolerance.

Hetao Irrigation District, an important production area of commodity grain and oil in China, is facing serious soil salinization problem, which threatens crop production and farmer's income increase. Li R P *et al.* (2012) reported that about 75% of the farmland in this region has suffered mild to moderate soil salinization and 25% farmland has severe soil salinization. Because of the influences of natural and anthropogenic factors, soil salinity spatially varies greatly among different fields. Crop yields also vary significantly, and are even completely lost because of extremely high concentrations of salinity. Therefore, a comprehensive assessment of the ecological suitability for the main local crops against soil salinity is urgently needed for optimization of cropping structure and crop allocation in this region.

The objectives of this work are (1) to evaluate the major local crop salinity tolerance in Hetao Irrigation District by