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Sunflower seed yield estimation under the interaction of soil salinity and nitrogen application

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ABSTRACT

Understanding the interaction effects of salinity and fertilizer is of great economic and environmental importance for improving crop yield and fertilizer used efficiency. The present study established a sunflower seed yield prediction model for saline soils directly from soil salinity (S) and nitrogen application (N) and related the results to the optimum N rate in saline soils. Two years of field trial data on sunflower growth under different S levels and N rates were collected at the Yichang Experimental Station in the Hetao Irrigation District of Inner Mongolia, China. Statistical techniques, including bootstrap resampling and artificial neural network (*ANN*) analysis, were used for data analysis and model establishment. The results indicated that sunflower crop characteristics varied in relation to S and N rates. The changes in plant height (H) with time before the late mature stage could be fitted with a linear function under different S and N treatments. Furthermore, the leaf area index (*LAI*) varied from the day after sowing and was expressed using a quadratic polynomial. The salt tolerance threshold (EC_{th}) values for sunflower at the seedling, bud, flowering, and mature stages were 6.93, 14.46, 14.46, and 17.26 dS m^{-1}, respectively. When S was smaller than EC_{th}, relative evapotranspiration (*RET*) fluctuated with S and was estimated using an artificial neural network (*ANN*); moreover, when S was larger than $\mathrm{EC_{th}}$, *RET* decreased with S and was simulated using linear regression. In addition, effective nitrogen application (*ENA*) was determined coupled with S, and the positive and negative effects of *ENA* on *RET* were expressed as a quadratic polynomial. The sunflower seed yield was estimated using a modified Jensen model (*SNJ* model) ($R^2 = 0.51$). The maximum relative seed yield (*MRSY*) decreased rapidly with soil salinity until 12 dS m^{-1}; when the soil salinity level was below 18 dS m^{-1}, the optimal N application rate fluctuated from 100 to 160 kg ha^{-1}.

1. Introduction

Due to a large population and scarce land resources, food security is becoming a major challenge in China (Zhang, 2011). Food crops and industrial crops have been competing for arable land in recent years because of the requirements of economic development, together with land degeneration and environmental degradation. A reasonable solution is to plant industrial crops on degraded land using appropriate farming practices and to reserve high-quality arable land for grain production to ensure food security (Zhang et al., 2012). The Hetao Irrigation District in Inner Mongolia, China, is a good example of this solution. Because of high evaporation and low precipitation, groundwater containing high salt moves upward, resulting in salt accumulation across soil surface layers; approximately 70% of cultivated lands in this area suffer from salinization (Li et al., 2014). Local farmers usually plant wheat and corn in the nearly 30% of non-saline or slightly saline soils and plant sunflower, which is easy to plant (hole sowing in plastic mulched soils) and requires no irrigation during the growing period, in other salt-affected soils of the Hetao Irrigation District (Zeng et al., 2014). Sunflower seeds are of great value for oil expelling and edible uses, and statistical data indicate that the income from the sunflower seed yield (*SY*) to local farmers is greater than 1.5 billion Yuan (Shi and Takeo, 2003). Although sunflower is classified as exhibiting moderate salt tolerance (Francois, 1996), soil salinity remains an important factor that affects its growth and yield (Torabian et al., 2016; Zeng et al., 2014). Previous studies have indicated that salt applied to the root systems of plants inhibits the growth and accumulation of biomass by decreasing the osmotic potential of the external solution, making it difficult for plants to fully utilize water and nutrients (Munns and Tester, 2008; Stadler et al., 2015). Some specific ions (e.g., Na^+) that are taken up by plants

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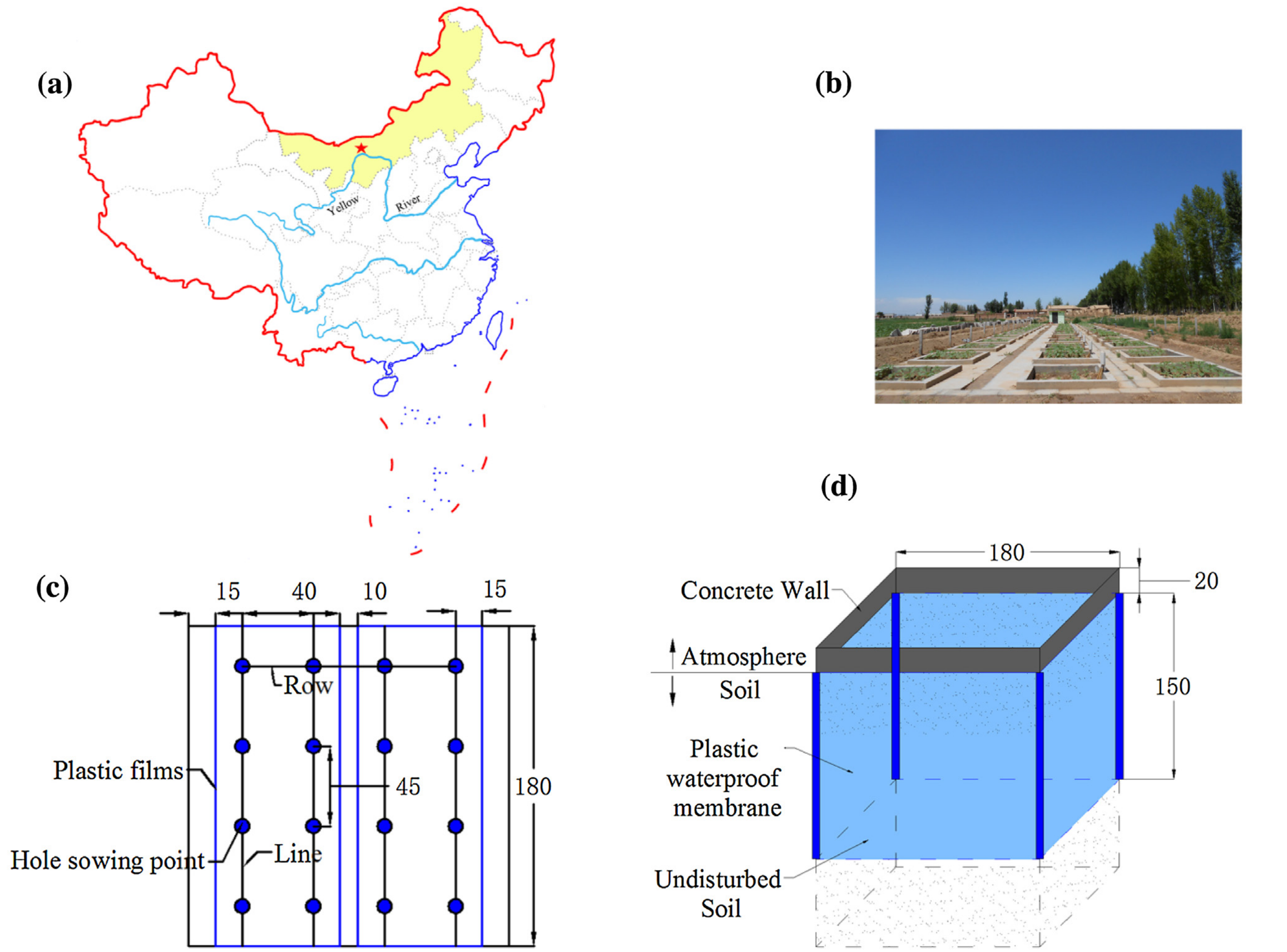

Fig. 1. Study site description (a is the location of study area: the yellow area indicates the location of Inner Mongolia in China, and the red star is the location of Yichang experimental station; b is the arrangement of Micro-plots; c indicates the plant sowing strategy; d is the schematic diagram of the profile of a Micro-plot), unit: cm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

may also result in salt-specific damage (Tang et al., 2011; Yang et al., 2009). Nitrogen (*N*) may enhance the salt resistance of plants through alteration of endogenous phytohormone contents, such as cytokinin and kinetin (Mansour, 2000). Therefore, *N* is widely used by local farmers to alleviate the adverse effects of salinity (*S*) on sunflowers. However, because *N* also plays osmotic roles in saline soils, inadequate rates of *N* impede plant growth. Rinehardt et al. (2004) reported that an over-dose of *N* under non-saline conditions results in numerous disadvantages, ranging from increased insect damage to defoliation issues. Greef (1994) reported that a high nitrogen rate decreased the activity of phosphoenolpyruvate carboxylase (PEP). Additionally, excessive *N* application leads to a risk of environmental pollution, such as increasing NO_3^- levels in water (Min et al., 2012) and greenhouse gasses (e.g., N_2O) released into the atmosphere from fertilized soils (Lompo et al., 2012). Furthermore, an insufficient N supply would decrease the leaf *N* content, which may decrease photosynthesis and, thus, the growth and yield of a crop (Dietz and Harris, 1997; Živčák et al., 2014).

In addition, scientists also find that soil salt restrains nitrogen transformation (Rietz and Haynes, 2003). Pathak and Rao (1998) reported that when the electrical conductivity (EC) of a soil solution is greater than 70 dS m^{-1}, accumulated ammonium *N* decreases with *S*.

Therefore, *N* management is very important, and researchers have developed numerous models to estimate plant growth according to irrigation and *N* application. Examples of such models include GLEAMS, EPIC, APSIM, DSSAT, WOFOST and SMCR_N (Aschonitis et al., 2012; Diepen et al., 1989; Jones et al., 2003; Kang et al., 2015; McCown et al., 1996; Zhang et al., 2010), which are generally based on the specific agronomic and biophysical processes that occur in the plant during specific short stages of the growing period, thus predicting the effects of varying conditions and management practices on crop yields and the environment. However, few of these models integrate *N* application and Wang and Baerenklau (2014) employed process-based simulation models to generate seasonal crop yield datasets and established crop response functions considering water (*W*), *N*, and *S* together. However, the effects of soil *S* on *N* availability were not considered by Wang and Baerenklau (2014). In addition, the large number of parameters in the crop response functions would also limit its practical application.

The Jensen model, a multistage crop water production model based on relative evapotranspiration at different growth stages, which is extremely closely related to the crop yield (Jensen, 1968; Zhang and Oweis, 1999) and has been widely applied for crop yield estimation and optimal irrigation scheduling in recent decades due to its simple form and smaller number of physically based parameters (Minhas et al., 1974; Vaux and Pruitt, 1983). These studies have proved the reliability of the model. Recently, this model has been modified into many different forms for adaptation to saline soils and N management (Tian, 2011; Zhou et al., 2003). These modifications usually added empirical terms to indirectly take accounts the effects of salinity or N, which are less process based.