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Effects of shallow groundwater table and fertilization level on soil physico-chemical properties, enzyme activities, and winter wheat yield

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ABSTRACT

Waterlogging adversely affects winter wheat (*Triticum aestivum* L.) growth by deteriorating soil environmental factors. The objective of this study is to test the effects of groundwater depth and fertilization level on soil properties, enzyme activities, and wheat yield. Experiments were carried out in micro-lysimeters at the groundwater depths of 0.2, 0.4, 0.5, 0.6, and 0.8 m under low, normal, and high fertilization levels in the winter wheat growth season from Oct. 2015 to May 2016. Soil water content, pH, organic matter content, total N, available P, available K as well as sucrase, urease, and phosphatase activities were measured in various growth stages of winter wheat, and yield component and grain yield were also measured after its harvest. Results indicated that soil water content and pH decreased with the increased groundwater depth. The lower contents of soil organic matter and nutrients appeared when groundwater depth was 0.5–0.6 m. Sucrase in the heading stage, urease in the jointing stage, and phosphatase activities increased significantly with the increased groundwater depth. Grain yield increased with groundwater depth to its maximum or approximate steady value. Total N and available P contents and urease activity appeared to increase with fertilizer application rate but available K content showed a contrary tendency. Grain yield increased with fertilizer application rate, but the effect of fertilization level on grain yield was lower than that of groundwater depth. A significant interaction between groundwater depth and fertilization level on grain yield existed. Soil enzyme activities were significantly correlated with available P content, and phosphatase activity was correlated with soil water, pH, organic matter, total N, and available K contents. It can be concluded that controlling groundwater depth and appropriate fertilizer application level can improve crop growth environment and promote winter wheat growth and its grain yield.

1. Introduction

Central China is a main grain production region and its winter wheat planting area accounts for about 12% of total acreage in China, but this region frequently suffers waterlogging disasters because of high intensity rainfall during the wheat growing season and poor drainage conditions (Ren et al., 2016). As a major abiotic stress affecting crop productivity (Bansal and Srivastava, 2015), about 10–15 million hectares of the world's wheat growing acreage are affected by waterlogging each year and subsequently results in a 20%–50% reduction on winter wheat yields (Yu and Chen, 2013).

Groundwater table, as an index to distinguish the oxygenated soil layer and the water-saturated aquifer below, is important to soil physico-chemical properties, soil fertility, and subsequent crop growth (Pereira et al., 2015; Ren et al., 2016). Excessive rain under a shallow groundwater table condition results in waterlogging problems and hence aggravates oxygen supply, which adversely affects photosynthesis due to low oxygen stress on roots (Yang et al., 2013; Bansal and Srivastava, 2015; Najeeb et al., 2015; Ghobadi et al., 2017), enzyme activity, and plant growth (Pereira et al., 2015; Ren et al., 2016). In addition, a shallow groundwater table is more likely to result in secondary soil salinization or sodification if excessive salt exists in the groundwater or soil (Xu et al., 2013; Abliz et al., 2016). However, on the other hand, groundwater is an important water source for plant growth, and a deep groundwater table is a disadvantage to plant water replenishment from groundwater (Zimmermann et al., 2017). Excessively deep groundwater worsens plant growth environment and decreases crop yield as a result of the shortage of water supplies (Trillo

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and Fernández, 2005), and hence increases agricultural production costs (Scheumann, 1997).

Soil fertility is closely related to groundwater table depth (Zimmermann et al., 2017). Groundwater depth affects soil moisture and in turn controls soil aerobic microbe activity and subsequently organic matter mineralization, and either high or low soil water content is disadvantageous for soil fertility and crop growth (Guan, 1986; Adiku et al., 2008; Ren et al., 2016). As compared to continuous wet soil under a high groundwater level, soil drying stimulates N mineralization and reduces its denitrification, with both effects leading to an increase of N availability (Venterink et al., 2002). Furthermore, drying soil also increases K release from the soil (Venterink et al., 2002). As an important index on the health status of soil fertility and soil productivity (Xiao et al., 2016), soil enzymes, that are closely related to microbial activity, can catalyze some important reactions of soil nutrient cycling and control its cycling rate (Yang et al., 2014; Chandra et al., 2016; Xiao et al., 2016; Pascazio et al., 2018). Sucrase hydrolyzes sucrose into glucose and fructose to provide energy for the growth of crop roots and microorganisms (Guan, 1986; Kang et al., 2013; Hu et al., 2014), urease accelerates the hydrolysis of nitrogen to ammonia, and phosphatase improves the rate of dephosphorization where organic phosphorus is decomposed into inorganic phosphorus (Guan, 1986; Hu et al., 2014). Lots of research results indicate that soil sucrase, urease, and phosphatase activities correlate with total C and N due to higher microbial biomass and greater stabilization (Nannipieri et al., 2012; Kang et al., 2013). Soil enzyme activity is also affected by soil nutrition status as an inhibiting / promoting factor or metabolic product. Soil pH, metal or non-metallic ions and compounds are common inhibitors for enzyme activity (Guan, 1986; Hu et al., 2014). Sucrase activity would be enhanced with a little sugar in the soil and urease activity is stimulated by amino acid (Guan, 1986). Phosphatase activity is inhibited by high P availability (Olander and Vitouser, 2000). The mineralization of P in excess of demand would rapidly result in a negative feedback that represses phosphatase production and maintains P level below or near its threshold level for inhibition to occur (Olander and Vitouser, 2000).

Present studies about enzyme activity mainly focus on the relationship among soil physico-chemical properties and its response to irrigation measures, fertilizer application, cultivation methods, and edaphic conditions etc. (Kang et al., 2009; Han et al., 2012; Wei et al., 2012; Yang et al., 2014; Xiao et al., 2016). Crop growth, crop yield, and soil nutrient transformation under a shallow groundwater table are mostly affected by hypoxia inhibition and water stress on root growth as well as microbial activity (Anuradha et al., 2013; Pereira et al., 2015; Ren et al., 2016). However, the effects of the groundwater table depth on soil physico-chemical properties, enzyme activity, and crop growth have not been widely investigated. By adjusting the groundwater table, the relations among soil physico-chemical properties, enzyme activity, and crop growth can be best managed and hence alleviate waterlogging hazards on crop growth (Li et al., 2015; Si et al., 2018), and this is important to improve the crop growth environment and to utilize groundwater more efficiently. Therefore, the objective of this research is to assess the effects of a shallow groundwater table and fertilization levels on soil physico-chemical properties, soil enzyme activity, and winter wheat yield, so as to explore the optimal growth environments of winter wheat under a shallow groundwater table.

2. Materials and methods

2.1. Experimental site and experimental treatments

The experimental site is located at the Experimental Station of Yangze University (latitude 30°21'N, longtitude 112°09'E, elevation 31.8 m above sea level) in Jingzhou, Hubei, China, and it belongs to a northern subtropical humid monsoon region, with a rainy spring and summer. The mean annual precipation and air temperture are 1156 mm and 16.9℃, respectively, and the average monthly rainfall increases from 21.9 mm in Jan. to 216.9 mm in June, then progressively decreases in the other months. Groundwater depth in the experimental region is 0.5 m on average over a year, total salinity in the groundwater is less than 1 g L^{-1}, and pH is 6.7–8.9 (Deng et al., 2014). The soil is yellow brown paddy soil, and its texture is loam with 22.0% clay (0–2 μm), 75.0% silt (2–50 μm) and 3.0% sand (50–2000 μm).

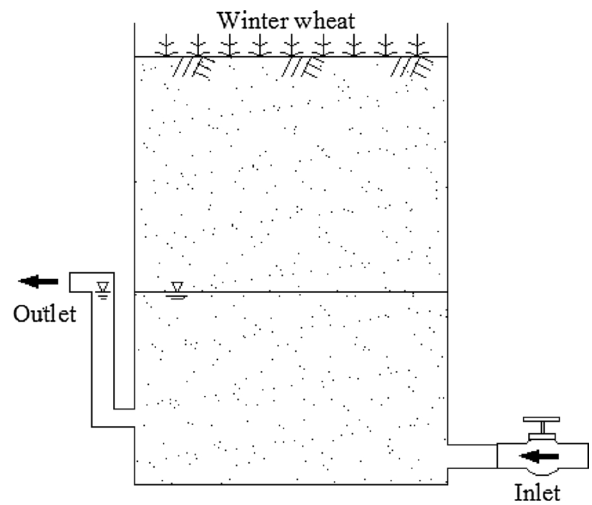

Fig. 1. Schematic diagram of micro-lysimeter.

The experiments were conducted in micro-lysimeters which were 1.12 m deep and 0.7 m in radius from Oct. 2015 to May 2016. The micro-lysimeters were evenly filled layer by layer with soil collected from a local farm field at the bulk density of 1.27 g cm^{-3}. The groundwater level in the micro-lysimeters was controlled at the constant depths of 0.2, 0.4, 0.5, 0.6, and 0.8 m from the soil surface by water inlet and outlet appratus and excess water was drained out of micro-lysimeters automatically (Fig. 1). Soil organic matter, total N, available P, and available K contents as well as soil pH (soil: water ratio of 1 : 2.5) were measured when the soil was prepared and they were 8.63 g kg^{-1}, 1.29 g kg^{-1}, 16.90 mg kg^{-1}, 153.76 mg kg^{-1}, and 7.8, respectively. Micro-lysimeters were located in the farmland and arranged row by row, and their surroundings were normal wheat field with a width greater than 5.0 m. Experimental arrangement for different treatments was shown in Fig. 2.

Winter wheat (*Triticum aestivum* L.) was sowed on 28 Oct., 2015 at a density of 210 plants m^{-2} and harvested on 4 May of the following year. During the wheat growth period, compound fertilizer (N : P_2O_5 : K_2O of 14 : 16 : 15) and urea were applied at three times: before sowing, at the seedling stage, and then again at the jointing stage, and their proportion for the three times was 7 : 1 : 2. According to the habits of local farmers, N, P, and K application rates in the whole growth period of winter wheat respectively were 180, 65, and 60 kg ha^{-1}, for the normal fertilization level (NF) treatment. There was no supplementary irrigation during the whole growth period of winter wheat and all water that wheat growth needed came from groundwater.

Experimental treatmeats contained five groundwater depths of 0.2, 0.4, 0.5, 0.6, and 0.8 m and three fertilization levels of low, normal, and high fertilizer application rates (Table 1). The application rates of compound fertilizer for the low fertilization level and the high fertilization level were 75% (75% NF) and 125% (125% NF) of the normal fertilizer application rate (NF) treatment, respectively. All experimental treatments in the study were replicated three times.

2.2. Monitoring items and measurement methods

Daily rainfall and air temperature were obtained from a standard automatic weather station located in the experimental station (Fig. 3). The data of monthly rainfall from 1952 to 2016 obtained from National