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Will wheat be damaged by heavy metals on exposure to coal fly ash?

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ABSTRACT

The mining industry and coal-fired power plants are among the major sources of atmospheric particles that cause air pollution. Can crops be damaged as they are exposed to foliar deposits of particulate matter enriched with various metal(loid)s from coal-mining regions? This study investigated the effects of atmospheric particles on wheat seedlings grown in a region north of Xuzhou, East China, where five coal mines, three coal-fired power plants, two large fly ash yards, and several coal yards coexist. More than two-thirds of the land area of this region is cropland. Atmospheric deposition analysis showed that the daily bulk deposition fluxes of Cr were generally higher in this region than those in other regions worldwide, and the highest fluxes were found in the area between the two-major coal-fired power plants. Wheat was grown under different soil and atmospheric conditions in the coal-fired region (north of Xuzhou) and a non-coal-fired region (south of Xuzhou). Heavy metal analysis showed that the accumulation of Cu, Cd, Pb, Zn, Cr, and As in the cell wall, cell organelles, and soluble fraction of wheat seedling shoots, particularly the percentage in the cell wall, was higher in the coal-fired region than in the non-coal-fired region. Analysis of the changes in the ultrastructure of seedling root and leaf cells revealed that atmospheric particles released in the coal-fired region damages the cellular structure of various parts of the wheat seedling and affects photosynthetic processes by damaging the chloroplasts.

1. Introduction

Coal mining and burning are major anthropogenic sources of atmospheric particles and heavy metals (Wang et al., 2011). Atmospheric particles can reduce the total irradiance and diffuse solar radiation reaching the Earth's surface (Chang et al., 2009; Kara et al., 2014; Kulmala et al., 2004), the main drivers of photosynthesis in terrestrial plants. The proportion of diffused radiation reaching the plant canopy affects the light-use efficiency for canopy photosynthesis (Cheng et al., 2015; Mercado et al., 2009). The plant response to diffused radiation is also dependent on the characteristics of the plant, such as functional type, leaf physiology, leaf area, leaf inclination, canopy structure, and shape (Kanniah et al., 2012).

The deposited particles are inert, so airborne particles are important heavy-metal carriers, especially in coal-mining regions. Heavy metals are commonly taken up by the surface of dust particles and are normally present in loosely bound forms, which are highly mobile and potentially bioavailable (Marx et al., 2008). Atmospheric particles exist in various sizes; the residence time of the particles in the atmosphere and their association with heavy metals depend on the particle size. Coarse particles settle near the particle source, whereas fine particles settle slowly (Candeias et al., 2014). Thus, deposition is a significant pathway for the transfer of heavy metals from the atmosphere to terrestrial surfaces and soils.

Several studies have reported that the plant canopy can efficiently adsorb particulate matter (PM) and reduce the PM ratio by capturing airborne PM on their foliar parts (Shahid et al., 2017), strongly affecting the elemental composition of wheat grain in mining and industry polluted area (Bermudez et al., 2012). Additionally, the growth and yield of rice and wheat crops grown near to the thermal power plant in Uttar Pradesh were reduced compared with fields located farther away (Chakrabarti et al., 2014). The characteristics of the particles, such as physical, chemical, and nutrient properties, may affect vegetation health (Burkhardt, 2010; Pariyar et al., 2013; Yan et al., 2014). Heavy metals emitted from mining and industrial areas may attach to atmospheric particles in highly mobile and potentially bioavailable forms (Eqani et al., 2016). Foliar absorption of heavy metals due to PM deposition is therefore of great concern (Bermudez et al., 2011). However, unlike root absorption (Boussen et al., 2013; Jamali et al., 2009), fewer studies have focused on the uptake of heavy metals from plant shoots.

In the present study, we investigated the plant response to phytotoxicity at the cellular level of wheat seedlings growing in a region where atmospheric particles are released from coal-fired electricity-

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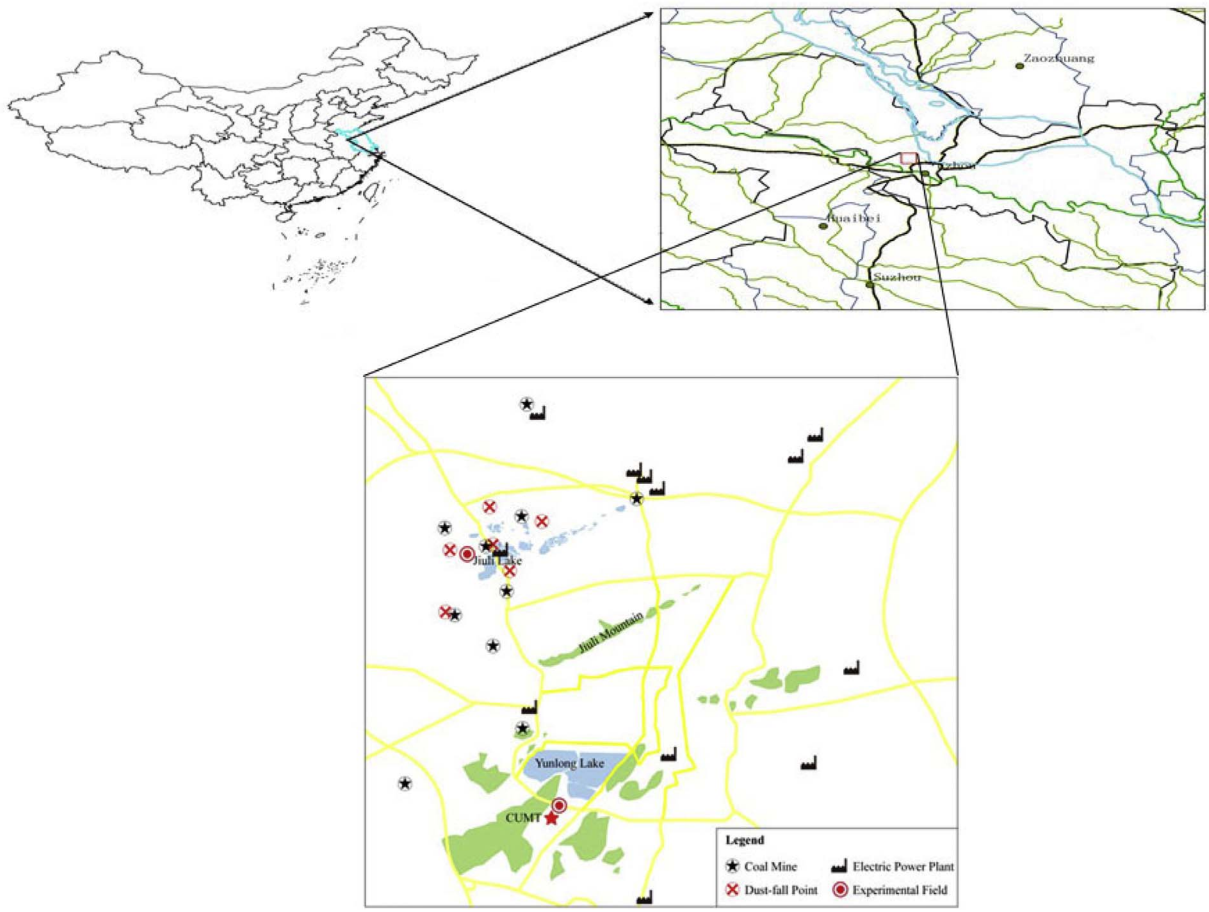

Fig. 1. Experimental area and sampling sites located north of Xuzhou, northwest Jiangsu Province, east China. The major coal-fired power plants are Huarun, Huamei, Pengcheng, and Chacheng. The major coal mine is Pangzhuang

producing power plants. The results were compared with those for plants growing in a non-coal-fired region with relatively clean air. The aims of the study were to: (a) evaluate the atmospheric pollution in a coal-fired electricity-producing region via atmospheric deposition analysis; (b) determine the subcellular distribution of heavy metals in wheat seedling shoots exposed to aerosols using tissue fractionation; and (c) investigate the ultrastructural alterations of plant cells induced by heavy metals through autometallography.

2. Materials and methods

2.1. Study site

The study was conducted in a coal-fired electricity-producing region around 8 km northwest of Xuzhou, Jiangsu Province, China (34°32′–34°36′ N and 117°07′–117°19′ E, Fig. 1). The climate in this area is characterized by a typical warm humid monsoon with an average annual temperature of 14 °C and rainfall of 900 mm. The bedrock consists mainly of carboniferous grey limestone, and the micro-landform is mainly composed of extensive diluvial plains and sporadic uplands. The main soil is typical fluvo-aquic soil formed on alluvium (Wang et al., 2005).

Xuzhou has exploited coal mines for over 124 years. In 2006, the city produced 259.7 million tons of coal and generated 7.2×10^9 kWh of electric power (Huang et al., 2009). Most of the coal mines and coal-fired power plants are located in the northern part of the city and bitumite is popular in the section. Our study site is more than 50 km^2 contains five coal mines, three coal-fired electric plants, two large fly ash yards, and several coal yards. More than two-thirds of the area is cropland, and almost all coal mines and electricity plants are surrounded by cropland. Wheat, paddy rice, maize, and soybean are the main crops produced in this area.

2.2. Bulk deposition sampling

Bulk deposition samples were collected using polyethylene containers with a 0.15-m-diameter mouth, which were covered with a polyethylene web to prevent large parts of materials entering (Bermudez et al., 2012). Six containers were located at six sites surround two primary sources of pollution from mining in the north and south of Xuzhou, respectively (Fig. 1) and fitted on artificial roofs at approximately 4 m above the ground. Both rainwater and the settling particles were collected over a period of 180 days from 1 November 2014 to 1 May 2015.

2.3. Plant growth and treatment

Wheat (*Triticum aestivum* Anti-50) seeds were supplied by Xuzhou Seeds Company (Xuzhou, Jiangsu, China). All seeds were sterilized with 10% H_2O_2 for 20 min and then washed several times with ultrapure water before use. Soil was obtained from a non-coal-fired region located south of Xuzhou and the coal-fired electricity-producing region located north of Xuzhou. Table 1 shows the heavy-metal concentrations in each soil from the different regions of Xuzhou and Table 2 shows the daily bulk deposition fluxes of heavy metals in each region. Each sample was assayed in triplicate.

The experiments were performed in plastic pots with a diameter of 35 cm and a depth of 30 cm during November 5-25, 2015. Each pot