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Particulate matter characteristics during agricultural waste burning in Taichung City, Taiwan

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ABSTRACT

Agricultural waste burning is performed after harvest periods in June and November in Taiwan. Typically, farmers use open burning to dispose of excess rice straw. $PM_{2.5}$ and $PM_{2.5-10}$ measurements were conducted at National Chung Hsing University in Taichung City using a dichotomous sampler. The sampling times were during straw burning periods after rice harvest during 2002–2005. Ionic species including SO_4^{2-}, NO_3^-, NH_4^+, K^+, Ca^{2+}, Cl^- and Na^+ and carbonaceous species (EC and OC) in $PM_{2.5}$ and $PM_{2.5-10}$ were analyzed. The results showed that the average $PM_{2.5}$ and $PM_{2.5-10}$ concentrations were 123.6 and 31.5 $\mu g\,m^{-3}$ during agricultural waste burning periods and 32.6 and 21.4 $\mu g\,m^{-3}$ during non-waste burning periods, respectively. The fine aerosol ionic species including Cl^-, K^+ and NO_3^- increased 11.0, 6.7 and 5.5 times during agricultural burning periods compared with periods when agricultural waste burning is not performed. K^+ was found mainly in the fine mode during agricultural burning. High nitrogen oxidation ratio was found during agricultural waste burning periods which might be caused by the conversion of Nitrogen dioxide (NO_2) to NO_3^-. It is concluded that agricultural waste burning with low dispersion often causes high $PM_{2.5}$ and gases pollutant events.

1. Introduction

Biomass burning, the burning of living and dead vegetation, has become a global issue in the past decade [1,2] and is a significant source of atmospheric particles and gaseous pollutants [3–7]. Most of these particles come from residual waste burning including forests, grasslands and crops through natural or anthropogenic fires [8–11]. In general, numerous particulates (e.g., polycyclic aromatic hydrocarbons and other organics) and gaseous compounds (e.g., carbon monoxide (CO) and volatile organic compounds) that come from biomass burning are known to be hazardous to human health [12,13]. Metzger et al. [14] reported that mass concentrations of CO, Nitrogen dioxide (NO_2), $PM_{2.5}$ (particulate matter with aerodynamic diameters less than 2.5 μm), organic carbon (OC) and elemental carbon (EC) in $PM_{2.5}$ (fine particles) were significantly associated with emergency department visits at hospitals due to cardiovascular diseases.

Particulate matters are composed of secondary particles like organic carbon, nitrate and sulfate formed by homogenous or heterogeneous reactions with their precursor gases in the atmosphere. Biomass burning is one of the dominant sources of particulate organic carbon [15,16]. Cao et al. [17] reported that emission rates of OC were 1.83–3.46 $g\,kg^{-1}$ from crop residues. Higher ionic contributions during combustion were observed in aerosols produced from combusted plant materials and soil suspended particles [3]. The aerosol composition of K^+, NO_3^- and Cl^- ions increased during cereal waste burning periods and were found to be an independent source of NO_3^- not linked to SO_4^{2-} sources [18]. Potassium ion can be a trace species during biomass burning [19]. KCl and K_2SO_4 are formed by homogeneous nucleation from straw combustion [20]. The smoke from vegetation fires can act as condensation nuclei and indirectly change the radiation budget and albedo [21].

Taiwan is in a subtropical region with rice as one of the main farm products. There are two rice crops in June and November. The amount of rice straw produced every year is about 2.6 million tons [22]. Rice straw contains mainly total organic material (78.1–85.0%), K_2O (0.91–2.1%) and nitrogen (0.6–1.3%) [23]. Farmers use open agricultural burning to infuse the ground with nutrients for the next growing season. Agricultural waste burning emits lots of aerosols into the atmosphere and these emissions may have a significant impact on air quality. The objective of this research was to study the effect of agricultural waste burning on the particulate matter and water-soluble inorganic ions in the atmosphere by collecting samples of atmospheric particulate matter during the waste burning and non-burning periods.

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2. Materials and methods

2.1. Sampling of $PM_{2.5}$ and $PM_{2.5-10}$

The ambient particulate matter during agricultural waste burning period was characterized at an urban site in Central Taiwan. Measurements were conducted on the roof of a seven-story building. The sampling site is located at National Chung Hsing University (NCHU) in Taichung City. There were two roads and no industrial emissions near the site. There were three sampling campaigns during agricultural waste burning periods (27 November 2002, 29 June 2004, and 25–27 November 2005) and non-waste burning periods (30–31 October 2002, 24 June 2004, 26–27 June 2004, and 24–27 October 2005), respectively. The collection time lasted 12 h, from 8:00 a.m. to 8:00 p.m. or from 8:00 p.m. to 8:00 a.m. The details for the sampling location are shown in Fig. 1. Twenty-six samples were collected from three agricultural waste burning and non-agricultural waste burning periods during 2002–2005. The season was autumn during periods I and III and summer during period II.

Two dichotomous samplers (Sierra & Andersen, model 241) using both Teflon membrane filters (R2PL037, PALL Life Sciences) and quartz fiber filters (2500QAT-UP, PALL Life Sciences) were used to collect fine ($PM_{2.5}$) and coarse aerosols ($PM_{2.5-10}$). The sampler equipped with Teflon membranes was used to analyze ions in the fine and coarse modes and the other one equipped with quartz fiber filters was used for the OC and EC. The total flow rate of the dichotomous sampler was 16.7 lpm. The unit was equipped with an inlet designed for 10 μm cut-point. The sampler contained a virtual impactor with a 2.5 μm cut-point used to separate entering particles into fine and coarse sizing ranges. NO_2, nitrogen monoxide (NO), CO, sulfur dioxide (SO_2), ozone (O_3), temperature, wind speed and wind direction data were collected from the air quality monitoring station located near NCHU.

2.2. Water-soluble ion species and carbonaceous analysis

After each sampling, both $PM_{2.5}$ and $PM_{2.5-10}$ were analyzed for water-soluble ions and carbonaceous species content. The Teflon filter was placed in a vial with 10 ml of ultra-pure water and sonicated for 90 min. The extracted solution was then filtered through a 0.22 μm cellulose esters filter and stored at 4 °C until further analysis. All SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, Ca^{2+} and K^+ ionic extracts were determined using Dionex ion chromatography (Dionex, DX 100).

Before the carbon samples were collected, the quartz filters were pre-fired to 900 °C for 2 h before usage in order to remove the impurities. After the samples were collected, the filters were stored with refrigerator before analyzing the carbon contents in order to minimize the possible desorption of volatile organics from the particulates [24]. OC and EC were determined using IMPROVE Thermo-Optical Refection (TOR) as previously described by Chow et al. [25,26].

A Quality Assurance and Quality Control program for method detection limit (MDL), precision and accuracy were conducted during the experiments. The MDLs, calculated as three times the standard deviation of blanks, were 0.02, 0.02, 0.02, 0.02, 0.01, 0.01, 0.03, 0.01 and 0.02 μg m^{-3} for SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+}, OC and EC. Precision of the chemical analysis was determined to be less than 10%. The average recoveries for all species appeared in the range of 100 ± 5%.

3. Results and discussion

3.1. Concentrations of $PM_{2.5}$, $PM_{2.5-10}$ and gaseous pollutants

Fig. 2(a) shows daytime and nighttime concentration of $PM_{2.5}$, $PM_{2.5-10}$ as well as $PM_{2.5}/PM_{2.5-10}$ ratio during the three periods. The mean $PM_{2.5}$ concentrations during agricultural waste burning periods and periods when agricultural waste burning periods is not performed were 123.6 and 32.6 μg m^{-3}, respectively, whereas the corresponding concentrations for $PM_{2.5-10}$ were 31.5 and 21.4 μg m^{-3} (Table 1). On average, $PM_{2.5}$ concentration was 3.8 times higher during agricultural waste burning compared with non-waste burning periods. Overall, $PM_{2.5}$ concentrations during

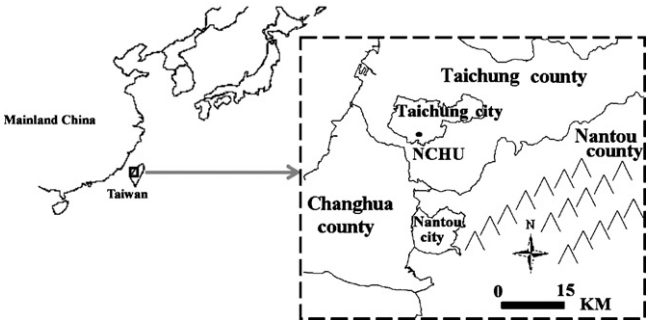

Fig. 1. Location of the sampling site at NCHU in central Taiwan.

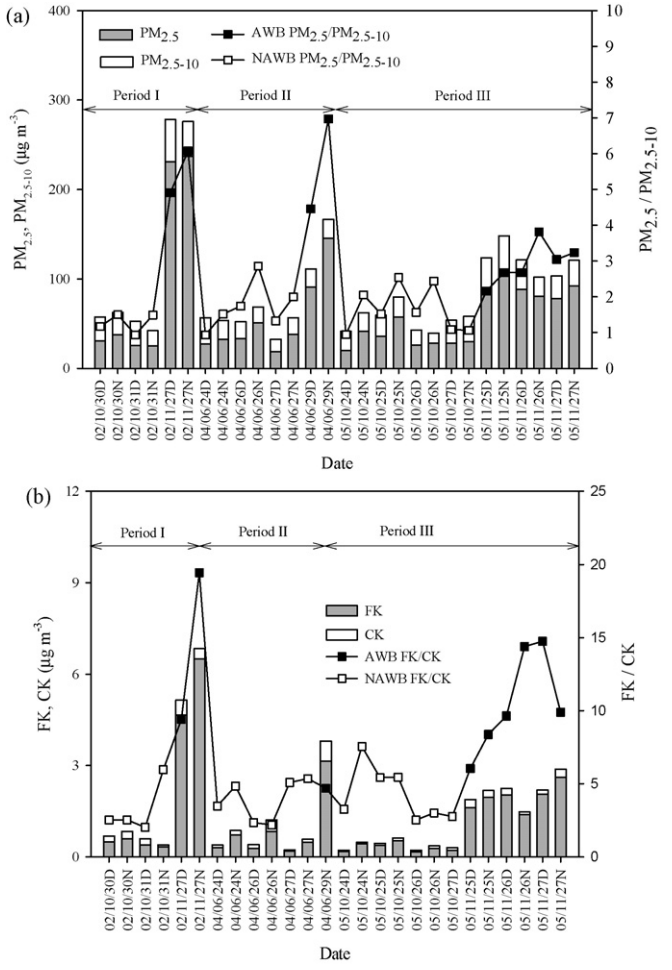

Fig. 2. (a) Daily concentrations of $PM_{2.5}$ and $PM_{2.5-10}$ and ratio of $PM_{2.5}/PM_{10}$ and (b) daily concentrations of potassium in fine mode (FK) and coarse mode (CK) and ratio of FK/CK during the three periods of agricultural waste burning (AWB, Black square) and non-agricultural waste burning (NAWB, White square).