Pol. J. Environ. Stud. Vol. 28, No. 1 (2019), 303-310
DOI: *10.15244/pjoes/81695* ONLINE PUBLICATION DATE: 2018-08-13

Original Research

Effects of Different Mulching Materials on Reducing Soil Dust from Bare Soil

Bingpeng Qu, Suyan Li*, Xiangyang Sun, Binghui Yun, Hua Zhang, Xinyu Wang, Kaiyi Xiong

Forestry College, Beijing Forestry University, Beijing, China

Received: 29 September 2017
Accepted: 2 January 2018

Abstract

Soil dust is one of the sources of $PM_{2.5}$, and most soil dust is derived from bare soil. Our laboratory experiment was conducted to explore the effects of different mulching materials, including cobblestones (CS), green waste (GW), pine bark (PB), and organic mulching mats (OMM) on reducing the generation of soil dust from bare soil by different wind speeds near the ground (2 m/s, 4 m/s, 7 m/s, 9 m/s, and 12 m/s). The results showed that all 4 mulching materials reduced the generation of atmospheric soil dust. Both GW and OMM had the best effect at reducing dust generation when the wind speed near the ground ≤4 m/s, and OMM had the best effect when wind speed was >4 m/s. The mulching materials GW and PB could be completely blown away when the wind speed near the ground reached 7 m/s and 9 m/s, respectively. It appears that OMM is the best mulching material for covering bare soil in Beijing.

Keywords: mulching material, mulch, $PM_{2.5}$, soil dust, Beijing

Introduction

$PM_{2.5}$, which refers to particulate matter (PM) in air that is less than 2.5 μm in aerodynamic diameter [1], impacts the environment significantly, including reducing visibility, altering cloud formation processes [2], damaging forests and crops, and reducing biological diversity [3]. Evidence has shown that when inhaled, $PM_{2.5}$ is very toxic and more harmful to human health than coarse particles (particles with a median aerodynamic diameter >2.5 μm) [4-10]. Long-term exposure of the human body to combustion-related fine particulate air pollution has become a significant risk factor in lung cancer and cardiopulmonary disease mortality [11].

Owing to sharp population rise, rapid economic development, and continuous urbanization, $PM_{2.5}$ has become one of the most serious environmental problems in many cities in China [12-14] – especially in Beijing, China's capital [15]. Beijing has suffered terrible hazes in recent years, causing many environmental and ecological problems, and also is causing trouble in human travel [16-20].

$PM_{2.5}$ is a complex mixture of various sources, from natural to anthropogenic, from primary to secondary. Recent studies mainly focused on composition and sources of particulate matter, measurement and simulation, health risk assessment of $PM_{2.5}$ and particulate monitoring methods, attempting to make clear the chemical components and sources and then try to find out some effective measures to reduce the negative effects [14, 21]. Yu et al. (2013) identified seven likely sources of $PM_{2.5}$ in Beijing by applying the PMF

*e-mail: lisuyan@bjfu.edu.cn

model, with relative contributions following the order secondary sulfur (26.5%), vehicle exhaust (17.1%), fossil fuel combustion (16.0%), road dust (12.7%), biomass burning (11.2%), soil dust (10.4%), and metal processing (6.0%) [22].

However, research on soil dust as one of the main sources of $PM_{2.5}$ in Beijing is especially lacking, and few studies have explored the methods to reduce soil dust. Soil dust comes from bare soil, construction sites, and roads [23], and most of it is derived from bare soil in Beijing [24]. The soil surrounding nearly every tree planting bed is exposed, and some other areas, including irrigation furrows and the edges of flower beds, are also unplanted in Beijing (Fig. 1). So under dry and warm conditions, the bare soil can be broken into fine particulates that are blown into the air by winds near the ground in winter and spring, increasing the $PM_{2.5}$ concentration.

Mulching materials can be used to cover bare soil. The materials usually used to cover bare soil include cobblestones (CS), green waste (GW), and pine bark (PB) in China [25]. In some plantings of luxury apartments and hotels, "eco-mats" and "organic mulching mats" (OMM) are used to cover the soil. These mulching materials can help maintain soil moisture, reduce erosion, and increase soil fertility [26-30]. However, the effects of these mulching materials on decreasing soil dust generated from bare soil have not been assessed.

The main objective of this paper is to explore the effects of different mulching materials on reducing the generation of soil dust from bare soil. We used these mulching materials which had already been used in China: CS, GW, PB, and OMM, and different wind speed conditions are simulated. Therefore, the results can contribute to choosing the best mulching material to cover bare soil so as to reduce the generation of soil dust in Beijing.

Materials and Methods

Materials

The soil dust was collected from the bare soil on Tsinghua East Road, Haidian, Beijing, and then passed through a sieve with 40 mesh sieve (a sieve with 0.42 mm openings in order to take out the sands and pebbles). After that, it was stored in a dry and ventilated location before the experiment.

The CS (4-6 cm diameter) were purchased from the Haoyuan Factory in Liuhe District, Nanjing. The PB (5-10 cm long and 0.5-1 cm thick) was purchased from the Shanghai Eve Environmental Protection Technology Co., Ltd. The GW, which mainly consisted of tree branches, was obtained as part of municipal curbside collection. The GW was cut into small pieces (about 1-3 cm particle size) and air dried (moisture content <10%).

The OMM were made in our laboratory in February 2017. The materials used to make the OMM included green waste and a water-based polyurethane adhesive, and water-based polyurethane adhesive was purchased from the Hefei Huayue New Materials Co., Ltd. An 80-g quantity of GW and a 20 g quantity of water-based polyurethane adhesive were fully mixed and placed in a 10×10×3 cm plastic mold. The mixture in the mold was then subjected to 30,000 Pa for 30 minutes before it was placed in a dry and ventilated location for 24 h. An OMM weighing 100 g was made already after taking shape from the mold. Four OMMs were floored together to cover the bare soil in every treatment.

Experiment

The experiment was conducted in the laboratory of soil science at Beijing Forestry University, Beijing. The experiment was conducted indoors in order to maintain control over wind speed. The temperature in the laboratory was about 22ºC, and the relative humidity was about 20%.

A 200-g quantity of the dried and sifted soil was evenly laid (about 0.3 cm thick) over a 20×20 cm square area on a test stand in the laboratory. The soil simulated the soil dust on the surface of bare soil under dry conditions in winter and spring in Beijing. Multiple soil-covered squares were prepared and were left uncovered (CK) or were covered with CS, GW, PB, or OMM (Fig. 2). The thickness of all mulching materials is 3 cm and the weight of mulching material per square

Fig.1. Examples of bare soil in tree planting beds in Beijing.

Fig. 2. Mulching materials used to cover bare soil; from left to right: CK, CS, GW, PB, and OMM (CS, cobblestone; GW, green waste; PB, pine bark; OMM, organic mulching mat).

was 800 g, 100 g, 150 g, and 400 g for CS, GW, PB, and OMM, respectively.

The experiment included 25 treatments: 5 mulching materials (including the CK) × 5 wind speeds. There is no general international standard for wind speed near the ground, only Zhang et al. (2015) did some research to simulate the Aeolian transport by changing wind speed from 6 to 14 m/s [31], so 5 wind speeds were chosen from the Beaufort wind scale (the speed of the wind 10 m above the ground), ranged from a light breeze (2 m/s) to a strong breeze (12 m /s) (mean and range): 2.0 (1.6-3.3), 4.0 (3.4-5.4), 7.0 (5.5-7.9), 9.0 (8.0-10.7), and 12.0 m/s (10.8-13.8). Each treatment was represented by 3 replicate squares of soil, and different squares were used for each replicate.

Wind was supplied by a variable speed blower (XP-311, China) that was first located parallel (at the same level) and to the side of the soil square (Fig. 3). The blower was then relocated 1 m above and to the side of the soil square (Fig. 4), and its position was similar to that in the experiment by Yuwono et al. [32]. In both cases, the blower nozzle was 1 m away from the center of the soil square. With the blower in the first location, each wind treatment was consecutively applied from

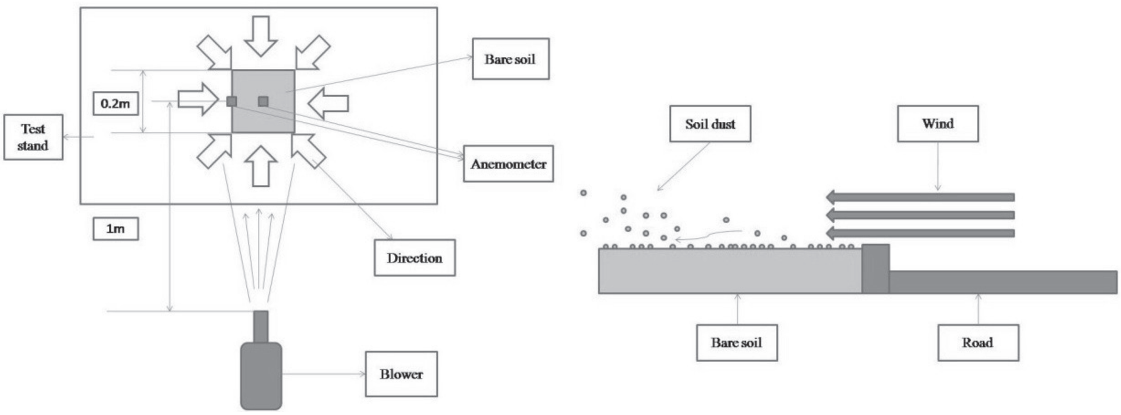

Fig. 3. Application of wind to the soil squares from a location that was parallel to the soil surface; the diagrams on the left and right illustrate the setup from above and from the side, respectively.

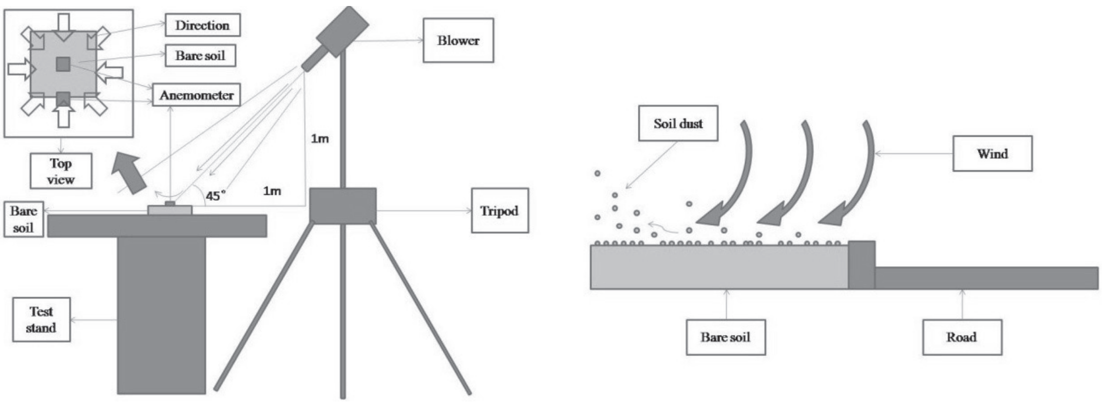

Fig. 4. Application of wind to the soil squares from a 45°angle above the soil surface; both diagrams illustrate the setup from the side (the diagram on the right provides a closer view of the soil square).

8 directions (north, south, east, west, northeast, northwest, southeast, and southwest) to simulate the wind from different directions outdoors and for 1 min per direction. The wind was applied for 1 min per direction because preliminary experiments indicated that the rest of the soil dust would not be blown by the wind after 1 min per location. The blower was then moved to the second location, and each wind treatment was again applied from 8 directions (north, south, east, west, northeast, northwest, southeast, and southwest) and for 1 min per direction. Thus, wind was applied for 8 min from a source parallel to the ground (Fig. 3) and for 8 additional minutes from a source that was not parallel to the ground and with an angle of 45º (Fig. 4); the total time of wind treatment was 16 minutes.

For each soil square, wind speed was recorded by 2 anemometers (AR816, China) located at the center and edge of the square during the experiment. The anemometer at the center and at the edge measured the maximum and minimum wind speed, respectively.

After the wind treatments had been applied, the soil and mulching materials remaining in the square were separately weighed. The weight of mulching material that was blown away and the weight of soil not blown away as dust were determined by subtracting the remaining weights after the experiments from the initial weights before. The percentage of mulching material that was blown away and the reduction in wind-blown dust (relative to CK) were calculated with the following formulas:

$$\text{The percentage of mulching material that was blown away}(\%) = \frac{\text{initial weight} - \text{remaining weight}}{\text{initial weight}} \times 100 \quad (1)$$

$$\text{The reduction in wind} - \text{blown dust } (\%) = \frac{\text{dust blown with the CK} - \text{dust blown with the mulch}}{\text{dust blown with the CK}} \times 100 \quad (2)$$

Results and Discussion

The percentage of mulching material that was blown away was significantly affected by mulching material (Fig. 5). The percentage substantially increased with wind speed for PB and GW but not for CS or OMM.

The percentage of PB and GW that was blown away was < 10% when wind speed was <2 m/s. The quantity of GW that was blown away by low wind speed was small because the GW could form a cross structure by covering the soil. At 7 m/s, the cross structure was broken and all of the GW was blown away. Because of its large size and high density, PB were not easily blown away by wind speed <2 m/s. However, all of the PB was blown away at 9 m/s. The OMM was relatively heavy, and only a small quantity of OMM was blown away by the highest wind speed (12 m/s). None of the CS was blown away by any of the wind treatments. Earlier studies have shown that gravel and pebbles (cobblestones) were hardly moved by the wind near the ground, and similar results were observed in the present study [31, 33]. However, few studies have mentioned the effect of wind speed near the ground on the percentage of other mulching material that was blown away.

When the wind speed near the ground was 2 m/s, the quantity of blown-away soil dust was significantly decreased compared to CK by all of the mulching materials (Fig. 6a). The decreases were least for CS, intermediate for PB, and greatest for GW and OMM (although the mean separations were not always statistically significant).

The quantity of soil dust blown away was relatively large for PB and especially for CS because soil dust was blown away from areas between PB or between CS. In contrast, soil dust was only blown away from the edges of soil squares covered with OMM or GW.

Although the quantity of blown soil dust increased at wind speeds of 4 m/s (Fig. 6b) and 7 m/s (Fig. 6c), the pattern was similar to that obtained with a wind speed of 2 m/s, i.e., the quantity among mulching materials was highest for CS, lowest for GW and OMM, and intermediate for PB. All of the soil dust in the CK was blown away when the wind speed near the ground was 7 m/s (Fig. 6c). Among the mulching materials, the quantity blown away was highest for CS and PB, intermediate for GW, and lowest for OMM. And when the wind speed was 9 m/s, the quantity of blown-away soil dust did not significantly differ among the CK, CS, and GW; all or nearly all of the soil dust was blown away in these treatments (Fig. 6d). The quantity was lowest for OMM and intermediate for PB. All of the soil dust in the CK, CS, GW, and PB treatments was blown away when the wind speed near the ground was 12 m/s

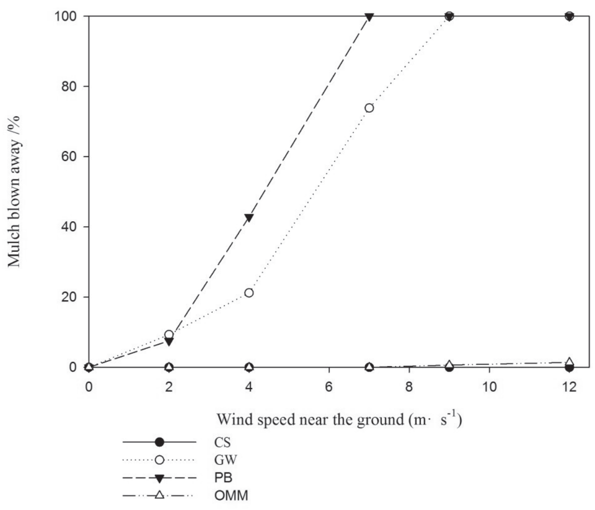

Fig. 5. The percentage of mulching material that was blown away as a function of wind speed near the ground (CS, cobblestone; GW, green waste; PB, pine bark; OMM, organic mulching mat).

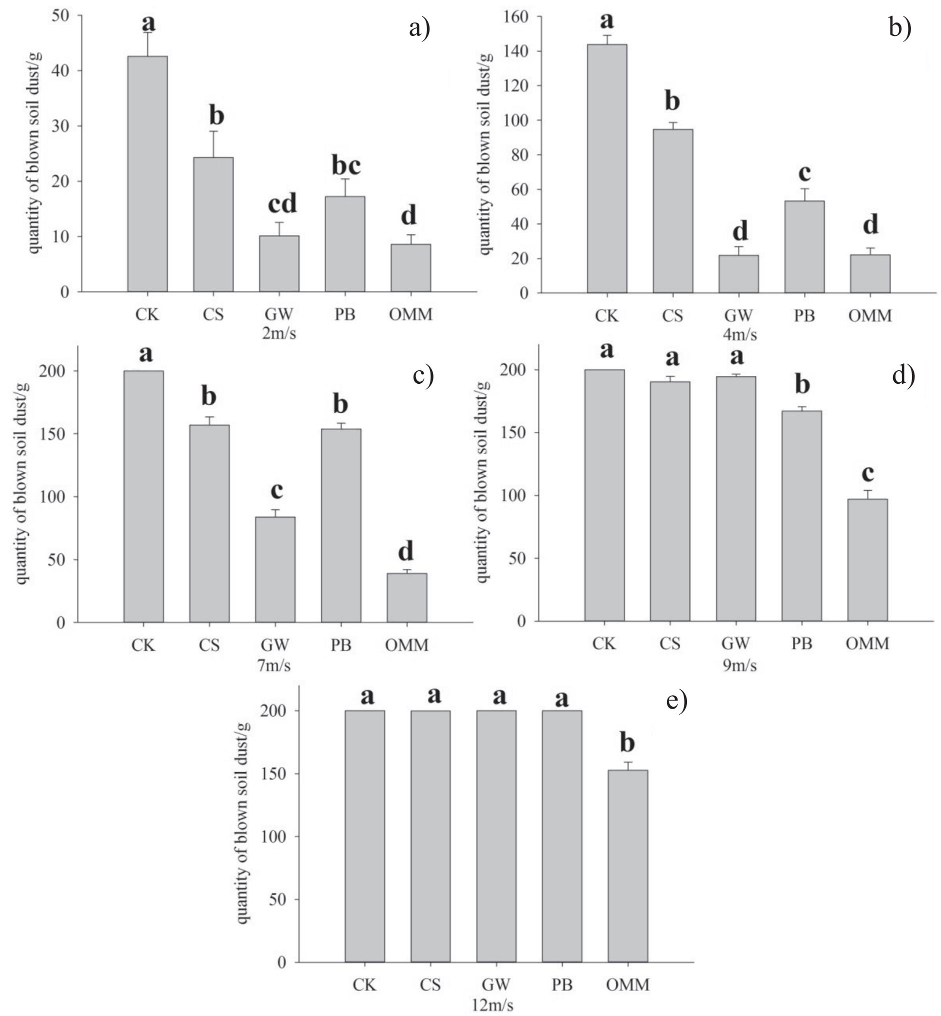

Fig. 6a-e. Effects of different mulching materials on the quantity of blown soil dust when the wind speed near the ground was a) 2 m/s, b) 4 m/s, c) 7 m/s), d) 9 m/s, or e) 12 m/s (CK, bare soil; CS, cobblestone; GW, green waste; PB, pine bark; OMM, organic mulching mat); values are means + SEMs; for each wind speed, means followed by different letters are significantly different at p≤0.05 according to LSD.

(Fig. 6e). OMM, in contrast, decreased the blown-away soil dust by about 25%.

Previous studies have mainly focused on the reduction of soil and water losses by mulching vegetative residues in different contexts, such as agricultural lands, fire-affected areas, rangelands, and anthropic sites [34-37]. Straw and grass mulching and mulching with prunings have been found to achieve good results in reducing soil erosion rates [38-39]. Wood mulching, as the most long-lived of the mulch treatments, was also effective in reducing runoff coefficients [40]. These studies mentioned above have shown that mulching could protect soil surface well, and the results in the present study also showed that soil dust which came from covered bare soil surface could become less relative to uncovered bare soil because of the protection by mulching.

The percentage of soil that was not blown away in each treatment decreased as the wind speed near the ground increased (Fig. 6). Note that Fig. 6 summarizes the data presented in Figures a to e. As indicated in

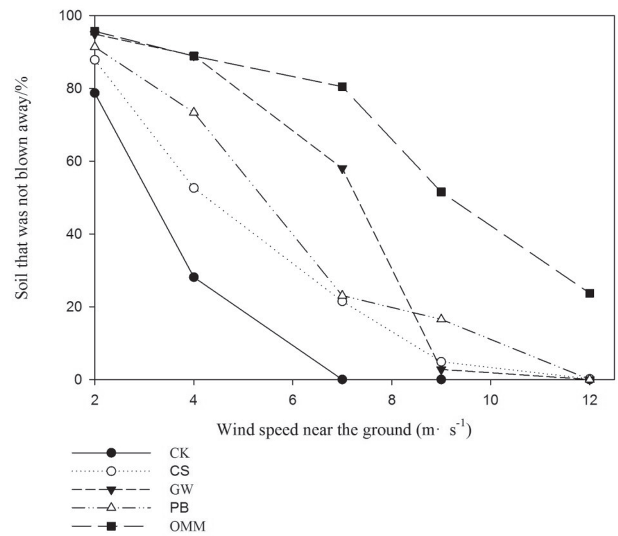

Fig. 6. The percentage of soil that was not blown away as affected by mulching materials (CK, bare soil; CS, cobblestone; GW, green waste; PB, pine bark; OMM, organic mulching mat).

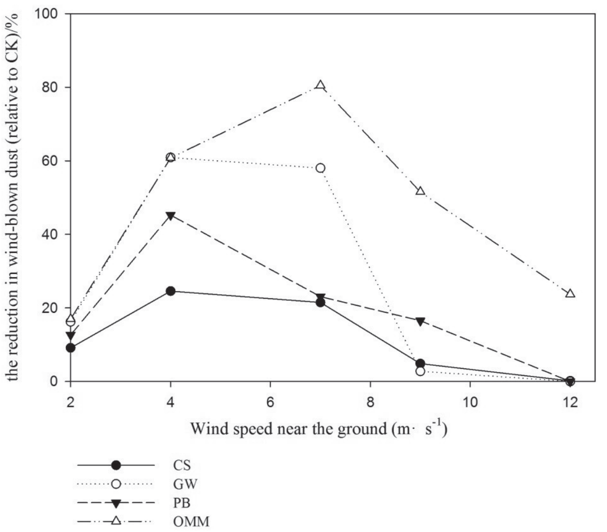

Fig. 7. The reduction in wind-blown dust (relative to CK) as affected by mulching materials (CS, cobblestone; GW, green waste; PB, pine bark; OMM, organic mulching mat).

those figures, all of the mulching materials reduced dust generation to some extent. The reduction was greatest for OMM, was least for PB and CS, and was intermediate for GW. When the wind speed was 9 m/s, CS and GW provided little or no reduction of soil dust generation and PB provided < 20% reduction. When the wind speed was 12 m/s, OMM was the only mulching material to reduce dust generation and it provided only about 24% reduction. Zhang et al. reported that sand transport rate was strongly correlated with the same power of wind velocity due to the insufficient supply and the trap of gravel coverage on Gobi surface [31]. The results of the present study have shown that more wind-blown dust could be generated with the wind speed near the ground increasing, and they were synonymous with the report mentioned above.

The reduction in wind-blown dust (relative to CK) in each treatment increased as the wind speed near the ground increased when wind speed was ≤7 m/s, the highest was 4 m/s for CS, PB, and GW, and 7 m/s for OMM. After these, the reduction in each treatment decreased as the wind speed near the ground increased. When the wind speed near the ground ≤4 m/s, GW and OMM had the same effects of reducing dust generation relative to CK, and when wind speed was >4 m/s, OMM had the best effect relative to other treatments.

Conclusions

All 4 mulching materials (CS, GW, PB, and OMM) could help reduce the generation of atmospheric soil dust. However, the mulching materials GW and PB were completely blown away when the wind speed near the ground reached 7 m/s and 9 m/s, respectively. The quantity of blown-away soil dust increased as the wind speed near the ground increased, but the increase was lowest for OMM followed by GW, PB, and CS. Both GW and OMM had the best effects of reducing dust generation when the wind speed near the ground was ≤4 m/s, and OMM had the best effect when wind speed was >4 m/s. When the wind speed near the ground was ≥9 m/s, OMM still decreased soil dust, but the other 3 mulching materials did not. Therefore, OMM is the best mulching material for covering bare soil and thereby reducing dust pollution in Beijing. GW is also useful for reducing soil dust pollution when strong wind weather is less frequent.

Acknowledgements

This work was supported by the Beijing Municipal Science and Technology Project (Z161100001316004) and the Graduate Training and Development Program of Beijing Municipal Commission of Education (BLCXY201510). We thank Bruce Jaffee, professor emeritus at the University of California at Davis, for his advice.

Conflict of Interest

The authors declare no conflict of interest.

References

1. WANG J.L., ZHANG Y.H., SHAO M., LIU X.L., ZENG L.M. CHENG C.L., XU X.F. Quantitative relationship between visibility and mass concentration of $PM_{2.5}$ in Beijing. Journal of Environmental Sciences, **18** (3), 475, **2006**.
2. TANG X.Y., ZHANG Y.H., SHAO M. Atmosphere Environmental Chemsitry. Book, Higher Education Press, Beijing, China, 268, **2006**.
3. MYHRE G. Consistency between satellite-derived and modeled estimates of the direct aerosol effect. Science. **325**, 187, **2009**.
4. AILSHIIRE J.A., CRIMMINS E.M. Fine particulate matter air pollution and cognitive function among older US adults. American Journal of Epidemiology, **180** (4), 359, **2014**.
5. LIANG R.J., ZHANG B., ZHAO X.Y., RUAN Y.P., LIAN H., FAN Z.J. Effect of exposure to $PM_{2.5}$ on blood pressure: a systematic review and meta-analysis. Journal of Hypertension, **32** (11), 2130, **2014**.
6. HUANG F.F., LI X., WANG C., XU Q., WANG W., LUO Y.X., TAO L.X., GAO Q., GUO J., CHEN S.P. $PM_{2.5}$ spatiotemporal variations and the relationship with meteorological factors during 2013-2014 in Beijing, China. Plos One, **10** (11), **2015**.
7. TURNER M.C., KREWSKI D.,POPE C.A.,CHEN Y., GAPSTUR S.M., THUN M.J., MICHAEL J. Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. American Journal of Respiratory and Critical Care Medicine, **184** (12), 1374, **2011**.

8. WU S.W., DENG F.R., HAO Y., WANG X., ZHENG C.J., LV H.B., LU X.L., WEI H.Y., HUANG J., QIN Y. Fine particulate matter, temperature, and lung function in healthy adults: findings from the HVNR study. Chemosphere, **108**, 168, **2014**.
9. SCHWARTZ J., NEAS L.M., Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. Epidemiology, **11** (1), 6, **2000**.
10. PETERS A., VERONESI B., CALDERON-GARCIDUENAS L., GEHR P., CHEN L.C., GEISER M., REED W., ROTHEN-RUTISHAUSER B., SCHURCH S., SCHULZ H. Translocation and potential neurological effects of fine and ultrafine particles a critical update. Particle and Fibre Toxicology, **3** (1), 13, **2006**.
11. POPE C.A., BURNETT R.T., THUN M.J., CALLE E. E., KREWSKI D., ITO K., THURSTON G.D. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of the American Medical Association. **287** (9), 1132, **2002**.
12. CAO G.L., ZHANG X.Y., GONG S.L., AN X.Q., WANG Y.Q. Emission inventories of primary particles and pollutant gases for China. Chinese Science Bulletin, **56** (8), 781, **2011**.
13. LI L., WANG W., FENG J.L., ZHANG D.P., LI H.J., GU Z.P., WANG B.J., SHENG G.Y., FU J.M. Composition, source, mass closure of $PM_{2.5}$ aerosols for four forests in eastern China. Journal of Environmental Sciences, **22** (3), 405, **2010**.
14. WU J.S., XIE W.D., LI W.F., LI J.C. Urban landscape pattern on $PM_{2.5}$ pollution-a Beijing case study. Plos One, **10** (11), **2015**.
15. CHEN B., LU S.W., ZHAO Y.G., LI S.N., YANG X.B., WANG B., ZHANG H.J. Pollution remediation by urban forests: $PM_{2.5}$ reduction in Beijing, China. Polish Journal of Environmental Studies, **25** (5), 1873, **2016**.
16. GUO Y.M., LI S.S., TIAN Z.X., PAN X.C., ZHANG J.L., WILLIAMS G. The burden of air pollution on years of life lost in Beijing, China, 2004–08: retrospective regression analysis of daily deaths. BMJ-British Medical Journal, **347** (22), **2013**.
17. ZHANG A., QI Q.W., JIANG L.L., ZHOU F., WANG J.F. Population exposure to $PM_{2.5}$ in the urban area of Beijing. Plos One, **8** (5), **2013**.
18. WANG X.H., BI X.H., SHENG G.Y., FU J.M. Chemical composition and sources of PM_{10} and $PM_{2.5}$ aerosols in Guangzhou, China. Environmental monitoring and assessment, **119** (1/3), 425, **2006**.
19. DAI W., GAO J,Q., CAO G., OUYANG F. Chemical composition and source identification of $PM_{2.5}$ in the suburb of Shenzhen, China. Atmospheric Research, **122** (9), 391, **2013**.
20. DING A.J., FU C.B., YANG X.Q., SUN J.N., ZHENG L.F., XIE Y.N., HERRMANN E., NIE W., PETAJA T., KERMINEM V.M. Ozone and fine particle in the western Yangtze River Delta: an overview of 1 yr data at the SORPES station. Atmospheric Chemistry and Physics, **13** (11), 5813, **2013**.
21. WU S.W., DENG F.R., WANG X., WEI H.Y., SHIMA M., HUANG J., LV H.B., HAO Y., ZHENG C.J., QIN Y. Association of lung function in a panel of young healthy adults with various chemical components of ambient fine particulate air pollution in Beijing, China. Atmospheric Environment, **77**, 873, **2013**.
22. YU L.D., WANG G.F., ZHANG R.J., ZHANG L.M., SONG Y., WU B.B., LI X.F., AN K., CHU J.H. Characterization and source apportionment of $PM_{2.5}$ in an urban environment in Beijing. Aerosol and Quality Research, **13** (2), 574, **2013**.
23. PARK S.H., GONG S.L., GONG W., MAKAR P.A., MORAN M.D., ZHANG J., STROUD C.A. Relative impact of windblown dust versus anthropogenic fugitive dust in $PM_{2.5}$ on air quality in North America. Journal of Geophysical Research Atmospheres, **115**, **2010.**
24. TANG Y., HAN G.L. Characteristics of major elements and heavy metals in atmospheric dust in Beijing, China. Journal of Geochemical Exploration, **176**, 114, **2017**.
25. YANG Y.M., LIU X.J., LI W.Q., CUN Z. Effect of different mulch materials on winter wheat production in desalinized soil in Heilonggang region of North China. Journal of Zhejiang University. Science. B, **7** (11), 858, **2006**.
26. BALDWIN B., HENSLER K., GOATLEY J. Comparing seeded organic-fiber mat with direct soil seeding for warm-season turfgrass establishment. Horttechnology, **11** (2), 243, **2001**.
27. FANG S., LI H., XIE B. Decomposition and nutrient release of four potential mulching materials for poplar plantations on upland sites. Agroforestry Systems, **74** (1), 27, **2008**.
28. HUANG Z., XU Z., BLUMFIELD T.J., CHEN C., BUBB K. Soil nitrogen mineralization and fate of $(^{15}NH_4)_2SO_4$ in field-incubated soil in a hardwood plantation of subtropical Australia: the effect of mulching. Journal of Soils and Sediments, **8** (6), 389, **2008**.
29. PAL P.K., MAHAJAN M. Tillage system and organic mulch influence leaf biomass, steviol glycoside yield and soil health under sub-temperate conditions. Industrial Crops and Products, **104**, 33, **2017**.
30. ZRIBI W., ARAGUES R., MEDINA E., FACI J. M. Efficiency of inorganic and organic mulching materials for soil evaporation control. Soil and Tillage Research, **148**, 40, **2015**.
31. ZHANG K.C., ZHANG W.M., TAN L,H., AN Z.S., ZHANG H. Effects of gravel mulch on aeolian transport: a field wind tunnel simulation. Journal of Arid Land, **7** (3), 296, **2015**.
32. YUWONO A.S., MULYANI F., MUNTHE C.R., KURNIAWAN A., MULYANTO B. Estimating dustfall generation affected by wind speed, soil moisture content and land cover. ARPN Journal of Engineering and Applied Sciences, **10** (20), 9339, **2015**.
33. GOOSSENS D. Effect of rock fragment embedding on the aeolian deposition of dust on stone-covered surfaces. Earth Surface Processes & Landforms, **30** (4), 443, **2005**.
34. KEESSTRA S., PEREIRA P., NOVARA A., BREVIK EC., AZORIN-MOLINA C., PARRAS-ALCANTARA L., JORDAN A., CERDA A. Effects of soil management techniques on soil water erosion in apricot orchards. Science of the Total Environment, **551**, 357, **2016**.
35. SADEGHI S.H.R., GHOLAMI L., HOMAEE M., KHALEDI DARVISHAN A. Reducing sediment concentration and soil loss using organic and inorganic amendments at plot scale. Solid Earth Discussions, **6** (2), 63, **2015a**.
36. PRATS S.A., MARTINS M.A.D., MALVAR M.C., BEN-HUR M., KEIZER J.J. Polyacrylamide application versus forest residue mulching for reducing post-fire runoff and soil erosion. Science of the Total Environment, **468**, 464, **2014**.
37. PEREIRA P., GIMENEZ-MORERA A., NOVARA A., KEESSTRA S., JORDAN A., MASTRO R.E., BREVIK E., AZORIN-MOLINA C., CERDA A. The impact of road

and railway embankments on runoff and soil erosion in eastern Spain. Hydrology & Earth System Sciences Discussions, **12** (12), 12947, **2015**.
38. BARTON A.P., FULLEN M.A. MITCHELL D.J., HOCKING T.J., LIU L.G., BO Z.W., ZHENG Y., XIA Z.Y. Effects of soil conservation measures on erosion rates and crop productivity on subtropical Ultisols in Yunnan Province, China. Agriculture Ecosystems & Environment, **104** (2), 343, **2004**.
39. LIU Y, TAO Y., WAN K.Y., ZHANG G.S., LIU D.B., XIONG G.Y., CHEN F. Runoff and nutrient losses in citrus orchards on sloping land subjected to different surface mulching practices in the Danjiangkou Reservoir area of China. Agricultural Water Management, **110** (3), 34, **2012**.
40. ROBICHAUD P.R., LEWIS S.A., WAGENBRENNER J.W., ASHMUM I.E. BROWN R.E. Post-fire mulching for runoff and erosion mitigation: Part I: Effectiveness at reducing hillslope erosion rates. Catena, **105** (6), 75, **2013a**.