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Clay and Carbonate Effect on Fine Dust Emissions as Generated in a Wind Tunnel

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Introduction

A growing concern for health effects and climatic impact of airborne dust has motivated a number of studies focusing on sediment properties and meteorological conditions that influence dust emissions. Determination of the capacity of different soil types to produce PM_{10} emissions and identification of the causes for variations in PM_{10} production among them, is critical to improve the estimation of PM_{10} emission by wind erosion (Hagen *et al*, 1996). PM_{10} is particulate matter having aerodynamic diameter ≤ 10 μm. Wind erosion is the main source of these types of dust emissions in the Southern High Plains of Texas (Gill *et al.,* 1999). In this study, we used a suction-type wind tunnel where wind erosion was reproduced to evaluate the effect of soil clay and calcium carbonate ($CaCO_3$) content on aerosol PM_{10} production from eight agricultural soils of the Southern High Plains near Lubbock, Texas.

Materials and Methods

Eight agricultural soils from the Southern High Plains near Lubbock, Texas, with different combinations of carbonate and clay content were selected from a preliminary study. Two levels (low and high) of soil clay content and two levels (low and high) of soil $CaCO_3$ content were evaluated. Levels of clay content were < 20% for low and > 20% for high. For $CaCO_3$ content the low level was < 3% and the high level was > 3%. Selected soils series were: Amarillo (low $CaCO_3$, low clay); Acuff (two soils) and Olton (low $CaCO_3$, high clay); Gomez (high $CaCO_3$, low clay); and Drake (three soils) (high $CaCO_3$, high clay). Soils clay and carbonate content ranged from 12.7 to 32.6% and from 0.2 to 13.0%, respectively.

A suction-type wind tunnel, 10 *m* in length and 0.5 *m* wide by 1 *m* high cross section, was used to conduct the experiment. The wind profile was developed on the first 7.8 *m* of the wind tunnel over a fixed roughness, and the test section occupied the next 2.2 *m*. A fan at the end of the tunnel draws air from the work section of the tunnel and generates the air stream. An array of 10 pitot tubes mounted on a vertical bracket was used to measure velocity gradients in the wind tunnel, just upwind of the test section. Pitot tubes were connected to a scanivalve pressure transducer. A 21X-micrologger program controlled the valve sequence to make the pressure readings, and provided the wind velocities at the different heights. The wind profile parameters were then determined according to the Prandtl-von Karman equation (Nickling, 1994).

A wind profile with a similar aerodynamic roughness length (Z_O) to that measured at a highly erodible agricultural field near Lubbock, Texas (Stout and Zobeck, 1996), was developed in the wind tunnel. To develop the desired wind profile in the wind tunnel, it was necessary to manipulate diverse roughness elements. The wind profile friction velocity (U_*) was 0.79 *m/s*.

Before each test, a layer of 2.01 to 19.0 *mm* soil aggregates was placed in the test section of the wind tunnel. An effective area of 217 *cm* by 47.6 *cm* of the wind tunnel floor was totally covered by soil aggregates. Abrader sand (0.65 *mm* diameter) was released into the wind tunnel during a test, 9 *cm* above the tunnel floor near the tunnel entrance at a feed rate of 0.277 *g/cm/s*. Abrader sand had to travel 4.6 *m* before impacting the soil aggregates in the test section to generate PM_{10} aerosol.

An isokinetic vertical dust sampler was mounted at the end of the test section in the wind tunnel. A blower connected to the top of the sampler (the outlet) produced a flow of air by drawing air from the sampler. Soil being eroded was sampled through a 3 *mm* wide vertical inlet that extended the entire height of the wind tunnel on the centerline of its width. PM_{10} aerosol was sampled at the center of a 10.16-*cm* diameter duct that connected the blower to the outlet of the vertical soil sampler. A DataRAM dust monitor was used to measure generated PM_{10} aerosol with an isokinetic sampling probe to sample the dusty air from the center of the pipe. A running time of 10 *min* was given to measure PM_{10} concentrations. A background of the PM_{10} concentration with the saltating sand alone was taken for each test. Five replications for each soil were made.

Results and Discussion

PM_{10} tended to decrease as the soil clay content increased and airborne PM_{10} concentration for soils with low clay content was significantly larger ($P = 0.034$) than that for soils with high clay content (Figure 1). Average PM_{10} concentration for the low and high soil clay content levels were 118.9 and 91.2 $\mu g/m^3$, respectively. Conversely, PM_{10} tended to increase as soil $CaCO_3$ content increased and significantly larger ($P < 0.0001$) aerosol PM_{10} concentrations were produced by soils with high $CaCO_3$ content than those with low $CaCO_3$ content (Figure 1). Average PM_{10} concentrations of 69.1 and 127.1 $\mu g/m^3$ were observed for the low and high soil $CaCO_3$ content levels, respectively. As can be seen in Figure 1, differences in soil $CaCO_3$ content levels produced greater differences in aerosol PM_{10} concentrations than those produced by differences in soil clay content levels.

In a wind tunnel study, Mirzamostafa (1996) and Mirzamostafa *et al*. (1998) reported significant differences in the suspension fraction (of the eroded soil) generated by the abrasion of aggregates from soils with different clay content. The suspension fraction (< 0.106 *mm*) decreased as the soil clay content increased up to 20%, but increased when the soil clay content was >20%. On the other hand, the PM_{10} fraction of suspension increased as the soil clay content increased (Mirzamostafa, 1996; Hagen *et al*, 1996). Gillette (1978) found that fine particle (< 25 μm diameter) fluxes in a wind tunnel were relatively independent of the soil texture. Gillette attributed the lack of effect to the short length (21.7 *cm*) of the soil bed in the test section of the wind tunnel over which abrasion from saltating sand took place. Fryrear *et al*. (1994) and Usman (1995) reported that soil aggregates > 0.84 *mm* increased as the soil clay content increased and, therefore, the soil erodibility decreased. Since PM_{10} production is directly related to soil erodibility, wind tunnel results are in agreement with these findings. The increase in aggregate stability with increases in soil clay content has also been observed by a number of researchers (e.g. Skidmore and Layton, 1992; Usman, 1995).

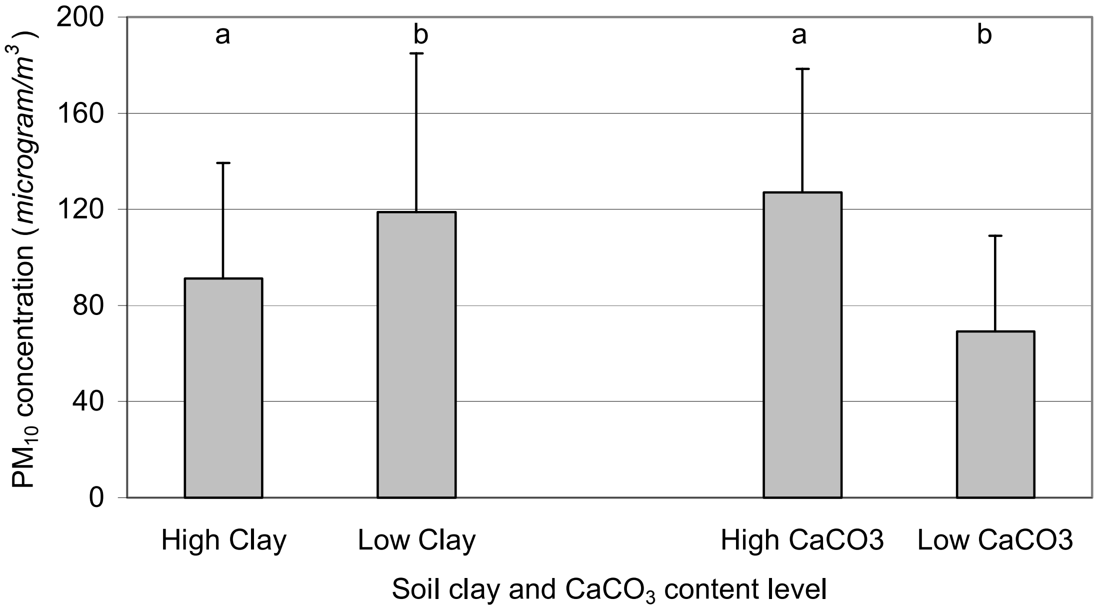

Figure 1. Means comparison of soil clay and $CaCO_3$ content levels. Means with the same letter within clay and $CaCO_3$ factors are not significantly different.

Fryrear *et al*. (1994) and Usman (1995) also observed that the soil aggregation increased as soil $CaCO_3$ content increased up to about 25%, which in turn decreased the soil erodibility. Fryrear *et al* (1994) also mention that, depending on soil clay content and type, soil $CaCO_3$ content of about 40% or greater tend to increase soil erodibility. However, PM_{10} concentration increased significantly in this study for soils in the high level of $CaCO_3$ content, which varied from 3.1 to 13.0% This result suggests that even if the soil aggregation increases, soil $CaCO_3$ content of about 3% and more significantly weakens the stability of the soil aggregates. As a consequence, soil aggregates were more easily abraded and the aerosol PM_{10} increased.

The variation in the ability to produce aerosol PM_{10} among the tested soils was highly significant ($P < 0.0001$). The Gomez soil (the only soil with low clay content among soils with high $CaCO_3$ content) produced the largest average aerosol PM_{10} concentration (174.2 $\mu g/m^3$). On the other side, an Acuff soil (the soil with the highest clay content) produced the lowest average aerosol PM_{10} concentration (42.6 $\mu g/m^3$).

Conclusions

Soil clay and $CaCO_3$ content significantly affected airborne PM_{10} emissions from soil aggregates. Airborne PM_{10} concentrations increased as soil clay content decreased and soil $CaCO_3$ content increased, with $CaCO_3$ having the greatest impact. Consequently, soils from agricultural fields in the Southern High Plains of Texas that would produce the highest PM_{10} concentrations have more than 3% by weight $CaCO_3$ content and less then 20% clay. Conversely, the lowest PM_{10} concentrations were observed in soils with low $CaCO_3$ content (< 3%) and high clay content (> 20%). PM_{10} production from abraded soil aggregates was found to be significantly different among soils.

Disclaimer: Names of commercial products and/or their manufacturers are necessary to describe the equipment, processes and products in this study. Colegio de Postgraduados and USDA-ARS imply no approval of these products to the exclusion of others that may also be suitable.

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