Effect of Dust Source Clay and Carbonate Content on Fugitive Dust Emissions

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ABSTRACT

Wind erosion of soils, roads, and other bare land surfaces is a major source of fugitive dust in the Southern High Plains of Texas. Little is known about the relationship of the characteristics of the source of this fugitive dust and $PM_{2.5}$, and PM_{10} concentrations. A dust generation, analysis and sampling system has been developed in Lubbock (LDGASS) to relate the properties of sediments with $PM_{2.5}$ and PM_{10}. In this study, we evaluate the effect of sample clay and calcium carbonate content on $PM_{2.5}$ and PM_{10} generated from the samples. Eight soils from three sites located on the Southern High Plains were selected for this study. Dust particle concentrations were measured with DataRam and MiniVol dust monitors and dust particle size distributions were measured with a laser particle sizer in LDGASS. Particulate matter concentrations increased with soil clay content for the PM_{10} data set from the MiniVol dust monitor, but did not significantly increase ($P<0.05$) for PM_{10} and $PM_{2.5}$ as measured with DataRAMs. However, $PM_{2.5}$ and PM_{10} emissions were significantly increased as carbonate content increased. $PM_{2.5}$ was highly correlated with PM_{10} concentration ($R=0.92$) and composed about 27% of the total PM_{10}. Dust particle size distributions also were significantly affected by soil clay and carbonate content. The median particle size decreased as clay and carbonate content increased. Significant variation in dust emissions also was found within the same farm field, mapped as the same soil unit.

INTRODUCTION

Solid particles suspended in the air by different processes and from different source materials are called dust. The largest dust particles from soil erosion by wind range between 0.02 and 0.1 *mm* in diameter. Because of their exceptionally low settling velocity, even under low wind speeds, fine dust may be transported great distances and kept suspended in the atmosphere for a very long time (Gillette, 1981). Dust emissions from wind erosion are a significant component of the atmospheric aerosol in regions of highly erodible soils (Gatz, 1995; Matsumura *et al*., 1992). A particle is suspended in the air when the vertical lift of wind acting on the particle overcomes its weight. Frequently, human activities and the force of the wind give rise to suspended dust in the atmosphere. Dust created in this way is called “fugitive dust” (Pewe, 1981).

The Columbia Plateau of Washington State, the San Joaquin Valley, the Owens Valley of California, and the Southern High Plains of Texas and eastern New Mexico are among the areas significantly affected by fugitive dust in the US. In the San Joaquin Valley agricultural operations are the major source of fugitive dust, while in the Columbia Plateau and the Southern High Plains of Texas wind erosion is the main source (Gill *et al.*, 1999).

Because field evaluation of fugitive dust presents serious difficulties (Nickling and Gillies, 1989), considerable effort is now directed toward developing equipment and techniques to generate and analyze aerosol PM_{10} emissions in the laboratory. In this study, we used the Lubbock Dust Generation, Analysis and Sampling System (LDGASS) (Gill *et al*., 1999; Singh, 1994; Zobeck *et al*., 1997) developed by the USDA-ARS Wind Erosion and Water Conservation Research Unit in Lubbock, Texas. The LDGASS includes a dust generator module that applies kinetic energy to a dust source sample to simulate aerosol emissions by wind erosion. This system is capable of generating fugitive dust, measuring particle characteristics of the generated dust *in situ*, and collecting PM_{10} and $PM_{2.5}$ particulate aerosol samples. This paper will present an evaluation of the effect of soil clay and calcium carbonate ($CaCO_3$) content on aerosol PM_{10} and $PM_{2.5}$ production as determined by the LDGASS for eight soils from the Southern High Plains near Lubbock, Texas.

METHODS

Initial versions of the LDGASS involved a rotating drum-type dust generator and have been described by Zobeck *et al*. (1997) and Gill *et al*. (1999). We have modified this system by using a smaller, tubular dust generation chamber in place of the rotating drum found in the latter system (Figure 1).

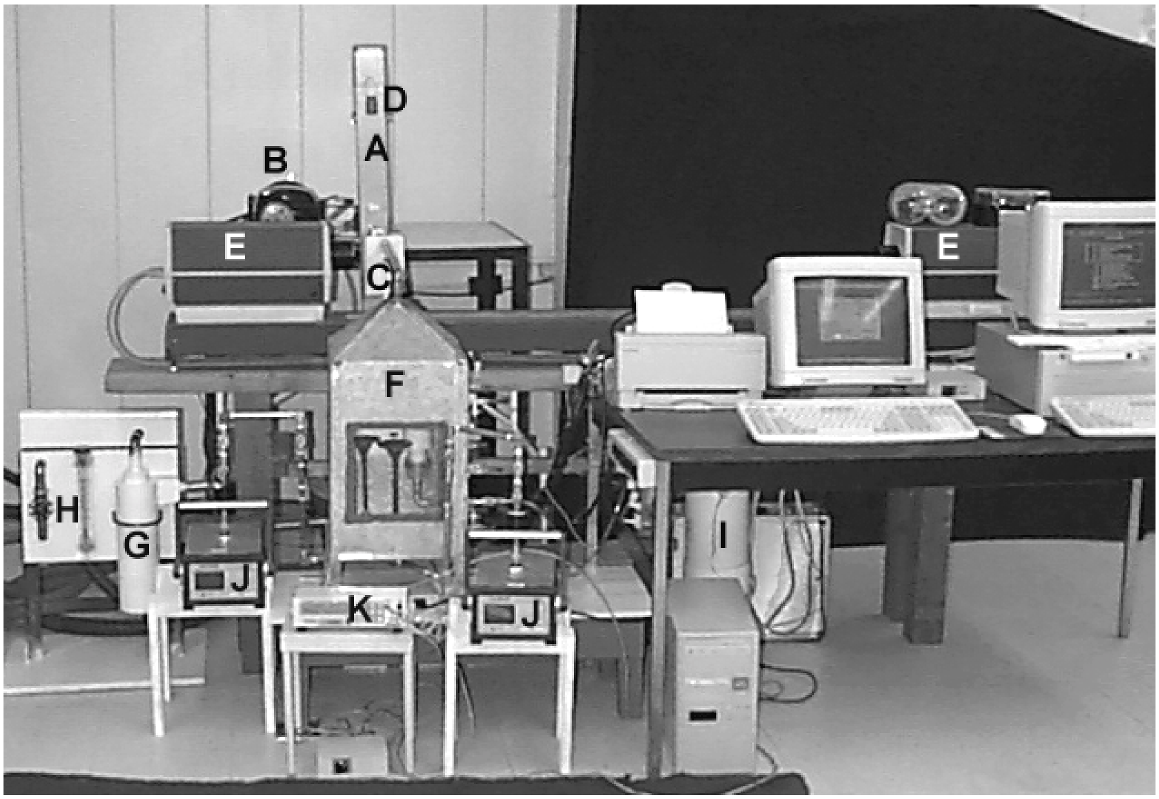

Figure 1. The Lubbock Dust Generation, Analysis and Sampling System.

Kinetic energy is applied by gravity to a dust source soil sample to generate dust. The dust generator is built from a 1-*m* long, 7 *cm* square aluminum tube (Figure 1-A). At the extremes, the square tube has removable caps that are kept in place by elastic fasteners. An electric motor (Figure 1-B), connected perpendicularly at the longitudinal center of the tube, oscillates the chamber 180 degrees from a vertical position 27 times per minute (at 13.5 rpm). Since the soil sample adheres to the extreme of the tube by the centrifugal force in effect while the tube is oscillating, this dust source material is carried from a bottom to a top position in the tube and, at this point, the tube oscillation stops. The soil sample then falls to the bottom of the tube. The kinetic energy gained by the fall of the soil sample acts on it when the sample impacts the bottom of the tube and a dust plume is generated. The dust is drawn out of the chamber by air flowing through a 1.5-*cm* diameter orifice toward a dust transport pipe (Figures 1-C) connected at its longitudinal center. A vacuum situated at the end side of the system (suction side) originates the airflow. Air enters the system through one of two 2.54-*cm* diameter openings in the square tube (Figures 1-D). The centers of the openings are situated 10 *cm* from the longitudinal extremes of the generator tube. A simple valve mechanism using a marble ensures that air enters only from the upper extreme when the source material impacts the bottom, generating dust.

Airflow exits the dust generator and enters the transport section. While flowing through the dust transport pipe, the particle size distribution of generated dust is determined by laser diffraction spectroscopy. A Malvern model 2600 is the laser diffraction particle sizer used for this analysis (Figure 1-E). The Malvern model 2600 (Figure 1-E) includes an optical helium-neon laser light scattering-based particle measurement unit and a computer program that performs particle size analyses. The laser particle size distribution analysis of the dust plume at any given time during a run is made through a perforation in the transport pipe while the dust is being transported by the airflow. The perforation in the 19-*mm* diameter transport pipe is 15.6-*mm* diameter located 50 *cm* from the exit of the dust generator and 35 *cm* to the inlet of a settling chamber section. Suction from the vacuum makes this point a source of fresh air into the flow rather than a source of dusty air out of the transport pipe, which prevents the air in the laboratory from being contaminated by the dust. The laser diffraction data are stored on a personal computer. Stored data can then be downloaded and later analyzed to determine the particle size distribution of the dust generated from a given soil sample.

Dust flow is then directed to a 45-*cm* tall airtight settling chamber with a 30-*cm* square base and a 20-*cm* tall pyramidal top (Figures 1-F). On one of its sides, the settling chamber has an observational window. Dusty air enters the settling chamber at its top and then is sampled at a constant flow rate by various fine dust monitors. Sampling inlets are distributed inside the settling chamber in symmetrical locations to ensure similar sampling conditions. One of the inlets for a MiniVol PM_{10} sampler is attached to a removable side, which is sealed airtight with stainless steel toggle clamps. The MiniVol is an impactor-type gravimetric instrument for monitoring PM_{10} and gaseous pollutants. Airborne particulate matter (PM_{10} and $PM_{2.5}$) samples were also obtained by using DataRam dust monitors (Figure 1-J). The DataRAM dust monitor is a high-sensitivity impactor-type nephelometric monitor whose light scattering sensing unit is optimized to optically measure *in situ* airborne particulate matter (Monitoring Instruments for the Environment, Inc. 1995). DataRam instruments provide real-time mass concentrations of particles. Dusty air exits the settling chamber at the center of its bottom cross section through a 2.54-*cm* diameter pipe.

Most of the coarse particles suspended and transported by the airflow deposit in the settling chamber. In addition, after the settling chamber, airflow passes through a cyclone separator (Figures 1-G) which collects most of the dust particles leaving the settling chamber. Zobeck (1989) gives a description of this cyclone. Airflow finally ends at the vacuum, which is kept outside the laboratory.

Airflow is controlled by valves (Figures 1-H) and measured with a flowmeter connected at the end of the piping system on the suction side. Reported airflow rates in this document for the LDGASS correspond to those flow rates measured at this point of the system. With the commercial vacuum that was used during this study, the maximum airflow rate that can be reached is near 500 *l/min* when the air filter in the vacuum is clean.

A preliminary study was performed to select agricultural soils with combinations of carbonate and clay content. 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%. In addition, three sites or locations within selected soils were sampled to assess soil variability within a field.

Sites within the selected soils were sampled in a triangular pattern with at least 50 *m* of separation among them. A small bulk soil sample was taken within the top 5 *cm* of the soil surface to determine soil texture and $CaCO_3$ content. A modified Bouyoucos method was used to determine particle size distribution (Bouyoucos, 1951). The sand fraction was separated by wet sieving. Sand was separated into very fine (0.05 to 0.10 *mm*), fine (0.10 to 0.25 *mm*), medium (0.25 to 0.5 *mm*), coarse (0.5 to 1 *mm*), and very coarse (1 to 2 *mm*) subfractions. Soil texture classes were designated according to definitions of the USDA classification system (Soil Survey Staff, 1993). The acid neutralization method was used to determine calcium carbonate equivalent (US Salinity Laboratory, 1954).

Particle size distribution and $CaCO_3$ equivalent for the selected agricultural soils are show in Table 1. Selected soils were of the series Acuff (Fine-loamy, mixed, superactive, thermic Aridic

Table 1. Particle size distribution and calcium carbonate ($CaCO_3$) content of selected agricultural soils in Texas.

Soil series	Site	Sand	Silt	Clay	Sand subfractions† VC	C	M	F	VF	Clay/Silt	$CaCO_3$ equivalent	Texture Class‡
		---- % ----									%	
Low $CaCO_3$ level, low clay level												
Amarillo (Amr)	1	81.0	6.3	12.7	0.0	0.6	8.2	65.1	26.1	2.0	0.2	fsl
	2	70.5	11.6	17.9	0.1	0.5	6.2	60.2	32.9	1.5	0.3	vfsl
	3	74.3	10.8	14.8	0.0	0.6	6.7	60.9	31.9	1.4	0.2	vfsl
Low $CaCO_3$ level, high clay level												
Olton (Olt)	1	47.1	24.8	28.1	0.0	0.4	4.6	41.9	53.0	1.1	0.7	scl
	2	49.0	23.8	27.2	0.0	0.6	5.2	43.4	50.8	1.1	0.7	scl
	3	44.6	28.0	27.4	0.1	0.5	5.0	43.2	51.2	1.0	0.7	cl
Acuff (Acf1)	1	47.7	25.1	27.2	0.0	0.8	5.8	41.2	52.2	1.1	0.5	scl
	2	43.2	30.9	26.0	0.1	0.8	6.3	42.8	50.0	0.8	0.9	l
	3	49.9	24.0	26.2	0.2	1.0	7.7	44.3	46.8	1.1	1.5	scl
Acuff (Acf2)	1	41.2	27.5	31.3	0.1	0.5	7.3	45.8	46.3	1.1	0.8	cl
	2	39.2	29.8	31.0	0.0	0.6	7.3	43.2	48.8	1.0	0.7	cl
	3	43.3	24.4	32.3	0.0	0.8	7.6	45.1	46.5	1.3	0.8	cl
High $CaCO_3$ level, low clay level												
Gomez (Gmz)	1	85.4	1.0	13.6	0.1	0.2	8.8	69.6	21.3	13.6	3.6	lfs
	2	81.4	2.9	15.7	0.1	0.2	8.5	70.0	21.1	5.5	6.2	fsl
	3	78.8	3.7	17.5	0.1	0.2	8.8	69.1	21.7	4.8	6.9	fsl
High $CaCO_3$ level, high clay level												
Drake (Drk1)	1	42.0	25.4	32.6	0.0	0.2	4.8	52.0	43.0	1.3	12.1	cl
	2	49.5	26.1	24.3	0.2	0.2	5.4	53.9	40.4	0.9	6.6	scl
	3	36.9	30.6	32.5	0.2	0.2	4.6	47.6	47.3	1.1	13.0	cl
Drake (Drk2)	1	38.8	32.8	28.4	0.4	0.9	7.2	44.0	47.5		3.1	cl
	2	34.4	37.3	28.4	0.5	0.9	6.1	33.7	58.8	0.8	5.5	cl
	3	57.6	20.5	21.9	0.8	1.3	9.2	50.6	38.0	1.1	6.8	scl
Drake (Drk3)	1	42.7	29.1	28.1	0.1	0.2	7.5	53.1	39.1	1.0	10.3	cl
	2	46.9	23.8	29.3	0.2	0.3	6.7	59.4	33.4	1.2	9.9	scl
	3	50.8	19.4	29.8	0.1	0.3	7.4	58.2	34.0	1.5	11.6	scl

† VC = very coarse, C = coarse, M = medium, F = fine, VF = very fine; ‡ fsl = fine sandy loam, vfsl = very fine sandy loam, scl = sandy clay loam, cl = clay loam, l = loam, lfs = loamy fine sand.

Paleustoll), Amarillo (Fine-loamy, mixed, superactive, thermic Aridic Paleustalf), Drake (Fine loamy, mixed, superactive, thermic Aridic Haplustept), Gomez (Coarse-loamy, mixed, active, thermic Aridic Calciustept), and Olton (Fine, mixed, superactive, thermic Aridic Paleustoll). A large sample of about 110 liters of soil aggregates from 2.01 to 19.0 *mm* in diameter also was obtained from each site within a soil. Soil aggregates of the indicated size were separated from soil sampled within the top 5 *cm* of the soil surface. Aggregate separation was done at the field by using a compact rotary sieve (Chepil, 1962). The soil aggregates were collected only when soils were apparently dry. Soils were fallow when sampled, with the exception of the Olton soil that was cultivated with cotton. Soils were located in the Southern High Plains near Lubbock, Texas.

Obtaining small fractions representative of the bulk gross sample in grain size distribution and the relative fraction of its constituents is essential to derive reliable results from the bulk sample (Allen, 1981). For this reason, a rotary sample divider was used to obtain uniform soil aggregate sub-samples for five replications of each combination of soil and site. Allen (1981) describes various sample dividers, including the rotary sample divider or spinning riffler. The sampler divider uses a vibratory feeder that provides a constant flow rate of soil aggregates from a mass feed hopper to a rotating set of collecting glass bottles. Soil aggregates that did not pass through an 8 *mm* sieve were crushed to avoid clogging of the splitter's opening to the glass containers. Soil aggregate samples from the splitter's containers were weighted and carefully placed into the dust generator.

Each one of the 24 combinations of eight soils and three sites (Table 1) was replicated five times. As a result, 120 individual tests were made with the LDGASS. The airflow rate as measured at the -suction side of the system was set to 200 *l/min*. A mass of 25 *g* of aggregates (2.01 to 19.0 *mm* in diameter) was used to generate airborne dust. Rotation of the dust generator caused source sample to impact its bottom 27 times per minute from a fall distance of 1 *m* (the length of the dust generator chamber). The dust generator was agitated 30 *min* for each test.

Average aerosol PM_{10} concentrations in 30 *min* were obtained with DataRAM-A and MiniVol instruments within the settling chamber. Both recorded and gravimetric PM_{10} concentrations were provided by DataRAM-A. Average $PM_{2.5}$ concentrations in 30 *min* (recorded and gravimetric) were also obtained with DataRAM-B. DataRAMs were "zeroed" before each run and set to provide 180 real-time measurements in 30 *min.* Before each run, clean glass fiber filters were placed on the impactors of the DataRAMs. Also, clean pre-weighted polycarbonate filters (37-*mm* diameter), equilibrated at <30*%* relative humidity, were used with the DataRAMs to collect a sample of aerosol. Similarly, airborne PM_{10} was sampled on a clean pre-weighted polycarbonate filter (47-*mm* diameter) by the MiniVol instrument.

The laser diffraction particle sizing instrument (Malvern) collected particle size distribution data of created dust plumes in transit to the settling chamber. Before a test was initiated, the Malvern gathered a background measurement of the light scattered by particulate matter already present in the air of the laboratory. The Malvern was set to provide 60 measurements of particle size distributions during the 30 minute test period. The instrument also provided derived particle diameters and distribution statistics. The Malvern used a 100-*mm* lens and was set for a "particle in air" type of experiment and model independent analysis mode.

Prior to each test the system was cleaned, the desired airflow rate in the system was set, and a soil aggregate sample from the rotary sample divider was placed into the dust generator. The vacuum and the dust generator were activated. Airborne dust analysis by the dust monitors was started. The instruments were stopped when they collected data for 30 *min* (the Malvern automatically stopped when 60 measurements were gathered). After a test, standard protocols were followed to post-weigh polycarbonate filters with sampled PM_{10} or $PM_{2.5}$ and to clean dust monitors.

Only average gravimetric concentrations of PM_{10} and $PM_{2.5}$ calculated from the particulate matter collected on the analytical filters of the dust monitors were used for statistical analyses. Given that PM_{10} and $PM_{2.5}$ data grouped by clay and $CaCO_3$ levels were not normally distributed and the variances were not equal, Z-tests (Iman and Conover, 1989) were performed to compare their respective means. Analyses of variance were performed to analyze the data when the data were normally distributed. Data transformations were tried to improve equality of variances when they were not equal. When analyses of variance showed significant effects for the sources of variation, the treatment means were separated by the Tukey's studentized range test. Degree of association and functional relationships among variables were evaluated through correlation and multiple linear regression analyses.

RESULTS AND DISCUSSION

Differences Among Soils

Figure 2 shows the gravimetric aerosol PM_{10} and $PM_{2.5}$ concentration data sets averaged by soil. Notable differences were observed in PM_{10} measurements among MiniVol and DataRAM-A instruments. PM_{10} concentrations varied from 25.4 to 67.1 mg/m^3 and from 16.1 to 43.8 mg/m^3 for data sets from MiniVol and DataRAM-A, respectively. The differences, however, were proportional in all soils. Averages by soil and site combinations (24) showed a Spearman correlation coefficient (r) of 0.97 among PM_{10} as measured by DataRAM-A and MiniVol. PM_{10} data sets were not normally distributed,

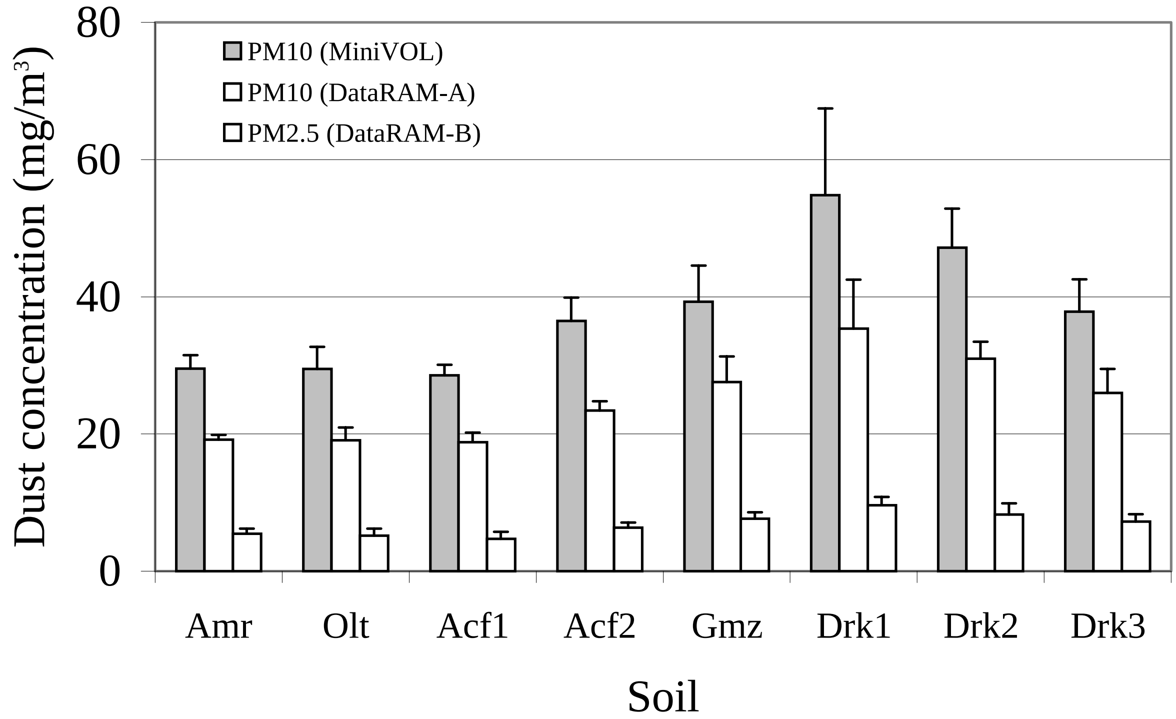

Figure 2. Aerosol PM_{10} and $PM_{2.5}$ concentrations as measured by the MiniVol and DataRAMs dust monitors.

therefore, Spearman correlation coefficients (Iman and Conover, 1989; SAS Institute Inc., 1990) were performed to find the degree of association among these variables. The average proportion of PM_{10} as measured with DataRAM-A in relation to PM_{10} as measured with the MiniVol for the 120 observations was 66*%*. Average proportion by soil varied from 64*%* for the Acuff2 soil to 71*%* for the Gomez soil.

Paired *t*-test results showed significant differences ($\alpha = 0.05$) among overall means for DataRAM-A and MiniVol as well as by soil means. We believe the devices produced different results due the different impactor designs. The DataRam impactor is a fiberglass filter mounted in a plastic holder. The MiniVol uses an Apiezon grease covered Teflon impactor.

Also $PM_{2.5}$ as measured by DataRAM-B was proportional in relation to PM_{10} as measured by DataRAM-A and MiniVol in all soils (Figure 2). Spearman correlation coefficients among $PM_{2.5}$ and PM_{10} as measured by DataRAM-A and MiniVol were 0.92 and 0.87, respectively. The range in $PM_{2.5}$ concentrations was from 3.0 to 11.3 mg/m^3. The overall average proportion of $PM_{2.5}$ in relation to PM_{10} as measured with DataRAM-A was 27*%*. The Acuff1 soil had the lowest proportion (25*%*) and the Amarillo showed the highest proportion (29*%*).

Soil Clay and $CaCO_3$ Content Effects

A general trend was observed for aerosol PM_{10} and $PM_{2.5}$ concentrations to increase as soil clay and $CaCO_3$ content increased (Figures 3 and 4). Statistical analyses of soil clay and $CaCO_3$ combinations are presented in Table 2. The effect of soil $CaCO_3$ content on aerosol PM_{10} (as measured with both DataRAM-A and MiniVol) and $PM_{2.5}$ concentrations (as measured with DataRAM-B) was clearly significant ($\alpha = 0.05$) as indicated in Table 2 and Figure 3. Soil clay content, on the other hand, produced significant ($\alpha = 0.05$) effects for the PM_{10} data set for the MiniVol but no significant effects for PM_{10} and $PM_{2.5}$ data sets from DataRAM-A and DataRAM-B, respectively (Table 2 and Figure 4).

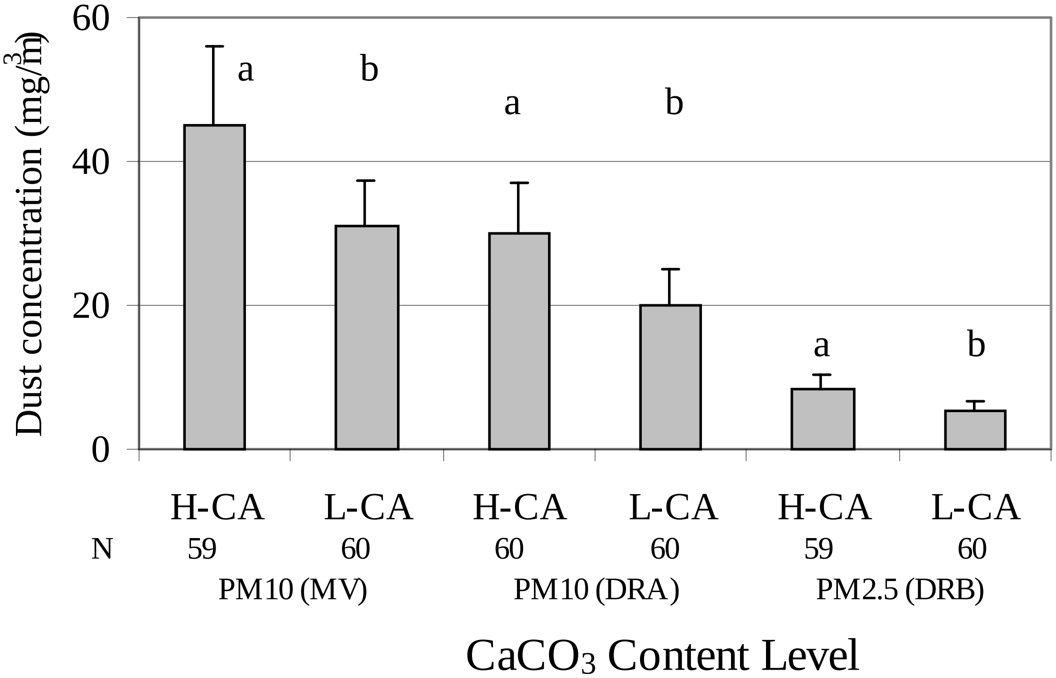

Figure 3. Means comparison of $CaCO_3$ level (H-CA = High $CaCO_3$, L-CA = Low $CaCO_3$) by instrument (MV = MiniVol, DRA = DataRAM-A, DRB = DataRAM-B) for LDGASS data. Means with the same letter within measurement device are not significantly different at $\alpha = 0.05$.

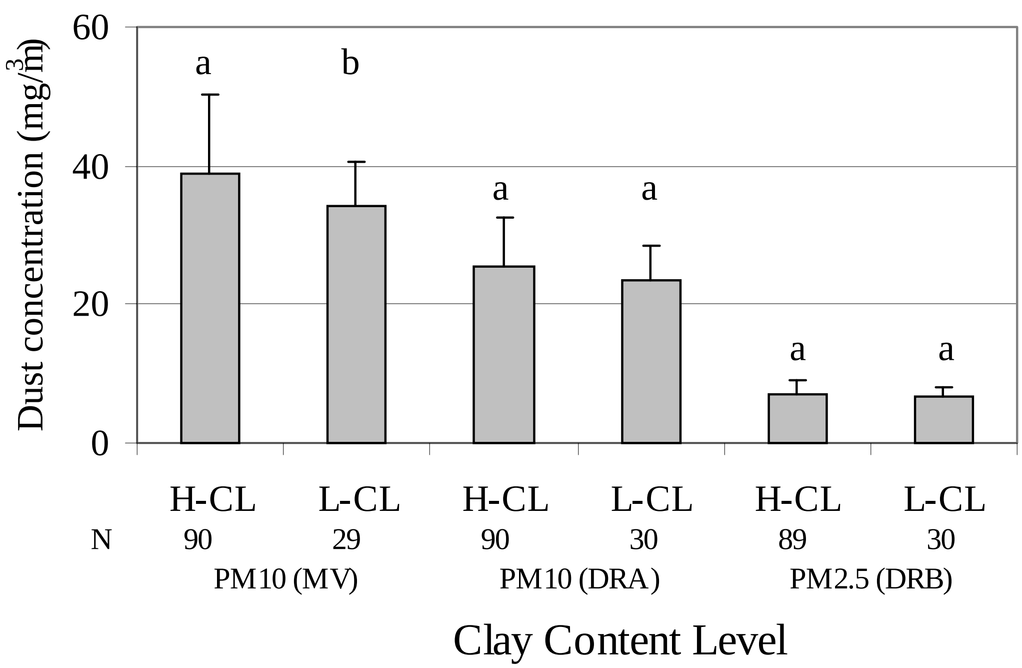

Figure 4. Means comparison of clay level (H-CL = High clay, L-CL = Low clay) by instrument (MV =MiniVOL, DRA = DataRAM-A, DRB = DataRAM-B) for LDGASS data. Means with the same letter within measurement device are not significantly different at $\alpha = 0.05$.

As *P*-values in Table 2 and Figures 3 and 4 indicate, differences among levels of soil $CaCO_3$ content produced greater differences in dust generation than differences among levels of soil clay content. Gill *et al*. (1999) reported that a calcareous Drake soil produced a higher PM_{10} concentration than an Amarillo soil of the same soil texture. They suggest that a lower binding energy in highly calcareous aggregates in

Table 2. Derived *P*-values from Z-tests and analyses of variance of the data.

Source of variation	PM_{10} (DataRAM-A)	PM_{10} (MiniVOL)	$PM_{2.5}$ (DataRAM-B)
Clay content group†	0.06	*	0.35
$CaCO_3$ content group†	*	*	*
Soil group	*	*	*
Soils Within Carbonate Levels			
Soil within high clay level group	*	*	*
Soil within low clay level group	*	*	*
Soil within high $CaCO_3$ level group	*	*	*
Soil within low $CaCO_3$ level group	*	*	*
Soil within high clay-high $CaCO_3$ group	*	*	*
Soil within high clay-low $CaCO_3$ group	*	*	*
Sites Within Soils			
Site within Amarillo soil	0.31	*	0.29
Site within Acuff1 soil	*	0.29	*
Site within Acuff2 soil	*	*	*
Site within Drake1 soil	*	*	*
Site within Drake2 soil	*	*	*
Site within Drake3 soil	*	*	*
Site within Gomez & Arch soil	*	*	*
Site within Olton soil	*	*	*

* Significant effect (*P*-value < 0.05).

the silt fraction of the Drake soil resulted in much less stable aggregates than those of the Amarillo soil, and that this fact might have favored their easier dissagregation into fine dust. Also, the increase in aerosol PM_{10} concentration with increases in soil clay content has been previously reported. Zobeck *et al.* (1999) observed a general increase in airborne PM_{10} concentration as the clay content in agricultural soils of the Southern High Plains increased. PM_{10} concentration for a clay soil, however, was the lowest because the soil aggregates were very resistant to abrasion. Stetler *et al.* (1994) and Stetler and Saxton (1995) also have pointed out the higher potential of fine textured soils to generate dust when disturbed or eroded by wind.

Soils Variability

Analyses of variance were performed to evaluate variation among soils. Data sets grouped by soils were reasonably normally distributed. Equality of variances tests among soils indicated that most of the time the variances were equal for the data set from DataRAM-B ($PM_{2.5}$), but most of the individual comparisons showed the variances were different for PM_{10} data sets (DataRAM-A and MiniVol). These two data sets were transformed with reciprocals to improve the equality of variances. Analyses of variance for soils in general showed significant differences ($\alpha = 0.05$) among them as indicated in Table 2. Even when soils were grouped by levels of clay content, $CaCO_3$ content or level combinations of clay and $CaCO_3$, the *P*-values were in all cases < 0.05 (Table 2), which denotes a significant variability among the soils involved in this study. Ranking of soils according to the overall mean PM_{10} or $PM_{2.5}$ concentration was identical for the three data sets, but they were separated slightly differently by the Tukey's studentized range test. Soil mean PM_{10} concentrations for the DataRAM-A data set and results of their comparison are shown in Figure 5. The observation that soils with high $CaCO_3$ levels had larger means than soils in the lower $CaCO_3$ level illustrates the greater effect of

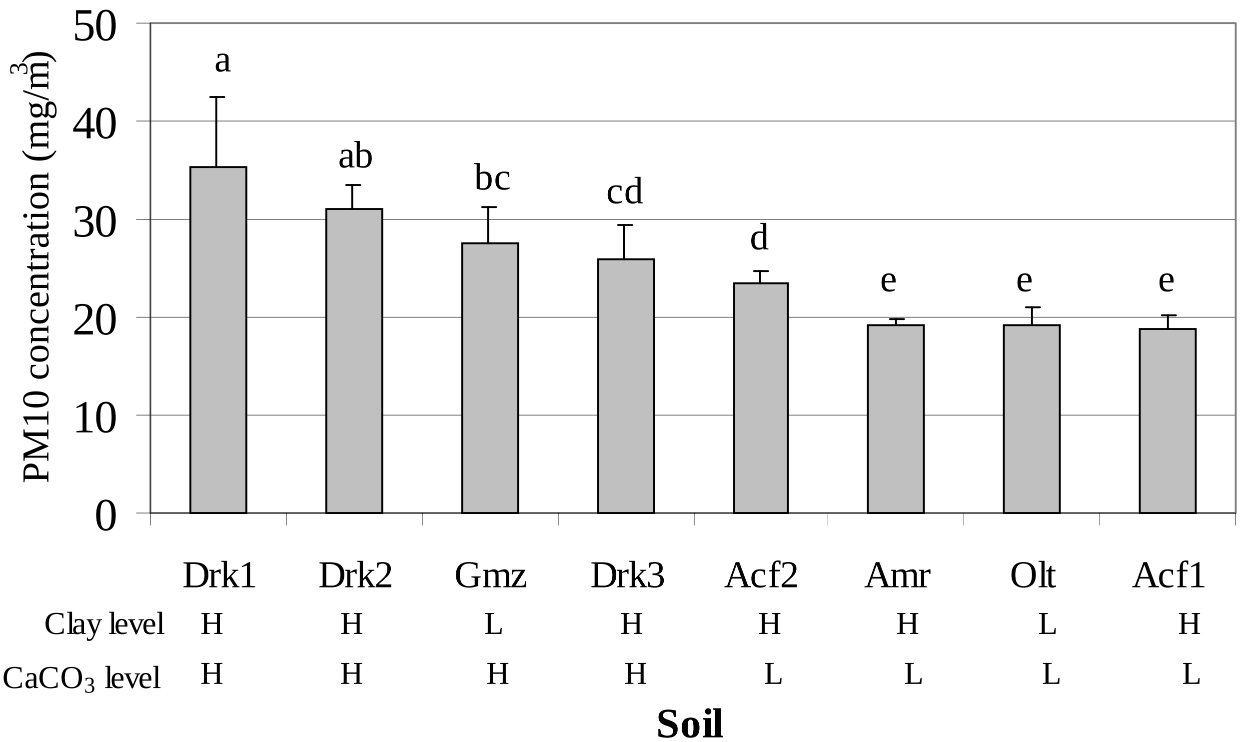

Figure 5. Soil means comparison for LDGASS PM_{10} (from DataRAM-A) data set. Means with the same letter are not significantly different at $\alpha = 0.05$. H and L indicate high and low, respectively.

$CaCO_3$ on aerosol PM_{10} concentration than that of clay.

Analyses of variance performed by soil showed that most of the time the effect of site on fine dust emission was significant ($P < 0.05$) (Table 2). With the exceptions of Amarillo and Acuff1 soils, the effect of site on dust generation was significant for the three data sets. The soil with the least variation was Amarillo where the site effect was not significant for data sets from both DataRAMs. These results indicate that the variation in fine dust emission within fields mapped as the same soil unit was large. The high variation present among soils and within soils significantly increased the internal variability when the data were grouped by clay and by $CaCO_3$. Despite that fact, the effect of soil $CaCO_3$ content on PM_{10} and $PM_{2.5}$ concentration was significant for the three data sets.

Particle Size Distribution of Generated Dust Plumes

The median particle size of generated dust clouds increased with running time. Both soil clay and $CaCO_3$ content affected particle size distributions and corresponding median diameters. A general trend was observed for the median particle size to decrease as soil clay and $CaCO_3$ content increased. Figure 6 illustrates these trends through two representative tests. Five particle size distributions, including the first (1 *min*) and the last (30 *min*) ones, of individual tests for Amarillo and Drake1 soils are presented in graphs on the left side of Figure 6. Graphs on the right show the median particle size for all the particle size distributions measured by Malvern in the 30 *min* of running time for those tests. The Amarillo soil had low clay and $CaCO_3$ content and the Drake1 soil had high clay and $CaCO_3$ content. Larger median particle sizes were observed at all times for the Amarillo soil, which shows a rapid increase in median particle size in the first 10 min, then the increase becomes very small till the end of the test. On the other hand, the Drake1 soil, with smaller median particle sizes, shows a more gradual increase but remains more constant through the test.

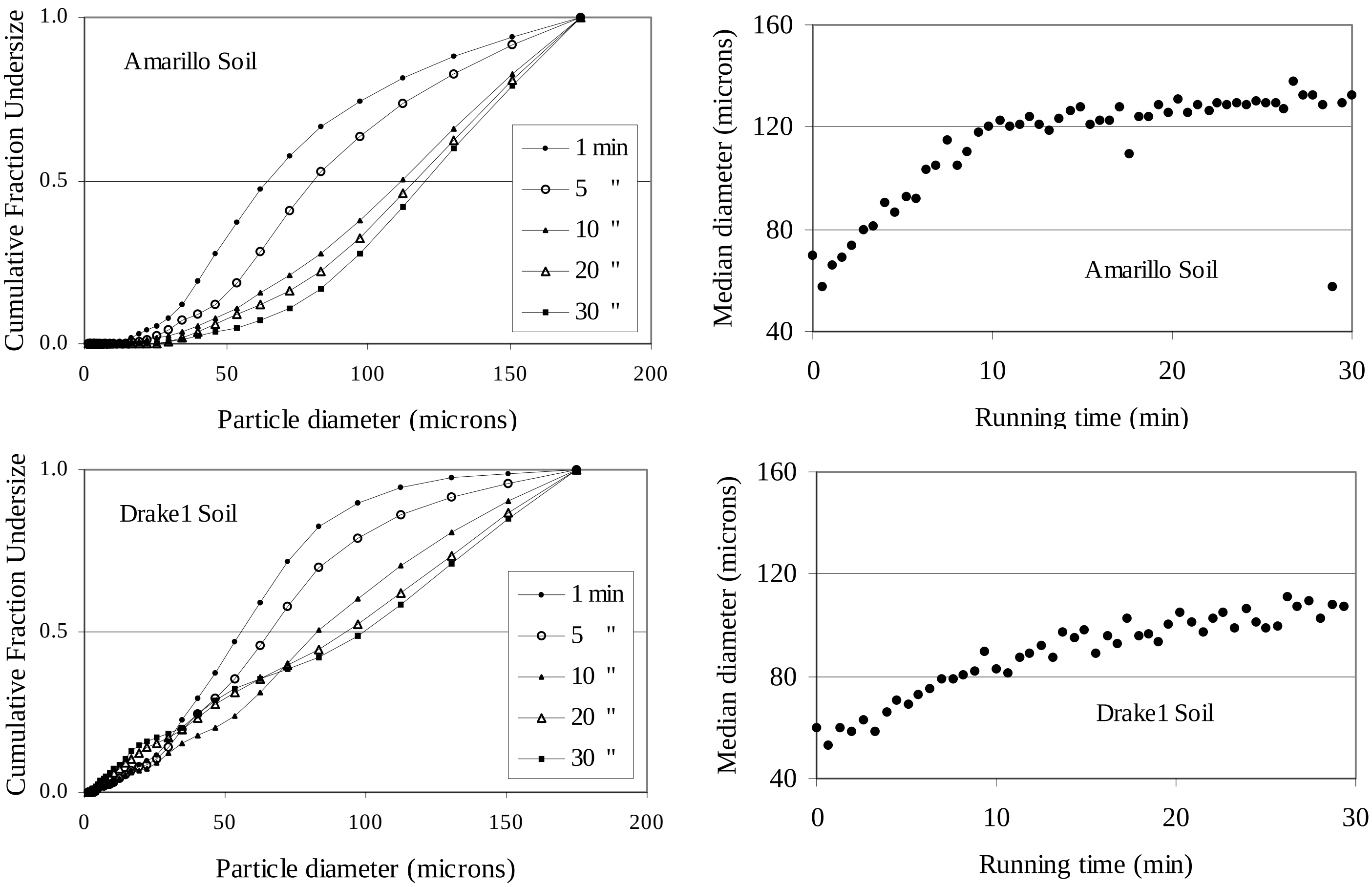

Figure 6. Changes in aerosol particle size distribution and medium diameter with running time for soils with low clay and $CaCO_3$ content (Amarillo) and high clay and $CaCo_3$ content (Drake1).

Table 3 shows the means comparison results as obtained with Tukey's test. Average median particle size for the first record was significantly different ($\alpha = 0.05$) among levels of clay but not among levels of $CaCO_3$. Means of average particle size for all records in 30 *min* were significantly different among levels of both clay and $CaCO_3$ factors. Conversely compared to results for the first record, average median particle size for the last record were significantly different among levels of $CaCO_3$ but not among levels of clay.

Trends in particle size distribution in Figure 6 might partially explain this opposite result among first and last records. Contrary to what is observed with Amarillo soil, particle size distributions for Drake1 soil show in increase with running time in the fraction of fine dust. The cumulative fraction of particles less then 25 μm for instance, is the largest at the 30 *min*. Particle size distributions for Amarillo soil are representative of the particle size distributions obtained from soils with low $CaCO_3$ content, while those for Drake1 soil were representative of soils with high $CaCO_3$ content. As a consequence, significant differences among means were found for low and high levels of $CaCO_3$ for the average and last record median particle size.

Table 3. Means comparison for median particle size by clay and $CaCO_3$ levels.

Level of factor	Average median particle size (μm) First record	Average	Last record
Low clay level	65.12 a[H]	104.19 a	122.24 a
High clay level	59.43 b	96.26 b	117.96 a
Low $CaCO_3$ level	60.76 a	101.39 a	122.87 a
High $CaCO_3$ level	60.84 a	95.80 b	116.10 b

[H] Means with the same letter by columns within clay and $CaCO_3$ levels are not significantly different at $\alpha = 0.05$ (Tukey's test).

Gill *et al.* (1999) also observed a smaller mean particle size for a calcareous Drake soil than that for an Amarillo soil of the same texture (fine sandy loams). The PM_{10} fraction of the total amount of airborne dust was also larger for the Drake soil. However, they made two measurements within the first 5 minutes of sample agitation (from 0.5 to 2.0 *min* and from 3.0 to 4.5 *min* of the running time) and a decrease was observed in the mean particle size for the second measurement in relation to the first one (the rotating drum dust generator was used).

CONCLUSIONS

Significant differences were found among measurements of PM_{10} concentration made by DataRAM and MiniVol instruments. DataRAM PM_{10} measurements were on average 66% of measurements made by the MiniVol. Measurements between instruments, however, were proportional with a Spearman correlation coefficient of 0.97. $PM_{2.5}$ concentrations obtained with a DataRAM were also proportional to PM_{10} production. The overall average proportion of $PM_{2.5}$ in relation to PM_{10} as measured by a DataRAM was 27%. Spearman correlation coefficients of 0.92 and 0.87 were found among $PM_{2.5}$ and PM_{10} as measured by a DataRAM and a MiniVol, respectively.

The increase of aerosol PM_{10} and $PM_{2.5}$ concentrations with the increase of soil $CaCO_3$ content was significant for the three datasets. The increase of particulate matter concentrations with the increase of soil clay content was significant for the PM_{10} data set from the MiniVol dust monitor, but was not significant for PM_{10} and $PM_{2.5}$ as measured with DataRAMs. Differences in soil $CaCO_3$ content produced greater differences in aerosol PM_{10} and $PM_{2.5}$ concentrations than the differences in soil clay content. Soils with high $CaCO_3$ content produced the largest aerosol PM_{10} and $PM_{2.5}$ concentrations. The within soil variability as well as the variation among soils were significant.

Particles in the generated dust plumes increased in size with running time. Soil clay and $CaCO_3$ content significantly affected the median particle size (average for the 30 min of running time), and consequently, the dust particle size distributions. The median particle size decreased as the soil clay and $CaCO_3$ content increased.

REFERENCES

Allen, T. *Particle size measurement*; Powder Technology Series, Chapman and Hall, Third edition; New York. 1981, p 678.

Bouyoucos, G. J. "A recalibration of the hydrometer method for making mechanical analysis of soils", *Agron. J.* 1951, 43, 434-438.

Chepil, W.S. “A compact rotary sieve and the importance of dry sieving in physical soil analysis”, *Soil Science Society of America Proceedings* 1962, 26(1), 4-6.

Gatz, D.F. “Soil aerosol composition: Comparison of source sample generation methods”, Air and Waste Management Association. 88th Annual Meeting & Exhibition. San Antonio, TX. June 18-23, 1995, p 13.

Gill, T.E.; Zobeck T.M.; Stout J.E.; Gregory J.M. “Fugitive dust generation in the laboratory”, Proceedings of the Wind erosion International Symposium-Workshop USDA-ARS Wind Erosion Research Unit, Kansas State University, Manhattan, Kansas, 1999.

Gillette, D.A. “Production of dust that may be carried great distances”. In *Desert Dust: Origin, Characteristics, and Effect on Man*, Pewe, T.L., Ed.; The Geological Society of America, Special Paper 186, 1981, pp 11-26.

Iman, R.L.; Conover W.J. *Modern Business Statistics*; John Wiley & Sons, Second edition; New York, 1989, p 910.

Matsumura, R.T.; Flocchini R.G.; Cahill T.A.; Carvacho O.; Lu Z. “Measurement of fugitive PM_{10} emissions from selected agricultural practices in the San Joaquin Valley”. In *PM_{10} Standards and Nontraditional Particulate Source Controls. Volume I.*, Chow J.C.; One, D.M., Ed.; Air and Waste Management Association, A&WMA/EPA International Specialty Conference, 1992, pp 417-432.

Monitoring Instruments for the Environment, Inc. *DataRAM. Instruction manual*; Billerica, MA. 1995.

Nickling, W.G.; Gillies J.A. “Emission of fine-grained particulates from desert soils”. In *Paleoclimatology and Paleometeorology: Modern and Past Patterns of Global Atmospheric Transport.*, Leinen, M.; Sarnthein, M., Ed.; Kluwer Academic Publishers; Norwell, MA, 1989, pp 133-165.

Pewe, T.L. “Desert dust: An overview”, In *Desert Dust: Origin, Characteristics, and Effect on Man*, Pewe, T.L., Ed.; The Geological Society of America, Special Paper 186, 1981, pp 1-10.

SAS Institute Inc. *SAS/STAT User’s guide. Version 6*, Fourth edition; Cary, NC, 1990, p 1686.

Singh, U.B. *Wind Erosion: Mechanics of Saltation and Dust Generation*; Ph.D. Dissertation in Civil Engineering, Texas Tech University; Lubbock, TX. 1994.

Soil Survey Staff. *Soil Survey Manual*; USDA Handbook 18, US Government Printing Office; Washington, DC, 1993, p 437.

Stetler, L.D.; Saxton K.E. “Fugitive Dust (PM_{10}) Emissions and Eroded Soil Relations From Agricultural Fields on the Columbia Plateau”, Air and Waste Management Specialty Conference: Particulate Matter; Pittsburgh, PA, April 4-6, 1995; Paper 139.

Stetler, L.D.; Saxton K.E.; Fryrear D.W. “Wind Erosion and PM_{10} Measurements From Agricultural Fields in Texas and Washington”, Air and Waste Management Association. 87th Annual Meeting & Exhibition; Cincinnati, Ohio, June 19-24, 1994, p 14.

US Salinity Laboratory, *Diagnosis and Improvement of Saline and Alkali Soils;* USDA Agric. Handbook 60, US Government Printing Office; Washington, DC. 1954, p 160.

Zobeck, T. M. "Fast-Vac: A Vacuum System To Rapidly Sample Loose Granular Material", Trans. Am. Soc. Ag. Eng. 1989, 32, 1316-1318.

Zobeck, T.M.; Gill T.E.; Popham T.W. "A Two-parameter Weibull Function To Describe Airborne Dust Particle Size Distributions", Earth Surf. Processes and Landforms, 1999, 24, 943-955.

Zobeck, T.M.; Gill T.E.; Stout J.E.; Zhang M.L.; Kennedy A.C.; Gregory J.M. "Analysis of Laboratory-generated Dust Suspensions Derived From Soils and Roads", Presented at the 1997bvASAE Annual International Meeting; St. Joseph, MI, 1997; Paper No. 972030

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ACKNOWLEDGMENTS

The authors are grateful to Dean Holder, USDA-ARS for assistance with data collection and compilation and Texas Tech University, Dept. of Civil Engineering for the use of their wind tunnel.

KEY WORDS PM_{10}, $PM_{2.5}$, fugitive dust, wind erosion,