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Particle Size Distribution of PM Emitted from Cotton Harvesting

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Abstract. *Poor air quality in some areas of the US has caused regulators to increase regulatory pressure on sources of air pollution. Historically, cotton producers have not been targeted by regulators to reduce emissions through mandatory implementation of particulate matter (PM) control strategies. However, the use of inaccurate PM emission factors for field operations (including cotton harvesting) has resulted in the identification of agricultural operations as a significant source of PM pollution in California. Little work has been conducted to accurately determine emission factors for* PM_{10} *and* $PM_{2.5}$ *from cotton harvesting operations. Furthermore, no research has been conducted to characterize the physical parameters of the PM emissions from cotton harvesting in terms of the* *particle size distribution (PSD), particle density, and PM composition. Therefore, the work presented in this manuscript describes the results of an investigation into the physical parameters of the PM < 100 micrometers (µm) contained in seed cotton samples taken from harvesting operations in Texas and New Mexico. It is anticipated that the PM < 100 µm contained in harvested seed cotton samples will provide a representative sample from which to make inferences on the physical parameters of the PM emitted from the harvesting operation. PM was air-washed from seed cotton samples taken from 2 locations in Texas and New Mexico and was analyzed for particle density, PSD, and PM composition. The results of the particle density analysis indicate that PM air washed from the seed cotton samples has a particle density on the order of 2.24 ± 0.175 g/cm*^{3}*. Significant differences in the particle density of the PM air washed from seed cotton samples were detected by location. PSD analyses indicate that the mean percent mass of the PM<100 µm for* PM_{10} *and* $PM_{2.5}$ *are on the order of 27.5 ± 4.91% and 8.1 ± 2.34%, respectively. No significant differences were observed between the samples by location or harvester type for percent* PM_{10} *or* $PM_{2.5}$*. A compositional analysis of the PM air washed from the seed cotton samples indicates that soil material and plant material likely account for 78.7 ± 14.6% and 21.3 ± 14.6% of the PM <100 µm contained in the seed cotton samples, respectively.*

Keywords. Particulate Matter, Cotton Harvesting, Particle Size Distribution, Particle Density, Ash Composition

Introduction

Cotton producers in some states across the cotton belt are facing increased regulatory pressure from state air pollution regulatory agencies (SAPRA) due to poor air quality (PM_{10} and $PM_{2.5}$ non-attainment status) and a lack of accurate emission factors. Cotton producers in California have been identified as a significant source of PM_{10} due to the use of emission factors developed using protocols with high levels of uncertainty. As a result, agricultural producers are required to obtain operating permits from the SAPRA (CARB, 2003) and submit Conservation Management Practice (CMP) plans detailing the actions to be taken by the producer to reduce fugitive particulate matter (PM) emissions (SJVAPCD, 2004a and 2004b). Further, the reduction of the $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) implemented during the five year review of the NAAQS (Federal Register, 2006) will present cotton producers with new air quality regulation challenges due to the lack of an emission factor.

Emission factors are estimates of the amount of a pollutant emitted by an operation per unit of production (i.e. lbs. PM_{10} per acre of cotton harvested). Emission factors are used by air pollution regulators to determine annual emissions inventories and in dispersion models to predict downwind concentrations resulting from the pollutant emissions from a source.

Few studies have been conducted to quantify PM emission factors from cotton harvesting operations. Moreover, little work has been done to characterize the physical characteristics of the PM emitted from cotton harvesting in terms of particle size distribution (PSD) analysis and parent material composition analysis.

A study conducted under contract with the USEPA by Snyder and Blackwood (1977) reported emissions of particulate matter less than 7 µm (mean aerodynamic diameter) on the order of 0.96 kg/km^2 ($8.4*10^{-3}$ lbs/acre) for harvesting operations using cotton pickers. This emission factor represented the total emission factor from harvesting operations including emissions from the harvesting machine, trailer loading operations, and trailer transporting operations. It was reported by Snyder and Blackwood (1977) that particulate matter samplers followed the harvesting machine at a fixed distance within the plume to collect particulate matter concentrations. The authors stated further that particulate matter concentrations downwind of trailer loading operations were taken by placing samplers at a fixed downwind distance. No detail is given by the authors as to the method used to back-calculate emission factors from the measured concentrations, and the concentrations measured by the samplers (concentrations of PM_7) do not accurately represent the concentration of the regulated PM sizes currently used by EPA. (PM_{10} and $PM_{2.5}$ are the current PM criteria pollutants.) Further, no investigation into the physical characteristics of the PM measured was reported.

Flocchini et al. (2001) conducted a study to measure the emissions from cotton harvesting operations using cotton pickers harvesting between two and five rows per pass. The results of the study by Flocchini et al. (2001) indicate that the PM_{10} emissions from cotton picking machines in the San Joaquin valley of California are on the order of 1.7 lbs/acre. $PM_{2.5}$ emission factors were not reported. The sampling protocol used by Flocchini et al. (2001) employed federal reference method (FRM) PM_{10} samplers to measure downwind concentrations from the harvesting operations. These concentrations were subsequently used in a mass balance box-model to back-calculate the emission factor. This work represents the most up-to-date research focusing on quantifying the emissions of PM from cotton harvesting. However, Flocchini et al. (2001) did not provide any analysis into the inherent sampling bias of the FRM PM_{10} sampler described by Buser (2004). Buser (2004) indicates that the FRM PM_{10} sampler over-states true PM_{10} concentrations due to the interaction between the sampler performance characteristics and the PSD of the sampled dust.

Accurate, science-based emission factors are essential for the appropriate regulation of agricultural operations. Thus, the physical characteristics of PM emitted from agricultural operations must be investigated in order to minimize inaccuracies in the resulting emission factors due to measurement bias and uncertainty.

The objective of the work presented in this manuscript is to investigate the physical characteristics of fine dust generated by cotton harvesting operations in terms of the particle size distribution, particle density, and PM composition (i.e. percent soil material vs. plant material contribution). It is anticipated that the PM < 100 μm contained in harvested seed cotton samples will provide a representative sample from which to make inferences on the physical parameters of the PM emitted from the harvesting operation. It is hypothesized that the primary constituents of the PM emitted from cotton harvesting operations (and thus contained in the harvested material) originate from soil and plant material. It is expected that the results of this work will aid in the development of a protocol to accurately quantify the PM_{10} and $PM_{2.5}$ emission factors from cotton harvesting operations.

Methods

Eight – 22.7 kg (50 lb) seed cotton samples were collected from harvesting operations on the High Plains of Texas and Mesilla Valley of New Mexico during 2005. The four samples taken from the Mesilla Valley (samples 1 – 4) were all Pima (*G. barbadense*) varieties and were harvested using spindle-type cotton pickers. The four samples taken from the Texas High Plains (samples 5 – 8) were all conventional upland (*G. hirsutum*) varieties and were harvested using stripper and picker harvesters. The harvester type, variety, and production practice used at each sampling location are shown in table 1.

Three sub-samples of each seed cotton sample were taken for fractionation analysis using the method described by USDA (1972). The results of the fractionation analysis give the percent by mass of the original sample comprised of burs, sticks and stems, fine trash, and cleaned seed cotton. The plant material (burs, sticks and stems) collected from the samples during the fractionation analysis was used in later analysis of the PM derived from plant material.

Soil samples (1 kg) were also collected from within each field where the cotton samples were harvested.

Table 1. Harvester type, management practice, and species of the cotton samples used.

Sample	Harvester Type	Management Practice	Variety
1	Picker	Conventional	Pima
2	Picker	Organic	Pima
3	Picker	Conventional	Pima
4	Picker	Organic	Pima
5	Picker	Conventional	Upland
6	Stripper	Conventional	Upland
7	Stripper	Conventional	Upland
8	Stripper	Conventional	Upland

Air Wash Analysis

The seed cotton samples were air washed to extract the fine dust less than 100 μm onto a filter for subsequent analysis. The air washing procedure consisted of the following:

- A 400 g sub-sample of seed cotton was placed in a 0.03 m^3 (1 ft x 1 ft x 1 ft) tumbler box located inside the air-tight outer box. The tumbler box was covered with 100 μm mesh screen to prevent material larger than 100 μm from being collected on the filter.
- The tumbler was rotated at a speed of approximately 60 rpm for 20 min.
- A centrifugal fan was used to pull air from outside the sealed outer box through air ports leading to the inside of the tumbler box at an approximate flow rate of 1.13 m^3/min (40 ft^3/min). The fine PM passed from the tumbler box to the filter via the induced air stream.
- A 20.3 by 25.4 cm (8 x 10 in) borosilicate glass microfiber filter (Pall Corp., Pallflex Emfab filter material, East Hills, NY) was placed in the air wash machine to collect the PM extracted during the procedure. PM from several sub-samples (from the same seed cotton sample) was allowed to accumulate on the filter. Once the PM loading on the filter reached the point where the air flow rate dropped below 1.0 m^3/min (35 ft^3/min), the accumulated PM was removed from the filter (by placing the filter upside-down on a clean sheet of paper and lightly tapping on the back of the filter to dislodge the PM) and placed in a sample jar for later particle density, PSD, and ash analysis. This process was repeated until 10 g of PM was collected from each sample.
- The residual PM remaining in the tumbler box after processing all of the sub-samples from one seed cotton sample was removed by vacuuming before processing the next sample.

The fine dust content in each of the seed cotton samples was evaluated by performing the air wash procedure on a 400 – 500 g sub-sample using an unexposed 20.3 by 25.4 cm (8 x 10 in) borosilicate glass microfiber filter. The filters used in this evaluation were pre- and post-weighed using a high precision analytical balance (AG245, Mettler-Toledo, Greifensee Switzerland). This process was replicated three times for each seed cotton sample and the dust content was determined by dividing the net filter mass by the original mass of the seed cotton sub-sample.

Soil Sieve Analysis

Size distribution data from each soil sample were obtained by sieve analysis. The designation of the sieves used are 22.4 mm (7/8 in), 16 mm (5/8 in), 9.5 mm (3/8 in), 8 mm (5/16 in), 2 mm (#10), 1.4 mm (#14), 710 μm (#25), 180 μm (#80), 106 μm (#140), and 75 μm (#200). The sieves were divided into two stacks and the soil samples were processed for 20 min (in each stack) on a Tyler Ro-Tap® sieve shaker (Model RX-94, W.S. Tyler Inc., Mentor, OH). The net material mass remaining in each sieve was used to determine the mass percent of the original soil sample mass within each size range. A 10 g sample of the soil material passing through the #200 sieve (< 75 μm) was collected for later particle density, PSD, and ash analysis.

Plant Material Analysis

The plant material collected from the fractionation analysis of each seed cotton sample was processed through a small laboratory scale mill to generate PM. The plant material was milled until the material passed though a 6 mm screen. The milled material from each sample was passed through a #200 sieve to collect the PM < 75 μm. Approximately 5 g of plant material PM < 75 μm was collected for later particle density, PSD, and ash analysis.

Particle Size Distribution Analysis

PSD analyses of the PM < 100 µm from the air washing procedure, soil material < 75µm, and plant material < 75µm, from each seed cotton sample, were conducted using a Malvern Mastersizer 2000 (Malvern Instruments Ltd., Worcestershire, UK, 1999). The Mastersizer 2000 utilizes light scatter patterns measured from two light sources passed through the suspended PM sample with the absorption and refractive index of the PM material to develop an equivalent spherical diameter (ESD) PSD. Mie theory is the basis of the measurement principal used by the Mastersizer 2000 (Malvern Instruments, 1999). The refractive index used for the PM was 1.544 with an absorption value of 1.0. The PM was suspended in ethanol with a refractive index of 1.36.

The PSD results reported by the Mastersizer 2000 in terms of ESD were converted to an aerodynamic equivalent diameter (AED) basis using the results of particle density analyses of the air wash PM, soil material < 75 µm, and plant material < 75 µm.

$$AED = ESD\sqrt{\rho_p} \tag{1}$$

where:

ρ_p = particle density (g/cm^3).

The particle density of the air wash PM < 100 µm, soil material < 75 µm, and plant material < 75 µm was measured using a pycnometer (Micromeritics, AccuPyc 1330 Pycnometer, Norcross, GA) according to the procedure described by Wanjura (2005).

Ash Analysis

Ash analysis was performed on the air wash PM < 100 µm, soil material < 75 µm, and plant material < 75 µm using the ASTM Standard Test Method for Ash in Biomass (ASTM, 2001). Three, 1 g sub-samples of each material sample were analyzed. The percent ash in each sub-sample was determined by (2) and an average of the three replicates was taken as the ash content of each material sample.

$$A = \left[\frac{m_a - m_c}{m_s - m_c}\right] \times 100 \tag{2}$$

where:

A = percent ash in sample (by mass),

m_a = mass of ash (g),

m_c = mass of sample container (g), and

m_s = mass of original sample (g).

The mass percent of material that was volatized (V) in the ash analysis was found by (3).

$$V = 100 - A \tag{3}$$

The estimated mass contribution of the soil and plant material to the PM air washed from the seed cotton were calculated using the linear system shown in (4).

$$\begin{vmatrix} A_s & A_p \\ V_s & V_p \end{vmatrix} \times \begin{Bmatrix} S \\ P \end{Bmatrix} = \begin{Bmatrix} A_{aw} \\ V_{aw} \end{Bmatrix} \tag{4}$$

where:

A_s = ash content of the soil sample (%),
A_p = ash content of the plant material (%),
V_s = volatile material content of the soil sample (%),
V_p = volatile material content of the plant material (%),
S = soil content of air wash material (decimal),
P = plant material content of air wash material (decimal),
A_{aw} = ash content of the air wash material (%), and
V_{aw} = volatile material content of the air wash material (%).

Results

The results of the fractionation analysis on the seed cotton samples are shown in table 2. An analysis of variance (ANOVA) was performed on the data to determine if there were significant differences between the samples with respect to percent burs, sticks and stems, fine trash, and seed cotton by location and harvester type. No significant differences were detected between locations for the percent burs, sticks and stems, fine trash, or seed cotton at the 0.05 level of significance (α). Differences were detected between the samples by harvester type (α = 0.05) for the percent burs (p = 0.003), sticks and stems (p = 0.02), and seed cotton (p = 0.008) but not for the percent fine trash (p = 0.322). This result is interesting because it is commonly perceived that stripper harvesters emit more dust than picker harvesters, from which it would be expected that the fine trash content of stripper harvested cotton would be higher than that of picker harvested cotton. However, the difference by harvester type determined for the percent burs, sticks and stems, and seed cotton was expected as stripper harvested cotton generally contains more plant/foreign material and has lower percent turnout than picker harvested cotton.

Table 2. Results of fractionation analysis of the eight seed cotton samples.

Sample	Burs (%)	Sticks and Stems (%)	Fine Trash (%)	Seed Cotton (%)
1	2.2	1.0	2.1	94.6
2	1.8	1.5	4.4	92.3
3	2.4	0.8	4.0	92.8
4	3.0	1.7	1.9	93.3
5	2.3	0.6	4.8	92.3
6	4.0	1.6	3.8	90.6
7	7.0	5.0	4.7	83.2
8	5.6	5.1	4.5	84.8
Mean by Location				
Texas	4.7[a]	3.1[a]	4.5[a]	87.7[a]
New Mexico	2.4[a]	1.3[a]	3.1[a]	93.3[a]
Mean by Harvester				
Picker	2.3[a]	1.1[a]	3.5[a]	93.1[a]
Stripper	5.6[b]	3.9[b]	4.4[a]	86.2[b]

Means within a column (by location or harvester) with the same letter are not significantly different (α = 0.05).

An ANOVA on the fine dust content of all samples from the air wash analysis (α = 0.05) indicates that there is no significant difference in the fine dust content of the samples by harvester type (p = 0.859). However, the fine dust content value for sample 5 was considered an outlier as its value is greater than 3 standard deviations from the mean for picker harvested samples. Removing sample 5 from the analysis, significant differences were detected between the fine dust content of the samples by harvester type ($p = 0.033$). Analysis of the interaction between harvester type and location is not possible because both types of harvesters were not used at both locations. Thus, statistical differences by location and harvester type must be interpreted with caution. In this case, removing the data for sample 5 causes the comparison of fine dust content by harvester type or location to yield identical results. The mean fine dust content of the samples harvested using pickers and strippers were 2.7 ± 1.3 and 10.6 ± 13.6 g PM <100 μm / kg seed cotton, respectively. The results of the fine dust content analysis from the air washing procedure are presented in table 3.

Table 3. Fine dust content (g PM <100 μm/kg seed cotton) results from the air wash procedure on the seed cotton samples.

Sample	Mean Fine Dust Content (g PM < 100 μm / kg seed cotton)
1	3.04
2	3.72
3	2.00
4	2.20
5	34.04*
6	16.69
7	9.09
8	6.05
Mean by Location	
Texas	10.61[a]
New Mexico	2.74[b]
Mean by Harvester	
Picker	2.74[a]
Stripper	10.61[b]

Means by location or harvester with the same letter are not significantly different ($\alpha = 0.05$).
*Outlier data.

The results of the soil sieving analysis are shown in table 4. The percent soil less than 106 μm (less than the #140 sieve) was correlated with the fine dust content from the air wash analysis and the percent fine trash from the fractionation procedure. Neither of the variables are significantly correlated ($\alpha = 0.05$). However, the correlation coefficient for the relationship between fine dust content and the soil material < 106 μm is 0.66. The correlation coefficients for the relationships between percent fine trash and fine dust content, and percent fine trash and soil material < 106 μm are 0.47 and 0.44, respectively.

Table 4. Soil sieve analysis results of the soil samples taken from the locations where the seed cotton samples were harvested.

	% of Total Material Mass Larger Than Size					
Sieve No.	**No. 14**	**No. 25**	**No. 80**	**No. 140**	**No. 200**	**Pan**
Nominal Opening Size (mm)	**1.400**	**0.710**	**0.180**	**0.106**	**0.075**	
Sample #						
1	28	15	31	9	5	13
2	47	12	22	5	2	11

3	39	13	34	7	2	6
4	7	6	48	21	7	10
5	4	4	33	23	12	23
6	3	5	32	22	12	26
7	6	7	33	15	12	26
8	13	12	32	12	8	23

Mean Mass % < 106 µm by Location

Texas	36[a]
New Mexico	14[b]

Mean Mass % < 75 µm by Location

Texas	25[a]
New Mexico	10[b]

Means by size fraction with the same letter are not significantly different (α = 0.05).

Further analysis of the soil sieve data using ANOVA indicated that there are significant differences (p < 0.001) between the samples for the soil material < 106 µm by location (α = 0.05). Similarly, significant differences were detected by location for the soil material < 75 µm (p < 0.001). These results are likely indicative of differences in soil texture between the two locations.

An ANOVA was performed on the particle density data to detect differences in the material species by location. Significant differences were detected in mean particle density of both the soil < 75 µm (p = 0.049) and air wash PM < 100 µm (p = 0.002) by location (α = 0.05). The results also show that there is no significant difference between the mean particle densities of the plant material < 75 µm grown on the Texas High Plains and Mesilla Valley of New Mexico (p = 0.95). Although the ANOVA results indicated a significant difference in the soil material particle densities by location, there is little practical difference between the particle densities from the two locations. Further analysis of the particle density data using Tukey's HSD test (α = 0.05) shows that there are significant differences between the particle densities of the three materials with the soil material and plant material having the highest and lowest mean particle densities, respectively. The results of the particle density analyses are presented in table 5.

Table 5. Particle density results of the soil material < 75 µm, plant material < 75 µm, and air wash PM < 100 µm (means shown with 95% confidence interval).

	Material Particle Density (g/cm^3)		
Sample	**Soil Material < 75 µm**	**Plant Material < 75 µm**	**Air Wash PM < 100 µm**
1	2.61	1.62	2.14
2	2.61	2.06	2.01
3	2.60	1.81	2.07
4	2.62	1.59	2.01
5	2.63	1.83	2.52
6	2.64	1.68	2.51
7	2.64	1.81	2.32
8	2.61	1.73	2.30
Mean	**2.62 ± 0.013[a]**	**1.77 ± 0.125[c]**	**2.24 ± 0.175[b]**

*Means with the same letter are not significantly different at the 0.05 level of significance using Tukey's HSD test.

The PSD analysis results of the soil, plant, and air wash material from samples 2 and 7 are shown in figures 1 and 2, respectively.

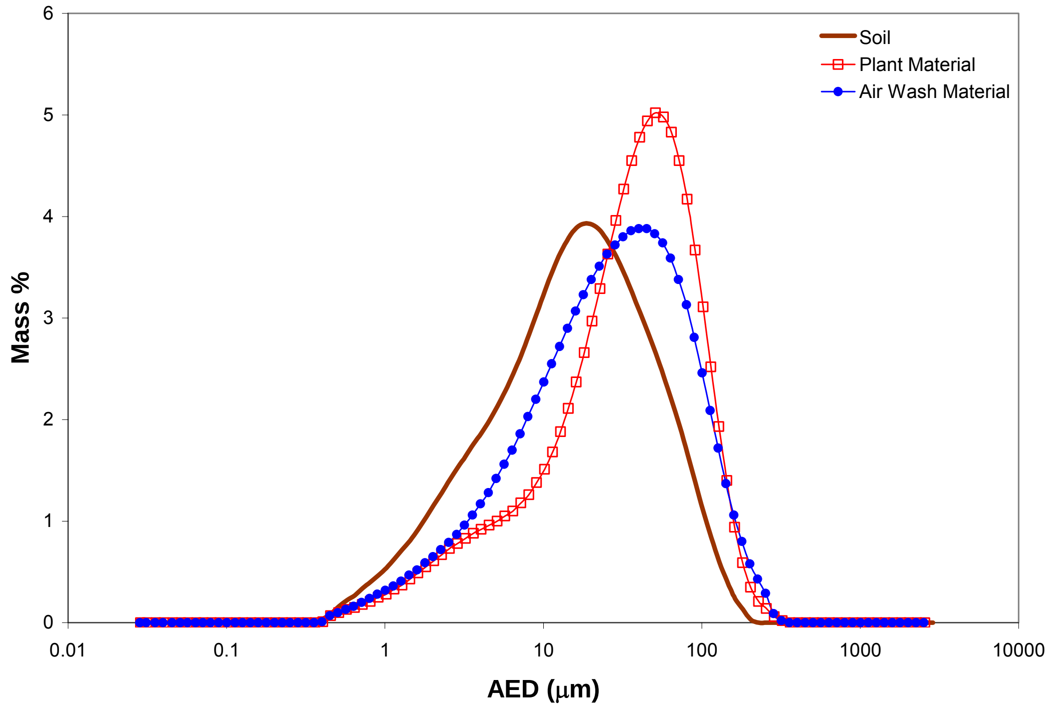

Figure 1. PSD results of the soil, plant, and air wash material collected from picker harvested sample 2.

The results of the PSD analyses on the soil material < 75μm, the plant material PM < 75 μm, and the air wash PM < 100 μm indicate that the PM contained in the harvested seed cotton is influenced by both soil and plant material. This is shown in figure 1 by the shift of the air wash PM PSD to the right of the soil PSD and to the left of the plant material PSD. In figure 2, the lower half of the air wash PM PSD is heavily influenced by the soil material PSD whereas the upper half of the air wash PM PSD is influenced more by the plant material PSD.

Several of the soil material PSDs exhibited the bi-modal characteristic shown in figure 2. This is likely due to differences in soil texture between sampling locations with regard to percentages of silt particles in the size range of 2 – 50μm.

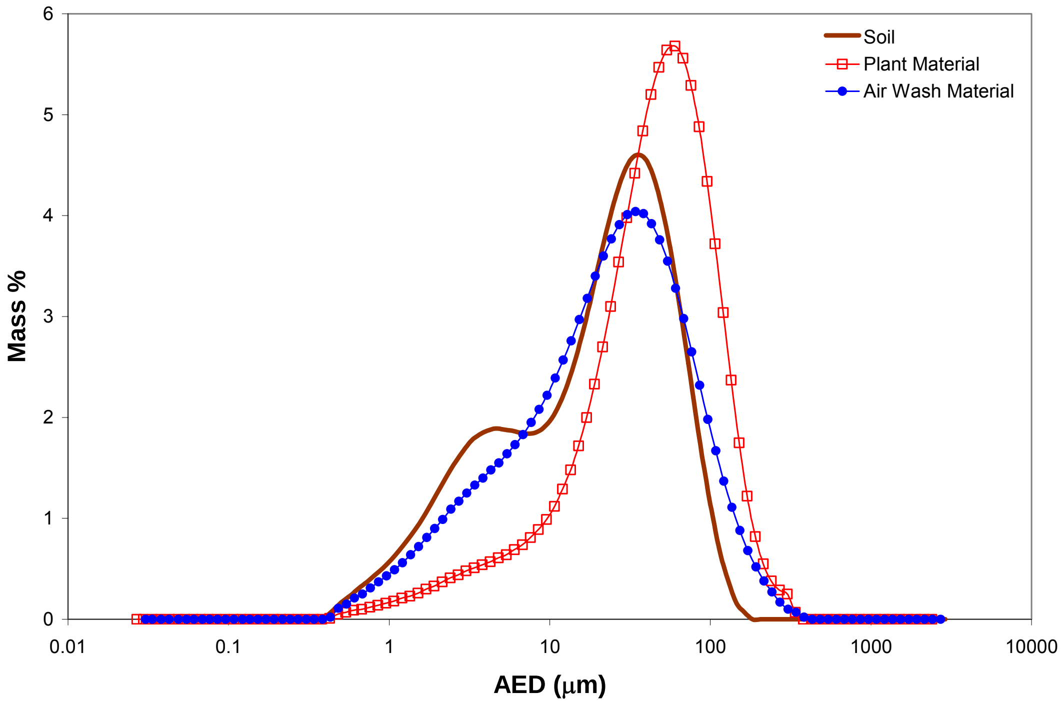

Figure 2. PSD results of the soil, plant, and air wash material collected from stripper harvested sample 7.

The PSDs of the air wash PM samples were used to estimate the mass percentage of PM_{10} and $PM_{2.5}$ contained in the PM emitted by the harvesters. An ANOVA performed on the percent PM_{10} data indicated that there are no significant differences between the samples by harvester type ($p = 0.657$) or by location ($p = 0.118$) using a 0.05 level of significance. Similar results were found using the percent $PM_{2.5}$ data for differences by harvester type ($p = 0.573$) and by location ($p = 0.088$) using the 0.05 level of significance. The percent PM_{10} and $PM_{2.5}$ data is shown in table 6.

A correlation analysis was performed using the percent fine trash, fine dust content, percent PM_{10}, and percent $PM_{2.5}$ data. The results show that the percentages of either regulated size of PM are not significantly correlated with percent fine trash from fractionation ($\alpha = 0.05$). However, the correlation analysis results indicate that fine dust content is significantly correlated with both percent PM_{10} ($R = 0.795$, $p = 0.018$) and percent $PM_{2.5}$ ($R = 0.803$, $p = 0.016$).

Table 6. Mass Percent PM_{10} and $PM_{2.5}$ of the air wash PM samples determined by the PSD analyses (means shown with 95% confidence interval).

Sample	% PM_{10}	% $PM_{2.5}$
1	26.2	7.0
2	22.1	5.2
3	30.0	9.3
4	18.5	4.2
5	36.6	12.4
6	33.4	11.2

7	27.7	8.1
8	25.3	7.4
Mean	**27.5 ± 4.91**	**8.1 ± 2.34**

The results of the ash analysis are shown in table 7. The mean percent ash of the soil material < 75 µm, plant material < 75 µm, and air wash PM < 100 µm samples are 94.3%, 36.9%, and 79.5%, respectively.

Table 7. Ash content data for the soil material < 75 µm, plant material < 75 µm, and air wash PM < 100 µm.

	Percent Ash in Sample		
Sample	**Soil Material < 75 µm**	**Plant Material <75 µm**	**Air Wash PM <100 µm**
1	92.8	24.4	74.7
2	92.8	62.0	65.4
3	91.9	43.0	70.6
4	92.8	17.5	65.5
5	95.9	42.7	94.9
6	96.4	25.9	94.6
7	95.8	44.9	86.3
8	96.2	35.0	83.9
Mean	**94.3**	**36.9**	**79.5**

Using the ash analysis results to determine the percent soil and plant material in the PM air washed from the seed cotton samples indicates that the primary constituent in the air washed PM is soil material. The analysis results of sample 2 are substantially different from the other results and may be considered an outlier. Removing the results of sample 2, an ANOVA using a 0.05 level of significance shows that there is a significant difference in the percent soil (and percent plant material) values by location ($p = 0.019$). However, the same analysis performed by harvester type indicates no significant differences ($p = 0.311$). The mean percent soil and percent plant material in the air washed PM samples are 78.7 ± 14.6% and 21.3 ± 14.6%, respectively (excluding sample #2). The estimated percent soil and percent plant material of each sample is shown in table 8.

Table 8. Estimated percent soil and plant material composition of the air washed PM samples (means shown with 95% confidence interval).

Sample	**% Soil**	**% Plant Material**
1	73.5	26.5
2*	10.9	89.1
3	56.5	43.5
4	63.7	36.3
5	98.2	1.8
6	97.5	2.5
7	81.3	18.7

8	79.9	20.1
Mean**	**78.7 ± 14.6**	**21.3 ± 14.6**

*Outlier data.
**Means do not include data from sample 2.

Further correlation analysis using the percent soil and plant material from the compositional analysis (excluding data from sample 2), percent fine trash, fine dust content, and percent PM_{10} and $PM_{2.5}$ data was conducted. The results, shown in table 9, indicate that the percent soil is significantly correlated with the fine dust content (R = 0.837, p = 0.019, α = 0.05). Percent soil was not significantly correlated with any of the other variables (α = 0.05). The indirect relationship between percent plant material and the other measured variables observed in the correlation coefficients (table 9) is due to the relationship between percent soil and percent plant material (i.e. percent soil = 100 – percent plant material).

Table 9. Correlation analysis results.

	% Fine Trash		**Fine Dust Content**		**%PM_{10}**		**%$PM_{2.5}$**	
	R	**p-value**	**R**	**p-value**	**R**	**p-value**	**R**	**p-value**
% Soil	0.488	0.267	0.837	0.019*	0.671	0.099	0.69	0.086
% Plant Material	-0.488	0.267	-0.837	0.019*	-0.671	0.099	-0.69	0.086

*Indicates significant correlation between variables at the 0.05 level of significance.

Conclusions

The major findings of the work presented here are:

- The mean fine dust content of the picker harvested cotton samples from the Mesilla Valley of New Mexico was 2.7 ± 1.3 g PM less than 100 µm per kg seed cotton. The mean fine dust content of the stripper harvested cotton samples from the Texas High Plains was 10.6 ± 13.6 g PM less than 100 µm per kg seed cotton.
- The particle density of the soil less than 75 µm and air washed PM less than 100 µm was 2.62 ± 0.013 and 2.24 ± 0.175 g/cm^3, respectively. Significant differences in the mean particle densities of the soil less than 75 µm and air washed PM less than 100 µm by location were observed. The particle density of the plant material less than 75 µm was 1.77 ± 0.125 g/cm^3 and no significant differences were observed in the samples by location.
- The PSD results of the PM air washed from the seed cotton samples indicated that the percent mass of PM_{10} and $PM_{2.5}$ emitted by the harvester could be in the range of 27.5 ± 4.91% and 8.1 ± 2.34%, respectively. Further, no differences were detected in the percent mass of PM_{10} and $PM_{2.5}$ by location or harvester type.
- The primary constituent in the PM air washed from the seed cotton samples was soil material. The mean estimates for the mass percent of soil and plant material in the air washed PM (over all samples) was 78.7 ± 14.6% and 21.3 ± 14.6, respectively.

Disclaimer

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