PERGAMON

Atmospheric Environment 37 (2003) 1163–1173

ATMOSPHERIC ENVIRONMENT

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Soil sample collection and analysis for the Fugitive Dust Characterization Study

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Received 20 August 2002; accepted 15 November 2002

Abstract

A unique set of soil samples was collected as part of the Fugitive Dust Characterization Study. The study was carried out to establish whether or not source profiles could be constructed using novel analytical methods that could distinguish soil dust sources from each other. The soil sources sampled included fields planted in cotton, almond, tomato, grape, and safflower, dairy and feedlot facilities, paved and unpaved roads (both urban and rural), an agricultural staging area, disturbed land with salt buildup, and construction areas where the topsoil had been removed. The samples were collected using a systematic procedure designed to reduce sampling bias, and were stored frozen to preserve possible organic signatures. For this paper the samples were characterized by particle size (percent sand, silt, and clay), dry silt content (used in EPA-recommended fugitive dust emission factors), carbon and nitrogen content, and potential to emit both PM_{10} and $PM_{2.5}$. These are not the "novel analytical methods" referred to above; rather, it was the basic characterization of the samples to use in comparing analytical methods by other scientists contracted to the California Air Resources Board. The purpose of this paper is to document the methods used to collect the samples, the collection locations, the analysis of soil type and potential to emit PM_{10}, and the sample variability, both within field and between fields of the same crop type.

Keywords: PM_{10}; $PM_{2.5}$; Source profiles; Soil dust; Dust emission

1. Introduction

Both annual average and 24-h PM_{10} standards are exceeded at most measurement locations in California's San Joaquin Valley, with the highest concentrations measured during fall and winter. Chow et al. (1992b, 1993, 1996) show that suspended fugitive dust is a major PM_{10} and a significant $PM_{2.5}$ component during the summer and fall in the San Joaquin Valley, though dust contributions are much lower during the winter.

Significant contributors to the PM_{10} geological fraction are believed to be: (1) paved and unpaved roads (including unpaved shoulders) and unpaved parking lots and staging areas, (2) agricultural operations such as land preparation, cultivation, and harvesting, (3) wind erosion of fallow land, (4) animal husbandry in feedlots and dairies, and (5) road and building construction (Ahuja et al., 1989; Houck et al., 1989, 1990). Contributions from these fugitive dust sources to PM_{10} and $PM_{2.5}$ measured at receptors need to be estimated to assign priorities to emissions studies and to determine the degree to which dust emissions must be controlled.

Saturation studies near San Joaquin Valley fugitive dust sources (Chow et al., 1997; Blanchard et al, 1999;

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1352-2310/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S1352-2310(02)01022-1

Flocchini et al., 1994; Watson et al., 1997) show that the zone of influence around a specific emitter, such as an unpaved road, is typically <100 m. Beyond this distance, the PM_{10} contribution from the specific dust source blends in with dust contributions from many other sources.

Source profiles with elemental, ion, and carbon abundances are sufficient to distinguish geological PM_{10} contributions from those of non-geological contributors such as motor vehicle exhaust, vegetative burning, coal burning, residual oil combustion, industrial emissions, and even among certain industrial dusts. Chow et al. (1992a, b) identified cement dust as a surrogate for construction owing to its high calcium abundance. Freeman et al. (1990, 1991) separated gold ore dust from overburden dust by the unique metal content in the ore. Much of the geological material in the San Joaquin Valley results from alluvial deposits that originated in the Sierra Nevada and Coast Range and have mixed and deposited over centuries to form a relatively homogeneous mixture of mineral compounds and elements. The currently measured species are insufficient to distinguish contributions of different soil sources across a wide range of contributions. Elemental, ionic, and carbon characterization are necessary, but are insufficient measurements when resolution of fugitive dust contributions is required.

In an exploratory attempt to search for new methods that might be able to distinguish soil sources from each other, the California Air Resources Board carried out the Fugitive Dust Characterization Study beginning in 1997. Forty-eight soil samples were collected in fall 1997 from a variety of sources in the San Joaquin Valley, and sample aliquots were prepared for a wide range of analyses by different scientists. Samples were characterized for soil texture and potential to emit PM_{10} and $PM_{2.5}$. This paper documents the samples that were collected, the methods by which they were prepared, and the analytical methods that were applied to them for soil texture, dry silt content, PM_{10} and $PM_{2.5}$ Index, and nitrogen and carbon content. It also documents the variability of the samples, both within the same sample type and between sample types. It is not an objective of this paper to resolve source types or construct source profiles, but to document the collection methods and locations and the basic soil characteristics of the samples collected.

2. Methods

2.1. Source type selection

The types of soil sources to use in the study were selected during a workshop held in spring 1997. The sources needed to represent a variety of soil types in the San Joaquin Valley that could emit fugitive dust, as described above. Dust sources were assigned priorities based on the amount of land dedicated to the dust-generating activity and the amount of dust expected to be generated by that activity during the fall period when atmospheric dust concentrations are highest. The sources identified included agricultural fields, dairies and feedlots, paved roads, unpaved roads, staging areas, and construction sites. The workshop resulted in a list of 50 soils to be selected for study. Table 1 shows the list of soils selected by the workshop participants.

Several types of agricultural fields were identified as particularly important: cotton, tomatoes, almonds, grapes, and safflower. These fields were thought to be important because of the soil-disturbing operations performed on them and the number of acres in the San Joaquin Valley. Samples were to be collected in the fall after the harvest and after the land was disked in preparation for the next crop, if applicable.

Paved roads are known to be sources of fugitive dust, so both urban and rural roads with high and low traffic density were selected for sampling. It is important to be able to distinguish between dust generated by agricultural activities and traffic on unpaved roads near agricultural fields, so soil samples were collected from unpaved agricultural roads adjacent to fields that were also sampled. Because the dust composition may be different at a staging area than in an adjacent field due to operation and maintenance of heavy vehicles, a staging area was also selected for sampling.

Finally, construction sites may emit fugitive dust with a different composition than other areas since the top layer of soil is often removed prior to construction.

2.2. Specific site selection

Based on the guidance provided in Table 1, specific sites were selected to collect soil samples. The site locations are shown in Fig. 1 and Table 2. The table also shows the soil type. In a few cases, the soil type was not defined; in those cases the soil type is designated by the soil texture as measured for this study. The agricultural fields were selected based on prior experience, and were fields that had been visited previously to perform air sampling. Some of the fields were sampled in triplicate to test the representativeness of the sample collection method. Each of the agricultural unpaved road samples was collected adjacent to fields that were also sampled. Two construction sites were selected in Fresno and Madera counties. Two areas of disturbed land with salt buildup were selected in Kern and Kings counties. Public unpaved roads were sampled in Corcoran, Kettleman City, and Lost Hills.

Samples were collected in triplicate at three cotton fields, one tomato field, and one almond orchard.

Table 1
List of soil types selected for study

Source	Profile ID	Sample ID	Location in San Joaquin Valley	Specific location	Sample rationale
Cotton					
FDCOT	FDCOT1	FDCOT1A	East-central	Field 1	Determine the variability of
	FDCOT1	FDCOT1B	Fresno County		sampling and analysis methods.
	FDCOT1	FDCOT1C			
	FDCOT2	FDCOT2A	East-central	Field 2	Determine whether the within-field
	FDCOT2	FDCOT2B	Fresno County		variability exceeds the between
	FDCOT2	FDCOT2C			field variability.
	FDCOT3	FDCOT3A	South Kern	Field 3	Determine within and between-
	FDCOT3	FDCOT3B	County		field variability in another part of
	FDCOT3	FDCOT3C			the SJV.
	FDCOT4	FDCOT4A	West Kings	Field 4	Determine variability with
	FDCOT5	FDCOT5A	County	Field 5	different soil types.
	FDCOT6	FDCOT6A		Field 6	
Tomatoes					
FDTOM	FDTOM1	FDTOM1A	East-Central	Field 1	Determine the variability of
	FDTOM1	FDTOM1B	Fresno County		sampling and analysis methods.
	FDTOM1	FDTOM1C			
	FDTOM2	FDTOM2A	East-central	Field 2	Determine variability with
	FDTOM3	FDTOM3A	Fresno County	Field 3	different soil types.
Almonds					
FDALM	FDALM1	FDALM1A	South Kern	Field 1	Determine the variability of
	FDALM1	FDALM1B	County		sampling and analysis methods.
	FDALM1	FDALM1C			
	FDALM2	FDALM2	West-central	Field 2	
	FDALM3	FDALM3	Fresno County	Field 3	
	FDALM4	FDALM4	N. Fresno Co.	Field 4	
Grapes					
FDGRA	FDGRA1	FDGRA1	West-central	Field 1	Determine variability for different
	FDGRA2	FDGRA2	Fresno County	Field 2	fields.
	FDGRA3	FDGRA3		Field 3	
Safflower					
FDSAF	FDSAF1	FDSAF1	West-central	Field 1	Determine variability for different
	FDSAF2	FDSAF2	Fresno County	Field 2	fields.
	FDSAF3	FDSAF3		Field 3	
Cattle					
Dairy	FDCTD1	FDCTD1	East Kings	Dairy 1	Determine differences between
	FDCTD2	FDCTD2	County	Dairy 2	different animal operations.
Feedlot	FDCTF1	FDCTF1	South Kern Co.	Feedlot 1	
	FDCTF2	FDCTF2	West Kings Co.	Feedlot 2	
Paved road					
Urban	FDPVR1	FDPVR1	East-central	Road 1	Determine differences between
	FDPVR2	FDPVR2	SJV	Road 2	different roads.

Table 1 (*continued*)

Source	Profile ID	Sample ID	Location in San Joaquin Valley	Specific location	Sample rationale
Rural	FDPVR3	FDPVR3	East-central SJV	Road 3	
	FDPVR4	FDPVR4	West SJV	Road 4	
Unpaved road					
Agricultural	FDUPR1	FDUPR1	East-central	Road 1	Determine differences between different roads. Look for some that have had suppressants applied in the past.
	FDUPR2	FDUPR2	SJV	Road 2	
	FDUPR3	FDUPR3	West SJV	Road 3	
Public/residential	FDUPR4	FDUPR4	East-central SJV	Road 4	
	FDUPR5	FDUPR5	West SJV	Road 5	
	FDUPR6	FDUPR6		Road 6	
Staging area	FDSTA1	FDSTA1	East-central SJV	Stage 1	Determine difference from unpaved road.
Disturbed land					
Salt buildup site	FDDIS1	FDDIS1	East-central SJV	Land 1	Windblown dust.
	FDDIS2	FDDIS2	West SJV	Land 2	
Construction					
Grading/ earthmoving phase	FDCON1	FDCON1	East-central SJV	Lot 1	Determine difference from roads and staging areas.
	FDCON2	FDCON2	West SJV	Lot 2	

All samples are obtained from within the domain surrounding Fresno.
Each sample consists of at least 5 kg obtained from five separate locations at each site.
Paved road samples are of at least 100 g.
Samples from unpaved roads and staging areas are obtained by sweeping loose surface material into a dustpan.
Samples from paved roads are obtained by vacuuming.

These samples were collected to investigate within-field variability using all the analytical methods. Single samples were collected at three additional cotton fields, two additional tomato fields, and three additional almond fields. Three separate safflower fields and vineyards were also sampled. These samples were used to investigate the between-field variability of soils. Finally, two or three samples were collected from disturbed land with salt buildup, rural paved roads, agricultural unpaved roads, and public residential paved roads to investigate the variability of these fugitive dust sources.

2.3. Sample collection

All soil samples were collected using procedures described by US EPA (1995a, b). A total of at least 1–1.5 kg of soil was collected at each site except the paved road sites, where it was impractical to collect such a large sample. Each sample was deposited into a 3.6-l glass jar with a Teflon-sealed lid. Additional samples were placed into plastic bags and sealed. At each site a separate sample was collected and stored in a moisture can for moisture analysis. The condition of the soil surface was noted, along with the type of irrigation system used on the field. A crop history was also obtained for the previous 5 years.

Each of the agricultural field sites was visited after all harvesting and land preparation activities had taken place, but before winter rains began. A center point for each sampling location was identified and recorded relative to an easily identifiable reference corner of the field, and using a handheld GPS unit. To avoid potential sampling bias, the exact spot for collecting the sample was selected by tossing an object over the shoulder, then designating the center point wherever it landed. From the center point, five sub-samples were collected; one at the center point and one each at 100 m north, south, east, and west of the center point. Each sub-sample was collected using a flat-bladed shovel by scraping the top 2–3 cm of soil from the surface of the field. All sub-samples were deposited into a bucket, then combined at the center point and thoroughly mixed prior to storage.

The unpaved road samples were collected using a dustpan and broom. A 1-m area was marked in the road and all loose dust was swept into the dustpan and deposited into a bucket. This procedure was repeated

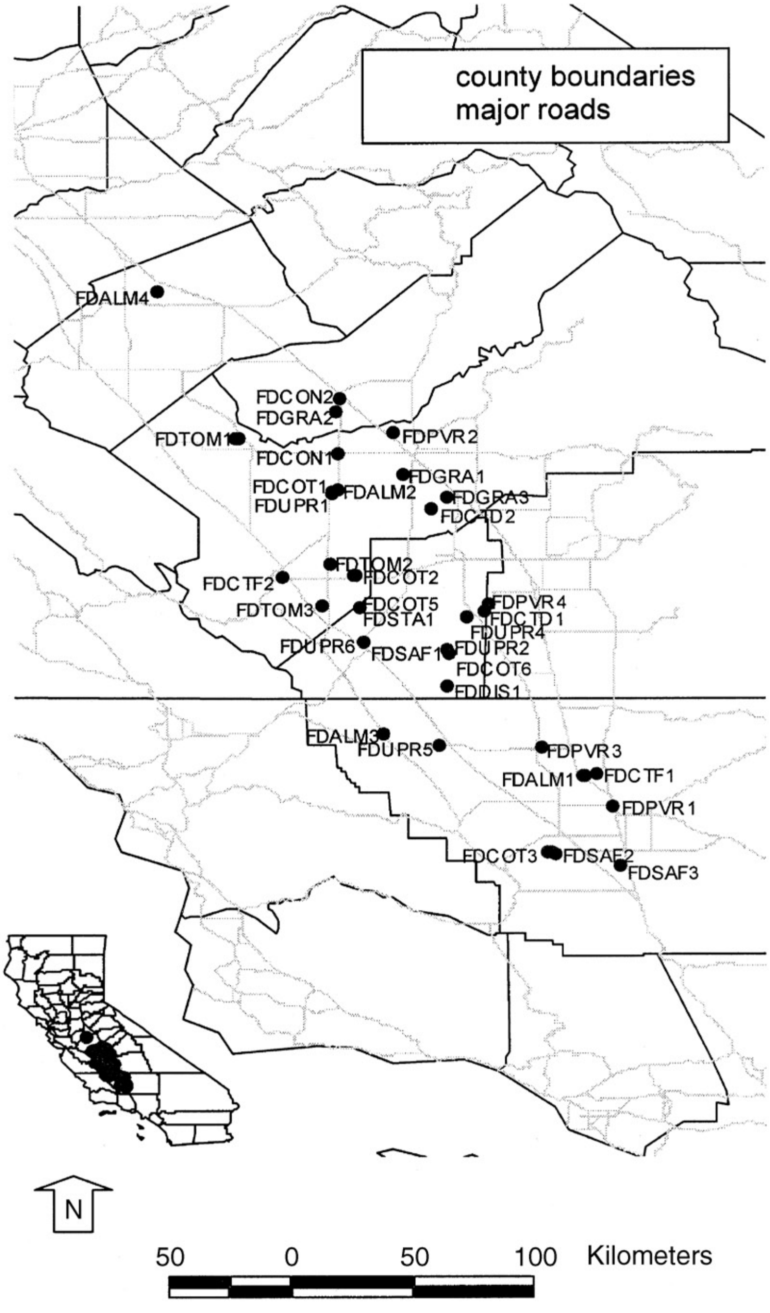

Fig. 1. Locations of sample collection sites.

until sufficient soil was collected, and then all sub-samples were thoroughly mixed and stored as described above. A similar procedure was carried out at the almond orchards. A 1-m area was scribed in the soil and all loose dust was collected from the surface. Five sub-samples were collected as in the agricultural fields.

The paved road samples were collected using a small Hoover™ vacuum cleaner. The sample was collected from the road surface only, not the shoulder. If a

Table 2
Soil sample locations and classifications

Sample ID	Source	County	Latitude	Longitude	Soil classification
FDCOT1A	Cotton	Fresno	36°34′30″	120°05′12″	Chino fine sandy loam
FDCOT1B	Cotton	Fresno	36°34′41″	120°05′13″	Chino fine sandy loam
FDCOT1C	Cotton	Fresno	36°34′43″	120°05′09″	Chino fine sandy loam
FDCOT2A	Cotton	Fresno	36°15′28″	119°59′45”	Cerini clay loam
FDCOT2B	Cotton	Fresno	36°15′44″	119°59′47″	Cerini clay loam
FDCOT2C	Cotton	Fresno	36°15′45″	120°00′14″	Cerini clay loam
FDCOT3A	Cotton	Kern	35°12′27″	119°16′42″	Copus silty clay
FDCOT3B	Cotton	Kern	35°12′05″	119°17′14″	Copus silty clay
FDCOT3C	Cotton	Kern	35°12′08″	119°16′20″	Copus silty clay
FDCOT4A	Cotton	Kern	35°08′59″	119°01′22″	Lokern clay
FDCOT5A	Cotton	Kings	36°08′05″	119°58′56″	Westhaven loam
FDCOT6A	Cotton	Kings	35°57′42″	119°39′08″	Tulare clay
FDTOM1A	Tomato	Fresno	36°47′15″	120°26′18″	Panoche silty clay
FDTOM1B	Tomato	Fresno	36°47′17″	120°26′00″	Panoche silty clay
FDTOM1C	Tomato	Fresno	36°47′11″	120°25′48″	Panoche silty clay
FDTOM2A	Tomato	Fresno	36°18′19″	120°05′24″	CLAY
FDTOM3A	Tomato	Fresno	36°08′33″	120°07′10″	Sandy clay loam (UCD)
FDALM1A	Almonds	Kern	35°29′52″	119°09′31″	Driver coarse sandy loam
FDALM1B	Almonds	Kern	35°29′47″	119°09′31″	Driver coarse sandy loam
FDALM1C	Almonds	Kern	35°29′40″	119°09′12″	Driver coarse sandy loam
FDALM2	Almonds	Fresno	36°35′28″	120°03′50″	Loamy sand (UCD)
FDALM3	Almonds	Kern	35°39′27″	119°53′39″	Kimberlina fine sandy loam
FDALM4	Almonds	Merced	37°20′47″	120°43′25″	Dinuba sandy loam
FDGRA1	Grapes	Fresno	36°38′51″	119°49′05″	Hesperia fine sandy loam
FDGRA2	Grapes	Madera	36°53’03″	120°04′03″	Sandy loam (UCD)
FDGRA3	Grapes	Fresno	36°33′36″	119°39′49″	Hanford fine sandy loam
FDSAF1	Safflower	Kings	35°58′43″	119°39′41″	Tulare clay
FDSAF2	Safflower	Kern	35°11′37″	119°15′39″	Zalvidea sandy clay loam
FDSAF3	Safflower	Kern	35°09′09″	119°01′22″	Oldriver loam
FDCTD1	Dairy	Tulare	36°07′13″	119°31′13″	Organic
FDCTD2	Dairy	Fresno	36°30′54″	119°43′04″	Organic
FDCTF1	Feedlot	Kern	35°30′02″	119°06′30″	Organic
FDCTF2	Feedlot	Fresno	36°15′10″	120°15′53″	Organic
FDPVR1	Urban Paved Road	Kern	35°22′57″	119°02′47″	Paved road
FDPVR2	Urban Paved Road	Fresno	36°48′30″	119°51′38″	Paved road
FDPVR3	Rural Paved Road	Kern	35°36′07″	119°18′41″	Paved road
FDPVR4	Rural Paved Road	Tulare	36°09′00″	119°30′27″	Paved road
FDUPR1	Ag Unpaved Road	Fresno	36°34′45″	120°05′05″	Unpaved road
FDUPR2	Ag Unpaved Road	Kings	35°58′38″	119°39′41″	Unpaved road
FDUPR3	Ag Unpaved Road	Kern	35°12′08″	119°16′22″	Unpaved road
FDUPR4	Pub/Res Unpaved Road	Kings	36°05′51″	119°35′09″	Unpaved road
FDUPR5	Pub/Res Unpaved Road	Kern	35°36′52″	119°41′35″	Unpaved road
FDUPR6	Pub/Res Unpaved Road	Kings	36°00′34″	119°58′03″	Unpaved road
FDSTA1	Staging Area	Kings	36°08′02″	119°58′56″	Unpaved road
FDDIS1	Disturbed Land Salt Buildup	Kings	35°50′20″	119°39′44″	Disturbed land
FDDIS2	Disturbed Land Salt Buildup	Kern	35°09′05″	119°01′19″	Disturbed land
FDCON1	Construction/earthmoving	Fresno	36°43′32″	120°03′32″	Construction
FDCON2	Construction/earthmoving	Madera	36°56′27″	120°03′26″	Construction

shoulder line was marked, the sample was collected from shoulder line to shoulder line. The length of roadway vacuumed depended on the surface loading, and was selected to collect a sample large enough to divide among the analysts.

The disturbed soil sites, i.e. the agricultural staging area, construction areas and areas with salt build-up, were sampled in a manner as similar as possible to the agricultural fields. Because animals were present on the dairies and feedlots, samples from those facilities were obtained by collecting surface material only near the corral fence.

The soil samples placed in glass jars were kept frozen at 20°C until they were prepared for shipment to other scientists for analysis. Immediately after preparation, the samples were returned to cold storage. The samples placed into plastic bags were used to characterize the soils by texture, carbon and nitrogen content, and dust potential emission index.

3. Analysis

All soil samples were characterized by analyzing for moisture content, particle size distribution, dry silt content, nitrogen and carbon content, PM_{10} index, and $PM_{2.5}$ index. Moisture content was calculated by weighing the sample before and after drying at 110°C for 24 h. The soil particle size distribution was obtained by a combination of wet sieving and pipetting, as recommended by the American Society for Testing and Materials (ASTM, 1984). The results of this analysis provided the percent sand (particles 50–2000 μm in size), silt (2–50 μm), and clay (<2 μm) in the soil for completely disaggregated particles. The carbon and nitrogen content were measured using a combustion method at the Division of Agriculture and Natural Resources (DANR) Analytical Laboratory at UC Davis. The PM_{10} index and $PM_{2.5}$ index were measured using procedures described by Carvacho et al. (2001).

Table 3 shows the soil characteristics for soil texture, particle size distribution, dry silt content, PM_{10} index and $PM_{2.5}$ index and carbon and nitrogen content. The soil textures, based on their placement on the soil triangle, are also shown in Fig. 2. The symbol on Fig. 2 depicts the type of soil sampled. The PM_{10} index and $PM_{2.5}$ index are a measure of the soil's potential to emit PM_{10} or $PM_{2.5}$, respectively. They are strongly related to the soil's sand or clay content, as described in Carvacho et al. (2001).

The cotton soils spanned the full range of soil textures as shown in Fig. 1. They also showed a wide range of carbon and nitrogen content, as shown in Fig. 3. The tomato fields sampled had relatively high clay content, and were in the low to middle range of C and N content. The almond fields had low clay and high sand content, but had some of the highest C and N content of all the soils sampled, possibly due to leaf litter buildup. The almond soils from Merced and Fresno Counties had lower C and N than the samples from Kern County. The grape soil samples had low C and N, and were low in clay content. Safflower fields, like cotton, spanned a wide range of clay content, and also had high variability on the soil texture triangle. There was insufficient material to analyze the paved road samples for soil texture. The agricultural unpaved roads had predominantly the same texture as the fields next to them, although FDUPR3 had considerably higher sand content than the adjacent cotton field. It also had much lower carbon and nitrogen content than the field next to it. FDUPR1 had a texture similar to its adjacent cotton field, but higher nitrogen and similar carbon content. FDUPR2 also had a texture similar to its adjacent safflower field, but higher nitrogen and carbon content. The construction area and public/residential unpaved roads had low carbon and nitrogen contents compared to the other soils. The paved roads, both rural and urban, were on the high range of both nitrogen and carbon content. The disturbed land with salt buildup and the staging area were mixed, but had generally middle to low nitrogen and carbon content.

The PM_{10} and $PM_{2.5}$ indexes are strongly related to the sand or clay content of the soil, as shown by Carvacho et al. (2001). The PM_{10} ($PM_{2.5}$) index is intended to indicate the maximum amount of PM_{10} ($PM_{2.5}$) dust that could be created by disturbance of the soil without disaggregating soil particles. Thus, a high index indicates a soil that may be a high emitter of airborne dust if the soil is disturbed.

Other analyses applied to these soils at other facilities included scanning electron microscopy, microbiological assessment, elemental composition, and organic composition (by a variety of analyses). The results of these other analyses are described elsewhere.

4. Discussion

Some groupings can be made in these soil samples based on crop type, possibly because of better growing conditions for certain crops on certain soils. Soils cropped to cotton tend to span a wide range of soil textures, and soils cropped to safflower span a slightly less wide range. Tomatoes are grown primarily in high clay soils, while grapes and almonds are found in sandy soils. Road dust tends to be sandier than the agricultural soils, even for agricultural roads adjacent to fields. This may be due to removal of fines by traffic, leaving the unpaved road enriched in sandier material, or it may be due to addition of sand to improve traction.

The variability of the soils within fields and between fields was evaluated by calculating the relative average deviation from the mean, defined as the average deviation of the measurements divided by the mean expressed as a percentage. Table 4 shows the results of this calculation for the five fields sampled in triplicate, the four types of field crops sampled in at least three separate fields, and the five soil types sampled at only two locations (or where there was sufficient sample for analysis from only two locations). In general, the within-field variation was higher than expected even for the soil texture measurement. This probably reflects real soil

Table 3
Results of soil analysis

Sample ID	Site	soil texture	% Sand	% Silt	% Clay	Dry silt content	PM_{10} index (mg//g)	$PM_{2.5}$ index (mg/g)	% Nitrogen	% Carbon
FDCOT1A	Cotton	Loamy sand	81.12	12.11	6.77	18.88	8.110±0.204	0.875±0.036	0.0454±0.0004	0.3804±0.0106
FDCOT1B	Cotton	Sandy loam	71.35	17.30	11.35	28.65	8.462±0.145	0.848±0.003	0.0619±0.0017	0.5685±0.0103
FDCOT1C	Cotton	Sandy loam	64.17	22.53	13.30	35.83	9.396±0.248	1.013±0.011	0.0654±0.0029	0.6719±0.0240
FDCOT2A	Cotton	Clay	27.92	30.63	41.45	72.08	18.087±0.265	1.820±0.028	0.0734±0.0004	0.7407±0.0076
FDCOT2B	Cotton	Clay loam	40.96	24.16	34.87	59.04	13.774±0.229	1.335±0.013	0.0634±0.0008	0.5772±0.0131
FDCOT2C	Cotton	Clay loam	27.83	32.82	39.35	72.17	14.577±0.027	1.378±0.005	0.0950±0.0042	0.7655±0.0020
FDCOT3A	Cotton	Sandy clay loam	57.31	19.10	23.59	42.69	11.610±0.416	1.150±0.041	0.1153±0.0038	1.1483±0.0666
FDCOT3B	Cotton	Clay	9.54	38.46	52.00	90.46	18.935±0.318	1.796±0.066	0.2715±0.0005	2.8653±0.0037
FDCOT3C	Cotton	Clay	19.00	31.10	49.90	81.00	17.949±0.359	1.749±0.013	0.2206±0.0032	2.3207±0.0011
FDCOT4A	Cotton	Clay	11.69	37.29	51.02	88.31	18.577±0.271	1.792±0.010	0.1897±0.0003	2.0185±0.0360
FDCOT5A	Cotton	Clay loam	41.70	25.72	32.57	58.30	13.101±0.354	1.343±0.021	0.1069±0.0013	0.8798±0.0116
FDCOT6A	Cotton	Clay	6.40	38.42	55.18	93.60	18.514±0.713	1.833±0.015	0.1701±0.0043	4.6132±0.0182
FDTOM1A	Tomatoes	Clay	21.74	31.01	47.25	78.26	17.957±0.043	1.712±0.106	0.1326±0.0024	1.3228±0.0292
FDTOM1B	Tomatoes	Clay	24.09	31.56	44.35	75.91	17.692±0.068	1.739±0.002	0.1325±0.0041	1.2507±0.0178
FDTOM1C	Tomatoes	Clay	13.05	32.29	54.66	86.95	18.221±0.087	1.881±0.010	0.1374±0.0042	1.3294±0.0279
FDTOM2	Tomatoes	Clay	28.72	28.60	42.68	N/A	16.325±0.046	1.644±0.002	0.0923±0.0064	0.5285±0.0123
FDTOM3	Tomatoes	Sandy clay loam	49.49	26.37	24.14	N/A	11.838±0.288	0.982±0.010	0.0747±0.0016	0.4791±0.0040
FDALM1A	Almonds	Sandy loam	80.31	7.13	12.56	19.69	9.293±0.093	0.958±0.006	0.5972±0.0039	8.8411±0.0854
FDALM1B	Almonds	Sandy loam	77.99	9.61	12.40	22.01	8.830±0.005	0.857±0.026	0.8522±0.0599	12.6011±1.4499
FDALM1C	Almonds	Loamy sand	83.32	6.37	10.32	16.68	7.797±0.036	0.767±0.042	0.6123±0.0265	8.5829±0.3533
FDALM2	Almonds	Loamy sand	81.78	11.42	6.81	18.22	7.472±0.038	0.912±0.134	0.2536±0.0141	2.2081±0.2214
FDALM3	Almonds	Sandy loam	69.48	11.62	18.90	30.52	10.120±0.131	0.966±0.023	0.7405±0.0413	9.3289±0.6720
FDALM4	Almonds	Sand	89.26	6.27	4.47	10.74	7.081±0.038	0.814±0.023	0.2008±0.0068	2.3060±0.1070
FDGRA1	Grapes	Sandy loam	72.49	21.38	6.12	27.51	8.563±0.129	0.949±0.008	0.0599±0.0022	0.6178±0.0141
FDGRA2	Grapes	Sandy loam	65.63	19.08	15.28	34.37	9.969±0.021	1.109±0.041	0.0741±0.0054	0.8894±0.0180
FDGRA3	Grapes	Loamy sand	83.82	12.37	3.81	16.18	7.565±0.046	0.846±0.034	0.0431±0.0035	0.4601±0.0010
FDSAF1	Safflower	Silty clay	7.19	42.14	50.67	92.81	18.990±0.533	2.091±0.021	0.1260±0.0018	3.4291±0.0045
FDSAF2	Safflower	Sandy clay loam	46.51	24.34	28.67	52.66	12.554±0.352	1.377±0.016	0.1160±0.0029	1.1896±0.0511
FDSAF3	Safflower	Clay loam	39.30	25.24	35.46	60.70	13.641±0.189	1.491±0.044	0.1864±0.0037	1.9327±0.0439
FDPVR1	Urban Paved Road	Sand	88.26	6.82	4.92	N/A	7.578±0.099	0.771±0.044	0.1609±0.0048	3.8390±0.0219
FDPVR3	Rural Paved Road	Sandy loam	56.79	29.41	13.80	N/A	9.875±0.031	1.100±0.017	0.2578±0.0031	4.3340±0.0099
FDPVR4	Rural Paved Road	Sandy clay loam	56.29	22.03	21.68	N/A	12.612±0.811	1.513±0.032	0.3035±0.0513	3.5532±0.6404
FDUPR1	Ag Unpaved Road	Sandy loam	75.09	14.93	9.98	N/A	9.290±0.131	1.129±0.064	0.1071±0.0086	0.4387±0.0583
FDUPR2	Ag Unpaved Road	Silty clay	8.78	42.39	48.83	N/A	17.940±0.336	1.956±0.059	0.1795±0.0124	3.7144±0.0325
FDUPR3	Ag Unpaved Road	Loamy sand	81.99	7.26	10.75	N/A	7.768±0.122	1.062±0.093	0.0428±0.0003	0.3349±0.0082
FDUPR4	Pub/Res Unpaved Road	Sand	92.43	3.83	3.74	N/A	6.820±0.093	0.746±0.021	0.0432±0.0024	0.4111±0.0350
FDUPR5	Pub/Res Unpaved Road	Sand	88.79	5.94	5.27	N/A	6.795±0.178	0.741±0.095	0.0244±0.0052	0.6866±0.0011
FDUPR6	Pub/Res Unpaved Road	Loamy sand	86.37	7.22	6.42	N/A	7.812±0.005	0.877±0.043	0.0368±0.0020	0.4415±0.0602
FDSTA1	Staging Area	Sandy clay loam	50.96	22.00	27.04	N/A	12.263±0.687	1.435±0.009	0.0941±0.0002	1.4153±0.0346
FDDIS1	Disturbed Land Salt Buildup	Clay loam	30.82	32.69	36.49	69.18	13.857±0.461	1.543±0.012	0.0388±0.0006	0.8796±0.0294
FDDIS2	Disturbed Land Salt Buildup	Sandy loam	52.55	27.62	19.83	N/A	10.149±0.392	1.122±0.010	0.1121±0.0068	1.0199±0.0173
FDCON1	Construction/Earthmoving	Loamy sand	77.75	18.66	3.59	22.25	7.766±0.149	0.790±0.113	0.0184±0.0003	0.3563±0.0260
FDCON2	Construction/Earthmoving	Sandy loam	72.83	17.88	9.28	27.17	8.733±0.355	0.952±0.080	0.0257±0.0008	0.2979±0.0157

differences from one part of a field to another. The most consistent measure of soil characteristics seems to be the PM_{10} and $PM_{2.5}$ indexes. For three of the five fields, the clay content was quite consistent, showing a relative average deviation of $<10\%$, but the other two were over 20%. The dry silt content was next in consistency, while percentage of silt, percentage of sand, and nitrogen and carbon content were less consistent within fields.

The between-field variability was higher than the within-field variability, as might be expected. Here it can be seen that the cotton fields spanned a wide range of soil types, with a high variability in all three soil texture parameters. Tomatoes seem to be grown in a consistent range of silt content, while almonds and grapes are grown in a consistent range of sandy soils. Nitrogen and carbon content of cotton and almond soils show a wide variation, with a slightly narrower, though still wide, range for tomatoes and grapes. Only the PM_{10} index measurement was relatively consistent for each of the field types (except cotton, which had the widest range of soil textures).

For the sites with only two samples, the variability was generally quite large. Disturbed land with salt buildup and public/residential unpaved roads showed very consistent sand content, but most other measures were highly variable. This may reflect different locations in the San Joaquin Valley, or it may be due to very a limited number of samples. There was insufficient sample to test the variability of dry silt content for four of these soils.

The overall variability of all samples ranged from 28–30% for the PM_{10} and $PM_{2.5}$ indexes to 70–85% for carbon and nitrogen content. The soil texture measures varied 40–65% among all soils sampled.

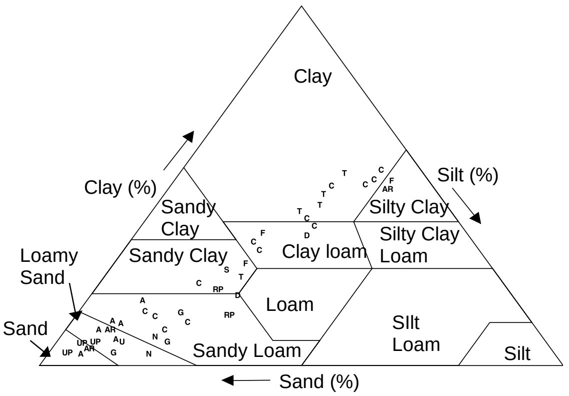

Fig. 2. Distribution of soil textures collected for the Fugitive Dust Characterization Study. C = cotton, F = safflower, T = tomato, A = almond, G = grape, N = Construction/earthmoving, D = disturbed land/salt buildup, S = staging area, U = Urban paved road, RP = Rural paved road, AR = agricultural unpaved road, UP = public unpaved road.

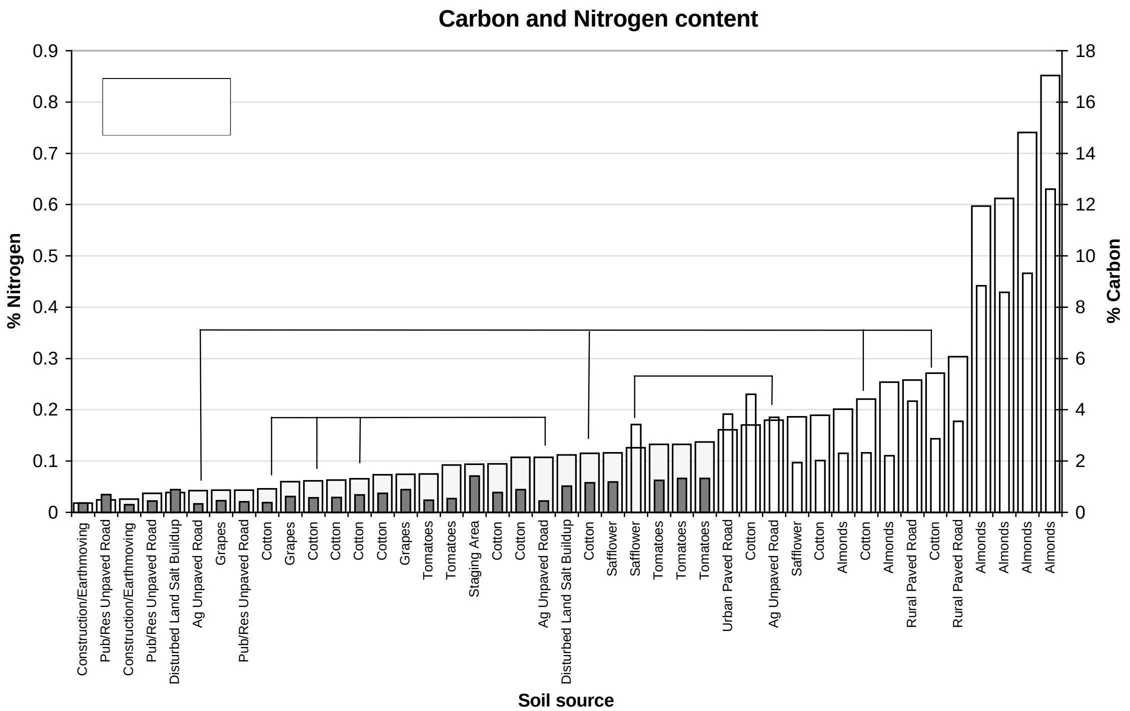

Fig. 3. Carbon and Nitrogen content of sampled soils. The unpaved agricultural roads are linked to their adjacent field sample measurements by the lines shown.

Table 4
Variability of soil measurements within fields and between fields

Site	% Sand	% Silt	% Clay	Dry silt content (%)	PM_{10} index (mg/g) (%)	$PM_{2.5}$ index (mg/g) (%)	% nitrogen	% carbon
Within-field variability								
Cotton 1	8.2	20.1	23.6	21.4	5.7	7.4	14.1	19.7
Cotton 2	18.0	11.5	6.4	8.6	11.2	13.6	15.3	11.3
Cotton 3	66.8	23.6	29.1	26.8	18.8	17.7	28.7	30.4
Tomatoes	22.3	1.4	8.1	5.5	1.0	3.9	1.6	2.6
Almonds	2.3	16.5	8.2	9.5	6.5	7.5	16.0	17.3
Between-field variability (three or more fields)								
Cotton	55.4	26.6	40.8	34.3	24.7	22.9	48.6	68.0
Tomatoes	34.1	6.6	17.3	5.5	11.3	15.3	21.4	39.0
Almonds	5.5	24.6	34.0	22.6	11.6	7.5	38.8	46.1
Grapes	8.9	19.8	54.6	25.2	9.7	9.7	18.0	23.8
Between-field variability (two samples only)								
Construction/ earthmoving	57.3	41.4	84.1	61.7	32.1	33.5	28.7	69.9
Disturbed land salt buildup	2.2	16.0	21.8	—	13.3	17.3	12.3	23.0
Rural paved road	20.2	27.2	52.3	—	21.5	20.6	67.6	110.3
Ag unpaved road	56.1	64.6	73.7	—	35.9	27.7	42.3	98.9
Pub./res. unpaved road	2.4	21.6%	18.2	—	6.3	7.5	19.9	22.5
Overall variability (all samples)								
All samples	44.8	42.5	63.2	50.6	30.5	28.5	71.8	85.2

The analyses conducted here were not intended to separate soil sources from one another, but were intended to document the basic soil characteristics to aid in later analyses. The soil samples collected spanned a wide range of soil types that was consistent with other samples collected in the San Joaquin Valley as part of an ongoing study for the USDA. Although some groupings of soil type by crop type was observed, it is not possible to distinguish fugitive dust from these sources on that basis. More important is the documentation of these characteristics for further analysis using other techniques.

5. Summary

The Fugitive Dust Characterization Study was carried out in 1997 to collect and analyze a wide range of soils in an attempt to construct source profiles that could be used to distinguish one soil type from another. The objectives of the sample collection were met by collecting 48 soil samples from a wide range of sources. Five sets of triplicate samples were collected to test the variability of samples collected in close physical proximity. Samples were collected from six different cotton fields, three different tomato fields, four different almond orchards, three different vineyards, and three different safflower fields to test the variation within and between crop types. Additional samples were collected from paved and unpaved roads, both rural and urban, from an agricultural staging area, from two different dairies and feedlots, from disturbed land with salt buildup, and from construction sites. The samples represent a wide range of sources in the San Joaquin Valley.

In general, the variability of samples was higher as more different soil types were included in the analysis. That is, the variability of fundamental soil characteristics, including soil texture and carbon and nitrogen content, was lower for samples collected within the same field than for samples collected in different fields of the same type, and both of these were generally lower than for all samples combined.

Acknowledgements

This work was carried out under grant 98-868825-6063 from the United States Department of Agriculture, Cooperative State Research, Education, and Extension Service (CSREES). The California Air Resources Board provided additional funding to other analysts for analysis of samples as part of the California Regional Particulate Matter Air Quality Study (CRPAQS).

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