Measurement of Harvest Dust Generation Using Opacity and Gravimetric Sampling

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Interpretive Summary:

Previously funded research work developed an opacity monitoring system that was used to qualitatively measure relative dust intensity, or visible dust, during nut pick-up operations. Results from that work indicated that measured dust intensity during pick-up operations was related to sweeper settings during windrow preparation. Additionally, results found that relative dust intensity generated during harvester operating conditions was related to ground speed, dirt/nut separation fan speed and cleaning chain speed.

The opacity measurement system is an efficient tool that can be used to assess operating conditions of agricultural equipment and changes in management and cultural practices that minimizes relative dust intensity. This measurement tool provides growers and operators a reasonably fast test system that can provide feedback within minutes of an actual sweeping or harvesting operation.

Measurements of dust inherent in the operations of agricultural equipment are generally based on gravimetric filter measurements of airborne particulate matter. While there continues to be concern over the absolute accuracy of gravimetric sampling devices in agricultural and rural environments, gravimetric samplers are the most common method for airborne particulate measurements.

The primary goal of this, and past, work has been to work with growers and equipment manufacturers on establishing the relationship between different agricultural equipment operating conditions and visible particulate matter. The focus has been to provide information on operating conditions that will lead to methods that reduce visible dust intensity and are easily adopted by growers within a relatively short term frame (1 – 3

years). For the recent 2006 harvest season, this project evaluated sweeper operating conditions in order to provide feedback to growers on methods (number and speed of passes, depth of sweeper head and tine material) that minimize relative dust intensity during this portion of the harvest operation. Additionally, the opacity measurement system was used to quantify the effects of orchard trees in reducing visible dust during the pick-up operation. This has implications for development of good neighbor harvest practices where edge rows may be treated differently than interior rows.

Objectives:

The objectives for the 2006 harvest season were:

1. Using gravimetric samplers, measure PM10 and PM2.5 dust levels within orchards specifically focusing on discharge air from harvesters and sweepers and within ambient air in the orchards.

2. Investigate dust generation and nut recovery from conventional-pass versus reduced-pass and modified sweeping operations.

3. Provide the opacity measurement system and subsequent analyses to manufacturers for assessing individual machines or machine design modifications.

Materials and Methods:

During the 2006 harvest season, this study used gravimetric samplers (MiniVol™ Portable Air Sampler, Airmetrics, Eugene, OR) for measuring different harvesting practices during all field test runs. The device is recognized and used by researchers, including the California Air Resources Board, for PM10 and PM2.5 measurements at high particulate concentrations even though it is not a Federal Reference Method (FRM) sampler. The portable, battery powered, samplers were operated at an airflow rate of 5 liters/minute and were fitted with the recommended manufacturer sampling heads to selectively sample TSP, PM10 and PM2.5 fractions of airborne particulate matter. Preparation, preweighing and postweighing of sample filters were done by Airmetrics, Inc. using calibrated, traceable methods. The samplers were calibrated prior to the 2006 harvest testing season by the manufacturer.

A recent study of these samplers by Baldauf et al. (2001) reported on the reliability and precision of these devices in ambient environments. The devices were operated in a similar manner as our study. Concentration results from collocated MiniVols were comparable and the MiniVols produced similar results as a dichotomous sampler (PM10/PM2.5 dichotomous Versatile Air Pollution Sampler) and a continuous mass sampling system (TEOM PM10 sampler). One concern was that there may be passive particulate matter collection, especially with PM10 inlets. Additionally, the inlet is not isokinetically designed and airflow into the sampler requires two 90 degree turns.

There continues to be concern over the validity of gravimetric samplers used within agricultural and rural settings. In a recent study by Faulkner et al. (2007) this problem is discussed in detail, indicating that some samplers exposed to particulate matter often found in rural and agricultural environments typically overestimate the concentrations of PM10 and PM2.5. Additionally, there can be confounding effects from particle charge and relative humidity. Baron (2003) indicates that if the sampler and freshly generated aerosols have electrical charges, particle acceleration can be greater than that caused by gravity, inertia and other mechanisms. Samplers can have high charge levels if they are electrically insulated from the ground and are "tribo-electrically" charged (due to contact or friction from other surface contact). Sampler charging as well as particle charging can occur more frequently at low relative humidities (generally less than 20%). In light of these concerns, field sampling of particulate matter during the 2006 season used MiniVol samplers to measure the mass of particulate matter rather than concentration. The particulate matter collected was a direct result of the respective agricultural machine during specific operating conditions and does not represent PM10 or PM2.5 concentration measurements. The measurements reported represent the mass of material that was collected by the MiniVol over brief time periods during machine operating conditions prior to the scrubbing effect of the trees.

The MiniVol samplers were positioned in the orchard approximately 3 feet above ground level. This height corresponded to the lower edge of tree canopy (Figure 1). Multiple samplers were positioned along the mid-point of the tree line and test block for each test run. Each treatment consisted of at least three replications; data presented are averages of replicates for the respective treatment.

Figure 1. Portable air samplers positioned within the orchard during sweeping and harvester test runs.

Windrow sweeping experiments were conducted in adjacent orchards, both in Colusa County, CA. In the first orchard, sampling was conducted concurrently with emission factor monitoring by the Texas A&M Air Quality Group and nut recovery measurements taken by Fresno State University. Plot size for each replicate field test was ten tree rows with alternate rows being harvested; rows were approximately ¼ mile long.

Two treatments were compared during the emission factor test runs. The first, Treatment A, was an intensive sweeping operation, consisting of three passes with sweeper and blower active (@ 3 mph) and three passes with only the sweeper active (@ 4 mph). The second treatment, Treatment B, was a minimal sweeping operation, consisting of one pass with the sweeper and blower active (@ 3 mph) and three passes with only the sweeper active (@ 4 mph).

Three additional sweeping treatments were measured in an adjacent orchard, independent of measurements by the Texas A&M Air Quality Group, however, nut recovery measurements were made by Fresno State University. Treatment C, a more typical grower sweeping operation, consisted of two passes with sweeper and blower active (@ 5.5 mph) and three passes with only the sweeper active (@4 mph). Treatment D and E, were the same as Treatment C except for the following changes: Treatment D re-set the sweeper head height ½ inch below equipment manufacturer recommendations and Treatment E used wire tines on the sweeper head rather than rubber tines. Additionally, Treatments C, D an E were conducted on smaller plots, with the test width of six tree rows in width (alternate rows being harvested) and approximately ¼ mile long.

Opacity during harvester runs was measured using a model FW300 dust monitor (Sick Maihak GmbH, Germany). The device is has been described in detail in previous reports. Field measurements of relative dust intensity during machine operations are given as percent opacity, where 0 % opacity (or 100% transmission) relates to clean air. This season, the opacity measurement system was mounted on a small portable trailer for ease of positioning within the orchard (Figure 2). This enabled measurements of relative, visible, dust intensity as a function of distance away from the harvester and the scrubbing effects of trees and foliage. The new portability allowed the opacity device and the gravimetric samplers to be used concurrently so that relationships between the two measurement methods could begin to be investigated.

Figure 2. Stationary opacity measurements and portable air samplers positioned within the orchard during harvester test runs.

Harvester pick-up operations were measured in an orchard near Salida, CA. Four tree rows were harvested while measurements were made with the opacity device and gravimetric samplers. Figure 3 shows the field set-up for the tests. The first harvest pass (row 1 in Figure 3) was done in the row next to the opacity device and subsequent passes were in rows progressively moving away from the opacity device. Gravimetric samplers were located near the opacity device and in the subsequent harvested rows. As with the sweeping measurements using the MiniVol sampler, mass measurements (TSP and PM10) are reported rather than concentrations.

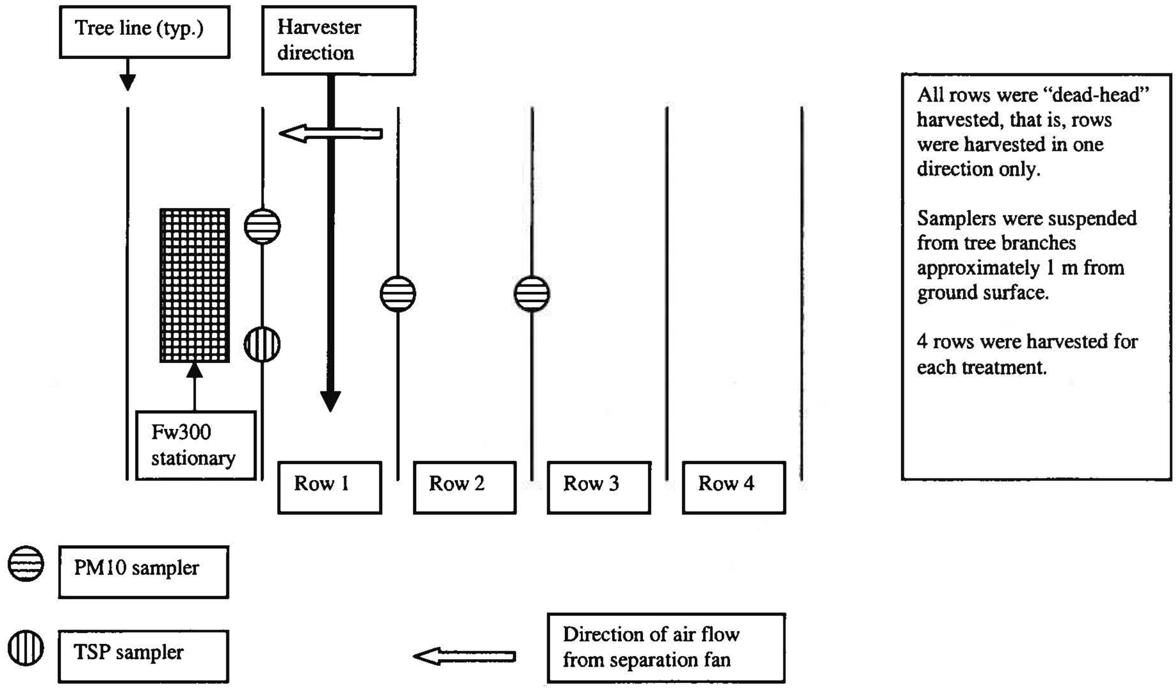

Figure 3. Equipment locations for dust intensity and gravimetric measurements during harvester testing.

Results and Discussion:

Sweeping

Sweeping data are reported as particulate mass collected (TSP and PM10) during the different test runs. The time period of interaction between equipment generated particulate matter and gravimetric sampling was observed to be brief in relation to total test run time. Data results are presented based on mass recovered, not concentration, and this allowed direct, relative comparisons to be drawn independently of the sampling time; all significant differences are at $\alpha < 0.05$.

Pooling of data from both orchards revealed that for total suspended particulates, the only treatment difference was observed for the "deep" sweeping operation, Treatment D (656 µg); all other treatments produced mass levels that were not significantly different from each other. While not statistically different, the "intensive" sweeping operation, Treatment A (246 µg) produced more particulates than the "minimal" sweeping operation, Treatment B (119 µg). While not statistically different, the wire tined sweeping operation, Treatment E (202 µg) produced fewer particulates than the rubber tined sweeping operation, Treatment C (322 µg). These data are shown in Table 1.

Pooling of data from both orchards revealed that for PM10 suspended particulates for the "deep" sweeping operation, Treatment D (195 µg), was significantly greater than all other treatments. The "intensive" sweeping operation, Treatment A (138 µg) produced significantly more particulates than the "minimal" sweeping operation, Treatment B (63 µg). The wire tined sweeping operation, Treatment E (90 µg) produced significantly fewer particulates than the rubber tined sweeping operation, Treatment C (143 µg). These data are shown in Table 2.

Pooling of data from both orchards revealed that for PM2.5 suspended particulates, there were no statistically significant differences in treatments and there were no consistent numerical trends. All observed mass data were in the 30 – 50 µg range.

Direct comparisons of the different treatments were based on pooling the respective mass measurements (TSP and PM10) from the different testing conditions. It should be noted that Treatments A and B were conducted in a different orchard than Treatments C, D and E. Although the orchards were within one mile of each other, the variability of adjacent orchards is evident as seen with the intensive sweeping operation showing a smaller mass measured versus the typical sweeping operation where there was one less blowing and sweeping pass.

The data show that lowering the head height results in the highest level of dust collected. Additionally, the wire tines resulted in less dust collected for that specific orchard tested. Additional conclusions may be possible when nut counts are compared with the measured mass based on the different sweeping operations.

Table 1. Mass measurements of total suspended particulates (TSP) during different sweeping operations.

Treatment Number	Test Type	Number and Pass type	Mass collected µg	Nut recovery
A	Intensive	3 Bl+Sw, 3 Sw	246	
B	Minimal	1 Bl+Sw, 3 Sw	119	
C*	Typical	2 Bl+Sw, 3 Sw	322	
D*	Head low ½"	2 Bl+Sw, 3 Sw	656	
E*	Wire tines	2 Bl+Sw, 3 Sw	202	

Bl+Sw indicate blower and sweeper simultaneously active.
Sw indicates sweeper active only.
* Tests conducted in an adjacent orchard to that of Treatments A and B.

Table 2. Mass measurements of PM10 particulate matter during different sweeping operations.

Treatment Number	Test Type	Number and Pass type	Mass collected µg	Nut recovery
A	Intensive	3 Bl+Sw, 3 Sw	138	
B	Minimal	1 Bl+Sw, 3 Sw	63	
C*	Typical	2 Bl+Sw, 3 Sw	143	
D*	Head low ½”	2 Bl+Sw, 3 Sw	195	
E*	Wire tines	2 Bl+Sw, 3 Sw	90	

Bl+Sw indicate blower and sweeper simultaneously active.
Sw indicates sweeper active only.
* Tests conducted in an adjacent orchard to that of Treatments A and B.

Harvesting

Concurrent opacity and mass measurements were made during two separate harvester pick-up operations at ground speeds of 2 and 4 mph. These tests show the scrubbing effect of trees on the appearance of dusty air, and in particular, the effect of reducing visible dust intensity as distance away from the harvester increases. Recalling Figure 3, all measurement devices were stationary for each test; the opacity system and samplers measured in-orchard, machine generated visible particulate matter as the harvester passed the tree gap for four successive rows. The 2 mph testing condition was replicated three times; the 4 mph condition was replicated twice. Table 3 shows the mass measured for successive harvester row passes and Figure 4 shows the time periods over which the opacity signature from in-orchard visible particulate matter was measured for the respective testing conditions.

Table 3 shows cumulative effects, that is, row 1 is the cumulative effect of four row passes, however, harvester distance from row 1 samplers increased for each successive pass. The temptation to average this result by four is incorrect since time periods change over when the different mass measurements occur, as shown in Figure 4. The results from Table 3 show two main effects: one is that a similar amount of visible dust intensity is created within two successive passes along the first two adjacent rows; the second is that a slower ground speed tends to produce less particulate mass during the harvest of the 3rd and 4th rows (cumulative effects). The response from opacity measurements show an increase in opacity for the slower ground speed, however, these are averaged results and there were only two replicates at the 4 mph ground speed. The results also show the effects of the inherent variability of windrow material within orchards. Additionally, Figure 4 shows that during the harvester pick-up operations, dust intensity decreased to an average of 2 % opacity (98 % transmission) by the fourth harvested row for both ground speeds tested.

Table 3. Mass measurements of TSP and PM10 particulate matter during two harvester ground speed testing conditions.

	Harvester ground speed			
	------------ 2 mph -------------		------------ 4 mph -------------	
Row	TSP mass µg	PM10 mass µg	TSP mass µg	PM10 mass µg
1	522	133	749	129
2	--	145	--	148
3	--	65	--	129

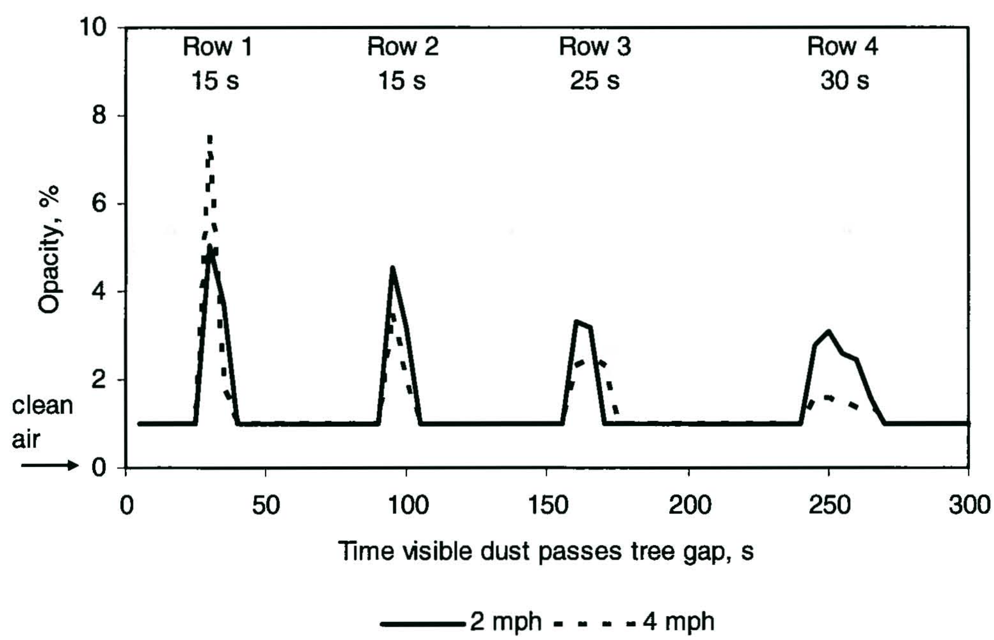

Figure 4. Stationary opacity time response as a function of harvester location and ground speed for the Flory 850.

From Figure 4 it is seen that opacity successively decreases as the harvester moves away from a stationary vantage point. These results quantify that distance and tree rows are effective in reducing the appearance of visible dust clouds emitted by the harvesters in motion within the orchards. The implication is that nuisance dust clouds emitted into areas adjacent to orchards can be reduced by altering practices in boundary rows. In these experiments, a four-row distance for dust reduction resulted in optical transmissions (recalling that transmission = 100 % - percent opacity) increasing from approximately 93 to 97%. While this difference may seem numerically small, the difference in appearance is significant and the potential change in concentration can be large. For example, manufacturer's performance data for the opacity instrument is shown in Figure 5. This indicates that a seemingly small increase in transmission, from 94% to 98% would correspond to a 75% to 80% reduction in dust concentration.

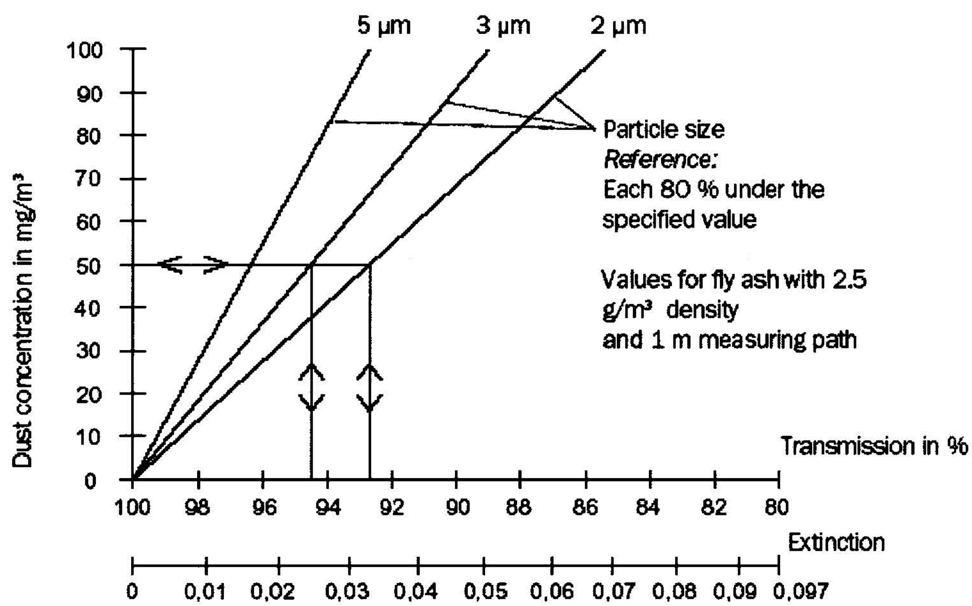

Figure 5. Relationship between optical transmission and concentration of dust in air (Source: FW300 operating manual, Sick Maihak, GmbH.)

Windrow materials

Samples of windrows were collected to measure particle size distributions as a first step in classifying pre-harvested material. Samples were at least 2 kg and were collected directly from the windrow. Windrow materials were sieved using a mechanical shaker for approximately 20 minutes in order to obtain a reasonable sample for particle size analysis. Sieves used were: No. 3 ½ (5.6 mm opening), No. 10 (2 mm opening), No. 18 (1 mm opening) and No. 40 (425 µm opening). The final mass collected after material was passed through the No. 40 sieve was used for the particle size analysis. Samples submitted for analysis were composite replicates; 5 g of each sample was submitted for particle size distribution analysis (Powder Technology, Inc., Burnsville, MN).

Results found that the median diameters (that is, the diameter where 50 % of the particles are greater than and 50 % of the particles are less than the median diameter) were 85.6, 70.8 and 147.6 µm for Colusa County orchard 1, Colusa County orchard 2 and the Salida test orchard, respectively.

Rather than report the entire range of data, Table 4 shows a small portion of the results from the particle size distribution test. These data are representative of material that passes through a 425 µm square opening. Regarding the effects of agricultural equipment and generated visible dust, it would be reasonable to assume that anything larger than this particle size (425 µm) would not be inherently detrimental with regards to air quality. Also, the size of sieve for sample preparation has a direct relation on the percentages of material in the particle size analysis results. Samples from 75 um sieve openings were also sent in for particle size analysis. Results found that although the median diameter of the material decreased by approximately half, the percentage of material less than the cut-off diameters listed in Table 4 were approximately doubled.

Table 4. Particle size assessment for windrow materials after sieving through 425 µm.

	Cut-off diameter, µm		
	2.6	10.1	26.1
Sample name	Percentage of sample less than cut-off diameter, %		
Colusa County, CA orchard 1	2.9	12.3	25.7
Colusa County, CA orchard 2	2.9	13.1	29.0
Salida, CA	0.7	6.4	16.8

Recent Publications:

Downey, D., D.K. Giles and J.F. Thompson. 2007. In-situ transmissiometer measurements for real-time monitoring of dust discharge during orchard nut harvesting. Journal Env. Qual. In Press.

References:

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Faulkner, W.B., Shaw, B.W. and R.E. Lacy. 2007. Coarse fraction aerosol particles: Theoretical analysis of rural versus urban environments. Applied Eng in Ag., 23(2)239-244.

Baron, P.A. 2003. Chapter O: Factors affecting aerosol sampling. NIOSH Manual of analytical methods. Avaialble from http://www.cdc.gov/niosh/nmam/chaps.html on 27 June 2007.