Emission Factors/Almond Harvesting

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Interpretive Summary

The focus of this project was to provide baseline PM_{10} emission factor data for almond sweeping operations as well as to move forward on quantification of a possible conservation management practice (CMP) for almond sweeping. In conjunction with the emission factor development work, continued quantification of sampler bias was conducted. This report provides an assessment of the progress and updates the almond sweeping portion of the current PM_{10} emission factor. Two sampling sites and 1 sweeping implement were used to conduct this research. The first sampling location was located in the Wasco area of the Southern San Joaquin Valley and is the same sampling site that has been used for the past several years. The second sampling location was located near Arbuckle, north of Sacramento, and had not been used for this research in the past. The goal was to use two geographically diverse orchards in order to quantify variability associated with almond sweeping.

Aerosol monitors developed by Texas A&M University (TAMU) were used throughout the experiment. These consisted of a total of 12 independent monitors located in 5 different locations around the source. There were a total of five (5) suspended particulate (TSP) samplers, 5 federal reference method (FRM) PM_{10} samplers and 2 FRM $PM_{2.5}$ samplers.

Past emission factors for almond operations had been developed using gravimetric FRM PM samplers and various dispersion models by UC Davis and TAMU. This year a single dispersion model was used to determine the emission factor. The model, Industrial Source Complex-Short Term version 3 (ISCSTv3), is the former EPA approved dispersion model. This was used to make the emission factors developed this year directly comparable to emission factors developed in previous years using the same model. This method also allows for the use of single height monitors allowing for quicker movement between sampling plots and the use of less labor at the sampling site.

The equipment used in all tests was the same Flory model 7677 with a 7.5' wide sweeper head and low profile cab. The equipment was operated by the same operator throughout all tests at

both sampling locations. This allowed the use of controllable variables such as operating speed and sweeping pattern through the orchard.

Table 1 shows the emission factors developed from this work. The true PM_{10} and true $PM_{2.5}$ emission factor for standard harvesting (3 blower passes) of 382kg/km^2 from this work agrees well with the previous true PM_{10} emission factor developed for traditional sweeping operations of 321kg/km^2. The measured emission factor with reduced blower pass was 194 kg/km^2. The reduction in emissions achieved through reducing blower passes not only improves environmental air quality, but has the potential to decrease the time needed to harvest a field resulting in possible reduced expenditures for the farmer.

The $PM_{2.5}$ emissions produced during harvest were calculated using the measured PSD of the TSP filters. The result is a true $PM_{2.5}$ emission factor of 16kg/km^2 for three blower passes and 8kg/km^2 for one blower pass. As with most agricultural sources that originate from soil material, there is very little emission in this size range.

Table 1. True PM_{10} and $PM_{2.5}$ emission factor (kg/km^2) and reduction in emissions for both sweeping treatments tested at both locations and the aggregated reductions.

	True PM_{10} Emission Factor		True PM 2.5 Emission Factor		
	3 Blower Passes	1 Blower Pass	3 Blower Passes	1 Blower Pass	% Reductions
Site 1	388	196	12	6	49.5
Site 2	374	192	20	10	48.7
Aggregate	382	194	16	8	49.5

Harvest efficiencies were determined by CSU Fresno. This consisted of comparing the amount of product left in the field for each treatment. The amount of product left in the field using the two different sweeping operations were reported in average yield of nut meat in pounds per acre.

Objectives

The overall goal of providing improvements to the PM10 emission factor for almond harvesting has not changed over the past years but the specific objectives for this year were focused on the emission factor for sweeping operations. The emission factor for sweeping operations in previous years was based on professional judgment and not on measured experiments. The research plans for the current year include strengthening of the baseline emission factor for sweeping and incorporate a possible mitigation measure. Therefore, the specific objectives are as follows:

1. quantify the possible emission reductions achieved through the use of reduced blower passes during sweeping operations;
2. quantify the amount of crop left in the field due to the reduction in blower passes;
3. propose improvement to the baseline emission factor for standard sweeping operations; and
4. continue the investigation of sampling bias of FRM PM samplers including the analysis of the particle size distribution of dust collected from ambient filters.

The field sampling campaign was augmented by CSU Fresno personnel who conducted the harvest efficiency sampling. This work allowed for the quantification of nut yield per acre with reduced blower passes. The data may be used for possible quantification of the economics of such management practice. All tests were conducted with the cooperation of Flory Industries, the Almond Board Environmental Committee and several almond grower groups. Flory Industries provided the machinery and operating personnel. Paramount Farms (Site 1) and 4 R Farming Inc. (Site 2) owned the almond orchards used in the study.

Materials and Methods

Test Sites

The two sites identified for this year's study were the Wasco site (Site 1), which has been used for the past several years, and the Arbuckle site (Site 2). The Arbuckle site was operated by the same cooperator as the Arbuckle site that has been used in past years, but this year a different orchard was used on the same property. Site 1 is managed by Golden Valley Ag., Incorporated and is owned by Paramount Farms. The trees were approximately 8 years old at the time the sampling was conducted. Site 2 is owned and operated by 4 R Farming Inc. The trees at site 2 were also 8 years old at the time of sampling.

Site 1 consisted of a sandy loam soil with 13% clay. The average soil moisture content of the berm was 7.1% and the between row moisture content was 5.8%. Irrigation was achieved through the use of microsprinklers. Site 2 consisted of a Hillgate loam with 18.8% clay. The average moisture content of the berm at site 2 was 7.0% and the between row moisture content was 3.3%. Irrigation was achieved through the use of a single above ground drip line. All orchards were oriented north-south with a prevailing southerly flow vector.

Experiment Summary

With the goal of quantifying the reduction in emissions of a single conservation management practice, a randomized test design was employed. In order to directly compare the emissions of a "standard" sweeping operation with one that uses a minimal amount of blower passes a balanced number of side by side tests was desired. Due to the past research conducted in this area at the Wasco sampling location, the "standard" or control sweeping pattern was deemed as three blower passes. This was done to allow for a comparison of results with past sampling data which has been used to develop the standard emission factor for sweeping operations. It is imperative that any reductions be compared to a standard emission factor. Previous studies have been conducted on the Wasco orchard using their standard practice of three blower passes. By assigning three blower passes as standard, operators that use less blower passes can claim emission reductions for any number of reduced blower passes.

The treatment used for each test was randomly determined with the goal of having equal representation of each method at each sampling location. Table 2 shows the number of tests run at each location and the number of blower passes used for each test. There were a total of 8 tests completed at Site 1 and 7 test at site 2 completed in 2006. For each test a total of 4 TSP samplers, 4 PM_{10} samplers and 1 $PM_{2.5}$ sampler were deployed. This provided multiple determinations of the emission factor during each test thereby increasing the number of samples that can be used for the emission factor calculation. For this sampling scheme, each test block provided up to 4 independent estimates of the emission factor.

Table 2. Test treatments for 2006 sampling campaign.

Site 1		Site 2	
Test #	# of Blower Passes	Test #	# of Blower Passes
1	3	1	3
2	3	2	1
3	1	3	1
4	1	4	1
5	3	5	3
6	3	6	3
7	1	7	1
8	3		

Harvest Equipment

All tests were conducted using the same sweeper model with the same configuration. It was a Flory model 7677 with a 7.5' sweeper head. The same operator conducted all sweeping test thus minimizing pattern differences throughout all tests. The operator maintained a constant speed of 2.5 mph for all blower passes and maintained a speed of between 3.0 and 3.5 mph for all sweeping only passes. The sweeping pattern control consisted of three blower passes and three clean up passes while the experimental treatment consisted of 1 blower pass and three clean up passes. During the blower passes the blower was fully open, and during the non-blower clean up passes the blower was completely closed. The unit was setup and maintained by the factory operator.

Particulate Measurements

Particulate measurements were conducted using custom built particulate samplers with federal reference method (FRM) inlets for PM_{10} and $PM_{2.5}$ and a custom built total suspended particulate (TSP) inlet, all operating at $1m^3$/hour sampling flow rates. The air control units were custom built to allow for more robust operation in harsh environments. The air measurement system was significantly improved over the standard FRM samplers. More accurate measurements of air flow were shown leading to more accurate measurement of concentrations. The TSP sampler was designed to obtain the same cut point as high-volume TSP samplers designated as FRM samplers prior to implementation of the PM_{10} standard. TSP samplers were used due to the well explained phenomenon of changing sampler performance characteristics in the presence of particulate matter (PM) that is larger than the cut point of the sampler (10μm for PM_{10} sampler, 2.5μm for $PM_{2.5}$ sampler) (Buser, 2007). Particle size distribution (PSD) analysis was conducted on all of the TSP filters to determine the true PM_{10} concentration. This allowed for the quantification of the change in performance of the PM_{10} samplers as well as allowing for the development of emission factors based on the true concentration of particulate less than 10μm.

Samplers were set up in order to measure the net concentration change across the orchard. A total of 5 sampling locations were used for each test. A single upwind location was used consisting of collocated TSP, PM_{10} and $PM_{2.5}$ samplers. Four downwind sampling locations were used for each test as well. They were spaced evenly across the width of the treatment area for the specific test. All four downwind sampling locations consisted of collocated TSP and PM_{10} samplers and 1 downwind location also had a $PM_{2.5}$ sampler. The sampler configuration is shown in Figure 1. Sampling location 2 or 3 always had the $PM_{2.5}$ sampler depending on the direction of the wind for that specific test. All orchards were configured with north south rows with a southerly flow vector required for all tests. In the calculation of concentrations to be used for modeling and emission factor reporting, the upwind concentration (also assumed to be the background concentration) was always subtracted from the downwind concentration measurements.

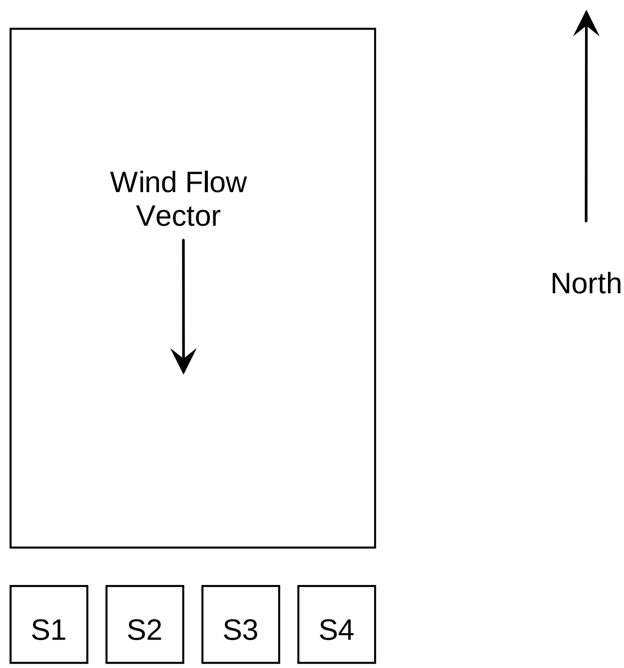

Figure 1. General sampling configuration for all tests. All prevailing winds were from a northerly direction and all orchard rows ran north-south.

Modeling

ISC-STv3 is a steady state Gaussian plume model that can be used to predict downwind concentration from area sources (EPA, 1995). ISC-STv3 is used to calculate 1-hour average concentrations at receptor locations placed anywhere around the source. The inputs for the model include the relative placement of sources and receptor locations, as well as meteorological conditions and emission fluxes. The equation that ISC-STv3 uses as the basis for all other calculations is a double Gaussian algorithm that represents a point source (equation 1).

$$C = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{\exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]\right\} \qquad (1)$$

where:

- C = predicted concentration ($\mu g/m^3$);
- Q = emission rate ($\mu g/s$);
- u = wind speed at the point of emissions release (m/s);
- σ_y = Pasquill-Gifford horizontal plume spread parameter based on stability class (m);
- σ_z = Pasquill-Gifford vertical plume spread parameters based on stability class (m);

- H = height of plume release (m);
- y = crosswind distance from source to receptor (m); and
- z = height of receptor for concentration prediction (m).

Each of the inputs to ISC-STv3 are either measured in the field or are calculated from measured values in the field. The Pasquill-Gifford dispersion parameters are calculated based on the atmospheric stability class. The stability class is determined using wind speed and incoming solar radiation during the time of interest. The stability class is then used to determine the coefficients used to calculate the plume spread parameters.

The ISC-STv3 area source algorithm is similar to the algorithm used in Point Area and Line Sources 2.0 (PAL) (Peterson and Rumsey, 1987). The concentration is predicted by simulating the area source as a series of line sources that are perpendicular to the wind. In ISC-STv3 the orientation of source and receptor is defined according to the wind direction for the modeling period. The crosswind distance (Y) is the distance perpendicular to the wind direction from an emission point to a receptor. The downwind distance (X) is the distance from an emissions point to the receptor, parallel with the direction of the wind.

The number of line sources used is increased until the predicted concentration using N line sources converges with the predicted concentration using N-1 line sources. The difference between ISC-STv3 and PAL is the criteria used to determine convergence of the predicted concentration. This change was made in order to optimize the computing time used to determine the concentration, but yields the same results (EPA, 1995). ISC-STv3 can also handle more variations in the configuration of area sources. PAL limits area sources to strictly North-South East-West orientations (Petersen and Rumsey, 1987), while ISC-STv3 allows for any configuration of area sources. The method used by ISC-STv3 allows for the placement of receptors at any location in or around area sources. The only limitation on placement of receptors is the upwind distance to the nearest line source, which is due to the calculation of the σ_z parameter. When the upwind distance from source to receptor approaches zero, σ_z approaches zero, yielding inconsistent results. Therefore, ISC-STv3 limits the minimum downwind distance, from source to receptor, to 1 meter.

In order to determine concentrations downwind of the source for varying wind directions ISC-STv3 effectively rotates the coordinates of the source and receptor to keep to that of the wind direction. This rotation maintains the ideal perpendicular orientation of wind direction and line source for all wind directions. Therefore, ISC-STv3 does not incorporate the change in wind direction into the Gaussian equation, but incorporates the change in wind direction before the Gaussian equation is used. This allows for much simpler calculations.

The evaluation of the area source algorithm is the result of the integration of equation 1. The integration is done numerically by using the infinite length line source model (equation 2), and then multiplying by a scalar to correct for edge effects (Turner, 1994). The effect of this calculation is that the area source closest to the receptor will have the largest effect on the total predicted concentration. As the distance from the receptor increases the relative contribution to the total concentration decreases. The decrease in concentration in the infinite length line source is attributed solely to the increased vertical dispersion of the plume with distance.

$$C = \frac{2q}{\sqrt{(2\pi)}\sigma_z u} \exp\left[-\frac{H^2}{2\sigma_z^2}\right] \qquad (2)$$

- where:

- C = concentration of pollutant ($\mu g/m^3$);
- y_1, y_2 = extent of line source;
- q = emission rate ($\mu g/m/s$);
- σ_z = Pasquill-Gifford vertical plume spread parameter based on stability class (m);
- u_s = average wind speed at pollutant release height (m/s);
- H = emission height.

The correction for edge effects is a function of the crosswind distance from the end of each line source, to the receptor (Y), and the horizontal plume spread parameter (σ_y). This is a different value for each line source in the model.

The model was used in reverse to allow for a flux to be determined from a measured concentration. Due to the complexity of the driving equations, the flux was not solved for directly, but was determined using the direct relationship between flux and concentration in equation 1. This is done by predicting a concentration using actual meteorological conditions for a given sampling period and a unit flux emission rate of 1 $\mu g/m^2$-s. The resulting predicted concentration is called a unit flux concentration (UFC) and is divided into the measured concentration. The resulting number is the emission flux (PM_{10}/area-time) for that sampling period. Using the actual area harvested during sampling, the emission flux is then converted to an emission rate (mass/time). This emission rate only represents a portion of the total emissions created during the sweeping operation at a single orchard due to multiple harvests occurring in each orchard.

Emission Factor Calculations

An emission factor is a representative value that attempts to relate the quantity of pollutant released to the atmosphere with an activity associated with release of the pollutant (EPA, 1995). As applied to almond harvesting, the pollutant in question is PM_{10} or $PM_{2.5}$ and the activities are shaking, sweeping and pick-up operations. The factors are usually expressed as the weight of the pollutant divided by a unit weight, volume, distance, area or duration of the activity emitting the pollutant. For the almond harvest operation, the emission factor is expressed in pollutant per unit of area harvested. The emission flux ($ug/m^2/s$) resulting from the dispersion modeling discussed in the previous section can be easily converted into units of $kg/m^2/hr$. Thus, the formula to estimate the emission factor when the emission flux is known is given below:

$$EF\ (kg/km^2) = ER\ (kg/m^2/hr)\ X\ Time\ of\ sampling\ (hrs)$$

It is implied that if one is using the same area for an operation, the emission factor is the sum of the pollutant emissions after the completion of all harvesting activities (shaking, sweeping and pick-up) in a given year or season. Note that the unit of area is the actual area covered by the machine during the operation. It a common practice by the almond growers to plant a combination of several almond varieties in a given area for cross pollination purposes. Thus, the usual combination is a NonPareil variety with another variety or a NonPareil with two other varieties such as Carmel and Butte per orchard. The varieties are normally planted every other row but during the harvesting of one variety, all windrows are used for the pick up operation virtually using the whole area for the harvest process. The overall emission factor is the sum of the two harvesting operations for each variety. In an orchard that is harvested twice, the pick up operation for the second harvest period is identical to that of the first field entry. There is no reason to expect that each of the harvest operations would result in significantly different emission factors. This is the reason that the studies in the past have not placed a high priority on returning to the same orchard later in the year to measure emissions from the same field for the different variety. The emission factor is simply doubled. Likewise for varieties where a row is skipped during pick up operations, the area used for the calculations of emission factors should be the actual area covered by the machine for that operation. The above procedure has been consistently used in previous year's emission factor estimates even though discussion of the actual calculation was not done.

Harvest Efficiency

An analysis of the harvest efficiency was conducted to determine the effectiveness of the experimental treatment in relation to the standard treatment. This was done in order to quantify the value of the product left in the field with reduced number of blower passes used.

This work was conducted in conjunction with the air sampling on the same experimental plots. Within the test plots, 5 replicate sample areas were chosen in a diagonal matrix across the plot. The sample area consisted of the area between 4 trees. String was used to delineate the berm area from the middle area. The berm area was determined as 3' on both sides of the tree row. The middle area went from the string to 1' away from the nut windrow. The pollinator row areas were 1' from the windrow to the middle of the berm and were pre-raked before the sweeping treatment to assure desired nut collection. Nuts were collected in plastic bags and refrigerated until being weighed. Weight of nuts included the total nut (hull, shell, and meat). For comparison purposes, the turnout for both fields was assumed to be 25%. Sample collection at the Arbuckle site only differed from the Wasco site in the number of trees sampled at each sample location within the test plot. (Wasco = 4, Arbuckle = 1).

Sample Areas Evaluated

- Berm (3' on both sides from tree row)
- Middle (Berm line to 1' from windrow)
- Pollinator Row –West (Non-harvested row from windrow to tree row)
- Pollinator Row – East (Non-harvested row from windrow to tree row)

Each of the regions of the orchard was sampled independently allowing for independent quantification of nut loss in each region. The regions considered harvested are all the nuts within 1 foot of either side of the windrow.

Particle Size Distribution

Due to the design parameters of EPA FRM samplers, there is an inherent over-sampling bias when they are operated in environments that have a significant mass of particulate matter greater than their cut point (10μm for PM_{10} samplers). This could lead to over estimation of measured concentrations by a factor of 2 or more. Therefore, particle size analysis is conducted in order to determine the true PM_{10} concentration measurements. The particle size analysis produces a log-normal distribution that is characterized by the mass media diameter (MMD) and geometric standard deviation (GSD). These values are then used to determine the true PM_{10} concentration. By regressing the true PM_{10} values against the collocated FRM PM_{10} values, the bias in measurement can be obtained for this location.

Similar to the PM_{10} sampler bias, the FRM $PM_{2.5}$ samplers produce a large bias as well. This bias is even more pronounced than the PM_{10} bias because of the larger discrepancy between the ambient particle size distribution and cut point of the $PM_{2.5}$ samplers.

Results and Discussion

Concentration Measurements

TSP particulate concentrations during the Site 1 sampling campaign are presented in Table 3. All downwind concentration measurements exceeded upwind measurements as expected. Test 6 produced the highest concentration measurements. The grand mean downwind concentration measurement is 916.0μg/m^3 and the grand mean upwind concentration is 250.7μg/m^3 representing an average increase in TSP across the sampling area of 665.3 μg/m^3 TSP. All sampling tests lasted less than 2.5 hours. Test 1 for Site 1 was discarded due to an extremely short sampling period.

Table 3. Measured TSP concentrations for site 1. (μg/m^3)

Location	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
UW	137	126	126	316	745	153
S1	1131	352	449	1053	3265	374
S2	650	369	832	619	2556	668
S3	456	346	950	947	3332	735
S4	335	329	1018	1304	1324	514

Site 2 concentrations are presented in Table 4. All 7 tests were successful from a particulate measurement stand point. The filter at sampler location S3 for Test 3 was dropped on the ground during sampling and is therefore invalid and not reported. The upwind filters were not changed between samples two and three resulting in the same upwind concentration for both. The same was done for Tests 4 and 5, and then again for Tests 6 and 7. The grand mean upwind TSP concentration is 110.9μg/m^3 and the mean downwind TSP concentration is 723.9μg/m^3 representing an average increase in TSP concentrations across the orchard of 613.0μg/m^3. Once again these concentrations were measured over a time period of 1.5 to 2.5 hours.

Table 4. Measured TSP concentrations for site 2. (μg/m^3)

Location	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
UW	57	209	209	105	105	72	72
S1	1556	879	663	2407	750	910	496
S2	491	963	131	597	701	853	125
S3	773	967	N/A	590	872	638	90
S4	769	593	577	479	900	700	78

Particle Size Distributions

The particle size distribution was completed for all TSP filters with satisfactory loading. Once this was completed, the resulting MMD and GSD are used to calculate the percent of mass that is less than 10μm on each filter. This value is then used to determine the true PM_{10} concentration. The average MMD for site 1 is 15.57μm with a GSD of 2.2. The resulting PM_{10} percentage is 28%. Therefore, the TSP emission factor for Site 1 can be multiplied by 28% to achieve the PM_{10} emission factor. For site 2 the average MMD is12.81 and the GSD is 2.2. Therefore the resulting PM_{10} percentage of the measured TSP value is 38%. The previously reported MMD and GSD recorded for sweeping was 12.83μm with a GSD of 1.9.

The MMD values for each sampling site are different for the two locations but the resulting scatter plot of FRM measured PM_{10} versus true PM_{10} shows statistically similar results.

Therefore the scatter plot and regression for both sampling locations are combined in the plot below. It can be seen that the true PM_{10} value is 85% of the measured value representing an over sampling rate of 17%. This is significant because the measured emission factors would be 17% higher if only the FRM PM_{10} samplers were used.

The difference in measured PSDs between the locations is not uncommon. There are significantly different soil types between the locations resulting in different parent material for entrainment.

Figure 2 shows the scatter plot with regression equation of the FRM PM_{10} measurements versus the true PM_{10} measurements derived through the use of the TSP sampler and measured PSDs. This shows that the true PM_{10} concentration is approximately 85.6% of that measured by the FRM sampler. This represents a source of possible error in emission factor development because the emission factors are directly related to the measured concentration through the use of the model.

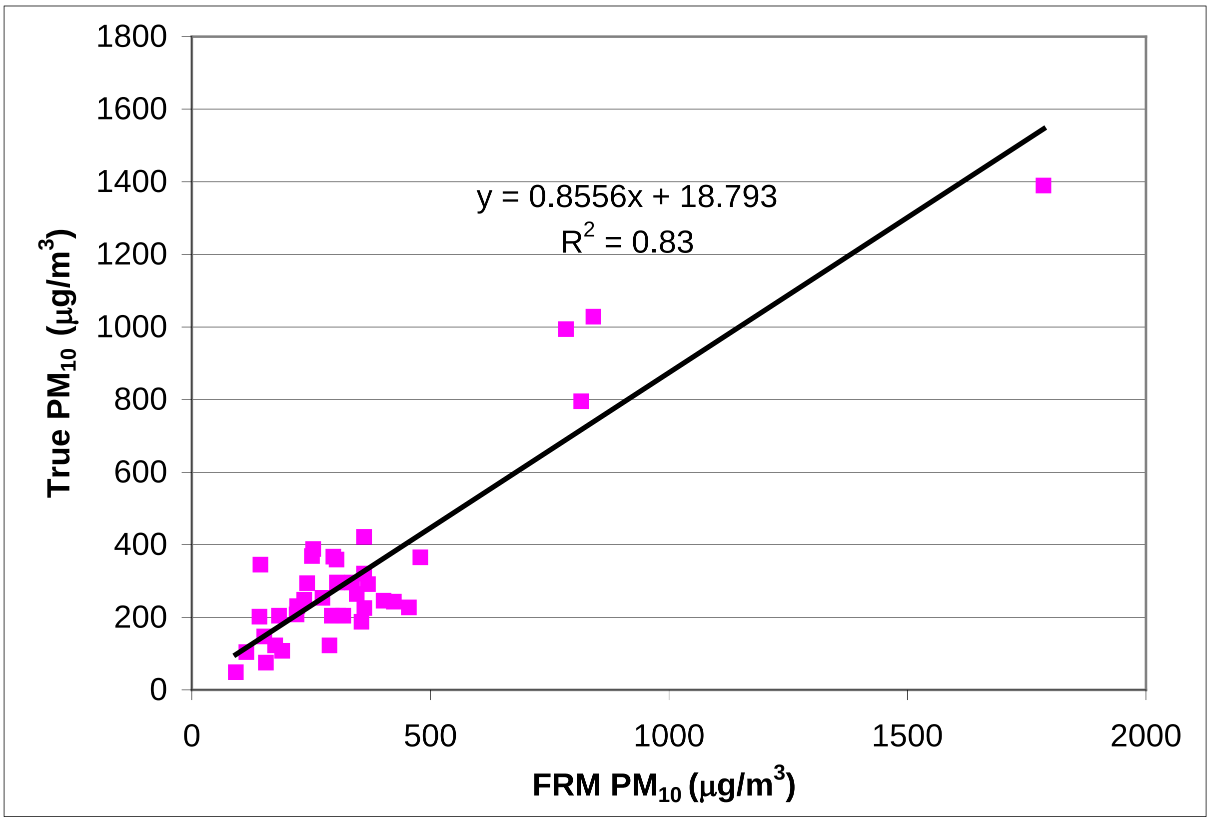

Figure 2. Scatter plot of FRM PM10 versus True PM10 concentrations.

Using the MMD and GSD for each sampling site the percent mass less than 2.5µm can also be determined. For site 1, 0.9% of the TSP concentration is the true $PM_{2.5}$ concentration. For Site 2, 2.0% of the TSP concentration is $PM_{2.5}$. Table 5 shows the summary of the particles size distributions for this work.

Table 5. Particle size distribution parameters for both sampling sites and PM_{10} and $PM_{2.5}$ percentages.

Location	MMD	GSD	True PM_{10} %	True $PM_{2.5}$ %
Site 1	15.57	2.17	28	0.9
Site 2	12.81	2.21	38	2.0

$PM_{2.5}$ information similar to that provided for PM_{10} is not available due to the extremely low measured $PM_{2.5}$ concentrations. Due to the short sampling time (less than 2 hours) and the extremely small $PM_{2.5}$ component of the emissions the sampled concentration was below detectable levels. The extremely low sampled concentrations lead to the use of the PSD information alone to determine $PM_{2.5}$ emission rates.

Emission Rates

The result of the modeling program is an emission flux with units of mass/area-time for the area covered during sampling. In order to translate this into an emission rate with units of mass per area it is multiplied by the duration of the test. This provides an emission factor in the units of mass per area harvested, in this case kg/km^2. This can be considered an emission factor per tree area. For example, these numbers represent the sweeping operation for ½ of an orchard that covers a total of $1km^2$ with a planting of 50% NonPareil. While the implement traveled up and down every tree row, it only swept nuts for ½ of the total trees in the target plot. Therefore, the operator had to return at a later date after the second variety had been shaken to complete its task. It is reasonably assumed in this research that the later harvesting activities will once again emit as much particulate as those measured, and therefore, any emission factor developed from a single field entry must be multiplied by the number of field entries.

The sampling conducted at Site 1 produced a total of 6 usable tests with four downwind sampling locations providing potential of 24 TSP emission rate determinations. Tests 1 and 8 did not meet the minimum time requirements due to smaller harvest areas at either end of the orchard and are not included in this analysis. Table 6 shows the results of the emission rate analysis for the 6 valid tests at Site 1.

Table 6. Site 1 TSP emission rate results (kg/km^2) for a single field entry.

Location	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Treatment	3	1	1	3	3	1
S1	1714	375	567	1394	905	212
S2	359	404	483	292	621	333
S3	189	230	404	530	989	302
S4	116	202	397	751	353	240

The average emission rate for 3 blower passes is 684 kg/km^2 TSP and the average emission rate for 1 blower pass is 346 kg/km^2 TSP. This represents a reduction of $338kg/km^2$ or 49% of emissions compared to the standard treatment. There were no outliers from this data set when treated independently. Using the Student's t-test we can reject the hypothesis that there is no difference between treatments and conclude that the difference is significant at $P<0.05$.

Sampling conducted at Site 2 produced a total of 6 usable tests as well resulting in a total of 24 usable emission rate determinations. At this sampling location, Test 3 did not have an adequate wind direction and is not shown in this analysis. Table 7 shows the results for the valid tests at Site location 2.

Table 7. Site 2 TSP emission rate results (kg/km^2) for a single field entry. Emission rate with grey backgrounds are statistical outliers.

Location	Test 1	Test 2	Test 4	Test 5	Test 6	Test 7
Treatment	3.0	1.0	1.0	3.0	3.0	1.0
S1	2151	387	3469	349	673	550
S2	496	406	229	299	509	83
S3	665	442	151	408	349	36
S4	704	350	104	579	392	26

Using SPSS outliers were identified and are marked in grey in Table 7. The mean emission rate for three blower passes is 493 kg/km^2 TSP and the mean emission rate for 1 blower pass is 251 kg/km^2 TSP. This represents a reduction in emission of 242 kg/km^2 or 49%. Once again using the Student's t-test we can reject the hypothesis that there is no difference between treatments and conclude that the difference is significant at $P<0.05$.

By combining the PSD information presented above with the TSP emission rate calculations, the true PM_{10} emission rate can be computed for each test. Applying the average PM_{10}:TSP ratio for the given sampling location to all samples within that test yields the PM_{10} emission rate for that test. Therefore, for Site 1 all TSP emission rates are multiplied by 28% to yield the emission rates in Table 8. The average PM_{10} emission rate for three blower passes is 194 kg/km^2 and the average PM_{10} emission rate for 1 blower pass is 98kg/km^2. Once again this is the same percentage reduction in emissions as presented in the TSP emission rate for this test.

Table 8. Site 1 true PM_{10} emission rates (kg/km^2) for a single field entry.

Location	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Treatment	3	1	1	3	3	1
S1	485.1	106.0	160.5	394.4	256.0	60.1
S2	101.5	114.3	136.7	82.5	175.9	94.2
S3	53.5	65.2	114.4	149.9	279.9	85.4
S4	32.9	57.2	112.5	212.5	99.9	67.9

Applying the PSD analysis to the TSP emission rates calculated at Site 2 yields the results in Table 9. The average PM_{10} emission rate for 3 blower passes at this location is 187kg/km^2 and the average PM_{10} emission rate for 1 blower pass is 96kg/km^2. Once again the reduction in emissions is the same as that presented for the TSP emission rates in Table 7. The same emission rates that were determined to be outliers in the TSP analysis are still outliers in this analysis.

Table 9. Site 2 true PM_{10} emission rates (kg/km^2) for a single field entry. Emission factors with grey backgrounds are statistical outliers.

Location	Test 1	Test 2	Test 4	Test 5	Test 6	Test 7
Treatment	3.0	1.0	1.0	3.0	3.0	1.0
S1	817	147	1318	133	256	209
S2	189	154	87	114	193	32
S3	253	168	57	155	133	14
S4	268	133	40	220	149	10

The grand mean true PM_{10} emission rate for the standard three blower pass treatment is 191 kg/km^2 and the grand mean PM_{10} emission rate for the experimental 1 blower pass treatment is 97 kg/km^2. This translates to an overall sweeping emission rate of 382 kg/km^2 for three blower passes and 194 kg/km^2 for reduced blower passes.

Evaluating the true PM_{10} emission rates between locations, it was found that the there is no statistical difference in the means of PM_{10} emissions for a given treatment at $P \leq 0.05$. For example, the emission rate for 1 blower pass at Site 1 is not statistically different from the emission rate at Site 2 for 1 blower pass. Therefore, the groups can be aggregated to provide one emission rate for 3 blower passes and 1 emission rate for 1 blower pass as well as a single reduction in emissions. The aggregated emission rate for 3 blower passes is 189.6 kg/km^2 and the emission rate for 1 blower pass is 96.2 kg/km^2. The difference between the treatments is 93.4 kg/km^2. The significance for this test has a minimal p-value ($P \leq .000$) representing a very strong rejection of the hypothesis that the means are equal. The present reduction in emissions for this analysis is 49.3% reductions. The 95% confidence interval for the reduction of emissions is 44 kg/km^2 to 142 kg/km^2 or a reduction percentage of 23.3% to 75%.

Table 10 shows the emission rates for true $PM_{2.5}$ for Site 1. The average true $PM_{2.5}$ emission rate for three blower passes at this location is 6 kg/km^2 and the average emission rate for 1 blower pass is 3 kg/km^2. The same statistics applied to the TSP and PM_{10} emission rates apply to these samples as well.

Table 10. Site 1 True $PM_{2.5}$ emission rates (kg/km2) for a single field entry. Emission rates with grey backgrounds are statistical outliers.

Location	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Treatment	3	1	1	3	3	1
S1	15.3	3.4	5.1	12.5	8.1	1.9
S2	3.2	3.6	4.3	2.6	5.6	3.0
S3	1.7	2.1	3.6	4.7	8.8	2.7
S4	1.0	1.8	3.6	6.7	3.2	2.1

Table 11 shows the emission rates for true $PM_{2.5}$ for Site 2. The average true $PM_{2.5}$ emission rate for three blower passes is 10kg/km^2 and the average true $PM_{2.5}$ emission rate for 1 blower pass is 5 kg/km^2.

Table 11. Site 2 true $PM_{2.5}$ emission rate results (kg/km2) for a single field entry. Emission rates with grey backgrounds are statistical outliers.

Location	Test 1	Test 2	Test 4	Test 5	Test 6	Test 7
Treatment	3.0	1.0	1.0	3.0	3.0	1.0
S1	43	8	69	7	13	11
S2	10	8	5	6	10	2
S3	13	9	3	8	7	1
S4	14	7	2	12	8	1

The $PM_{2.5}$ emissions for almond harvesting are very low as are other agricultural operations that generate emissions through work with the soil.

Harvest Efficiency

The reduction in emissions achieved through reducing blower passes is significant, but will not be adopted if the growers perceive a significant loss of yield due to the practice. Therefore, in conjunction with the air sampling work, CSU Fresno conducted an analysis of the amount of product left in the field. The results of this analysis are presented in Tables 12 and 13. Results are reported in meat lbs/acre assuming a plant population of 115 trees/acre for each site.

Table 12. Site 1 almond product losses (meat lb/acre).

Blower Passes	Berm		Middle		Pollinator West		Pollinator East		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Total Non-Harvested Nuts
1	10.9	6.5	4.5	2.4	36.4	3.8	5.4	2.9	57.3
3	7.8	8.5	3.5	0.4	13.4	5.8	3.9	2.4	28.7
Nut Loss	3.1		1.0		23.0		1.5		28.6

Table 13. Site 2 almond product losses (meat lb/acre).

Blower Passes	Berm		Middle		Pollinator West		Pollinator East		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Total Non-Harvested Nuts
1	3.9	0.8	5.7	3.6	3.3	2.7	4.9	1.8	17.8
3	0.4	0.1	11.5	3.4	2.2	0.2	1.9	0.8	15.9
Nut Loss	3.5		-5.8		1.1		3.0		1.9

There was a significant difference in the total nut losses between the two sampling locations. The nut losses at site 1 are primarily attributed to nuts that are left between the wind row and the west pollinator row, accounting for 80% of the total nuts lost. Site 2 had a much smaller difference between the two treatments. The middle region at this location actually had less nuts in the middle region for 1 blower pass.

Standard Sweeping Emission Factor

The emission rates presented in the previous section represent the emissions for ½ of each orchard sampled due to the alternating planning of varieties in the orchard. They represent an emission rate on a planning area basis. In order to convert them to an annual emission factor for all almonds, the emission rate must be adjusted to represent all the trees planted in a given field. Since all sampling was conducted during the harvest of 50% of each field, the total sweeping emission rate is doubled to account for the other half of trees in the field.

The standard sweeping emission factor presented in the 2005 report using three blower passes was 321 kg/km^2 true PM_{10}. The research this year produced a standard true PM_{10} sweeping emission factor of 191 kg/km^2 for ½ of the planted trees or 382kg/km^2 for the entire harvest. The reduced blower pass true PM_{10} sweeping emission factor is 97 kg/km^2 for ½ of the planted trees or, 194kg/km^2. For true $PM_{2.5}$ the 3 and 1 blower pass emissions factors are 8 kg/km^2 and 4 kg/km^2 for ½ half of the planed trees respectively or 16 kg/km^2 and 8 kg/km^2 for the total harvest. Table 14 shows the results for the 2005 and 2006 sampling campaigns for sweeping.

Table 14. Total seasonal emission factor (kg/km^2) for sweeping operations for 2005 and 2006 sampling.

	True PM_{10} Emission Facor (kg/km^2)		True PM 2.5 Emission Factor (kg/km^2)			2005 True PM10 Emission Factor (kg/km^2)
	3 Blower Passes	1 Blower Pass	3 Blower Passes	1 Blower Pass	% Reductions	3 Blower Passes
Site 1	388	196	12	6	49.5	321
Site 2	374	192	20	10	48.7	
Aggregate	380	192	16	8	49.5	

Conclusions

The quantification of the reductions in emissions achieved through reducing the blower passes allows growers to make informed decisions about their harvesting practices. Now growers can clearly see that their efforts to improve air quality by adopting this conservation management practice have clear benefits to the environment. The reductions found between treatments in this research also shows that the complete sampling algorithm used for this project can indeed quantify the reductions of some grower practices given the correct sampling conditions.

The lack of a significant difference between results at the two different sampling locations also indicates that the reduction in emissions can be applied to all orchards regardless of different management practices and the results will be similar.

By using the highest number of blower passes on an orchard (3) and the lowest number of blower passes on an orchard(1) the emission factor can be scaled to apply to operators who wish to operate with two blower passes by simply using the midpoint of the two treatments. This allows farmers to actually choose a range of operating parameters depending on their specific operating conditions.

By continuing to quantify the reductions achievable through various operating practices, farmers may eventually be able to sell the emission credits generated through the use of these reduction practices to new or expanding facilities that are required to purchase offsets for their emissions.

For example, new or expanding dairies are paying as much as $30,000 per ton of PM_{10} emissions to offset their emissions.

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