Summary of PM Emission Studies from Almond Harvest

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ABSTRACT:

An updated PM_{10} emission factor for almond harvesting operations of 3,152 kg $PM_{10}/km^2/yr$ is recommended based on data collected from 2002 to present and interpreted using improved analysis techniques. A brief description of data collected since the initial emission factor assessment is provided, and improvements in monitoring methodologies are described.

INTRODUCTION:

The current PM_{10} emission inventory shows almond harvesting to be one of the largest agricultural sources of PM_{10} in California. In 2009, approximately 1.4 billion pounds of almonds were harvested in California on approximately 630,000 bearing acres with a total value of $1.8 billion (USDA, 2009b). Over 80 percent (516,000 ac) of the bearing crop is located within the San Joaquin Valley Air Pollution Control District ("District"). The current emission factor applied to all almond harvesting operations is 4,570 kg PM_{10}/km^2-yr (CARB, 2003), accounting for 13,300 tons of PM_{10} in the inventory each year.

The accuracy of this inventory depends on estimates of emission rates from all operations during almond harvesting, including shaking, sweeping, and nut pick up. The PM_{10} emission factor currently used by the San Joaquin Valley Unified Air Pollution Control District (District) for almond harvesting is based on measurements from almond pick up operations reported by Robert Flocchini's group at the University of California, Davis (UCD; Flocchini et al., 2001). The measured emission factor for almond pick-up was used to estimate PM_{10} emission factors for shaking and sweeping. Based on visual observation, Gene Beach and the Agricultural Technical committee chaired by the District suggested a factor of 10% of the pick-up emission factor as the emission factor for sweeping, and 10% of that sweeping factor for shaking. Taken together, these three emission factors comprise the current almond harvest PM_{10} emission factor (**Table 1**).

Table 1. Current PM_{10} emission factors for almond harvest operations.

Operation	Emission Factor	
	(kg/km^2)	**(lbs/acre)**
Shaking	42	0.37
Sweeping	415	3.7
Pick up	4,117	36.7
Total	**4,574**	**40.8**

The current PM_{10} emission factor for almond pick up was derived from PM_{10} concentration measurements using a model called the Vertical Profiling Method (VPM). The principal shortcoming of the VPM is the requirement of sampling a representative portion of the plume. As a source moves away from the sampler, the plume disperses and rapidly becomes too large to be adequately sampled for VPM using ground-based measurements. It is this ability to account for plume dispersion that is the principal strength of the EPA-approved dispersion models, the Industrial Source Complex Short Term Version 3 (ISCST3) and the AMS/EPA Regulatory Model (AERMOD). These dispersion models use additional meteorological data as well as detailed information about the relative positions of the source and the samplers to estimate the impact (change in size and strength) of dispersion on the portion of the plume that is sampled. Since 2003, sampling events of almond harvest operations supported by the Almond Board of California have made use of dispersion models to improve the current PM_{10} emission factor for almond harvesting to better reflect true emissions of PM_{10}. In early years of this research (2003-2005), dispersion modeling results were supported by the VPM protocol coupled with use of light detection and ranging instrument (LIDAR) measurements to validate the improvement in emissions estimation made by the shift in methodology from the original emission factor development work by Flocchini et al. (2001).

The objective of this paper is to summarize the PM_{10} emission factor improvement work that has been conducted from 2002 to present and recommend a more appropriate PM_{10} emission factor for almond harvesting operations in California.

HISTORY OF EMISSION FACTOR IMPROVEMENT EFFORTS

The Almond Board of California has supported research regarding characterization and mitigation of PM_{10} emissions from almond harvest operations from 2002 to the present. Researchers from UCD and Texas A&M University (TAMU) have contributed to the body of knowledge described in this paper. Due to the oversampling bias of federal reference method (FRM) PM_{10} samplers in the presence of large particulates (Buser et al., 2007a, 2007b), researchers from TAMU have collocated low volume total suspended particulate (LVTSP) samplers with FRM PM_{10} samplers and used particle sizing techniques to determine unbiased concentrations of PM_{10}. USEPA has not yet taken action to address the biases of FRM PM_{10} samplers in rural areas, so **for the purposes of this paper, all reported emission rates have been developed based on concentrations measured using FRM PM_{10} samplers.** (either the BGI PQ/PM_{10} inlet (BGI Inc., Waltham, MA) or the Graseby Andersen SA246B inlet (Thermo Andersen, Smyrna, GA)).

A summary of data collection activities by year is presented below:

2002

In a preliminary study, researchers from UCD measured PM_{10} concentrations downwind of an almond pick up operation in San Joaquin County. The operation utilized an older (1984) self-propelled harvester. Downwind concentration measurements were collected at multiple heights, and a LIDAR system was used to monitor emissions plume dispersion. Three tests were conducted.

2003

Emissions from nut pick up operations were monitored at five sites (4 in Fresno County; 1 in Kern County). At three locations, a single harvester was used, comparable to other “baseline” data collection events, while multiple harvesters were used simultaneously at other locations. Several potential PM mitigation methods were also investigated in 2003, but the focus of this paper is improvement of “baseline” emission factors. Because the results of mitigation testing are outside the scope of this paper, results of these studies are not presented here. Emissions were monitored using LIDAR and gravimetric sampling. Emission rates were calculated using VPM and inverse dispersion modeling using ISCST3. A total of 17 tests were conducted with the focus on comparing the utility of the LIDAR, VPM, and ISCST3 for estimating emissions from almond harvest operations.

2004

Emissions from sweeping, conditioning, and pick up using a total of eight different pieces of equipment were monitored at three locations (2 in Kern County; 1 in Colusa County). PM emissions were again monitored using LIDAR and gravimetric sampling, and emission rates were calculated using VPM and inverse dispersion modeling with ISCST3. The focus of sampling in 2004 was to:

1. Continue comparing the utility of the LIDAR, VPM, and ISCST3 for estimating emissions from almond harvest operations, and
2. Ensure that differences in production practices (e.g. equipment selection, soil type, etc.) could be detected using the methods of emission rate calculation described above.

Results of 2004 testing (described in more detail below) demonstrated that VPM and inverse dispersion modeling with ISCST3 yielded similar emission rates, but more of the test data were usable for inverse dispersion modeling because this method is much less sensitive to sampler placement relative to the source of emissions than the VPM method.

2005

The goal of sampling in 2005 was to determine PM_{10} emission rates from conventional sweeping practices. Sweepers from two equipment manufacturers were monitored at two sites (1 in Kern County; 1 in Colusa County). PM emissions were also monitored using LIDAR and gravimetric sampling, and emission rates were calculated using VPM and inverse dispersion modeling with ISCST3.

2006

In 2006, the focus of research efforts shifted to evaluating proposed practices for reducing PM_{10} emissions from almond harvest operations. Conventional sweeping was compared to sweeping using a traditional sweeper but making fewer passes at two locations (1 in Kern County; 1 in Colusa County). No sampling was conducted during nut pick up. PM_{10} concentrations were collected at 1 m height using FRM PM_{10} samplers, and emission rates were calculated using inverse dispersion modeling with ISCST3. For the purposes of this paper, only the results of conventional sweeping are reported. The methods and results of research in 2006 have been published elsewhere (Goodrich et al., 2009).

2007

Data collection in 2007 focused on comparing emissions between nut harvesters operating at standard speeds (~5 mph) and those operating at slower speeds (~2.5 mph) based on differences in opacity measurements between treatments reported by Downey et al. (2008). No emissions data were collected during sweeping operations. Emissions from a single, broadly used model of equipment were observed at two locations (1 in Kern County; 1 in Colusa County). PM_{10} concentrations were again collected at 1m height using FRM PM_{10} samplers. FRM $PM_{2.5}$ samplers were also employed, but $PM_{2.5}$ concentrations were too low to yield concentrations with an acceptable level of uncertainty. (Goodrich et al. (2009) reported that only 0.9% of TSP samples were smaller than 2.5µm in diameter). Because the preferred regulatory dispersion model changed from ISCST3 to AERMOD in 2007, emission rates were back-calculated from measured concentrations using both models.

A regression analysis was conducted between emission rates from 2007 calculated with ISCST3 and AERMOD (**Figure 1**). The 95 percent confidence interval for the slope and intercept of the regression included the values of one and zero, respectively, indicating that no differences were observed in emission rates calculated with each model. These results differ from previous research comparing the models (Faulkner et al., 2007). However, the most marked differences in emission rates calculated with each model occur at night. Because most harvest activities (and all sampling activities) have occurred during daylight hours, no significant change in emission rates is expected when calculating emissions rates from measured concentrations with ISCST3 or AERMOD. The methods and results of research in 2007 have been published elsewhere (Faulkner et al., 2009).

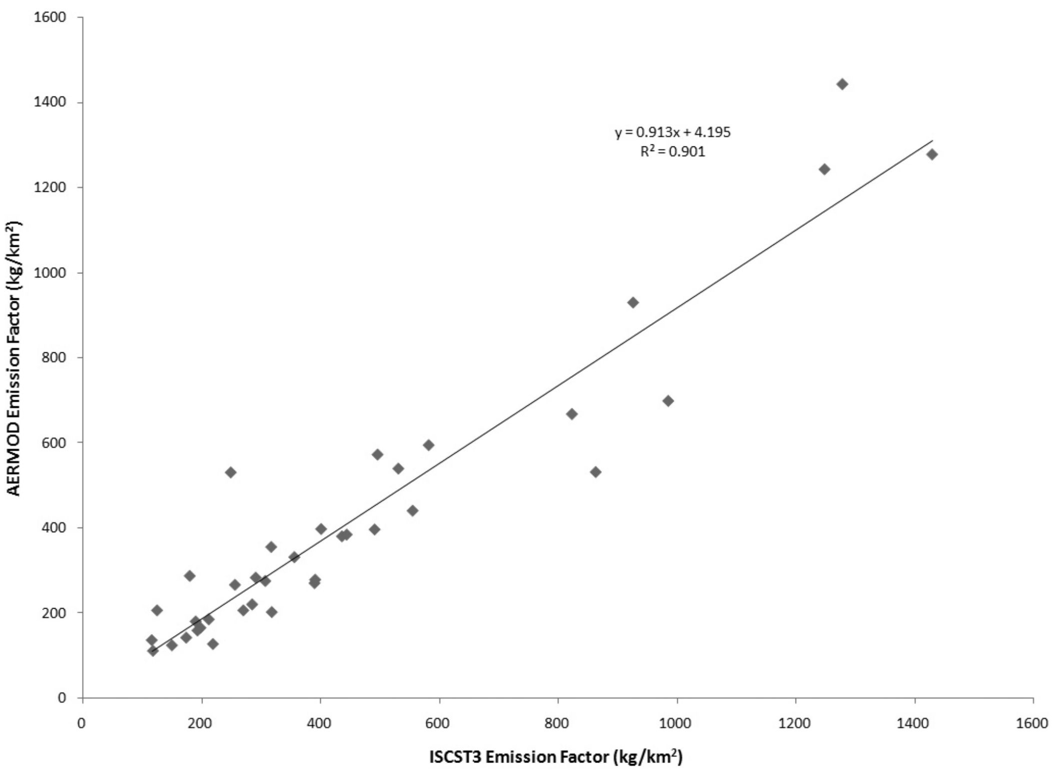

Figure 1. Regression analysis of 2007 ISCST3 and AERMOD emission rates (Faulkner et al., 2009).

2008

In 2008, research focused on the impacts of various sweeper settings on reducing PM_{10} emissions from almond sweeping and pick up operations. Emissions from both sweeping and pick up of windrows formed using manufacturer-recommended and non-standard sweeper settings were compared at one location in Colusa County. PM_{10} concentrations were collected at 1m height using FRM PM_{10} samplers, and emission rates were calculated using inverse dispersion modeling with AERMOD. For the purposes of this paper, only the results of manufacturer-recommended sweeper settings are reported. The methods and results of research in 2008 are undergoing peer-review for publication in *Transactions of the ASABE*.

2009

In 2009, differences in PM_{10} emissions between conventional and reduced-pass sweeping were compared, and the impact of harvester separation fan speed on PM_{10} emissions was analyzed. The three largest sweeper equipment manufacturers all produce reduced-pass sweepers that may prove to be viable options for reducing PM_{10} emissions, but only the results of conventional sweeping and pick up machine operation are presented in the present paper. Again, PM_{10} concentrations were collected at 1m height using FRM PM_{10} samplers, and emission rates were calculated using inverse dispersion modeling with AERMOD. The methods and results of research in 2009 are undergoing peer-review for publication in *Journal of the Air and Waste Management Association*.

EVOLUTION OF EMISSION FACTOR DEVELOPMENT METHODS

The current PM_{10} emission factors for almond harvesting were developed using the VPM method (Flocchini et al., 2001). The VPM method uses PM concentrations measured at several heights on a tower downwind of a source to estimate the total height of the plume and the change in concentration with plume height. This data is combined with wind speed data to estimate the size and strength of the plume generated by the source, from which pollutant fluxes are determined (Flocchini et al., 2001). From 2003-2005, VPM and inverse dispersion modeling using ISCST3 were both utilized to estimate PM_{10} emission rates from almond harvest operations. Inverse dispersion modeling utilizes measured pollutant concentrations downwind of a source and a pollutant dispersion model that predicts concentration profiles downwind of a source based on meteorological parameters to estimate the pollutant emission flux from an area source required to match observed pollutant concentrations. Detailed descriptions of each of these methods are described elsewhere (Flocchini et al., 2001; Faulkner et al., 2009; Goodrich et al., 2009). VPM was used by Flocchini et al. (2001) to establish the current PM_{10} emission factors shown in **Table 1**. However, the VPM method of emission rate calculation has several disadvantages relative to inverse dispersion modeling:

- The VPM method is more sensitive to sampler placement than the inverse dispersion modeling method, making collection of “valid” data more difficult (and less probable during any given test);
- The VPM method assumes a uniform concentration of pollutants in the horizontal plane, which is not a valid assumption if the wind vector is not parallel to the axis connecting the source and receptor;
- In effect, the VPM method assumes that particles are dispersed vertically throughout the profile between the ground and calculated mixing height and then travel horizontally from that point to the receptor, which is an oversimplification of dispersion processes;
- The VPM method has no mechanism for accounting for the distance between the source and receptors. For this reason, the VPM method does not work well when the source of emissions in more than 50m from the receptor, as is often the case in almond harvesting operations;

Inverse dispersion modeling techniques have been used successfully to calculate emissions of multiple pollutants from ground level area sources (e.g. Flesch et al., 1995; Flesch et al., 2005; McGinn et al., 2007; Todd et al., 2008; Faulkner et al., 2009; Goodrich et al., 2009). The ISCST3 model was used from 2003-2007 because it was the preferred regulatory model at the time. From 2007 to present, AERMOD has been used because it replaced ISCST3 as the preferred regulatory model. As described above, no significant changes in the calculated PM_{10} emission rates are expected due to the change from ISCST3 to AERMOD for back-calculating emission rates from measured concentrations.

ISCST3 and AERMOD were chosen over other available models to back-calculate emission rates because they are the most relevant models for the end-use of the data. That is, emission factors are used in the regulatory community to estimate total emissions of pollutants, but they are also used for dispersion modeling to assess the impact of new or modified sources on public exposure to pollutants. Such dispersion modeling is conducted with the most up-to-date EPA-approved regulatory model (presently either CALPUFF or AERMOD). As demonstrated by Faulkner et al. (2007), in general, emission factors back-calculated from ambient concentrations using one dispersion model should not be used as inputs into another model. For example, using the same downwind measured concentrations, Faulkner et al. (2007) reported that the emission flux of ammonia from an area source calculated using the backward Lagrangian stochastic model WindTrax™ was 14% lower than the average emission flux calculated using AERMOD. Therefore, if emission factors derived using WindTrax™ were utilized in AERMOD to predict pollutant concentrations to which the public may be exposed at the same receptor from which emission rates were calculated, AERMOD would predict a concentration 14 percent lower than the true concentration. If, on the other hand, emission factors were derived using AERMOD and utilized in AERMOD to predict concentrations at that same receptor, the modeled concentration would be equal to the measured concentration.

Dispersion modeling using measured concentrations was chosen over opacity measurements, which can produce a large number of data points in a short period of time, because opacity measurements are more closely correlated with concentrations of TSP than PM_{10} or $PM_{2.5}$.

RESULTS

Particle Size Analysis

High Volume TSP samples (2002-2003) or LVTSP samples (2004-2009) were analyzed to characterize the particle size distribution of PM emitted from almond harvest operations as described by Faulkner et al. (2009). Results are shown in **Table 2**. These data were not used to determine PM_{10} emission rates, but the consistently lower particle sizes observed in samples from Colusa County demonstrate that PM_{10} emission rates from these locations are likely conservative (i.e. would be more protective of public health) relative to emission rates derived from sampling events in the southern part of the State since a larger fraction of TSP would be smaller than 10µm in diameter.

Table 2. Particle size distribution characteristics of TSP samples.

Year	Location	MMD (µm AED)	GSD	ρ_p (g/cm^3)	Source
2002	Average	19.0	2.0	2.8	Flocchini (2002)
2003	Average	18.8	2.1	2.6	Flocchini (2003)
2004	Average	17.5	2.1	2.4	Flocchini et al. (2004)
2005	Average	15.8	2.0	2.6	Flocchini et al. (2005)
2006	Kern Co.	15.6	2.17	2.6	Goodrich et al. (2009)
	Colusa Co.	12.8	2.21	2.6	
2007	Average	14.3	11.0	2.0	Faulkner et al. (2009)
2008	Colusa Co. - Sweeping	11.7	3.0	2.6	Faulkner and Capareda[a]
	Colusa Co. - Pick up	12.3	2.6	2.6	
2009	Colusa Co. - Sweeping	10.7	2.0	2.0	Faulkner et al.[b]
	Colusa Co. - Pick up	10.6	2.0	2.0	

[a] Manuscript under review for publication in *Transactions of the ASABE*; data can be found in the 2008 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2009).
[b] Manuscript under review for publication in *Transactions of the ASABE*; data can be found in the 2009 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2010).

Sweeping

Measured emission rates from conventional sweeping operations are summarized in **Table 3**. The emission rate observed in 2008 is likely an erroneous data point. Based on visual observations and the authors' experience with PM sampling, dust plumes were not commensurate with an emission rate of over 1,600 kg $PM_{10}/km^2/yr$. Wind speeds during testing of conventional sweeping in 2008 ranged as low as 0.1 m/s with an average wind speed of 1.8 m/s. Faulkner et al. (2008) demonstrated that AERMOD is increasingly sensitive to changes in wind speed at values below 3 m/s (**Figure 2**). As wind speeds approach these low ranges, the Monin-Obukhov length calculated by AERMOD's meteorological pre-processor (AERMET) decreases below 1 m, indicating an extremely stable atmosphere that rarely occurs in most locations. These stable atmospheric conditions lead to higher estimates of emissions for a given downwind concentration. Dispersion modeling of these tests mostly occurred within the wind speed range at which AERMOD is particularly sensitive to changes in wind speed, as demonstrated by the unusually high standard error for this data point as well.

Table 3. Measured emission rates from conventional sweeping operations (kg $PM_{10}/km^2/yr$).

Year	Average Baseline PM_{10} Emission Rates (kg $PM_{10}/km^2/yr$)			Source
	VPM	ISCST3[a]	AERMOD[a]	
2004	676			Flocchini et al. (2004)
2005		611 (41)		Flocchini et al. (2005)
2006		443 (52)[b]		Goodrich et al. (2009)
2008			1,606 (533)[c]	Faulkner and Capareda[d]
2009			340 (80)	Faulkner et al.[e]

[a] Averages with standard errors in parentheses (where available).

[b] Emission rates from Goodrich et al. (2009) were multiplied by 1.17 to convert from what the authors refer to as "true PM_{10} concentrations" to concentrations measured by FRM samplers.

[c] Likely overestimated due to low wind speeds during sampling.

[d] Manuscript under review for publication in *Transactions of the ASABE*; data can be found in the 2008 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2009).

[e] Manuscript under review for publication in *Journal of Air and Waste Management*; data can be found in the 2009 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2010).

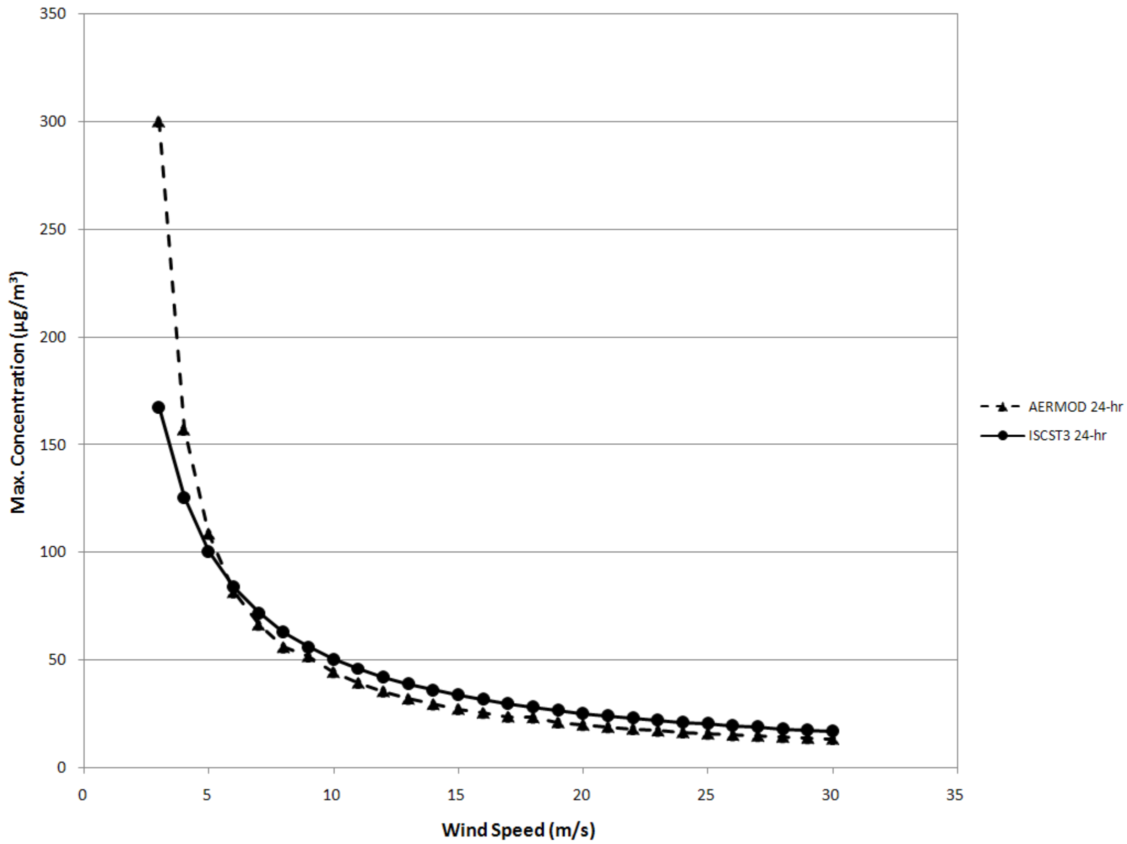

Figure 2. Maximum pollutant concentrations from a ground level area source modeled using a single emission rate (Faulkner et al., 2008). The sharp increase in predicted concentrations as wind speed decreases to ~3 m/s indicates AERMOD's extreme sensitivity to low wind speeds.

Pick up

Measured emission rates from conventional nut pick up operations are summarized in **Table 4**. Wind speeds during conventional pick up tests in 2009 ranged as low as 0.1 m/s with a maximum wind speed of 1.7 m/s. Therefore, this data point is subject to the same problems described above for sweeping in 2008. However, given the relatively large standard errors of observed emissions, this point was not statistically different than observed emissions from 2008 (α = 0.05) and was included in analyses as a conservative (i.e. protective) estimate of emissions.

Table 4. Measured emission rates from conventional pick up operations (kg $PM_{10}/km^2/yr$).

Year	Average Baseline PM_{10} Emission Rates (kg $PM_{10}/km^2/yr$)			Source
	VPM	**ISCST3**[a]	**AERMOD**[a]	
2002	2107			Flocchini et al. (2002)
2003		2,056		Flocchini et al. (2003)
2004		484 (63)		Flocchini et al. (2004)
2007		413 (50)	400 (55)	Faulkner et al. (2009)
2008			2,132 (1,351)	Faulkner and Capareda.[b]
2009			3,726 (770)	Faulkner et al.[c]

[a] Average with standard errors in parentheses (where available).
[b] Manuscript under review for publication in *Transactions of the ASABE*; data can be found in the 2008 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2009).
[c] Manuscript under review for publication in *Journal of Air and Waste Management*; data can be found in the 2009 Annual Report submitted to the Almond Board of California (Capareda and Faulkner, 2010).

RECOMMENDATIONS

Two factors must be considered in determining whether the PM_{10} emission factors determined in recent studies provide an improvement to the existing PM_{10} emission factors for almond harvesting. These are:

1. Relative merits of PM_{10} concentration measurements and emission factor computation techniques in terms of demonstrated accuracy, and,
2. The representativeness of the operations that took place at the time of measurements.

The techniques used to calculate PM_{10} emission rates from measured PM_{10} concentrations, including source characterization, sample collection, analysis, and computation, are far superior in recent years (post-2002) than those used to produce the PM_{10} emission factors currently in use for almond harvest operations. Important sensitivities have been uncovered in the VPM that restrict its useful range to a small number of experiments conducted under close to ideal circumstances. The ISCST3 and AERMOD models have been found to be far more reliable under a wide range of row direction, canopy, wind direction, and source to sampler proximity conditions (Flocchini et al., 2005). Thus, PM_{10} emission rates computed using the ISCST3 and AERMOD models from data collected explicitly with that intent are judged to be of superior accuracy to that computed using the VPM alone.

No data have been collected to characterize PM_{10} emissions from almond shaking operations as a part of the on-going projects sponsored by the Almond Board of California. The current emission factor was estimated as 10 percent of the emission factor for sweeping. (This was based on visual observation and the judgment of Gene Beach of the Almond Hullers and Processors Association and the Agricultural Technical Committee chaired by the District). Given the lack of data, we recommend that the emission factor for shaking be maintained as 10% of the emission factor for sweeping.

The average baseline emission rate for sweeping operations calculated using the improved method (i.e. back-calculating using ISCST3 or AERMOD) excluding data from 2008 is 465 kg $PM_{10}/km^2/yr$. Given the aforementioned problems AERMOD experiences with the Monin-Obukhov length is calculated to be less than 1m, we believe exclusion of the 2008 data point is justified. Therefore, **we recommend that an emission factor of 465 kg $PM_{10}/km^2/yr$ be utilized for conventional sweeping operations.** This recommendation represents an increase in the current emission factor of 50 kg $PM_{10}/km^2/yr$.

The average baseline emission rate for pick up operations calculated using the improved method (i.e. back-calculating using ISCST3 or AERMOD) and using a single value of 407 kg $PM_{10}/km^2/yr$ for 2007 (since ISCST3 and AERMOD data points are not independent) is 1,760 kg $PM_{10}/km^2/yr$. Given the obvious grouping of the data (with years 2004 and 2007 forming one group and years 2003, 2008, and 2009 forming the other group), the average of the three highest measurements is 2,640 kg $PM_{10}/km^2/yr$, which is still well below the current PM_{10} emission factor for almond pick up operations. To ensure that the public is sufficiently protected from high concentrations of ambient PM_{10}, we recommend that average of the three highest measured emission rates be used for pick up operations. Therefore, **we recommend altering the current emission factor for conventional almond pick up operations to 2,640 kg $PM_{10}/km^2/yr$**. This recommendation represents a decrease in the current emission factor of 1,477 kg $PM_{10}/km^2/yr$, but because it is based only on the three highest emission rates observed, it should still be protective of the public.

In evaluating PM_{10} emission factors for use throughout the District, it is important that they be derived using the best possible analytical techniques, but it is also essential that the operations monitored for emission factor development represent standard industry practices. For the sake of brevity, the representativeness of practices has not been addressed in this paper, but details of harvest practices are well documented in the cited literature. Harvest practices observed are common throughout the Central Valley, as attested by an industry observer that has acted as a liaison between researchers and cooperating almond producers since 2005.

Our recommendations for PM_{10} emission factors for almond harvesting are as follows (**Table 5**):

Table 5. Recommended PM_{10} emission factors for almond harvest operations**.**

Operation	Emission Factor	
	(kg/km^2)	**(lbs/acre)**
Shaking	47	0.41
Sweeping	465	4.15
Pick up	2,640	23.6
Total	**3,152**	**28.2**
Current	4,574	40.8
Change	-31%	

CONTEXT

The 2008 California Air Resources Board (CARB) Emissions Inventory for PM_{10} estimates statewide PM_{10} emissions of 771,000 tons PM_{10}/yr. Of that total, farming operations are estimated to contribute 59,700 tons/yr (7.7% of statewide total) of which 14,400 tons/yr is attributed to harvest operations (CARB, 2009).

The emissions inventory for agricultural harvest operations in California is based off of emission factors for almonds, cotton, and wheat (**Table 6**). Emissions for harvest of all other crops are determined by dividing the emission factors shown in **Table 6** by a subjective divisor specified by CARB (2003).

Table 6. California harvest emission factors (CARB, 2003).

Harvest Operation	Emission Factor (lbs PM_{10}/acre)
Almond	
Shaking	0.37
Sweeping	3.7
Pick up	36.7
Total	**40.8**
Cotton	
Picking	1.7
Stalk cutting	1.7
Total	**3.4**
Wheat	
Combining	5.8
Total	**5.8**

If carried through to other crops, the proposed reduction in almond emission factors would reduce the emissions inventory for harvest operations by approximately 5,600 tons PM_{10}/yr (**Table 7**). This reduction represents 9.5% of the total emission from farming operations and less than 1% of the total statewide emissions for California.

Table 7. Emissions inventory changes based on proposed emission factor**.**

Crop	Bearing Acres[a]	Current Emission Factor		Emissions (tons/yr)	
		Divisor[b]	Value (lbs PM_{10}/acre)	w/ Current EF[c]	Proposed EF[c]
Almonds	649,892	N/A	40.8	13,300	9,160
Chestnuts	334[d]	10	4.08	0.68	0.47
Dates	5,131	20	2.04	5.23	3.62
Dried Figs	9,069	20	2.04	9.25	6.39
Macadamia Nuts	102	10	4.08	0.21	0.14
Pecans	2,487	10	4.08	5.07	3.51
Pistachios	114,832	10	4.08	234	162
Walnuts	222,887	1	40.8	4,550	3,140
Total				**18,100**[e]	**12,500**

[a] Source: USDA, 2009a
[b] Emission factor = (Almond Emission Factor) / (Divisor) (CARB, 2003)
[c] EF = emission factor
[d] Total acres; bearing acres not available
[e] This number differs from the 2008 CARB emissions inventory number in the text (14,400 ton/yr), likely based on differences in bearing acres to which emission factors were applied.

SUMMARY

The current emissions inventory for harvest operations in California is based on measurements of emissions from three cropping systems using VPM methodology. The PM_{10} research supported by the Almond Board of California from 2002 to present represents the most comprehensive PM_{10} emissions measurement effort for agricultural operations to date.

Beginning in 2003, emissions have been estimated using dispersion modeling to back-calculate emission rates from downwind ambient concentrations. This methodology, developed to overcome the known shortcomings of the VPM model (Flocchini et al., 2001) can be considered a significant step forward in the development of emission factors for almond harvest operations. Based on seven years of data collection using this improved method, we recommend increasing the emission factors for almond shaking and sweeping to 46.5 and 465 kg PM_{10}/km^2/yr, respectively, and lowering the emission factor for almond pick up to 2,640 kg PM_{10}/km^2/yr. This estimate of pick up emissions is based on the three highest emission rates measured and is, therefore, a conservative estimate of emissions (i.e. it is protective of the public). These changes would result in an overall decrease in the emission factor for almond harvest of 31 percent.

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