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Evaluation of Conservation Management Practices for Reducing PM Emissions from Almond Harvesting Operations

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***Abstract*.** Almond harvest accounts for a significant amount of PM_{10} emissions in California each harvest season. This paper addresses the adjustment of sweeper depth and its effect on PM_{10} emissions from sweeping and pickup operations. Ambient total suspended particulate (TSP) and PM_{10} sampling was conducted during harvest with alternating control (proper sweeper setting) and experimental treatment (sweeper depth 1.27cm [0.5 in.] that is lower than recommended treatments). On-site meteorological data was used in conjunction with inverse dispersion modeling using the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) to develop emission rates from the measured concentrations.

The emission factors developed from this study using proper sweeper settings are 1,725 $\pm$1,345 kg $PM_{10}/km^2/yr$ for sweeping and 2, 232 $\pm$ 1,929 kg$PM_{10}/km^2/yr$ for pickup operations. The emission factor for sweeping is significantly higher than those reported in previous studies and is higher than the emission factor currently in use by the California Air Resources Board. The emission factor for nut pickup is similar to those reported in previous studies but lower than the emission factor of 4,120 kg PM_{10}/km^2 currently in use by the California Air Resources Board.

The results of this research showed no differences in emissions of regulated pollutants during the sweeping process as a function of sweeper depth, but emissions during pickup were significantly lower (by about half) for windrows formed using proper sweeper settings versus those formed using improper sweeper settings (i.e. 2,232 versus 4,858 kg $PM_{10}/km^2/yr$).

Keywords. *Almond PM, emission factors, conservation management practices, dispersion modeling, almond harvesting operations, sweeper depth adjustment.*

Introduction

California almond farmers produce over 75% of the world's almond supply. In 2007, approximately 617Gg of almonds were harvested in California on approximately 249,000 bearing hectares with a total value of $2.3 billion.[1] Over 70% (174,217 ha) of the bearing crop is located within the San Joaquin Valley Air Pollution Control District (SJVAPCD), which was only recently removed from non-attainment status for PM_{10} under the National Ambient Air Quality Standards (NAAQS). Due to the recent classification of the San Joaquin Valley (SJV) as a serious non attainment area for PM_{10}, the SJVAPCD is in the midst of an aggressive campaign to reduce PM_{10} emissions from all sources. With the removal of the permitting exemption from agriculture in 2007 and as a result of California Senate Bill 700, agricultural industries have become a target of scrutiny. The SJVAPCD has found that the available information on emission factors for agricultural operations is severely limited and needs improvement.

The current emission factor applied to all almond harvesting operations is 4,570 kg PM_{10}/km^2, accounting for 11Gg of PM_{10} each year.[2] The almond harvest emission factor is composed of the sum of the emission factors for the three different harvest operations: shaking, sweeping and pickup. First, the trees are shaken to remove the product from the tree allowing it to air dry sitting on the ground; this accounts for 41.5 kg PM_{10}/km^2 of the emission factor. The almonds are then swept into windrows, accounting for 415 kg PM_{10}/km^2. Finally, pickup machines remove the product from the field, currently accounting for 4,120 kg PM_{10}/km^2. Each harvest process accounts for significant emissions due to the total area to which the emission factors are applied.

Goodrich et al.[3] used inverse dispersion modeling with Industrial Source Complex Short Term version 3 (ISCST3) to determine a PM_{10} emission factor for conventional almond sweeping (using three blower-passes per harvested row) and reduced-pass almond sweeping (using one blower-pass per harvested row). They reported an emission factor of 379 ± 209 kg $PM_{10}/km^2/yr$ for conventional sweeping, which is slightly lower than the current emission factor for sweeping developed in the early 1990s. Goodrich et al.[3] also reported that reducing the number of blower-passes from three to one lowered the average PM_{10} emission factor by 49% to 192 ± 104 kg $PM_{10}/km^2/yr$.

Downey et al.[4] tested the effect of reducing harvester ground speed on opacity measurements in the exhaust plume of almond pick-up machines. They found that reducing harvester ground speed without reducing the PTO speed of the tractor led to lower opacity measurements in the plume relative to emissions from typical harvest operations, but Downey et al.[4] did not report emissions of PM_{10} or $PM_{2.5}$.

Faulkner et al[5] used inverse dispersion modeling with both ISCST3 and the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) to test the effect of reduced harvester ground speed on emissions of TSP, PM_{10}, and $PM_{2.5}$ from nut pickup operations in an effort to determine the implications of the work of Downey et al.[4] for regulated pollutants. Faulkner et al [5] reported no statistical differences in PM_{10} or $PM_{2.5}$ emission factors as a function of harvester speed or dispersion model used, but TSP emission factors were lower for the slower harvester speed, which supports the findings of Downey et al.[4] that plume opacity varies with harvester speed. The emission factors developed using AERMOD were 359 ± 275 kg $PM_{10}/km^2/yr$ and 24 ± 19 kg $PM_{2.5}/km^2/yr$. The PM_{10} emission factor developed by Faulkner et al[5] was significantly lower than the emission factor of 4,120 kg $PM_{10}/km^2/yr$ currently in use by the California Air Resources Board.

According to current emission factors, sweeping accounts for 10% of the total PM_{10} emissions from almond harvesting operations. As demonstrated by Goodrich et al[3], sweeping practices may dramatically affect PM emissions from sweeping operations. Sweeping practices may also affect emissions from pickup operations as increased soil material in the windrow may increase PM emissions during nut pickup. Sweeper manufacturers recommend setting the sweeper head such that the steel teeth of the implement just clear the surface of the orchard floor without causing ground interference. However, many sweeper operators set the sweeper head lower than recommended by manufacturers in an attempt to decrease the number of unharvested nuts left on the orchard floor. This lower setting leads to ground interference by the sweeper unit, which may increase emissions from sweeping operations, increase emissions from pickup operations, and increase the amount of dirt transported to the huller with the almonds, thus leading to increased processing costs for the producer. Downey et al.[4] reported a 32% increase in opacity measurements in the dust plume from nut pickup operations harvesting windrows of nuts formed using improper sweeper depth adjustments (1.27 cm [0.5 in.] lower than recommended by the manufacturer) compared to dust emitted from harvest operations of windrows formed with proper settings. Again, Downey et al.[4] did not report emissions of regulated pollutants.

Objectives

The objectives of this study are as follows:

1. Quantify the possible emission reductions during sweeping and pickup operations achieved through the use of proper sweeper height settings;
2. Quantify the difference in soil content of almonds taken to the huller between almonds windrowed using proper and improper sweeper height settings; and
3. Generate additional data regarding PM_{10} and $PM_{2.5}$ emissions from almond harvest to augment the existing dataset.

Materials and Methods

This research focuses on the emissions from sweeping and pickup operation of almond harvesting as a function of sweeper height setting. Sweeping treatments included a control treatment of proper sweeper setting (no ground interference) and an experimental treatment in which 1.27 cm (0.5 in.) ground interference occurred between the steel teeth of the sweeper and the orchard floor. Pickup operations for both sweeper treatments were identical in order to isolate the effect of sweeper setting on PM emissions. The sweeper used in this work was a Flory Model 9610, and the pickup machine was a Flory Model 850 PTO Harvester.

Plots were organized in a randomized complete block design with replication as the blocking factor. Each plot consisted of ten tree rows. Almond growers commonly plant a combination of almond varieties in a given area to achieve cross pollination. The usual combination is a Nonpareil variety with a “pollinator” variety or a Nonpareil with two “pollinator” varieties, such as Carmel and Butte, in each orchard. The Nonpareil varieties are normally planted every other row with the other varieties planted on an alternating basis, but during the harvesting of one variety, all windrows are used for the pickup operation, virtually using the whole area for the harvest process. Therefore, while each plot consisted of ten tree rows and ten windrows were created, only five tree rows were harvested.

The remaining tree rows are harvested when the nuts mature using an identical harvest process. The overall emission factor is the sum of the two harvesting operations for each variety Because the harvest processes are identical for each variety, the emission rates developed from sampling were assumed represent half the total annual emissions from harvest operations.

Sampling was conducted in the Central Sacramento Valley near Arbuckle, California, in an orchard with a Hillgate loam which was 18.8% clay. The trees in this orchard were ten years old and were oriented north-south. Trees were planted in 400 m rows with 6.7 m between rows and 5.5 m between trees in the same row. Sampling was conducted during sweeping of all plots. Nuts were then allowed to air dry in windrows for several days before sampling was again conducted on the same plots during nut pickup.

Ambient Sampling

Samplers were placed upwind and downwind of each plot to measure the ambient particulate matter (PM) concentrations during sweeping and pickup operations. At each sampling location, collocated, low-volume TSP and federal reference method (FRM) PM_{10} samplers (Model PQ100 Inlet; BGI Inc.; Waltham, MA) were used to determine PM concentrations. FRM $PM_{2.5}$ samplers were not used because the low concentrations of $PM_{2.5}$ emitted during almond harvest operations during the sampling period did not allow for sufficient loading on the filters to render reliable FRM $PM_{2.5}$ measurements. (According to Goodrich et al.[3] $PM_{2.5}$ constituted only 0.9% of TSP sampled during sweeping operations). Sampler sets were placed at four locations approximately 15 m from the edge of the plot such that there was enough room for the sweeper or harvester to make turns and remain upwind of the sampler array. The downwind sampling locations were spaced evenly along the width of each plot (Fig. 1). The four downwind sampler sets provided four independent measurements of concentration leading to four independent estimates of the flux for each test. Samplers were set up at both upwind and downwind locations to measure the net increase in PM concentrations due to the harvesting process.

Due to the errors associated with FRM sampling in agricultural environments identified by Buser et al.[6], both TSP measurements and FRM PM_{10} measurements were conducted. TSP measurements were conducted with samplers designed by Wanjura et al.[7] to reduce variations in sampler flow rate that lead to high uncertainty in FRM concentration measurements. PM_{10} measurements were conducted using the same air-flow control unit as the TSP samplers and an FRM PM_{10} sampling inlet.

The filters used in the TSP and PM_{10} samplers were weighed using a 10 μg analytical balance (AG245; Mettler-Toledo International Inc.; Columbus, OH). Each filter was pre- and post-weighed three times. If the standard deviation of the three weights was less than 50 μg, the average of the three weights were taken as the pre- and post-weights, respectively. If the standard deviation of the three weights was greater than 50 μg, the filter was reweighed. The change in filter mass, flow rate through the sampler, and sampling duration for each sampler and test were used to calculate the PM concentration (eq 1).

$$C = \frac{\Delta m_f}{Q_{air} \cdot t_D} \qquad (1)$$

where: C = concentration (μg/m^3),
Δm_f = change in mass on the filter (μg),
Q_{air} = sampling flow rate (m^3/sec), and
t_D = sampling duration (sec).

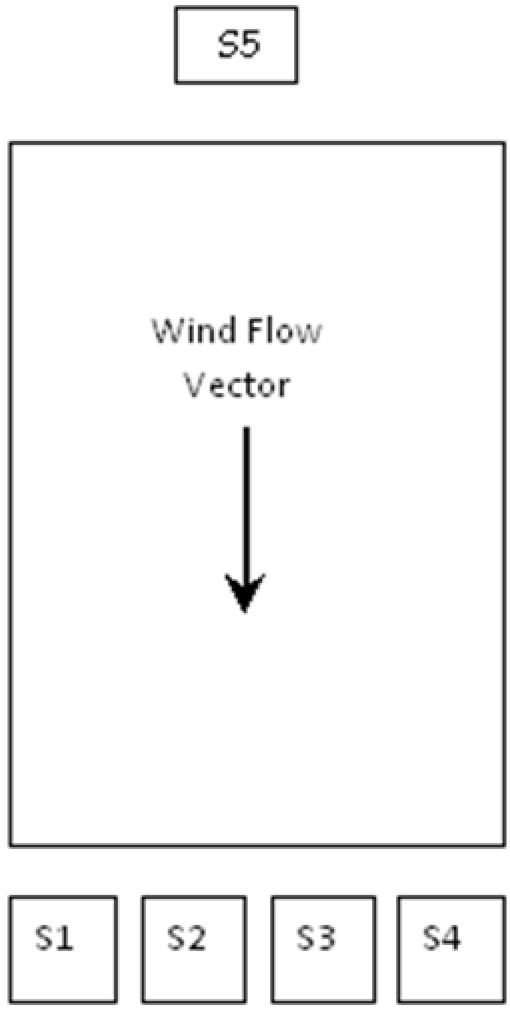

Figure 1. Sampler Configuration.

The particle size distribution (PSD) of PM collected on TSP filters having more than 200 µg of PM were analyzed using a particle size analyzer (Mastersizer 2000, Malvern Instruments Inc.) with a detection range of 0.2 µm to 2000 µm. Samples were prepared according to the procedure described by Faulkner and Shaw[8] with the exception that the entire filter was analyzed rather than core samples. A minimum net filter mass of 200 µm was required to obtain accurate PSDs. The PSD of most ambient PM can be described by a log-normal distribution, characterized by a mass median diameter (MMD) and geometric standard deviation (GSD).[9] The best-fit log-normal distribution of the percent mass vs. equivalent spherical diameter (ESD) was determined for each sample. The MMDs were converted from ESD to aerodynamic equivalent diameter (AED) using a particle density (ρ_p) of 2.6 g/cm^3 and a shape factor of 1.00.

$$AED = ESD\sqrt{\frac{\rho_p}{\chi}} \tag{2}$$

where: AED = aerodynamic equivalent diameter,
ESD = equivalent spherical diameter,
ρ_p = particle density (g/cm^3), and
χ = shape factor.

The resulting PSD was then used to determine the true percentage of PM_{10} and $PM_{2.5}$ on each filter according to eq 3:

$$C_i = C_{TSP}\int_o^i f(x)dx \tag{3}$$

where: C_i = concentration of PM smaller than or equal to size i,
C_{TSP} = concentration of total suspended particulate (TSP),
i = indicator size (10 μm for PM_{10} and 2.5 μm for $PM_{2.5}$), and
f(x) = probability density function of particle size distribution function of the dust.

The net increase in concentrations of TSP, PM_{10}, and $PM_{2.5}$ between upwind and downwind samplers was assumed to be solely attributable to the activity of interest (i.e. sweeping or pickup operations, respectively). During concentration measurements, the following instruments were used to collect onsite meteorological data:

- A 2D sonic anemometer (WindSonic1, Gill Instruments Ltd., Lymington Hampshire) was used to measure the wind speed and direction 3 m above the ground surface at a frequency of 4 Hz;
- A 3D sonic anemometer (Model 81000, R.M. Young Co., Traverse City, MI) was used to collect data for use in defining the stability of the surface layer at 2 m above the ground at a sampling frequency of 4 Hz;
- A barometric pressure sensor (Model 278, Setra Systems Inc., Boxborough, MA) recording every 5 minutes;
- A temperature and relative humidity probe mounted in a solar radiation shield at 2 m (HMP50, Campbell Scientific Inc., Logan, UT) recording every 5 minutes.
- Two pyranometers, one mounted face up (CMP 22, Kipp and Zonen, Delft, The Netherlands) and one mounted face down (CMP 6, Kipp and Zonen, Delft, The Netherlands) were used to measure net solar radiation at a sampling frequency of 5 minutes.

The dimensions of each test plot and corresponding meteorological data were then used with AERMOD to determine fluxes (μg/m^2-sec) for the each sampling period.

Modeling

AERMOD is a steady-state plume model used to relate near-field pollutant concentrations to pollutant emissions. AERMOD assumes that the horizontal distribution of a pollutant throughout the planetary boundary layer (PBL) can be described by a Gaussian distribution. The vertical distribution in the stable boundary layer (SBL) is also described by a Gaussian distribution, but in the convective boundary layer (CBL), the vertical distribution is described with a bi-Gaussian probability distribution function.[11] For this research, the model-user interface for AERMOD was BREEZE AERMOD 6 version 6.2.2 (Trinity Consultants, Dallas, TX).

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.[10] For this research, emission factors were developed for PM_{10} or $PM_{2.5}$ from almond sweeping and pick-up operations.

- Meteorological data measured onsite during each test and site data such as source-receptor orientation were processed into the proper formats and in put input into each dispersion model. A unit emission flux of 1 μg/m^2/sec was modeled.
- True PM_{10} and $PM_{2.5}$ concentrations were determined using the TSP filters and PSD analysis according to eq 3.
- The result of dispersion modeling runs (step 1) was a unit flux concentration (UFC) for each test at each sampling location. The UFC represents the change in predicted concentration for each unit increase of flux. The actual flux from the harvesting operation at each sampling location was obtained by dividing the measured pollutant concentration by the UFC (eq 4).

$$F = \frac{C_m}{UFC} \qquad (4)$$

where: F = pollutant emission flux (μg/m^2-sec),
C_m = measured concentration (μg/m^3), and
UFC= unit flux concentration.

- Step 3 was repeated for TSP, FRM PM_{10}, true PM_{10}, and true $PM_{2.5}$ concentrations.
- Fluxes were converted to emission factors by manipulating the units (eq 5) and multiplying by two to account for the multiple harvest operations required to harvest Nonpareil and "pollinator" varieties.

$$\text{EF (kg/km}^2\text{)} = \text{ER (kg/km}^2\text{-hr) X Time of sampling (hrs)} \qquad (5)$$

An analysis of variance (ANOVA) test was conducted using the General Linear Model function is SPSS (SPSS v. 14.0; SPSS, Inc.; Chicago, IL) to determine whether differences existed in emission factors between treatments ($\alpha = 0.05$). For both sweeping and pickup tests, the null hypothesis tested was that the means from each sweeping treatment were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test.

Soil Content

The soil content of the windrowed materials was compared by collecting three samples from the windrows of each plot. Samples weighed approximately 750g and were collected using a flat-blade shovel to pickup all of the material in 30.5 cm (12 inch) length of windrow.

During pickup operations, three samples from each plot were collected of the materials that were being transferred into the nut cart from the chain conveyor of the pickup machine after being conditioned by passing under the blower. Conditioned samples were collected within 25 feet of the windrow samples. Each conditioned sample was collected by filling a 2.0 gallon bucket as the material fell from the chain conveyor at the rear of the pickup machine. Because the samples were collected from the material stream that would have entered the nut cart to be taken to the huller, the soil content of the samples was representative of the soil content seen by the processors. Any differences in foreign matter contect between the windrow samples and the conditioned samples were assumed to be removed during pickup either by falling through the chain conveyor or being blown into air by the fan on the pickup machine.

After collection, all windrow and conditioned samples were analyzed using a RoTap sieve shaker (Model RX-94; W.S. Tyler; Mentor, OH) to determine the mass percent of soil less than 1 mm (#18 sieve) and 75 µm (#200 sieve), respectively . Samples were processed through a set of sieves for 20 min. each. The designation of the sieves used were: 16 mm (5/8 in), 9.5 mm (3/8 in), 8 mm (5/16 in), 1 mm (#18) and 75 µm (#200). The sieves were arranged in decreasing opening size from top to bottom. The net mass remaining in each sieve was used to determine the mass percent of the original sample mass within each size range. Stones, sticks, and leaves were also separated from the samples by hand and their masses determined.

An analysis of variance (ANOVA) test was conducted using the General Linear Model function is SPSS (SPSS v. 14.0; SPSS, Inc.; Chicago, IL) to determine whether differences existed in the composition of samples formed with proper and improper sweeper settings as well as conditioned nuts that were windrowed with proper and improper sweeper settings ($\alpha = 0.05$). For both sweeping and pickup tests, the null hypothesis tested was that the mean masses of sieved samples per kilogram of raw nuts from each sweeping treatment were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test.

Results and Discussion:

Emission Factors

Four emission factors were developed for each harvester speed treatment with each model: a TSP emission factor, an FRM PM_{10} emission factor, a true PM_{10} emission factor, and a true $PM_{2.5}$ emission factor. Emission factors were calculated on an annual basis rather than a per-harvest basis.

TSP and FRM PM_{10} concentrations were measured during all tests at the four downwind locations and one upwind location. Net concentration measurements from the TSP and FRM PM_{10} samplers were used to develop the annual TSP and FRM PM_{10} emission factors shown in tables 1 and 2, respectively. Statistical outliers, which occurred at the edge of the pollutant plume where the greatest uncertainties in dispersion calculations exist, were excluded. Statistical differences between treatments were detected in TSP emission factors from sweeping ($p = 0.014$) and pickup operations ($p = 0.009$). Surprisingly, the TSP emissions from sweeping with the improper sweeper setting were lower than those from the proper setting, but the TSP emissions from pickup of windrows formed with the improper sweeper setting were higher than those from pickup of windrows formed with proper sweeper setting. The emission factors for all treatments were highly variable as shown by the high standard deviations. TSP emission factors for sweeping using both treatments were substantially higher than those reported by Goodrich et al. (2008), and emission factors for nut pickup were higher than those reported by Faulkner et al. (2007). The results validate the results reported by Downey et al.[4] in that the higher TSP emissions from pickup of windrows formed with improper sweeper settings would lead to less opacity in the plume emitted by the pickup machine. It should be noted that differences in TSP emissions do not necessarily translate into differences in PM_{10} and/or $PM_{2.5}$ emissions.

Table 1. Annual TSP emission factors ($kg/km^2/yr$).[a]

Sweeping		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**12,282 x**	**3,514 y**
Standard Deviation	**13,395**	**2,494**
N	**21**	**16**
Pickup		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**4,223 x**	**14,885 y**
Standard Deviation	**3,965**	**15,208**
N	**17**	**14**

[a] No statistical differences were detected in means in the same row followed by the same letter ($\alpha = 0.05$).

Table 2. Annual FRM PM_{10} emission factors ($kg/km^2/yr$).[a]

Sweeping		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**5,771 x**	**5,287 x**
Standard Deviation	**1,710**	**1,667**
N	**19**	**20**
Pickup		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**2,348 x**	**4,672 x**
Standard Deviation	**2,481**	**3,855**
n	**16**	**12**

[a] No statistical differences were detected in means in the same row followed by the same letter ($\alpha = 0.05$).

No statistical differences were detected between treatments in FRM PM_{10} emissions from sweeping ($p = 0.840$) or pickup operations ($p = 0.063$), however differences in pickup operations were significant at the $\alpha = 0.10$ level. Again, FRM PM_{10} emission factors for sweeping using both treatments were substantially higher than those reported by Goodrich et al[3], and emission factors for nut pickup were higher than those reported by Faulkner et al[5].

Measured emissions for sweeping were substantially higher than the current PM_{10} emission factor for almond sweeping of 415 kg PM_{10}/km^2, while emissions for nut pickup using a proper sweeper setting were approximately half of the current emission factor of 4,120 kg PM_{10}/km^2. Emissions from pickup of windrows formed using improper sweeper settings are close to the current pickup emission factor for PM_{10}.

PSD analyses were conducted on all TSP filters for which sufficient loading was present (i.e. obscurance above 1%), and the PSDs were fit with log-normal distributions. Average MMDs and GSDs of the distributions are shown in Table 3, along with the average percentages of PM that are PM_{10} and $PM_{2.5}$, respectively. No statistical differences were detected in the MMDs or GSDs between treatments for sweeping ($p = 0.449$ for MMD; $p = 0.546$ for GSD) or pickup operations ($p = 0.236$ for MMD; $p = 0.622$ for GSD).

Table 3. Particle size distribution parameters from TSP filters.[a]

Sweeping		
	Proper Sweeper Setting	Improper Sweeper Setting
MMD (µm AED)[b,c]	**11.7 x**	**12.7 x**
GSD[d]	**3.0 x**	**2.9 x**
Pickup		
	Proper Sweeper Setting	Improper Sweeper Setting
MMD (µm AED)	**12.3 x**	**11.3 x**
GSD	**2.6 x**	**2.5 x**

[a] No statistical differences were detected in means in the same row followed by the same letter (α = 0.05).
[b] MMD = mass median diameter
[c] AED = aerodynamic equivalent diameter
[d] GSD = geometric standard deviation

The average true PM_{10} and $PM_{2.5}$ emission factors are shown in tables 4 and 5, respectively. No statistical differences were detected between treatments in the emission factors for true PM_{10} from sweeping operations ($p = 0.413$), but emission from pickup operations of windrows formed using proper sweeper settings were less than half of those of pickup operations of windrows formed using improper sweeper depth setting ($p = 0.033$). Similarly, no statistical differences were detected between treatments in the emission factors for true $PM_{2.5}$ from sweeping operations ($p = 0.215$), but emission from pickup operations of windrows formed using proper sweeper settings were less than half of those of pickup operations of windrows formed using improper sweeper depth setting ($p = 0.005$). Again, both true PM_{10} and true $PM_{2.5}$ emission factors for sweeping using both treatments were substantially higher than those reported by Goodrich et al[3], and emission factors for nut pickup were higher than those reported by Faulkner et al[5].

Again, measured emissions for sweeping were substantially higher than the current PM_{10} emission factor for almond sweeping of 415 kg PM_{10}/km^2, while emissions for nut pickup using a proper sweeper setting were approximately half of the current emission factor of 4,120 kg PM_{10}/km^2. Emissions from pickup of windrows formed using improper sweeper settings are close to the current pickup emission factor for PM_{10}.

Table 4. Annual true PM_{10} emission factors ($kg/km^2/yr$).[a]

Sweeping		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**1,725 x**	**1,335 x**
Standard Deviation	**1,345**	**517**
n	**7**	**10**
	Pickup	
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**2,232 x**	**4,858 y**
Standard Deviation	**1,929**	**2,846**
n	**10**	**8**

[a] No statistical differences were detected in means in the same row followed by the same letter (α = 0.05).

Table 5. Annual true $PM_{2.5}$ emission factors ($kg/km^2/yr$).[a]

Sweeping		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**298 x**	**173 x**
Standard Deviation	**282**	**65**
n	**7**	**9**
Pickup		
	Proper Sweeper Setting	Improper Sweeper Setting
Mean	**158 x**	**500 y**
Standard Deviation	**117**	**291**
n	**9**	**8**

[a] No statistical differences were detected in means in the same row followed by the same letter (α = 0.05).

A comparison of the average true PM_{10} concentration and the average FRM PM_{10} concentration for the same tests show a bias in the FRM sampler concentrations of approximately 20%, likely due to the inherent over-sampling bias of FRM samplers reported by Buser et al.[6] when sampling large particles. Correspondingly, true PM_{10} emission factors were lower than those calculated using FRM PM_{10} concentrations. No statistical differences were detected in the mean oversampling rates of sweeping and pickup operations ($p = 0.175$), as would be expected given the similarities in PSDs between operations.

Soil Content

After sieving, the hulls, and shells with meat remained on the 16 mm (5/8 in) and 9.5 mm (3/8 in) sieves along with most of the stones, sticks, and leaf material. All other foreign matter was contained in smaller sieves or the pan. The mass of foreign matter per kilogram of raw nuts (i.e. hulls, shells, and meats) from windrow and conditioned samples are shown in Table 6. As expected, the mass of all materials less than 8mm was reduced by conditioning. However, no differences were detected in the composition of windrow samples or conditioned samples as a function of sweeper setting indicating that producers likely do not introduce more soil into the hulling process by using a lower sweeper setting than that recommended by the manufacturer.

Table 6. Composition of windrow and conditioned samples (g/kg raw nuts[a]).[b]

Windrow Samples							
	Stones	Sticks	Leaves	8-9.5mm	1-8mm	75µm-1mm	< 75µm
Proper sweeper setting	**23.9 x**	**1.95 x**	**2.23 x**	**45.8 x**	**403.1 x**	**140.0 x**	**64.1 x**
Improper sweeper setting	**43.1 x**	**4.72 x**	**1.54 x**	**40.1 x,y**	**400.6 x**	**128.8 x**	**64 6 x**
Conditioned Samples							
	Stones	Sticks	Leaves	8-9.5mm	1-8mm	75µm-1mm	< 75µm
Proper sweeper setting	**22.6 x**	**2.30 x**	**0.00 x**	**22.9 y,z**	**54.7 y**	**22.9 y**	**15.6 y**
Improper sweeper setting	**23.5 x**	**3.13 x**	**0.00 x**	**17.5 z**	**46.5 y**	**21.8 y**	**17.8 y**

[a] "Raw nuts" includes meats, shells, and hulls.
[b] No statistical differences were detected in means in the same column followed by the same letter (α = 0.05).

Conclusion

TSP, PM_{10}, and $PM_{2.5}$ emission factors were determined for almond sweeping and pickup operations for windrows formed using the recommended sweeper height adjustment and those formed using a sweeper height 1.27 cm (0.5 inches) lower than that recommended by the manufacturer. The results of this research showed no differences in emissions of regulated pollutants during the sweeping process, but emissions during pickup were significantly lower for windrows formed using proper sweeper settings versus those formed using improper sweeper settings.

The emission factors developed from this study using proper sweeper settings are 1,725$\pm$1,345 kg $PM_{10}/km^2/yr$ for sweeping and 2,232 $\pm$ 1,929 kg$PM_{10}/km^2/yr$ for pickup operations. The emission factor for sweeping is significantly higher than those reported in previous studies and is higher than the emission factor currently in use by the California Air Resources Board. The emission factor for nut pickup is similar to those reported in previous studies but lower than the emission factor of 4,120 kg PM_{10}/km^2 currently in use by the California Air Resources Board.

IMPLICATIONS

The results of this research indicate that PM_{10} emissions from modern almond pickup operations are substantially lower than the current emission factor. They also demonstrate that use of proper sweeper depth settings may reduce emissions of PM_{10} or $PM_{2.5}$, thus demonstrating this as a potential conservation management practice for reducing emissions of regulated pollutants from almond harvesting operations.

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