Computing Agricultural PM_{10} Fugitive Dust Emissions Using Process Specific Emission Rates and GIS

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U.S. EPA Annual Emission Inventory Conference
San Diego, California
April 2003

ABSTRACT

Over the past eight years, an extensive field test program was performed in California to measure the geologic PM_{10} emissions from a number of agricultural land preparation operations. The research was carried out by researchers at the University of California, Davis, and was funded by the United States Department of Agriculture. PM_{10} fugitive dust emission factors were developed for agricultural discing, ripping, planing, and weeding, as well as harvesting of cotton, almonds, and wheat.

In this paper, we discuss how these new emission factors were used to develop a statewide inventory of PM_{10} emissions for all agricultural land preparation and harvest activities in California. A key element in this process was working closely with stakeholders to assign a limited number of emission factors to the many operations and crops that do not have specific emissions data. The agricultural emission estimates were further refined by temporally allocating the emissions based on representative crop calendars, and spatially allocating the emissions using detailed electronic crop maps and geographic information systems (GIS).

Our new methods, developed collaboratively with the agricultural industry, provide substantial improvements to California's agricultural fugitive dust emission estimates and increase our ability to make better-informed PM_{10} control strategy decisions.

INTRODUCTION

California's San Joaquin Valley has some of the nation's dirtiest air. This is due to a combination of geography as well as a concentration of air pollution sources. During the summer, the federal air quality standard for ozone is exceeded. During the fall and winter, PM_{10} concentrations exceed federal standards.

To help reduce the PM_{10} levels within the SJV, it is important to quantify all emission sources. Historically, PM_{10} emissions from on-field agricultural operations were estimated using relatively generic approaches. For example, a single emission factor, from U.S. EPA's AP-42[1], was applied to all agricultural land preparation activities, such as discing, tilling, or land planing. In addition, harvest related emissions were only estimated for three crops.

However, because of the magnitude of particulate matter pollution problem in the San Joaquin Valley (SJV), the agricultural industry has come under increasing public and regulatory scrutiny. With an intensified need to better understand the quantity of PM_{10} produced by on-field agricultural operations, and the need for further fugitive dust mitigation measures in the San Joaquin Valley, more refined agricultural emission estimation methods were needed.

To assist in this effort, the University of California at Davis has been performing on-field emissions testing of agricultural operations[2,3] in California for over the past 10 years. With significant work completed, new land preparation emission factors are now available for five separate on-field land preparation operations, and harvest emission factors were updated for three crop types. Working closely with agricultural experts and using the methods that follow, this information was used to develop activity specific, crop specific emission estimates for all agricultural land preparation and harvesting activities within California.

For the San Joaquin Valley, these changes produced a decrease in our PM_{10} emissions estimates for land preparation of about 60%, from 34,000 to 13,000 tons/year. This was primarily due to lower overall emission factors. For harvesting, the emissions estimates increased by about 75%, from 7,600 to 13,300 tons/year, which is due to including emission estimates for all harvest operations.

Though the consistent involvement of agricultural and other stakeholders in updating our methodology, we have reached a consensus on the current agricultural PM_{10} emission estimates. This is a critical step as we look at cost-effective ways to reduce fugitive dust emissions from agricultural operations, and identify future agricultural research needs related to air quality.

APPROACH

To improve our emission estimates for agricultural land preparation and harvest activities, three components were needed. These included: 1) county and crop specific acreage data, 2) crop calendars providing the number, type, and timing of agricultural operations for each crop, and 3) emission factors for various on-field agricultural operations. This information was used to develop crop specific PM_{10} mission estimates for both land preparation and harvest operations, which incorporates spatial and temporal information.

In addition to the technical elements, a helpful and engaged community of agricultural experts was also required to update our methodology. This cooperation was necessary to help extrapolate the limited available emission factor data to all of the other California practices and crops. This could not be done without experts intimately familiar with agricultural operations in the State.

Methodology Overview – The General Framework

Before describing the detailed components used to estimate our statewide agricultural land preparation and harvest emissions, an overview of the general approach follows. In summary, we begin with a single crop. The acreage for this crop is then determined. Next, the field activities needed to grow the crop, such as the number of discing passes, and when the crop is harvested, are derived from crop calendars. PM_{10} emission factors are then applied to each field activity to compute crop specific emission factors for land preparation and harvest activities on a per-acre basis. Finally, the acres for the crop are multiplied by the crop's emission factors to compute the land preparation and harvest emissions. This process is repeated for all crops using a database system.

Acreage Data

One of the foundations for computing land preparation and harvest emission emissions is crop acreage data. To perform credible emission estimates it is important that the crop acreage includes the following components.

> Current Data – Current data are needed because the agricultural industry can be dynamic, changing the crop acreages (sometimes significantly) from year to year, so it is important to have relatively current estimates of crop acreages.
>
> Comprehensive – For completeness, as well as to ensure equity between crops, acreage data must include all crops within the region of interest. In our case, this is the entire State of California.
>
> Spatial – To be useful, the acreage data must include some spatial component. Our primary data set includes only county level information, which is generally adequate. We also have a farm level data set for special analyses, but it is not as current as the county data.

Our crop acreage data was obtained from the California Department of Food and Agriculture (CDFA)[4]. The CDFA compiles the detailed data provided by county agricultural commissioners into a single electronic report, which makes it ideal for computing statewide emission estimates.

In addition to the CDFA data, a geographic information system (GIS) based data set is also available from the California Department of Water Resources. Although the data provides very specific spatial information about where crops are grown, the information is only updated only once every seven years for each California county.

Crop Calendars

The next element needed to perform emission estimates is crop calendars. Crop calendars provide information about what harvest and land preparation activities are performed for each crop, as well as when they are typically performed, as shown in Figure 1. The crop calendars were developed through face-to-face meetings with growers and other agricultural experts so that they accurately reflect current California growing practices.

Table 1. Crop Calendar for Corn

Farming Operations	Crop Cycles Per Year	Passes Per Crop Cycle	Fraction of Acreage Per Cycle	Passes During Month											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Land Preparation															
Stubble Disc	1	1	1.0											■	■
Finish Disc	1	1	1.0	■											
List & Fertilize	1	1	1.0			■									
Mulch Beds	1	1	1.0			■									
Planting	1	1	1.0			■	■								
Cultivation	1	2	1.0				■	■							
Harvesting	1	1	1.0									■	■		

Although there are hundreds of crops produced in California, it was not feasible or necessary to develop calendars for every crop. Instead, we developed crop calendars for the most important crops (primarily based on acreage and potential emissions). Crop calendars were developed for alfalfa, almonds, citrus, corn, cotton, dry beans, garbanzo, garlic, grapes (raisin, table, and wine), lettuce, melons, onions, safflower, sugar beets, tomatoes, wheat, rice, and general land maintenance.

After these 20 crop calendars were developed, we worked with agricultural experts to assign the best-fit calendars to all of the crops grown in the State. For example, a specific crop calendar was not developed for barley or oats. Therefore, we determined that the crop calendar for wheat would best represent the activities used to grow these crops.

Improved Emission Factors

Over the past eight years, an extensive field test program was performed in California to measure the geologic PM_{10} emissions from a number of agricultural land preparation and harvest operations. The research, which was performed by researchers at the University of California, Davis, was funded by the United States Department of Agriculture. PM_{10} fugitive dust land preparation emission factors were developed for agricultural discing, ripping, planing, and weeding, as well as harvesting of cotton, almonds, and wheat. Harvest emission factors were also developed for cotton, wheat, and almonds[2,3].

All of the field sampling was performed by measuring PM_{10} concentrations on field during actual agricultural operations in the San Joaquin Valley. A total of 149 tests were performed on different operations, for different crops, in different soils, using different equipment, at different times of the year. In summary, the emissions for each test were computed by calculating the difference between the upwind and downwind PM_{10} monitors. Measurements of similar operations were then averaged to produce composite emission factors, which were used for the ARB's emission estimates.

Land Preparation Emission Factors. Table 1 shows the emission factors developed by UC Davis for land preparation activities. Working with the agricultural industry, farm bureaus, academics, and regulators, the five emission factors were assigned to all of the land preparation activities listed in our crop calendars. Table 2 provides examples of which emission factors were assigned to some of the land preparation activities. In some cases, we could not make exact matches. However, this is a vast improvement from our previous estimates, which assumed 4 lbs PM_{10} per operation, regardless of the operation (based on AP-42[1] using default soil silt content assumptions).

Table 1. Land Preparation and Harvest Emission Factors

Activity	Emission Factor (lbs PM_{10}/acre-pass)
Land Preparation	
Root cutting	0.3
Discing, Tilling, Chiseling	1.2
Ripping, Subsoiling	4.6
Land Planing & Floating	12.5
Weeding	0.8
EPA AP-42 Tilling (old)	*4.0*
Harvest	
Cotton Harvest	3.4
Almond Harvest	40.8
Wheat Harvest	5.8

Harvest. A similar, but slightly more complicated and more subjective approach was used for assigning the harvest emission factors. In this case, only three emission factors were available, as shown in Table 1. These three emission factors were assigned to over 200 different crops. It was felt that this approach, although rough, clearly provides better estimates than our previous default approach, which assigned zero emissions to all crops except the three with emission factors.

Using the new method, we quickly determined that in many cases the available emission factors did not clearly represent the potential PM_{10} emission levels for many of the crops. To adjust for this, a division factor was applied to the emission factors to account for the subjective evaluation of the relative dustiness of harvesting various crops. These assumptions were made in

Table 2. Land Preparation Emission Factor Assignments*

Land Preparation Operation	Emissions Category	Emission Factor (lbs PM_{10}/ acre-pass)
List	Weeding	0.8
List & Fertilize	Weeding	0.8
Roll	Weeding	0.8
Spring Tooth	Weeding	0.8
Seed Bed Preparation	Weeding	0.8
Terrace	Weeding	0.8
Chisel	Discing	1.2
Plow	Discing	1.2
Mulch Beds	Discing	1.2
Disc & Stubble Disc	Discing	1.2
Disc & Furrow-out	Discing	1.2
Finish or Harrow Disc	Discing	1.2
Post Burn/Harvest Disc	Discing	1.2
Unspecified Operation	Discing	1.2
Land Preparation, Gen.	Discing	1.2
Subsoil-deep chisel	Ripping	4.6
Float	Land planing	12.5
Land Plane	Land planing	12.5
Laser Level & Leveling	Land planing	12.5

*Not complete list

consultation with agricultural experts with familiarity with the typical relative dustiness of crop harvesting operations.

For example, for grain corn, it was assumed that the emissions might typically be about one-half of the cotton harvest emissions. Therefore, the assigned harvest emission factor for grain corn was 1.7 lbs PM_{10}/acre (i.e., cotton harvest emission factor/2 = 3.4/2 = 1.7). For pistachios, it was assumed that the emissions might be about one-tenth of the almond harvest emissions. Examples of the some of the assignments and division factors are shown in Table 3.

Table 3. Harvest Emission Factor Assignments*

Crop Name	Crop Calendar Profile	Harvest EF Base Factor	Harvest EF Division Factor
Almonds	Almonds	Almonds	1
Beans, Dry	Dry Beans	Cotton	2
Corn, Grain	Corn	Cotton	2
Corn, Silage	Corn	Cotton	20
Cotton	Cotton	Cotton	1
Grapes, Wine	Grapes-Wine	Cotton	20
Alfalfa	Alfalfa	Zero	1
Oranges	Citrus	Cotton	40
Pistachios	Almonds	Almonds	10
Rice	Rice	Cotton	2
Safflower	Safflower	Wheat	1
Tomatoes	Tomatoes	Cotton	20
Wheat	Wheat	Wheat	1

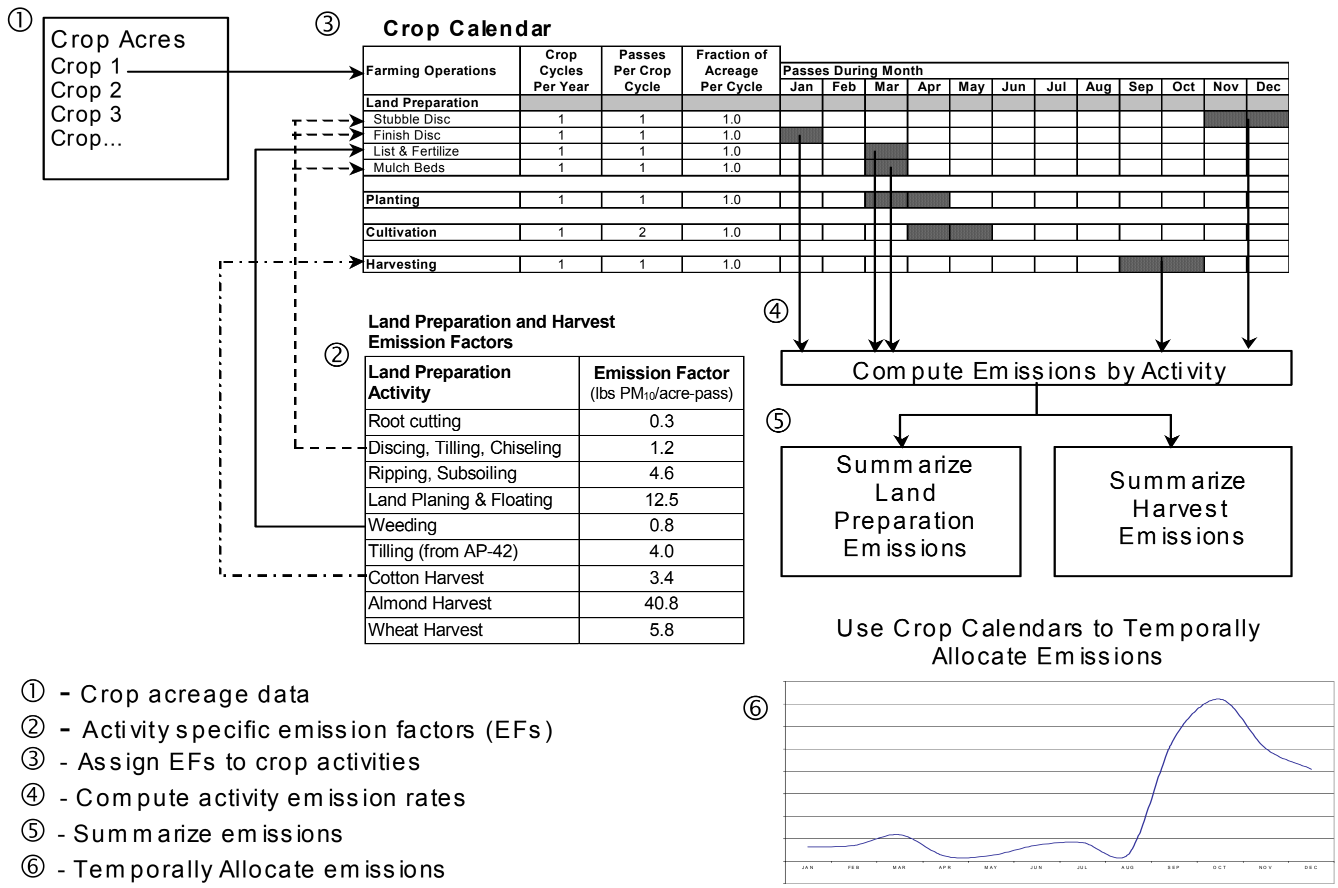
*Not complete list

As mentioned, the subjective approximations needed for this approach are clearly not ideal, but it is a substantial improvement from our previously incomplete methodology, which ignored most of the harvest emissions.

Putting it All Together

The previous sections describe all of the components necessary to calculate crop specific temporally resolved PM_{10} emission estimates for agricultural land preparation and harvest activities. All of these components were then encoded within a database system. This allows the data to be easily updated and makes it straightforward to run a variety of reports. Figure 2 below provides a schematic of the entire crop estimation process.

Figure 2. Estimating On-Field Agricultural PM_{10} Emissions



RESULTS

Figures 3a-c illustrate several of the improvements realized through using the new methodology for estimating PM_{10} emissions from agricultural land preparation and harvest activities. These graphs show the statewide PM_{10} emissions for agricultural land preparation activities, harvest activities, and the sum of both.

- By incorporating the crop calendars into our methodology, the monthly variations in emissions are clearly represented. Land preparation and harvest activities are concentrated in the fall and early winter months.
- By assigning activity specific emission factors to all land preparation and harvest activities, the relative emissions between these operations can be clearly compared (see Figures 3a and 3b). In addition, harvest emissions are now estimated for all crops. In the past, harvest emissions were only estimated for three crops.
- By using detailed crop acreage data, crop calendars, and crop specific emission factors, the estimated PM_{10} emissions from specific crops can be readily observed.

In summary, the changes decreased our land preparation emission estimates by about 60%, from 34,000 to 13,000 tons PM_{10} per year. This is primarily because on average, the new California land preparation emission factors are lower than the previous EPA AP-42 default value. The harvest emissions increased about 75%, from 7,600 to 13,300 tons PM10 per year, which is due to including harvest emissions for all crops, rather than just the three with specific emission factors. All of these improvements are important steps in identifying the largest sources of agriculturally related fugitive dust and when they occur.

An additional step in our analysis includes an evaluation of the detailed spatial allocation of the on-field agricultural emissions. Within California, the Department of Water Resources (DWR) periodically collects detailed, farm specific geographic information about what crops are grown where. Combining this geographic information with the crop and season specific emissions data previously described, we can generate emission maps to show when and where agricultural field emissions occur. Additional information about our work in spatially allocating agricultural emissions is available in the companion poster session for this paper[5], which is available on the conference website[6].

CONCLUSIONS

Using the new methodologies described, California's land preparation and harvest PM_{10} emission estimates are now much more comprehensive, representative, and defensible. This work helps us to better evaluate the relative contributions of various crop activities to PM_{10} emissions, and what can be done about it. In addition, the work has helped us to identify sources that are both in need of additional emissions testing, as well as those in need of special attention in terms of evaluating emission reduction approaches.

With the strong partnerships forged through the process of developing this new PM_{10} emission estimation methodology, the agricultural industry and the air quality regulatory community are fully prepared to cooperatively evaluate the best approaches for minimizing agricultural fugitive dust PM_{10} when it may contribute to elevated PM_{10} levels. For example, the agricultural industry is proactively working with the San Joaquin Valley Unified Air Pollution Control District to develop voluntary PM_{10} mitigation measures. These measures will be included in the PM_{10} State Implementation Plan for the Valley, which is due in the spring of 2003.

With the efforts of all those involved in developing this methodology, starting with funding the emissions research, then performing the research, compiling data, developing databases, generating estimation methods, providing agricultural expertise, and participating in dozens of meetings, we are making serious and concrete steps to help improve the air quality within California. Through this combination of applying the best available science, and a commitment to developing truly effective and economically viable PM_{10} mitigation approaches, California's air will be cleaner in the future.

Figure 3. California Agricultural Land Preparation and Harvest PM_{10} Emissions

Figure 3a. Monthly PM_{10} Emissions from Agricultural Land Preparation.

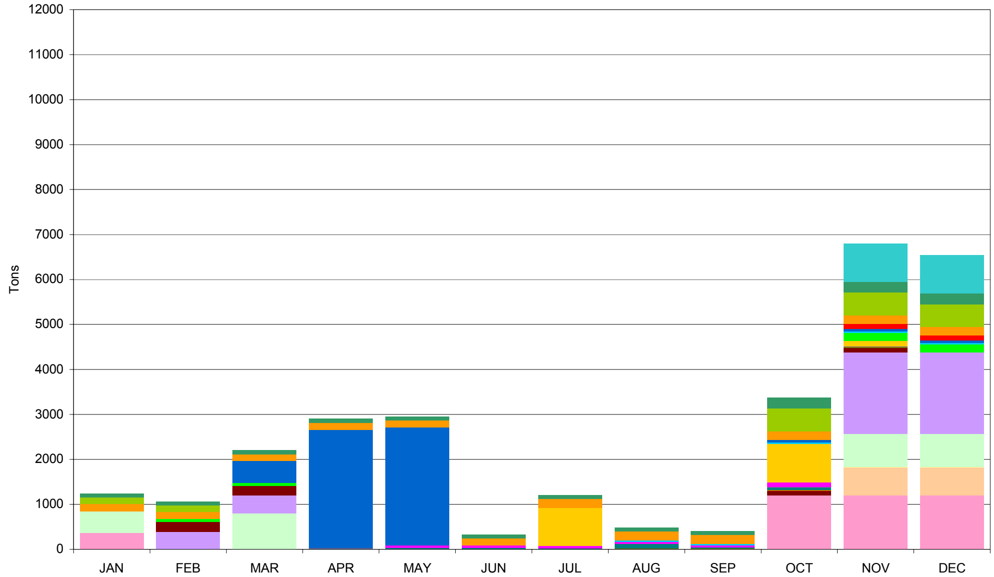


Figure 3b. Monthly PM_{10} Emissions from Crop Harvesting.

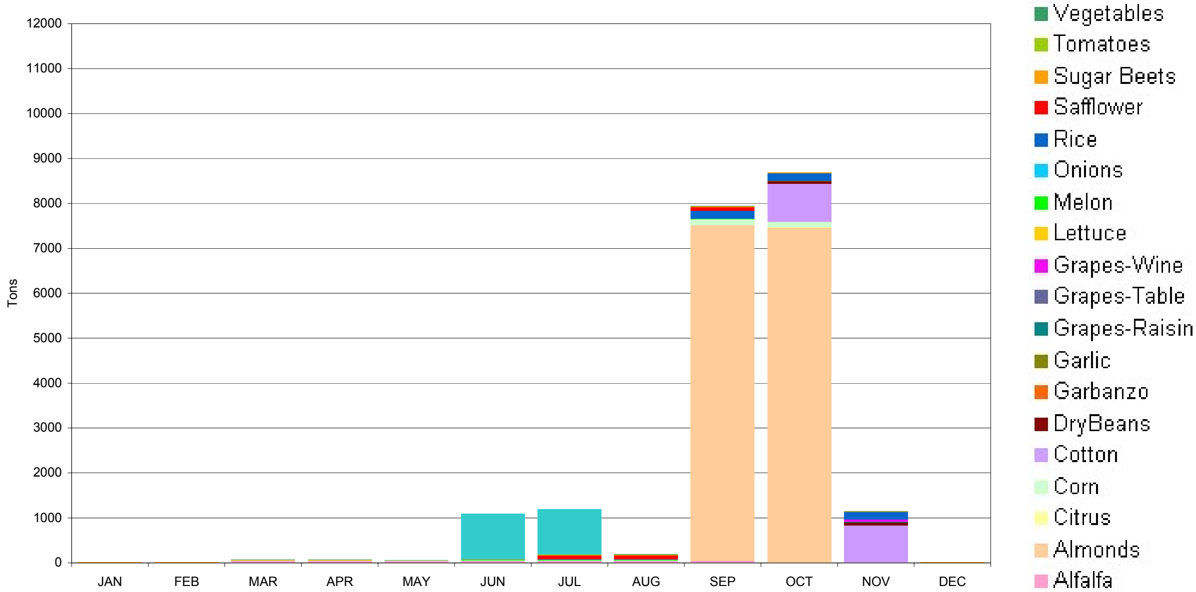
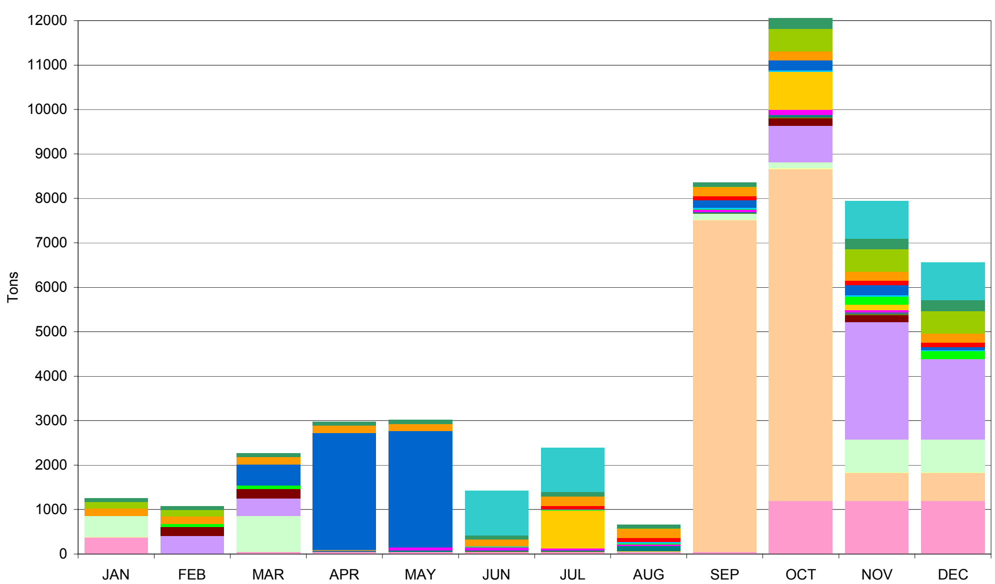


Figure 3c. Monthly PM_{10} Emissions Land Preparation and Harvest.



Acknowledgements

Thanks to the dedicated and helpful membership of the San Joaquin Valley Technical Advisory Committee. Not only was the group involved in helping to coordinate the basic research this paper is based on, they were also always patiently available to answer the dozens of questions that arose in trying to better understand the complexities of California's vast agricultural industry.

Disclaimer

The opinions, findings, and conclusions expressed in this paper are those of the staff and not necessarily those of the California Air Resources Board.

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Key Words

Agriculture, land preparation, harvest, PM_{10}, fugitive dust, inventory