This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This report was furnished to the Environmental Protection Agency by Pacific Environmental Services, Inc., in fulfillment of Contract No. 68-02-1004 TO #4. The contents of this report are reproduced herein as received from Pacific Environmental Services, Inc. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. EPA-450/3-75-087

EPA-450/3-75-087

CALCULATION OF EMISSION FACTORS FOR AGRICULTURAL BURNING ACTIVITIES

by

L.G. Wayne and M.L. McQueary

Pacific Environmental Services, Inc.
1930 14th St.
Santa Monica, California 90404

Contract No. 68-02-1004 TO #4

EPA Project Officer: Thomas F. Lahre

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

November 1975

FOREWORD

Pacific Environmental Services, Inc. is pleased to submit this report to the United States Environmental Protection Agency (EPA) in fulfillment of the requirements of Contract No. 68-02-1004, Task No. 4. Section II of this report provides a complete proposed revision for AP-42 Sections 2.4 and 6.12. Sections III and IV of this report describe in detail all information used to arrive at the proposed emissions factors. Abstracts of all documents from which data were obtained are provided in an appendix.

We wish to acknowledge the assistance of Dr. E.F. Darley, University of California, Riverside, Messrs. J. Thompson and G. Palo of the California Air Resources Board and Mr. T. Lahre, EPA Project Officer, in the work associated with this project and in the preparation of this report.

LIST OF TABLES

		Page
Table 2.4-1	EMISSION FACTORS FOR OPEN BURNING OF NONAGRICULTURAL MATERIAL	7
Table 2.4-2	EMISSION FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS	8
Table 2.4-3	FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS	10
Table III-1	EMISSION FACTORS FOR VARIOUS AGRICULTURAL MATERIALS, WITH SIGNIFICANT VARIATIONS ASSOCIATED WITH VARIOUS CONDITIONS OF BURNING	20
Table III-2	AVERAGES AND STANDARD DEVIATIONS OF POLLUTANT EMISSIONS FOR ORCHARD PRUNINGS	44

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
A. PURPOSE AND SCOPE OF THE EFFORT	1
B. TASK PERFORMANCE AND REPORT ORGANIZATION	2
II. PROPOSED REVISIONS TO AP-42	4
A. SUGGESTED REVISION TO SECTION 2.4	5
B. SUGGESTED REVISION TO SECTION 6.12	13
III. BACKGROUND DOCUMENT FOR SECTION 2.4	15
A. FIELD CROPS. (Alfalfa, asparagus, barley, bean, corn, cotton, hay, oats, pea, rice safflower, sorghum, wheat, field grasses, pineapple)	21
B. VINE CROPS (Boysenberry, grape)	38
C. WEEDS (Ditch bank, mixed, tules, Russian thistle)	40
D. ORCHARD CROPS (Almonds, apple, apricot, avocado, cherry, citrus, date, fig, nectarine, olive, peach, pear, prune, walnut)	43
E. FOREST PRODUCTS (Hemlock, Douglas fir, western red cedar)	55
IV. BACKGROUND DOCUMENT FOR SECTION 6.12	56

APPENDIX I. ABSTRACTS

B. TASK PERFORMANCE AND REPORT ORGANIZATION

Literature search, pursuant to Subtasks 1 and 4 as described above, revealed nine references containing information pertinent to this effort. Abstracts of these references are presented in Appendix I and complete copies have been provided under separate cover and are available from the Project Officer.

Techniques and results of the studies on pollutant emissions from agricultural burning were discussed with Dr. Ellis Darley, director of that project, and associated personnel at the University of California, Riverside. Dr. Darley furnished all available data from that project in the form of two reports, documents 7 and 8 which are abstracted in Appendix I of this report. An amended copy of Reference B is given in Appendix II. These data have been reviewed, analyzed, and cast into the form of emission factors; indeed, they constitute the overwhelming bulk of the data found to be available from all sources discovered.

Using Dr. Darley's information and the data from other sources identified in Appendix I, PES has prepared revised versions of Sections 2.4 and 6.12 of AP-42, pursuant to Subtask 5, above. These versions are presented below as Sections IIA and IIB, respectively, of this report.

For each of the proposed revisions of AP-42, PES has prepared a background document, pursuant to Subtask 6. These documents constitute Sections III and IV, respectively, of this report. Each of these documents presents extensive detail and complete experimental data required to explain the reasoning and the assumptions involved in deriving the proposed emission factors.

In Section IIA, which deals with open burning of agricultural materials, prunings and wood refuse, the wealth of new information provided by the Riverside studies has made it possible to estimate emission factors for the burning of some dozens of different materials and, in a number of cases, for various conditions of burning these individual materials. However, it is likely that in many applications, emission

I. INTRODUCTION

A. PURPOSE AND SCOPE OF EFFORT

This task order No. 4 is composed of six subtasks to be conducted in the sequence shown in the following summary description of each task.

Subtask No. 1 Conduct a brief background study of emission factors and agricultural burning data availability.

Subtask No. 2 Contact Dr. Ellis Darley, at the University of California, Riverside and other related personnel and obtain all available and appropriate reports, raw data, etc. which the University of California personnel have generated on agricultural burning. If possible, the Contractor shall further familiarize himself with the activities through a visit with the University of California, Riverside personnel at the burning simulation facilities.

Subtask No. 3 Compile all valid data obtained from Riverside, analyze it and reduce it to emission factor form when this has not already been done.

Subtask No. 4 Assemble the other references available in the literature on agricultural burning (especially those referenced in Sec. 2.4 of AP-42), and reduce the data therein to emission factor form.

Subtask No. 5 From the data available after performing (1) through (3) above, prepare revisions of Sections 2.4 and 6.12 in AP-42 which would appropriately reflect the new data available on agricultural burning. Said revisions shall be in the same general format as Sections 2.4 and 6.12, but shall be subject to minor technical change at the discretion of the Project Officer.

Subtask No. 6 For each section revised in AP-42, a corresponding background document shall be written which shall describe in greater detail, the various agricultural burning activities included in each section and shall clearly show how each emission factor was derived. The latter may require the inclusion of any calculations, histograms, material balances and assumptions, etc., used in deriving these factors. Accompanying each background document shall be copies of the references cited therein.

factors will be required for materials of uncertain composition under incompletely known burning conditions. For use in these circumstances, PES has also suggested aggregate emission factors which require less detailed information about fuel and burning conditions.

in certain instances, as a function of burning techniques and/or moisture content when these variables are known to significantly affect emissions.

Table 2.4-3 presents typical fuel loading values associated with each type of refuse. These can be used, along with the corresponding emission factors, to estimate emissions from certain categories of agricultural burning when one does not know the specific fuel loadings for a given area.

For more detailed information on this subject, the reader should consult the references cited at the end of this section.

SUGGESTED REVISION

2.4 OPEN BURNING

2.4.1 General [1]

Open burning can be done in open drums or baskets, in fields, and in large open dumps or pits. Materials commonly disposed of in this manner are municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, and bulky industrial refuse.

2.4.2 Emissions

Ground-level open burning is affected by many variables including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emission of particulates, carbon monoxide, and hydrocarbons and suppress the emission of nitrogen oxides. Sulfur oxide emissions are a direct function of the sulfur content of the refuse. Emission factors are presented in Table 2.4-1 for the open burning of municipal refuse and automobile components.

Emissions from agricultural refuse burning are dependent mainly on the moisture content of the refuse and in the case of field crops, whether the refuse is burned in a headfire or a backfire. (Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind.) Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (e.g. in piles, rows, or spread out) are also important in certain instances.

Emission factors for open agricultural burning are presented in Table 2.4-2. They are presented as a function of refuse type and also,

Table 2.4-2

EMISSION FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS
EMISSION FACTOR RATING: B.

REFUSE CATEGORY	EMISSIONS[a] Particulates[b] lbs/ton	Particulates[b] kg/MT	Carbon Monoxide lb/ton	Carbon Monoxide kg/MT	Hydrocarbons (as C_6H_{14}) lbs/ton	Hydrocarbons (as C_6H_{14}) kg/MT
1. Field Crops[c]						
Unspecified	21	11	117	58	23	12
Burning technique not significant[d]						
Asparagus[e]	40	20	150	75	85	42
Barley	22	11	157	78	19	10
Corn	14	7	108	54	16	8
Cotton	8	4	176	88	6	3
Safflower	18	9	144	72	26	13
Sorghum	18	9	77	38	9	4
Grasses	16	8	101	50	19	10
Pineapple[f]	8	4	112	56	8	4
Rice[g]	9	4	83	41	10	5
Sugar cane[h]	7	4	71	35	10	5
Headfire burning[i]						
Alfalfa	45	23	106	53	36	18
Bean (red)	43	22	186	93	46	23
Hay (wild)	32	16	139	70	22	11
Oats	44	22	137	68	33	16
Pea	31	16	147	74	38	19
Wheat	22	11	128	64	17	9
Backfire burning[j]						
Alfalfa	29	14	119	60	37	18
Bean (red), Pea	14	7	148	72	25	12
Hay (wild)	17	8	150	75	17	8
Oats	21	11	136	68	18	9
Wheat	13	6	108	54	11	6
2. Vine Crops	5	3	51	26	7	4
3. Weeds						
Unspecified	15	8	85	42	12	6
Russian thistle (tumbleweed)	22	11	309	154	2	1
Tules (wild reeds)	5	3	34	17	27	14
4. Orchard Crops[c,k]						
Unspecified	6	3	52	26	10	5
Almond	6	3	46	23	8	4
Apple	4	2	42	21	4	2
Apricot	6	3	49	24	8	4
Avocado	21	10	116	58	32	16
Cherry	8	4	44	22	10	5
Citrus (orange, lemon)	6	3	81	40	12	6
Date palm	10	5	56	28	7	4
Fig	7	4	57	28	10	5
Nectarine	4	2	33	16	4	2
Olive	12	6	114	57	18	9
Peach	6	3	42	21	5	2
Pear	9	4	57	28	9	4
Prune	3	2	42	21	3	2
Walnut	6	3	47	24	8	4
5. Forest Residues						
Unspecified[l]	17	8	140	70	24	12
Hemlock, Douglas fir, Cedar[m]	4	2	90	45	5	2
Ponderosa pine[n]	12	6	195	98	14	7

Table 2.4-1

EMISSION FACTORS FOR OPEN BURNING OF NONAGRICULTURAL MATERIAL.

EMISSION FACTOR RATING: B

	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons (CH_4)	Nitrogen Oxides
Municipal Refuse[a]					
lbs/ton	16	1	85	30	6
kg/MT	8	0.5	42	15	3
Automobile Components[b,c]					
lbs/ton	100	Neg.	125	30	4
kg/MT	50	Neg.	62	15	2

[a] References 2 through 6

[b] Upholstery, belts, hoses and tires burned in common

[c] Reference 2

Table 2.4-3

FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS

REFUSE CATEGORY	WASTE PRODUCTION[a] tons/acre	MT/hectare
1. Field Crops		
Unspecified	2.0	4.5
Alfalfa	0.8	1.8
Asparagus	1.5	3.4
Barley, Cotton	1.7	3.8
Bean, Pea	2.5	5.6
Corn	4.2	9.4
Hay (wild)	1.0	2.2
Oats	1.6	3.6
Rice	3.0	6.7
Safflower	1.3	2.9
Sorghum	2.9	6.5
Sugar cane	11.0	24.0
Wheat	1.9	4.3
2. Vine Crops	2.5	5.6
3. Weeds		
Unspecified	3.2	7.2
Russian thistle	0.1	0.2
4. Orchard Crops[b]		
Unspecified	1.6	3.6
Almond	1.6	3.6
Apple	2.3	5.2
Apricot	1.8	4.0
Avocado	1.5	3.4
Cherry, Citrus, Date palm	1.0	2.2
Fig	2.2	4.9
Nectarine	2.0	4.5
Olive, Prune, Walnut	1.2	2.7
Peach	2.5	5.6
Pear	2.6	5.8
5. Forest Residues		
Unspecified	70	157

[a] Reference 14

[b] If orchard removal is the purpose of a burn, 30 tons/acre (66 MT/hectare) of waste will be produced.

[a]Factors expressed as weight of pollutant emitted per weight of refuse material burned.

[b]Particulate matter from most agricultural refuse burning has been found to be in the submicron size range (12).

[c]Reference 12 and 13.

[d]For these refuse materials, no significant difference exists between emissions resulting from headfiring or backfiring.

[e]These factors represent emissions under typical high moisture conditions. If ferns are dried to less than 15 percent moisture, particulate emissions will be reduced by 30 percent, CO emission by 23 percent, and HC by 74 percent.

[f]When pineapple is allowed to dry to less than 20 percent moisture, as it usually is, the firing technique is not important. When headfired above 20 percent moisture, particulate emission will increase to 23 lb/ton (11.5 kg/MT) and HC will increase to 12 lb/ton (6 kg/MT). See reference 11.

[g]This factor is for dry (<15 percent moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emission will increase to 29 lb/ton (14.5 kg/MT), CO emission to 161 lb/ton (80.5 kg/MT) and HC emission to 21 lb/ton (10.5 kg/MT).

[h]See Sec 6.12 for discussion of sugar cane burning.

[i]See accompanying text for definition of headfiring.

[j]See accompanying text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally for limiting emissions, called into-the-wind striplighting, which involves lighting fields in strips into the wind at 100-200 M (300-600 ft.) intervals.

[k]Orchard prunings are usually burned in piles. No significant difference in emission results from burning a "cold pile" as opposed to using a roll-on technique, where prunings are bulldozed onto a bed of embers from a preceding fire.

[l]Reference 10. Nitrogen oxide emissions estimated at 4 lb/ton, 2 kg/MT.

[m]Reference 15.

[n]Reference 16.

13. Darley, E. F. Progress Report on Emissions from Agricultural Burning. California Air Resources Board Project 4-011. University of California, Riverside. Private communication with permission of Air Resources Board June 1975.

14. Private Communication on Estimated Waste Production from Agricultural Burning Activities. California Air Resources Board, Sacramento September, 1975.

15. Fritschen, L. et al, "Flash Fire Atmospheric Pollution", USDA Forest Service Research Paper PNW-97 , 1970.

16. Sandberg, D.V., Pickford, S.G. and Darley, E.F., "Emissions from Slash Burning and the Influence of Flame Retardant Chemicals", J. Air Pollution Control Association 25: 278 (1975).

REFERENCES FOR SECTION 2.4

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc., Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Gerstle, R. W. and D. A. Kemnitz. Atmospheric Emissions from Open Burning. J. Air Pol. Control Assoc. 12:324-327. May 1967.

3. Burkle, J. O., J. A. Dorsey, and B. T. Riley. The Effects of Operating Variables and Refuse Types on Emissions from a Pilot-Scale Trench Incinerator. Proceedings of 1968 Incinerator Conference, American Society of Mechanical Engineers. New York. May 1968. p. 34-41.

4. Weisburd, M. I. and S. S. Griswold (eds.). Air Pollution Control Field Operations Guide: A Guide for Inspection and Control. U.S. DHEW, PHS, Division of Air Pollution, Washington, D.C. PHS Publication No. 937. 1962.

5. Unpublished data on estimated major air contaminant emissions. State of New York Department of Health. Albany. April 1, 1968.

6. Darley, E. F. et al. Contribution of Burning of Agricultural Wastes to Photochemical Air Pollution. J. Air Pol. Control Assoc. 16:685-690, December 1966.

7. Feldstein, M. et al. The Contribution of the Open Burning of Land Clearing Debris to Air Pollution. J. Air Pol. Control Assoc. 13:542-545, November 1963.

8. Boubel, R. W., E. F. Darley, and E. A. Schuck. Emissions from Burning Grass Stubble and Straw. J. Air Pol. Control Assoc. 19:497-500, July 1969.

9. Waste Problems of Agriculture and Forestry. Environ. Sci. and Tech. 2:498, July 1968.

10. Yamate, G. et al. An Inventory of Emissions from Forest Wildfires, Forest Managed Burns, and Agricultural Burns and Development of Emission Factors for Estimating Atmospheric Emissions from Forest Fires. Presented at the 68th Annual Meeting, Air Pollution Control Association, Boston, Mass. June 1975.

11. Darley, E. F. Air Pollution Emissions from Burning Sugar Cane and Pineapple from Hawaii. Amendment to EPA Research Grant R800711, University of California, Riverside, August 1974.

12. Darley, E. F. et al. Air Pollution from Forest and Agricultural Burning. California Air Resources Board Project 2-017-1, University of California, Davis, April 1974.

REFERENCES FOR SECTION 6.12

1. Sugar Cane. In: Kirk-Othmer Encyclopedia of Chemical Technology, Vol. IX. New York, John Wiley and Sons, Inc. 1964.

2. Darley, E. F. "Air Pollution Emissions from Burning Sugar Cane and Pineapple from Hawaii." Amendment to EPA Research Grant R800711 Air Pollution from Forest and Agricultural Burning. Statewide Air Pollution Research Center, University of California, Riverside, August 1974.

3. Draft. Background Information For Establishment of National Standards of Performance for New Sources. Raw Cane Sugar Industry. Prepared for EPA Under Task Order 9c of Contract CPA 70-142 by Environmental Engineering, Inc. Gainesville, Florida. July 15, 1971.

SUGGESTED REVISION

6.12 SUGAR CANE PROCESSING

6.12.1 General [1-3]

Sugar cane is burned in the field prior to harvesting to remove unwanted foliage as well as to control rodents and insects. Harvesting is done by hand or where possible, by mechanical means.

After harvesting, the cane goes through a series of processes to be converted to the final sugar product. It is washed to remove larger amounts of dirt and trash; then crushed and shredded to reduce the size of the stalks. The juice is next extracted by one of two methods, milling or diffusion. In milling the cane is pressed between heavy rollers to press out the juice; in diffusion the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation, and crystallization in order to produce the final product. The fibrous residue remaining after sugar extraction is called bagasse.

All mills fire some or all of their bagasse in boilers to provide power necessary in their milling operation. Some, having more bagasse than can be utilized internally, sell the remainder for use in the manufacture of various chemicals such as furfural.

6.12.2 Emissions [2, 3]

The largest sources of emissions from sugar cane processing are the openfield burning in the harvesting of the crop and the burning of bagasse as fuel. In the various processes of crushing, evaporation, and crystallization, some particulates are emitted but in relatively small quantities. Emission factors for sugar cane field burning are shown in Table 2.4-2. Emission factors for bagasse firing in boilers are presented in Section 1.7.

of agricultural burning emission factors, estimates of emissions will be needed even though much of this information is not readily available.

PES, in compiling these emission factors, has adopted the approach of offering factors useful with different levels of detail in the fuel inventory information. Thus, in the tables presented in Section 2.4, there is a single emission factor for field crops, which may be used to obtain a rough estimate of emissions from burning of a specified amount of any or all of the various materials--alfalfa, barley, beans, etc.--listed as field crops on subsequent lines of the table. These additional lines provide a more accurate emission factor for the burning of a particular crop, e.g., alfalfa, using each of two common burning techniques, a headfire burn, a backfire burn.

In tabulating these emission factors, PES has elected not to include columns for emissions of sulfur oxides or nitrogen oxides. The new information available to us does not include data on these pollutants, which were not measured in the Riverside studies. Only in the case of nitrogen oxides from forest residues (Reference 10) has any such estimate been made, and this is incorporated as a footnote to the table.

No data from field fires have been used in preparing this document. Comparisons of field and laboratory burning of rice straw indicate the burning tower fires accurately simulate field conditions (7). This enables experiments to be conducted under more carefully controlled conditions, thereby minimizing variations among data. Quoting Darley (7),

> "The residue is rarely in a uniform condition in the field. Even in a field that appears to be very uniform there may be variations in residue moisture content as high as 50% about the mean value. Fuel loading will also vary by as much as 50% about the mean value, because of differences in plant populations in the field, straw spreader performance, and harvester patterns in the field. The smoke sampling technique only measures the particulates produced from .07 kg (.15 lbs.) of fuel or less. Unless a uniform mixing of the particulate emissions takes place between the fire and the sampler, the emissions measured may not be fully representative of the entire plot."

III. BACKGROUND DOCUMENT FOR SECTION 2.4 (OPEN BURNING)

Information suitable for estimating the emission factors listed in the tables of Section 2.4 is drawn mainly from two reports (references 7 and 8) obtained from Dr. Ellis Darley, University of California, Riverside and an estimation of waste produced in horticulture burning made by the California Air Resources Board (9). Abstracts of these and other relevant documents are provided in Appendix I. Full copies are obtainable from the Project Officer. In reference 7, Air Pollution from Forest and Agricultural Burning, Dr. Darley and his colleagues reported on extensive studies on burning of agricultural materials, both in the laboratory and in the field; reference 8 amounts to a compilation of data for similar experiments conducted more recently, covering a broader variety of materials.

The earlier Riverside report (7) presents statistically supported conclusions regarding various factors which were found to affect the rate of emission of particulates, carbon monoxide, and hydrocarbons in burning of certain agricultural materials. In brief, it is clear that, with most materials, emissions are strongly related to the moisture content of the fuel. The technique of burning--whether by headfires, backfires, or into-the-wind-striplighting--can also have a substantial influence on emissions. Finally, the amount of emissions per ton of fuel can also vary appreciably depending on whether the fuel is piled, rowed, or spread--a factor that was simulated, in the laboratory tests, by various loadings on the burning platform.

The main purpose of the Riverside studies was to demonstrate the potential value of tested fire-management techniques in minimizing the quantity of emissions produced in agricultural burning. By the same token, the results also demonstrated that emissions estimates for agricultural burning must be subject to a high degree of uncertainty, unless the burning techniques used and the condition of the material burned are known with unusual accuracy. Certainly, in many applications

For sets of data not having the same variance

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

In this case, two groups of data may be combined if the absolute value of t is less than

$$t\left(0.025,\ \frac{\left[\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right]^2}{\frac{(s_1^2/n_1)^2}{n_1 - 1} + \frac{(s_2^2/n_2)^2}{n_2 - 1}}\right)$$

In analyzing the data for orchard prunings, an analysis of variance was carried out for each pollutant in order to define the significant differences among the fourteen types of trees tested.

The determination of hydrocarbon emissions has been complicated by use of two analyzers during the 1975 burning schedule. Quoting from Dr. Darley's report (8), "Recently we had the opportunity of borrowing a newer model of hydrocarbon analyzer (Beckman 400) from EPA. When the new instrument was compared with our analyzer it was obvious that the response of the newer instrument was more sensitive so that at given peaks in a fire, it registered a higher value. In computing emission factors, the greater sensitivity has the net result of increasing the hydrocarbon yield from 25 to 35 percent, depending on the width of the peak. After consulting with staff of both the ARB and EPA it has been decided to use the newer instrument on future fires." In order to compare data obtained using two different instruments, PES has elected to convert all data collected on the first hydrocarbon analyzer to correspond to readings which would have been obtained on the Beckman 400. Nineteen burns were conducted with both analyzers operating so that a comparison of the two could be made. The average difference between readings was 30%, i.e., Following subsections of this Background Document deal with each individual agricultural material studied. Conditions affecting the emission factors--especially moisture content, firing technique, and fuel loading--are individually discussed in each case where they have been shown to have a statistically significant effect. Finally, the rationale for the tabulated emission factor values is explained in each subsection.

All data points used in calculating an emission factor are listed and means and standard deviations for each factor are given immediately below the data tabulation. The overall standard deviation for emissions from 196 field crop burns is 9.6 for particulates, 36.0 for CO and 6.8 for hydrocarbons. The recommended emission factors for field crops are summarized in Table III-1 and for orchard crops, in Table III-2.

Table III-1 presents a concise summary of average emissions based on the Riverside results for each field crop, vine, and weed. Table III-2 summarizes emission factors for orchard prunings, which are discussed in Subsection D.

In preparing these tabulations, the basic statistical tool was Student's _t_ test for the comparison of means. This was used in the form given by V. L. Maksoudian, "Probability and Statistics with Applications," International Textbook Company, Scranton, Pa., 1969 (p.239):

For sets of data having the same variance

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

Two groups of data are not significantly different, and may therefore be combined, if the absolute value of t is less than t $(0.025, n_1 + n_2 - 2)$, where n represents sample size and $\bar{x}$ represents the mean for each group.

TABLE III - 1

EMISSION FACTORS FOR VARIOUS AGRICULTURAL MATERIALS, WITH SIGNIFICANT VARIATIONS ASSOCIATED WITH VARIOUS CONDITIONS OF BURNING. VALUES IN POUNDS PER TON OF FUEL BURNED

Product and Burning Conditions		lbs. Emitted/Ton Fuel			Number of Test Fires
		Particulate	CO	HC	
Alfalfa	Headfire	45	106	36	2
	Backfire	29	119	37	2
Asparagus	Moisture <15%	28	116	17	11
	Moisture ≥15%	40	150	85	6
Barley		22	157	19	25
Bean (red)	Headfire	43	186	46	5
	Backfire	15	147	20	5
Corn		14	108	16	11
Cotton		8	176	6	2
Hay	Headfire	32	139	22	2
	Backfire	17	150	17	2
Oats	Headfire	44	137	33	5
	Backfire	21	136	18	9
Pea	Headfire	31	147	38	2
	Backfire	14	150	30	2
Rice	Moisture >15%	30	161	21	19
	Moisture ≤15%	9	83	10	47
Safflower		18	144	26	6
Sorghum		18	77	9	4
Wheat	Headfire	22	128	17	7
	Backfire	13	108	11	12
Field grasses		16	101	19	14
Vine Crops		5	51	47	12
Pineapple	Moisture ≤20%	7	106	8	10
	Headfire Moisture >20%	23	130	16	2
	Backfire Moisture >20%	9	117	9	2
Russian thistle		22	309	27	8
Tules		5	34	2	4
Weeds - Unspecified		15	85	12	12
Orchard Crops (except Avocado and Olive)		6	50	7	97
Avocado		21	116	32	3
Olive		12	114	18	8
Forest slash burning*		17	140	24	-

*For forest slash burning NO_x emissions have been estimated to be 4 lbs/ton fuel burned.

multiplying the value obtained on the first analyzer by 1.30 will yield the value recorded by the second. This has been done for all data values obtained at Riverside using the older hydrocarbon analyzer.

Dr. Darley calibrates the hydrocarbon analyzers with hexane and all values have been calculated based on this response. PES sees no need to alter the reporting base, which has been duly noted in the revision to Section 2.4 of AP-42. Both Fritschen, et al (2) and Sandberg, et al (3) reported hydrocarbons as carbon. These values have been corrected to correspond to all other hexane related results.

The legend for reading these data tables is as follows:

H-25 is a headfire conducted during 1974-5 with the with the burning table at a 25% incline.

H-15 is a headfire conducted during 1974-5 with the burning table at 15% incline.

B-25 is a backfire conducted during 1974-5 with the burning table at a 25% incline.

B-15 is a backfire conducted during 1974-5 with the burning table at a 15% incline.

Flat is a fire conducted during 1974-5 with a horizontal burning table.

Dates refer to the year or month a burn was made.

Sidefire is an attempt to simulate into-the-wind-striplighting of a field by slowly igniting the downwind corner of the material, slowly moving the flame into the wind (up the table)

Repeating, all hydrocarbon values are calculated compensating for 1) different responses between the old and new analyzers and 2) relating to calibration with hexane.

2. Asparagus fern (continued)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
B-25	10.5	29.5	145.4	22.5
	10.5	25.4	118.1	17.1
Flat	12.0	22.3	79.6	12.0
April 1973	14	27	165	12
	10	28	145	9
Mean		28	116	17
Standard deviation		3.8	26.4	4.8

Type of Fire	% Moisture, wet wt. basis		Emissions, lb. per ton fuel burned		
	Fern	Stem	Part.	CO	HC
December, 1972	18	46	35	103	86
	33	61	32	107	62
	29	50	53	171	113
	18	63	-	221	79
Mean			40	150	85
Standard deviation			11.4	56.4	21.2

A. Field Crops

1. Alfalfa

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-25	10.4	41.5	103.2	33.9
	10.4	48.0	107.8	38.2
Mean		45	106	36
Standard deviation		4.6	2.9	3.0
B-25	10.4	26.1	125.3	38.0
	10.4	31.4	112.4	35.1
Mean		29	119	37
Standard deviation		3.7	9.1	2.0

There is a significant difference between emissions from headfire and backfire burns. PES recommends both factors be given in AP-42 with the instruction that if the fire management technique is unknown, an average of the two values be used in calculating emissions. The recommended emission factors are listed in Table III-1 for all products.

2. Asparagus fern

H-15	10.9	24.5	98.6	17.0
	11.6	27.9	108.9	19.4
B-15	11.7	26.1	95.9	16.8
	10.9	29.7	107.3	19.5
H-25	10.5	34.4	90.4	19.4
	10.5	34.7	121.3	25.2

3. Barley

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
HEADFIRE				
H-15	8.6	6.6	85.1	7.2
	9.1	9.4	102.5	7.9
	11.8	11.4	91.6	5.3
H-25	~10.0	14.6	148.2	22.2
	~10.0	28.5	152.3	28.9
	8.1	21.3	156.5	27.6
1973	6	52.0	257.3	20.5
	14	75.5	267.0	35.8
	20.4	30.6*	138.0*	17.4*
	15	59.6	299.0	40.2
BACKFIRE				
B-15	10.5	7.1	80.4	7.3
	8.7	7.8	102.5	7.1
	10.1	9.6	110.7	8.5
B-25	~10.0	7.8	113.3	13.1
	~10.0	8.6	112.7	15.5
1973	4	31.9	230.7	15.0
	14	28.2	237.6	29.0
	20.3	19.4*	142.0*	20.3*
	18.0	30.1	271.7	40.2
	18.4	49.6	297.8	40.4
Flat	10.0	6.8	92.7	5.2
	10.0	9.4	96.9	5.7
	9.1	7.7	91.7	7.3
SIDEFIRE (1973)	6	26.6*	159.8*	15.0*
	18	42.0*	195.6*	26.4*
Mean		22	157	19
Standard deviation		18.2	76.1	11.9

*Fires conducted at lower fuel loading.

Dr. Darley has conducted burns of both freshly cut asparagus fern and air dried residues. The difference in emissions from the "wet" and "dry" materials is significant. Among the numerous backfire and headfire burns of low moisture material, there is no significant difference in the mean emissions at the 95% confidence interval.

In view of Dr. Darley's report (8) that asparagus fern may often be burned before the material has dried to a moisture level of 10-12%, PES suggests the emission factors determined in burning the "wet" ferns be the primary entry in AP-42. A footnote will be included stating that emissions are reduced when dry material is burned.

4. Bean (red)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-15	12.5	20.2	174.4	27.2
	11.6	19.5	156.5	10.3
	11.0	13.0	142.7	17.9
H-25	12.4	45.7	193.1	48.8
	9.7	40.4	179.1	44.2
Mean		43	186	46
Standard deviation		3.7	9.9	3.0
B-15	12.3	15.6	155.5	21.8
	11.2	16.4	70.1	19.0
	9.3	11.6	139.1	15.5
B-25	13.7	11.3	183.9	25.4
	9.7	12.4	149.9	24.0
Mean		15	147	20
Standard deviation		3.5	34.4	5.6

There is a significant difference between emissions from burns using headfire and backfire burning techniques. As in the previous case of burning barley, the average emissions for both headfires and backfires are to be listed in AP-42 along with the suggestion that if fire management technique is unknown, use the average emissions for the two different types fires, i.e., 29 lbs. particulates/ton fuel, 166 lbs. CO/ton fuel and 32 lbs. HC/ton fuel.

The data marked with asterisks represent fires conducted at a lower fuel loading than was used in all other burning tower trials--2 lbs., to simulate spread straw, as opposed to 6 lbs., to simulate rowed straw.

Fuel loading does affect the pollutant emissions. In laboratory fires, increasing fuel loading generally decreases particulate emissions. However, in these barley burns, the opposite occurred. Darley (7) suggests this might have resulted from substantially better air drying, less compaction or a lower required rate of oxygen supply at the lesser fuel loading. All of these variables have been shown to reduce production of emissions.

The 1973 fires burned at the higher fuel loading "may well not represent most field conditions. The residue quantity in the field usually corresponds to the .9 Kg [2 lb.] tests at the SAPRC tower." (7) Burns conducted in the field in 1972 have substantially lower particulate emissions--4.7 lbs./ton fuel was the average for 43 trials.

The range of data obtained in 1973 and 1974, even with the same .25 lb. fuel/sq.ft. load used, is so large that no meaningful comparisons of effects of moisture or fuel loading are possible.

There is no indication that any data may be discarded because of error in conducting the experiment, however, the experimental techniques used in 1973-1974 were not the same. In 1973 a slope of more than 25% was used and additional air flow from a fan was used to increase the rate of burning. At this time, because effects of different variables cannot be segregated with certainty, an emission factor obtained by averaging all available laboratory data is being proposed for inclusion in AP-42.

7. Hay (wild)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-25	10.4	27.4	137.8	21.8
	10.9	36.7	139.7	22.5
Mean		32	139	22
Standard deviation		6.6	1.3	.5
B-25	10.1	16.5	155.3	18.4
	11.1	17.4	144.4	14.7
Mean		17	150	17
Standard deviation		.6	7.7	2.6

There is a significant difference between emissions from headfire and backfire burns. PES recommends both factors be given in AP-42 with the note that if the fire management method is unknown, an average of the two values can be used in calculating emissions.

8. Oats

H-15	11.3	18.4	121.4	11.7
	9.1	23.5	154.0	23.1
	10.8	19.7	149.2	20.2
H-25	7.1	44.8	141.6	32.8
	9.6	43.8	132.5	33.3
Mean		44	137	33
Standard deviation		0.7	6.4	0.8
B-15	11.8	19.3	124.8	13.7
	9.2	22.2	135.8	16.1
	11.2	20.3	130.0	17.0
	10.2	22.0	156.4	18.7
B-25	8.1	17.9	134.0	23.8
	7.6	21.5	124.0	23.5

5. Corn

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-15	16.8	17.4	115.5	17.7
	14.5	16.1	107.9	17.7
	12.7	15.2	142.7	17.9
	13.4	12.7	99.9	13.8
H-25	9.0	15.0	120.5	20.4
	9.5	12.4	89.6	12.5
B-15	16.9	15.2	108.6	16.5
	10.8	13.2	95.6	13.9
	14.1	11.5	97.8	13.4
B-25	7.6	15.1	110.3	18.5
	11.7	13.2	102.4	14.3
Mean		14	108	16
Standard deviation		1.8	14.5	2.6

There is no significant difference between the means for any type of fire conducted. Thus an average of all data is used to obtain the emission factors in Table III-1.

6. Cotton

Windrow	14.4	10.7	182.8	5.6
	14.7	6.2	169.0	5.6
Mean		8	176	6
Standard deviation		2.1	3.7	

These were the only burns conducted. The average emissions are shown in Table III-1.

10. Rice

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-25	9	9.9	122.6	11.8
H-15	10	14.7	95.7	10.9
Headfire (1973)	6	16.2	78.4	7.5
	10	15.1	79.2	11.0
	10	11.2	96.3	12.5
	14	19.2	58.6	8.2
	15	9.8	86.8	11.0
	5	5.9	61.8	34.7
	13	14.1	78.4	15.1
	9	5.1	63.0	7.4
	8	7.8	64.5	9.5
	10	20.3	89.5	17.2
Headfire (1972)	12	8.0	96.3	5.7
	10	6.3	86.3	4.8
	14	15.5	132.2	9.9
Headfire (1973)	14*	19.2	58.6	8.2
	5*	5.9	61.8	34.7
Backfire (1973)	15*	4.9	64.9	9.8
	14*	9.8	76.0	8.6
	5*	3.4	72.0	8.2
	7	7.0	77.0	6.6
	10	6.5	66.1	7.0
	14	9.8	111.4	14.4
	13	12.9	104.1	18.3
	7	5.7	67.9	7.9
	7	4.8	64.2	7.5
	9	3.8	69.0	6.6
Backfire (1972)	10	6.2	103.4	11.2
	9	6.6	107.9	4.2

*Fires conducted with fuel load of 2 lbs.

Flat	9.5	19.6	131.9	15.1
	10.5	21.9	138.1	21.4
	12.7	21.5	135.4	13.5
		21	136	18
Standard deviation		1.7	11.5	4.2

There is a significant difference between emissions from headfire and backfire burns. PES suggests including these two emission factor sets in AP-42 with the instruction that if the fire management technique is unknown, an average of the two values be used in calculating emissions.

9. Peas

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-25	9.8	32.5	147.3	39.1
	9.8	29.6	147.4	37.4
Mean		31	147	38
Standard deviation		4.2	.3	1.2
B-25	9.8	14.3	157.4	31.8
	9.8	14.3	143.2	29.0
Mean		14	150	30
Standard deviation		.0	10	2.0

There is a significant difference between emissions from headfire and backfire burns. PES suggests including both factors in AP-42 with the instruction that if the fire management technique is unknown, an average of the two values be used in calculating emissions.

10. Rice (continued)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
Headfire (1973)	18	24.8	118.6	23.3
	17	22.1	109.5	22.8
	21	36.2	137.8	31.2
	26	39.8	156.5	34.1
Headfire (1972)	40	89.4	-	24.0
	20	51.2	227.1	22.4
	32	65.7	164.2	30.4
	20	38.9	137.3	17.8
	17	24.9	145.3	13.0
	21	17.3	159.9	13.8
Backfire (1973)	20	15.1	126.4	20.4
	17	7.3	92.5	13.4
	24	15.7	161.0	28.7
	23	12.1	137.4	24.7
Backfire (1972)	32	27.0	269.2	23.4
	24	27.2	300.7	28.7
	22	25.7	155.9	16.9
	16	12.2	140.3	8.3
	17	11.5	158.0	9.6
Mean		29.7	161.0	21.4
Standard deviation		20.7	53.3	7.5
(Fire conducted at .08 lb./sq.ft. loading, not included in calculations.)				
Headfire (1973)	20*	6.5	54.0	7.9

*Fires conducted with fuel load of 2 lbs.

10. Rice (continued)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
Backfire (1972)	11	2.8	84.5	2.6
	12	11.5	132.1	9.1
B-25	10	6.3	87.4	10.4
B-15	12	8.3	74.1	7.2
Sidefire (1973)	6	8.8	67.8	7.8
	6	7.0	58.0	5.1
	6	9.1	72.1	7.4
	9	9.4	65.6	7.4
	8	5.6	77.3	9.2
	7	2.7	51.4	5.2
	16	5.1	58.0	5.7
	18	11.2	127.7	22.4
	21	10.2	79.5	13.6
	13	9.7	77.6	12.7
	15	9.9	72.8	10.3
	13	9.5	72.4	10.4
	8	4.6	64.5	9.2
	13	9.1	77.6	9.5
Mean		8.8	82.6	9.5
Standard deviation		3.9	20.3	3.9

There is no significant difference between the means for either type of fire conducted. Thus an average of all data is used to obtain the emission factors.

12. Sorghum

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-25	66.0	11.8	68.3	6.6
	43.9	31.7	79.2	8.8
B-25	46.6	13.4	80.9	9.1
	29.3	13.4	79.2	10.3
Mean		17.6	77	9
Standard deviation		9.4	5.8	1.5

Four burns were completed. The average of all results is used as the emission factor in Table III-1.

13. Wheat

H-15	7.6	9.6	91.8	7.2
	8.4	12.6	105.0	8.3
	9.4	12.2	100.9	7.4
H-25	7.2	20.5	143.1	32.2
	10.7	35.5	167.1	28.8
Headfire (1973)	17.2*	31.5	134.8	20.3
	6.2	29.5	157.1	17.7
Mean		21.6	128.5	17.4
Standard deviation		10.6	29.5	10.4

*Fire conducted at fuel loading of .08 lbs/sq. ft.

The first step in correlating this substantial quantity of data was to group results in terms of year of test, type of fire, moisture content and fuel loading. Students' t-test, with the statistics described on p.17 was used to compare means of several combinations of these groups of data. The results of all low moisture headfires and backfires and all sidefires can be combined to yield one set of emission factors. The high moisture headfires and backfires, with the exception of one fire conducted at the unusually low fuel loading of .08 lbs. fuel/sq.ft., yield substantially higher quantities of pollutants and have been combined to provide a separate set of factors.

There is insufficient information to make any statement about emissions from high moisture, low fuel load headfires, so this one burn has been excluded from any calculations.

To minimize the number of factors, particularly in consideration of the practice of allowing rice straw to dry before burning PES suggests the "low moisture" be incorporated into AP-42 with a footnote stating that if a high moisture burn has been known to have been conducted, particulate emissions will be increased to 29 lbs./ton, CO to 161 lbs./ton and HC to 21 lbs./ton.

11. Safflower

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
H-15	16.9	14.7	125.9	21.6
	10.9	12.4	130.1	12.1
	14.4	23.8	177.9	33.8
B-15	18.3	14.6	122.6	17.8
	12.2	24.9	139.2	36.8
	12.2	20.8	165.2	31.7
Mean		18	144	26
Standard deviation		5.3	22.8	9.9

at the 95% confidence level, fuel loading did not affect the values for backfires, but the one 1973 headfire noted in the data table, was significantly different from other headfire results and was not included in further calculation.

Both factors for headfires and backfires, plus a sidefire, are included in the suggested revision of AP-42.

14. Field Grasses

Grasses from the Willamette Valley, Oregon were burned under varying conditions by Boubel et al. (AP-42, § 2.4, Ref. 8).

Summarizing from this report, the yields of various pollutants resulting from burning in the tower at Riverside are as follows:

	% Moisture	Emissions lb/ton fuel burned		
		Part.	CO	HC
Blue	5	16.5	147	28.0
Per. Rye	6	12.0	104	21.7
Bent	2	14.0	124	21.7
Ann. Rye	9	10.5	85	12.4
Fescue	9	13.0	122	18.6
Orchard	15	11.5	89	10.9
Blue	23	15.0	95	12.4
Per. Rye	71	26.0	106	29.5
Bent	60	24.0	109	29.5
Ann. Rye	20, 55	10.0	58	7.8
Fescue	66	17.0	77	14.0
Orchard	66, 47	17.5	100	23.3
Mean		16	101	19
Standard deviation		5.1	23.4	7.6

13. Wheat (Continued)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
B-15	7.8	7.9	82.1	4.2
	8.6	9.7	95.9	6.9
	8.5	12.5	89.0	8.6
	9.7	10.6	110.2	8.8
B-25	7.5	11.8	110.8	19.8
	6.6	10.6	110.7	13.0
Flat	7.4	7.4	84.1	4.7
	8.9	10.5	95.0	7.3
	11.6	11.4	105.8	8.1
Backfire (1973)	9.6	22.1	186.2	18.8
Sidefire (1973)	15.7*	16.5	123.6	17.9
	14*	20.2	99.1	18.1
Mean		12.6	107.7	11.4
Standard deviation		4.6	29.6	5.8

Fire conducted with fuel load of only 2 lbs., not included in calculations.

Headfire (1973)	10.9*	11.8	48.0	4.8

The 1973 series fires were conducted at different loading levels--.08 lbs./sq.ft., simulating spread straw and .25 lbs./sq.ft., simulating rowed straw. The 1975 series fires were conducted at a .25 lb./sq.ft. loading. Fuel loading does influence the amount of emissions, but at this time there is insufficient data to allow calculation of emission factors for both categories. In determining the factors shown, it was found that

*Fires conducted at fuel loading of .08 lbs./sq.ft.

Type of Fire	% Moisture, dry wt. basis	Emissions lbs. per ton fuel burned		
		Part.	CO	HC
Backfire	8.1	6.2	113.9	4.2
	10.4	6.6	100.9	5.5
	15.6	6.5	112.9	6.0
	17.9	7.4	103.1	6.9
	16.1	9.2	121.5	10.7
	25.0	8.2	110.7	8.6
	23.8	9.9	122.7	10.1

Darley (4) reports significant differences at the 99% confidence level in pollutants emitted from burning pineapple trash under these three conditions:

	≤20	7.4	106.4	7.6
	>20			
Headfire		23.2	129.8	15.9
Backfire		9.0	116.7	9.4

Because of this, PES considers these three sets of emission factors be included in AP- 42.

B. Vine Crops

1. Boysenberry

Pile	11.0	3.8	64.3	2.3
	11.0	3.9	62.9	1.3
	12.0	3.6	43.7	1.0
	12.0	3.7	51.7	.8
Mean		4	56	1
Standard Deviation		.4	9.8	.7

The emissions listed in Tables III-1 are the averages of these four trial burns.

2. Grape

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
Cold	40.7	6.6	36.9	6.6
Roll-on	40.0	8.2	49.9	10.4
Cold	39.6	7.4	46.1	7.6
Roll-on	37.5	8.2	50.2	9.2
Cold	24.0	3.4	46.2	2.7
Roll-on	26.1	5.2	58.3	5.4
Cold	22.8	3.8	44.4	3.3
Roll-on	22.3	5.1	59.3	3.7
Mean		6.0	49	6.1
Standard deviation		1.9	7.4	2.8
Average of four 1973 Trials	30.0	5.7	62.	7.7
Average of all Trials		5.8	51	6.9

As is described more fully in the Orchard Crops section, grape prunings were burned at two moisture levels, 24% H_2O and 30% H_2O, and with two ignition techniques, a cold start and a roll-on start. Because both the moisture levels in actual field burns may vary between these two test contents, and actual field burns may use the roll-on technique to maintain a fire, the appropriate field emission factor represents average emissions from all test fires. The averages given in III-1 were obtained by first finding the average emissions from the 1974 - 1975 burning series and then combining this number with the overall emissions from the four 1973 trials.

The unusually high concentration of CO produced by burning Russian thistle warrants providing a separate emission factor for this material of 22 lbs./ton fuel of particulate, 309 lbs./ton fuel of CO and 27 lbs./ ton fuel of hydrocarbons. Dr. Darley does point out that because of the low density of fuel (on the order of one ton per acre), the total emissions may not impact on the air pollution potential as greatly as these results may suggest.

4. Russian Thistle (Tumbleweed)

Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
		Part.	CO	HC
	Dry	24	(1)	12
	Dry	25	(1)	20
	Dry	22	(1)	20
	Dry	26	336	25
	Dry	20	361	31
	Dry/Green	19	230	44
	Dry	20	308	23
	Dry/Green	21	310	42
Mean		22	309	27
Standard deviation		2.6	49.2	11.2

(1) Concentration exceeded range of recorder

Ditch bank weeds were a mixture of species which are found along ditch banks. Mixed weeds were an assortment of 10 to 15 species found in an unspecified area. In both cases all materials growing in a sample area were cut and used in the burning tower tests. Tules are a particular species of wild reed; Russian thistle is also a species, more commonly known as tumbleweed.

An average emission factor for unspecified weeds or a variety of weeds is obtained by combining the results of all fires using ditch bank weeds or mixed weeds: 15 lbs. particulate/ton fuel, 85 lbs. CO/ton fuel and 12 lbs. HC/ton fuel.

Tules emit substantially less when they are burned, therefore a separate listing of 5 lbs. particulate/ton fuel, 34 lbs. CO/ton fuel and 2 lbs. hydrocarbons/ton fuel is provided.

Table III-2

AVERAGES AND STANDARD DEVIATIONS OF POLLUTANT EMISSIONS FOR ORCHARD PRUNINGS. VALUES IN POUNDS PER TON OF FUEL.

Orchard Material	Particulates		Carbon Monoxide		Hydrocarbons		Number of Burns
	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.	
Almond	5.9	0.5	46.1	9.8	7.9	1.9	8
Apple	4.2	0.5	41.6	5.4	4.3	0.5	8
Apricot	6.3	1.8	48.9	10.3	8.3	3.0	8
Avocado	20.6	3.0	116.5	16.7	32.0	5.3	3
Cherry	7.9	2.0	43.8	5.2	10.4	3.1	8
Citrus	6.0	2.5	80.6	26.8	11.8	4.6	13
Date Palm	9.5	3.4	56.0	9.3	6.9	2.0	4
Fig	7.4	1.4	56.8	7.0	10.0	3.2	8
Nectarine	4.4	0.5	32.9	4.4	4.1	0.7	7
Olive	12.3	3.7	114.4	11.6	17.5	1.8	8
Peach	5.6	1.4	42.5	4.5	5.3	1.8	8
Pear	9.1	4.4	56.8	6.2	8.6	2.2	8
Prune	3.4	0.5	41.8	4.5	3.2	0.8	8
Walnut	6.2	1.3	47.3	5.8	7.8	2.7	9
Entire Group	6.5	3.7	51.7	20.7	9.9	7.4	108

D. Orchard Crops

Variables examined by Darley (8) in the amount of pollutants emitted by burning orchard residues were moisture content and fire management technique. Low moisture fuels generally contained 20-30% water while high moisture fuels contained over 30% water. As with field crops, persons interested in determining emissions will generally not have information on moisture content available to them. Thus, PES again suggests that emissions be obtained by averaging results from burning both "wetter" and "drier" fuels.

The fire management techniques are "cold ignition" and "roll-on ignition." Cold ignition means "There were no hot coals on the table and the fuel was ignited with a large propane torch." Roll-on ignition means the fire "was ignited by rolling the pile of fuel onto the glowing embers" of the cold ignition fire. Continuing to quote Dr. Darley, "After roll-on it took two to three minutes before the pile started to flame. The reason for using the roll-on method was to simulate in some way the field practice of placing residues on the hot coals of a previous fire." To better represent the emissions from field fires conducted in this manner, PES suggests the results from cold and roll-on fires be averaged.

Table III-2 summarizes the averages and standard deviations of observed emissions for orchard prunings.

To determine whether the averages listed in the table were significantly different, PES carried out a statistical analysis, a one-way analysis of variance, for each of the three contaminants. This analysis confirmed that the emissions of each contaminant are significantly different for different orchard crops, and yielded the following estimates of the extent of difference necessary for 95 per cent confidence in the difference between any two averages: particulates, 4 lbs/ton; CO, 21 lbs/ton; HC 7 lbs/ton.

Using these criteria, it appears reasonable to suggest the use of common emission factors for most orchard crops. Avocado and olive

Crop	Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
			Part.	CO	HC
Almonds	Cold	39.7	4.4	35.1	7.4
	Roll-on	-	6.8	47.0	10.6
	Cold	38.7	4.1	35.3	6.6
	Roll-on	38.4	5.5	47.0	9.0
	Cold	39.3	3.8	44.4	7.4
	Roll-on	38.2	6.2	61.7	10.4
	Cold	39.5	3.4	34.8	6.1
	Roll-on	38.6	6.6	45.4	11.9
	Cold	28.1	3.4	21.1	4.3
	Roll-on	24.8	4.5	30.2	6.6
	Cold	25.4	3.6	23.4	3.2
	Roll-on	25.4	5.3	40.5	6.7
	Cold	27.2	3.7	10.3	1.3
	Roll-on	26.6	5.2	35.1	8.0
	Cold	26.0	3.7	25.5	3.3
	Roll-on	27.2	7.0	40.1	7.8
	3 Fires 1973	33	8.1	75	11.1
	4 Fires 1973	28	8.5	64	9.2
Apple	Cold	27.9	3.8	32.3	3.5
	Roll-on	34.8	4.8	37.7	6.2
	Cold	28.2	4.4	31.4	3.6
	Roll-on	38.6	5.1	44.6	6.7

emissions are distinctly higher, for all three contaminants, than the other crops tested; and, for CO, emissions from citrus burning are significantly higher than for any of the remaining eleven crops. Averages calculated for these eleven crops, pooled, are: particulates, 6.3; CO, 46; and HC, 7.0, lbs./ton. Averages for all the orchard crops studied, including avocado, citrus and olive, are: particulates, 6.5; CO, 52; and HC, 10. lbs./ton.

To summarize, briefly, the relative emissions from burning various orchard prunings, we can characterize three main groups of materials, as follows:

Relatively high emissions: avocado, olive, citrus
Near average emissions: apricot, cherry, data, fig, pear, walnut
Relatively low emissions: almond, apple, nectarine, peach, prune.

Complete results from the orchard crop fires are tabulated below:

Crop	Type of Fire	% Moisture, dry wt. basis		Emissions, lbs. per ton fuel burned		
		Leaves and Twigs	Branches	Part.	CO	HC
Avocado	Cold	33.0	85.8	22.2	126.9	34.8
	Roll-on	-	83.5	24.6	134.3	38.2
	Cold	31.5	91.8	21.9	126.8	36.3
	Roll-on	-	77.6	24.2	116.8	36.8
	Cold	17.4	35.6	18.1	112.0	26.5
	Roll-on	15.7	35.8	17.8	101.7	28.2
Cherry	Cold	42.3		10.7	41.9	12.2
	Roll-on	37.7		13.8	49.3	14.7
	Cold	37.3		7.3	36.6	7.2
	Roll-on	40.3		10.9	49.2	12.9
	Cold	38.9		6.6	43.6	8.8
	Roll-on	47.2		8.5	57.9	11.2
	Cold	42.8		6.4	40.1	7.8
	Roll-on	42.4		10.8	62.4	15.4
	Cold	30.3		4.9	31.0	6.9
	Roll-on	33.0		7.0	46.0	10.0
	Cold	27.4		5.4	32.1	7.2
	Roll-on	30.5		8.3	45.8	11.3
	Cold	29.6		5.1	35.4	8.2
	Roll-on	31.6		8.2	52.6	13.0
	Cold	31.5		4.8	28.0	5.5
	Roll-on	37.5		8.2	48.0	12.8

Crop	Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
			Part.	CO	HC
Apple	Cold	34.7	4.3	36.6	3.0
	Roll-on	30.4	5.5	48.1	5.1
	Cold	33.9	4.5	31.9	3.5
	Roll-on	33.7	4.5	36.1	4.5
	Cold	20.7	3.3	28.0	2.5
	Roll-on	21.6	4.1	62.7	5.8
	Cold	23.7	4.1	27.2	2.4
	Roll-on	17.9	3.6	62.8	4.7
	Cold	16.6	3.5	26.3	2.3
	Roll-on	23.5	4.2	72.6	6.8
	Cold	20.7	4.2	26.5	2.2
	Roll-on	20.4	3.9	60.4	5.9
Apricot	Cold	42.0	5.7	38.4	6.3
	Roll-on	42.8	7.8	65.9	10.7
	Cold	37.9	4.6	43.6	5.3
	Roll-on	42.5	6.7	57.6	7.6
	Cold	40.6	6.5	51.7	7.1
	Roll-on	39.7	11.7	70.6	14.4
	Cold	36.3	8.1	60.6	8.3
	Roll-on	39.4	9.6	68.9	15.0
	Cold	29.9	4.2	23.8	2.4
	Roll-on	28.6	7.4	52.0	7.7
	Cold	26.2	4.2	35.8	3.3
	Roll-on	-	6.2	46.4	5.7
	Cold	24.6	4.1	33.5	3.4
	Roll-on	25.8	4.9	44.3	5.5
	Cold	26.6	4.1	30.3	3.6
	Roll-on	29.0	5.1	55.4	5.3

Crop	Type of Fire	% Moisture, dry wt. basis		Emissions lbs. per ton fuel burned		
				Part.	CO	HC
		Pinnae	Peticles			
Date Palm	Pile	11.2	15.2	7.1	48.3	5.4
	Pile	11.3	15.3	6.4	48.0	5.7
	Pile	11.6	16.7	13.6	61.1	9.7
	Pile	10.8	14.3	10.8	66.6	6.8
Fig	Cold	40.8		5.3	48.6	7.4
	Roll-on	46.8		14.6	89.9	22.1
	Cold	36.5		4.9	41.0	5.0
	Roll-on	41.5		10.0	83.5	16.1
	Cold	38.6		4.8	44.2	7.5
	Roll-on	36.0		8.1	66.5	14.7
	Cold	39.4		6.0	44.5	9.4
	Roll-on	40.2		10.0	75.4	18.9
	Cold	-		4.9	40.2	4.5
	Roll-on	19.8		7.8	63.1	10.4
	Cold	21.2		5.0	36.6	4.7
	Roll-on	21.1		11.9	71.8	9.8
	Cold	19.0		5.4	43.6	6.2
	Roll-on	20.5		6.4	49.1	7.8
	Cold	21.9		5.8	38.3	5.5
	Roll-on	18.6		8.0	71.6	10.1
Nectarine	Cold	35.3		4.9	37.3	4.0
	Roll-on	37.2		4.5	40.3	5.0
	Cold	34.5		4.1	37.8	5.1
	Roll-on	37.6		5.2	39.7	5.8
	Cold	34.2		3.2	26.0	2.8
	Roll-on	28.4		3.8	30.3	4.6

Drying Time weeks	Percent moisture, wet weight basis: leaves, twigs	branches ½-1½"	branches 1½-3"	Emissions, Kg/MT (lb/ton) of weight loss: Part.	CO	HC
			Orange, November-December, 1972			
0	52	40	36	7.5 (15.0)	52 (103)	8.9 (17.8)
1	20	32	32	3.8 (7.6)	43 (86)	5.0 (9.9)
2	(skipped due to bad weather)					
3	19	29	30	3.0 (6.0)	38 (76)	9.9 (19.8)
4	13	26	27	3.1 (6.2)	37 (73)	10.7 (21.4)
			Orange, April-May, 1973			
0	48	33	37	5.1 (10.1)	64 (123)	10.4 (20.9)
1	29	37	34	2.4 (4.8)	60 (120)	5.0 (9.9)
2	18	32	32	2.0 (4.0)	43 (85)	4.5 (9.0)
3	14	32	33	1.7 (3.4)	36 (71)	2.9 (5.8)
4	15	29	32	1.5 (2.9)	39 (77)	2.9 (5.8)
6	16	14	22	1.7 (3.3)	23 (46)	2.8 (5.5)
25	(base fuel)	13[1/]		1.2 (2.4)	12 (23)	0.6 (1.2)
			Lemon, December, 1972			
7	11	27[1/]		4.1 (8.1)	40 (80)	9.1 (18.2)
8	12	19	27	2.4 (4.3)	43 (85)	3.9 (7.8)

[1/] Diameter classes combined.

Crop	Type of Fire	% Moisture, dry wt. basis	Emissions lbs. per ton fuel burned		
			Part.	CO	HC
Peach	Cold	35.5	4.8	43.2	5.8
	Roll-on	38.0	4.2	49.3	6.3
	Cold	44.3	5.6	43.6	5.5
	Roll-on	48.6	7.5	45.8	11.1
	Cold	50.7	4.6	46.3	7.0
	Roll-on	42.5	4.8	48.7	8.0
	Cold	42.1	6.2	52.6	7.4
	Roll-on	40.6	6.1	50.2	7.6
	Cold	25.5	5.2	36.2	2.9
	Roll-on	26.6	5.9	44.1	5.8
	Cold	24.4	5.5	34.9	3.0
	Roll-on	24.0	5.2	41.8	3.4
	Cold	24.2	9.6	37.9	2.7
	Roll-on	24.1	8.2	61.3	6.3
	Cold	24.6	5.7	35.0	3.2
	Roll-on	25.0	7.6	56.0	6.5
	4 Fires 1974	28	3.8	31	3.3
Pear	Cold	46.7	9.2	47.2	7.6
	Roll-on	43.1	10.1	65.7	11.3
	Cold	-	8.8	47.4	5.1
	Roll-on	41.5	12.9	67.1	10.7
	Cold	47.0	18.9	63.8	10.7
	Roll-on	48.6	17.2	72.2	15.2
	Cold	40.6	-	55.3	7.9
	Roll-on	39.5	-	61.8	12.9

Crop	Type of Fire	% Moisture, dry wt. basis		Emissions, lbs. per ton fuel burned		
				Part.	CO	HC
Nectarine	Cold	30.8		3.2	24.4	3.1
	Roll-on	35.8		4.7	33.2	5.6
	Cold	31.3		3.9	29.1	3.0
	Roll-on	29.7		4.9	33.5	4.2
	Cold	28.6		4.5	30.2	3.4
	Roll-on	32.0		5.1	36.4	4.8
	Cold	29.7		3.8	30.0	3.0
	Roll-on	27.8		4.8	32.0	3.6
		Leaves and Twigs	Branches			
Olive	Cold	22.1	42.5	12.3	111.1	15.0
	Roll-on	19.2	45.5	15.3	108.0	18.8
	Cold	25.8	45.8	12.7	105.4	16.9
	Roll-on	21.6	45.9	12.7	96.3	16.6
	Cold	25.7	42.6	9.9	100.8	15.0
	Roll-on	-	48.6	19.3	118.4	22.6
	Cold	22.2	45.7	12.6	98.9	14.4
	Roll-on	28.4	46.5	16.4	111.8	19.6
	Cold	11.1	34.9	13.6	91.6	14.0
	Roll-on	12.2	31.1	12.9	171.9	25.3
	Cold	11.1	30.6	12.0	84.3	14.6
	Roll-on	11.8	28.3	11.0	136.0	23.3
	Cold	9.6	33.1	8.9	88.3	10.0
	Roll-on	11.1	33.2	11.2	127.0	19.0
		Twigs only				
	Cold	14.9	30.8	8.2	134.2	17.1
	Roll-on	12.6	30.5	7.4	146.1	17.8

Crop	Type of Fire	% Moisture, dry wt. basis	Emissions, lbs. per ton fuel burned		
			Part.	CO	HC
Walnut	Cold	43.4	4.9	42.9	5.8
	Roll-on	45.5	6.6	57.3	8.1
	Cold	40.6	5.7	44.0	7.1
	Roll-on	49.4	7.3	54.6	8.5
	Cold	44.7	6.1	42.9	7.1
	Roll-on	46.1	8.8	63.6	13.6
	Cold	45.4	7.5	47.7	9.7
	Roll-on	46.6	10.3	66.6	17.3
	Cold	31.5	5.5	40.7	5.2
	Roll-on	36.5	5.7	42.9	6.6
	Cold	31.6	4.8	40.2	5.2
	Roll-on	36.6	5.5	44.1	6.6
	Cold	38.1	6.0	50.2	9.3
	Roll-on	32.5	4.3	38.9	5.6
	Cold	-	5.6	42.0	5.3
	Roll-on	30.0	6.1	45.7	6.7
	1974 Fire	32.5	4.6	40	4.6

Crop	Type of Fire	% Moisture, dry wt. basis	Emissions lbs. per ton fuel burned		
			Part.	CO	HC
Pear	Cold	31.8	6.7	39.5	7.0
	Roll-on	25.7	5.7	54.0	6.7
	Cold	28.3	5.4	51.7	5.6
	Roll-on	24.1	6.5	51.8	7.2
	Cold	24.5	5.7	45.7	6.3
	Roll-on	19.5	7.2	74.9	9.6
	Cold	24.5	6.3	48.4	6.7
	Roll-on	19.3	6.7	62.4	8.1
Prune	Cold	29.6	2.8	35.3	1.8
	Roll-on	27.6	3.3	53.1	3.9
	Cold	35.4	4.3	39.0	2.5
	Roll-on	33.9	3.6	45.8	3.6
	Cold	26.3	3.9	31.7	2.9
	Roll-on	28.2	2.9	39.0	4.4
	Cold	26.4	3.3	28.6	2.6
	Roll-on	36.4	4.8	47.9	7.4
	Cold	20.9	2.8	37.5	2.0
	Roll-on	21.4	3.2	45.8	3.6
	Cold	21.1	2.4	31.8	1.3
	Roll-on	21.6	3.5	40.7	3.5
	Cold	18.9	-	33.3	1.7
	Roll-on	20.1	4.0	31.6	3.9
	Cold	18.4	3.5	26.3	2.1
	Roll-on	19.1	3.5	39.1	3.7

IV. BACKGROUND DOCUMENT FOR SECTION 6.12 (SUGAR CANE PROCESSING)

New data on emissions from the burning of sugar cane have been furnished in a draft copy of a report (reference 4) by Dr. E. F. Darley, director of the agricultural burning research studies at the University of California, Riverside. Experiments were undertaken, to simulate burning conditions in Hawaiian pineapple fields. To quote Darley's description of the project,

> The principal object of burning cane is to get rid of much of the leaf material so that the cane stalk itself is relatively clean for factory processing. Thus the great bulk of material consumed in a fire is dead leaf material on the ground and those dead leaves still attached to the bottom and midportions of the cane. Some green leaves in the top may also burn. Therefore, in order to duplicate the field conditions as nearly as possible on the burning table, sectioned whole cane, attached leaves, and leaf trash on the ground were sent to Riverside.
>
> Cane to be sent to Riverside was cut from given commercial fields on Oahu on the morning that the field was to be burned. Four plots measuring 5' x 5' were selected at random in the field and corner stakes placed 2 ½ feet on either side of the center of the planting furrow and for a length of 5' along the furrow. All of the cane contained within the vertical block above two of the plots was cut....All material was taken to the DOA laboratories, fumigated...and then well aerated to remove all methyl bromide....

Packages of cane would arrive in Riverside approximately 24 hours after cutting and the material would be burned the following day. This handling is reflected primarily in the differences in amount of material which would burn. In the laboratory an amount equivalent to 15.8 tons fuel/acre burned, while in the field, the weight of cane and ash indicate 10.9 tons

E. Forest Products

Fritschen, et al. (2) have conducted laboratory fires on logging slash found in the Pacific Northwest. Their data from five fires are summarized below:

Fuel	lbs. Emitted/ton fuel		
	Part.	CO	HC
Hemlock	4.0	60	3.7
	4.0	92	3.7
Douglas fir	4.6	64	5.0
Western red cedar	3.4	112	6.8
	4.4	118	6.8

Sandberg et al. (3) studied the effects of flame retardants on emissions from ponderosa pine. The emissions in lbs per ton of fuel burned for untreated pine are 12 lbs. particulates, 195 lbs. CO and 14 lbs. HC. Yamate, et al. (6) summarized information Dr. Darley presented in a paper at the 1972 Spring Meeting, West States Section/The Combustion Institute as follows: particulates 17 lbs/ton fuel burned; CO, 140 lbs/ton fuel; HC, 24 lbs/ton; NO_x, 4 lbs/ton. Based upon the statement in his report, "...unpublished results and opinions of experienced wildfire observers in the U.S. Forest Service were weighted heavily in selecting high emission values from the range of values reported by Darley," PES suggests that these emission factors be used for AP-42.

fuel/acre burned. The average emissions for whole cane found in the lab are 7.2 lbs. particulate/ton fuel, 70.6 lbs. CO/ton fuel and 10.4 lbs. HC/ton fuel. Corresponding values in lbs. pollutant per acre fuel burned, based on the field fires, would be 79 lbs. particulate/acre, 770 lbs. CO/acre and 113 lbs. HC/acre.

No new data on NO_x emissions have been available to us; therefore, the current values of 2 lbs./ton fuel are being retained.

Estimates of emissions from laboratory tests on burning of slash range from 30 to 59 grams CO, and from 1.2 to 2.2 grams of carbon in hydrocarbons, per kilogram of fuel. Corresponding figures in pounds per ton are : CO, 60 to 118; HC, 3 to 5.

3. Sandberg, D. V., Pickford, S. G. and Darley, E. F. "Emissions from Slash Burning and the Influence of Flame Retardant Chemicals." J. Air Poll. Control Assoc. 25, 278 (1975).

Ponderosa pine fuelbeds were burned to simulate slash fires. Studies showed (a) emission rates varied with burning intensities, (b) diammonium phosphate flame retardant increased emissions; (c) the smoldering combustion phase accounts for most of the gaseous pollutant emissions from such fires. Overall, emissions sampled during ten burns with ponderosa pine fuelbeds yielded emission factors for carbon monoxide, hydrocarbons and particulate matter of 140 ± 10, 8.4 ± 2.0 and 9.1 ± 1.4 lb/ton of initial fuel, respectively. Treating similar fuelbeds with diammonium phosphate flame retardant significantly increased these factors to 166 ± 28, 11.7 ± 2.1 and 19.3 ± 3.3 lb/ton of initial fuel, respectively.

4. Darley, E. F. "Air Pollution Emissions from Burning Sugar Cane and Pineapple from Hawaii." Amendment to EPA Research Grant R800711 Air Pollution from Forest and Agricultural Burning, Statewide Air Pollution Research center, University of California, Riverside, August, 1974.

This paper discusses thoroughly the various aspects of sampling and burning numerous examples of sugar cane and pineapple trash. Results reported and analyzed include the yield of particulates, carbon monoxide and hydrocarbons, the yield of benzo(a)pyrene and selected trace metals, and the particle size distribution.

APPENDIX I

ABSTRACTS

Abstracts of literature appearing after the publication of AP-42 are provided below. Data from these reports have been used to supplement the latest results of Dr. Darley's simulations to calculate emission factors. When the data are subsequently discussed, references to the appropriate document will be made.

1. Middleton, J. T. and Darley, E. F. "Control of Air Pollution Affecting or Caused by Agriculture," in Pollution: Engineering and Scientific Solutions, E. S. Barrekette (ed.), Plenum Publishing Corp., New York.

This chapter reviews the effects of various pollutants on vegetation, the general types of pollution control mechanisms, and summarizes the nation-wide emissions estimated for selected source categories for the year 1969. Estimated emissions from open burning of agricultural refuse and forest materials were 11.2×10^6 tons of particulates, 17.7×10^6 tons carbon monoxide, 4.6×10^6 tons hydrocarbons, and 1.9×10^6 tons nitrogen oxides.

2. Fritschen, L., Bovee, H., Buettner, K., Charlson, R., Monteith, L., Pickford, S., Murphy, J. and Darley, E. Slash Fire Atmospheric Pollution. USDA Forest Service Research Paper PNW-97, 1970.

Results of an investigation of slash burning contributions to air pollution are presented. The hypothesis is incomplete combustion and greater emissions result from low-temperature fires associated with broadcast burns. Results of field tests and laboratory tests with respect to burning characteristics, gaseous and particulate emissions are reported in detail.

6. Yamate, G., Stockham, J., Becker, D., Waterman, T., Llewellen, P. and Vatavuk, W. M. "Development of Emission Factors for Estimating Atmospheric Emissions from Forest Fires." Paper (#75-36.7) presented at the 68th Annual Meeting, Air Pollution Control Association, Boston, Mass., June 1975.

Emission factors have been developed for estimating atmospheric emissions from forest wildfires. The factors, for particulates, hydrocarbons, carbon monoxide, nitrogen oxides and sulfur oxides, expressed as pounds pollutant released to the atmosphere per acre forest land burned, were developed using pollutant yield data from experimental burns and estimates of the fuel consumed per acre by a wildfire. Consumption estimates were developed from available fuel inventories. Pollutant yield data were obtained from measurements made on laboratory, burning tower, field experimental and managed fires. Each ton of forest fuel consumed yields an average estimated 17 lbs particulates, 140 lbs carbon monoxide, 24 lbs hydrocarbons and 4 lbs nitrogen oxides.

7. Darley, E. F., Miller, G. E., Jr., Goss, J. R. and Biswell H. H. Air Pollution from Forest and Agricultural Burning, ARB Project 2-017-1, University of California, Davis April 1974.

In order to obtain information on the effect of atmospheric conditions, residue management and fire management techniques on particulate, hydrocarbon and carbon monoxide emissions from open field burning, burns were conducted with cereal grains such as wheat, reice and barley; asparagus fern and orchard prunings. Many burns were conducted in the field and laboratory simulations of field burns were done at the SAPRC burning tower. Both laboratory and field data agreed that moisture content of fuel residues was the most significant factor influencing emission levels. At higher moisture contents particulate emissions can be reduced by lighting the field only on the downwind edges (backfiring) or using an into-the-wind striplighting technique. All raw data are provided and a thorough analysis of all results is presented.

For nineteen batches of whole sugar cane, average emissions (± standard deviation) in pounds per ton of fuel were: Particulates, 7.2 ± 1.6; CO, 70.6 ± 17.3; HC 10.4 ± 8.3. For eighteen batches of sugar cane leaf trash, the corresponding values were: Particulates, 5.3 ± 2.0; CO, 59.4 ± 15.3; HC 8.4 ± 7.5.

From eighteen burns of pineapple trash, particulate emissions varied from 6 to 25 pounds per ton of fuel; the larger emissions correspond to head-fire burning of trash with a high moisture content. Average emissions from these burns were: Particulates, 9.9 lbs; CO, 111 lbs; and HC, 6.5 lbs (all per ton of fuel).

5. Yamate, G., Stockham, J., Vatavuk, W. and Mann, C. "An Inventory of Emissions from Forest Wildfires, Forest Managed Burns, and Agricultural Burns." Paper (#75-36.6) presented at the 68th Annual Meeting, Air Pollution Control Association, Boston, Mass., June 1975.

An information search was conducted to obtain data on acreages burned and tons of fuel burned per acre in forest wildfires, forest managed burning and agricultural burning. Estimated emission factors were applied to these data for each of the burn categories. The expression provided to estimate emissions released to the atmosphere using the tabulated data is $E_p = Y_p \times F \times A \times C$
where

E_p = tons of pollutant, p, emitted to the atmosphere
Y_p = yield factor for pollutant, p, in lb per ton of fuel consumed
F = tons of fuel consumed per acre burned
A = number of acres burned
C = constant to convert pounds to tons, 1/2000.

Emission factors utilized were, in pounds per ton of fuel: Particulates, 17; CO, 140; HC (as methane), 24; NO_x, 4.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-75-087	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CALCULATION OF EMISSION FACTORS FOR AGRICULTURAL BURNING ACTIVITIES		5. REPORT DATE November 1975
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) L. G. Wayne and M. L. McQueary		8. PERFORMING ORGANIZATION REPORT NO. 075
9. PERFORMING ORGANIZATION NAME AND ADDRESS Pacific Environmental Services, Inc. 1930 14th Street Santa Monica, California 90404		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-1004 Task Order 4
12. SPONSORING AGENCY NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED FINAL
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Copies of all references cited have been provided to the Sponsoring Agency under separate cover.

16. ABSTRACT

Proposed revisions to the emission factors for agricultural burning activities given in Sections 2.4 and 6.12 of AP-42, Compilations of Air Pollutant Emission Factors, are made.

The data, calculations and supplemental information upon which the proposed emission factors are based are provided. A substantial amount of the test data was obtained from the work of Dr. E. F. Darley, University of California, Riverside, California.

Abstracts of all references are included.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
EMISSIONS WASTE DISPOSAL AGRICULTURAL WASTE	AGRICULTURAL BURNING EMISSION FACTORS	13B

18. DISTRIBUTION STATEMENT RELEASE UNLIMITED	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 66
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

8. Darley, E. F. Progress Report on Emissions from Agricultural Burning, ARB Project 4-011. Statewide Air Pollution Research Center, University of California, Riverside, Private communication with permission of California Air Resources Board, June 1975.

This is a listing of all data from burning simulations conducted for this project since July 1, 1974.

9. Communication from the California Air Resources Board (ARB) stating estimates of waste produced by agricultural burning activities.

This is a listing of factors used by staff of the ARB in calculating pounds of pollutant per acre of vegetation burned. The references they used in arriving at these factors are listed.