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Darley, E.F., et al. "Contribution of Burning of Agricultural Wastes to Photochemical Air Pollution." Journal of the American Pollution Control Association, vol. 11 (12), December 1966.

This article provides a very detailed description of the equipment and analytical procedures used for the experiment which measured the yield of hydrocarbon, CO, and CO^2 in lbs/ton of waste material of barley, cotton, rice, almond, apple, apricot, cherry, grape, peach, pear, prune, walnut, and some native bush and wood chips. The percent of ethene, olefins, and paraffins + acetylene of total C from burning as well as the maximum yield of hydrocarbon per day and the yield of hydrocarbons in lbs/ton of fuel between ethene, olefins, and saturates + acetylene from burning fruit prunings, barley straw, and native brush are also presented. This article is quite outdated.

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Contribution of Burning of Agricultural Wastes to Photochemical Air Pollution

Agricultural wastes from orchards, grain fields, and range lands are burned each year in California as the most practical means of ridding the land of these wastes. In order to determine the relative contribution of the burning of such material to photochemical air pollution, the effluent from 123 fires of known weights of range brush, both dry and green, barley and rice stubble, and prunings from various fruit and nut trees were monitored in a special tower which provided an open burning situation. Analyses were made for total hydrocarbon, expressed as C, by flame ionization detection, and for 24 individual hydrocarbons by gas chromatography, as well as for CO and CO_2 by infrared spectroscopy. A few analyses were made for oxides of nitrogen. These data, coupled with temperature and airflow measurements, allowed calculations to be made on pounds of effluent per ton of material burned and demonstrated that the emissions from agricultural burning are much less than those from the automobile, a principal source of such emissions.

The burning of agricultural wastes to rid orchards and vineyards of prunings and dead trees, grain fields of straw and stubble, and range lands of brush, has been the standard practice in California for disposing of such wastes. From 30 to 80% of the some 240,000 acres of rice in the eight Sacramento Valley counties are burned annually. About 41,000 tons of orchard tree wastes were burned in Merced County in 1960. Range improvement programs in the foothills bordering the San Joaquin Valley involve burning of several thousand acres each year.

The continuing need for improving air quality requires that the relative importance of various pollutant sources be examined. Brandt[1] has discussed the problems involved when burning agricultural wastes. For several years studies have been underway to evaluate the relative contribution to photochemical air pollution from the open burning of agricultural wastes. Two field studies, one conducted on range lands and grain stubbles in 1959[2] and the other on rice stubble near Sacramento in 1960,[3] indicated that the concentrations of photochemically active hydrocarbons were rather negligible at a mile or more from the fire when more than 1000 acres of wastes were being burned. In the second study it was concluded that most of the hydrocarbon burden downwind from Sacramento originated in the urban community and that the burning of stubble, upwind from the city, did not add significantly to the hydrocarbon level.

Feldstein, *et al.*,[4] using data from single chamber incinerator studies, have estimated the emissions from the burning of plant material in land clearing operations and concluded that such burning contributes a significant burden to the hydrocarbon level.

Since the two field studies did not permit an evaluation of emissions in terms of units of pollutant per unit of waste burned, and the values given by Feldstein, *et al.*, were not based on open burning, experiments were conducted wherein known weights of various agricultural wastes were burned in a manner to simulate open burning and to permit adequate monitoring of the effluents. It is the purpose of this paper to report on the results of these experiments.

Methods

Burning Tower

Details of the tower used for burning various agricultural wastes are shown in Fig. 1. A burning table 8 ft in diameter was positioned on a scale which was equipped with an automatic print-out capable of recording the weight every 5 sec. A tower in the form of an inverted funnel was erected over the burning table. The dimension of the broad base of the tower, its height above the burning table, and the diameter of the exit stack were constructed to give an open burning situation without causing smoke to be spilled from the base of the tower during periods of peak burning. Probes and instruments were placed in the stack of the tower to permit readings of temperature and airflow and to provide for gas sampling. A glass fiber filter was placed in the gas sampling line to protect instruments from particulate matter. A small shed near the tower contained instrumentation for the analysis of total hydrocarbon, CO, and CO_2 and apparatus for taking grab samples for subsequent analysis of individual hydrocarbons and oxides of nitrogen. The shed also contained a potentiometer for registering temperature and an automatic device for recording the accumulated revolutions of the anemometer for 5-sec periods. The anemometer had been calibrated in linear feet per revolution by using a velometer in the stack coupled with a squirrel cage blower on the burning table; the value obtained was 5.8 ± 0.3 ft/rev at linear flows of 400–1000 fpm.

Analytical Procedures

Appropriate air pumps brought air and effluent gases from the stack to the analytical instruments in the shed adjacent to the tower. Carbon monoxide and CO_2 were measured on Beckman Model 15A infrared gas analyzers. Hydrocarbon as total carbon was analyzed on a Beckman Model 109 flame ionization total carbon analyzer. Grab samples for chromatographic analysis of individual hydrocarbons and for analysis of oxides of nitrogen were also taken.[5] Methane, ethane, and ethene were determined on an Aerograph Model 600 flame ionization gas chromatograph equipped with a 5-ft × 1/8-in. column packed with 60/80 alumina

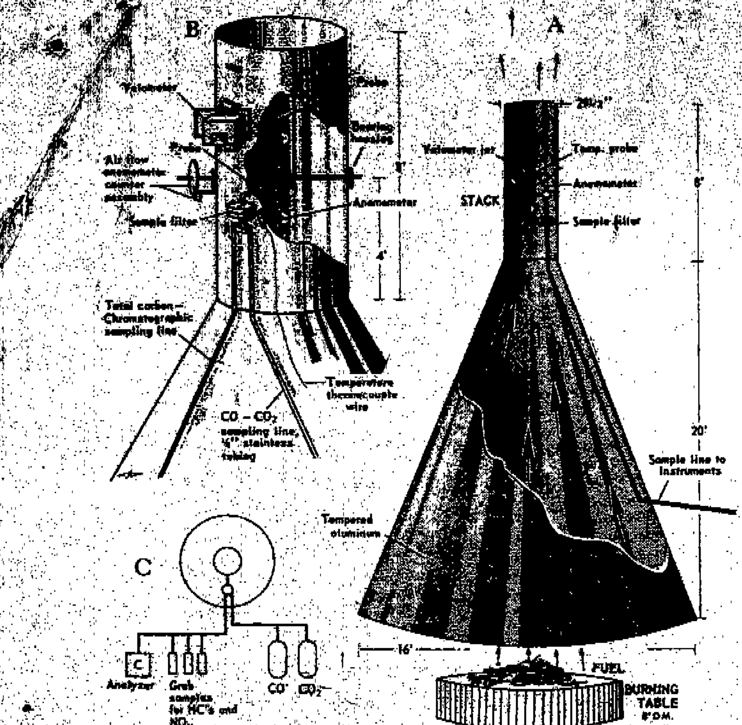

Fig. 1. Drawing of tower used in burning agricultural wastes. (A) Complete unit showing relative position of fuel bed and sampling sites. Burning table is mounted on scales. (B) Detail of instrumentation and probes at sampling site in stack of tower. (C) Schematic relationship of tower and analytical instruments in shed next to tower.

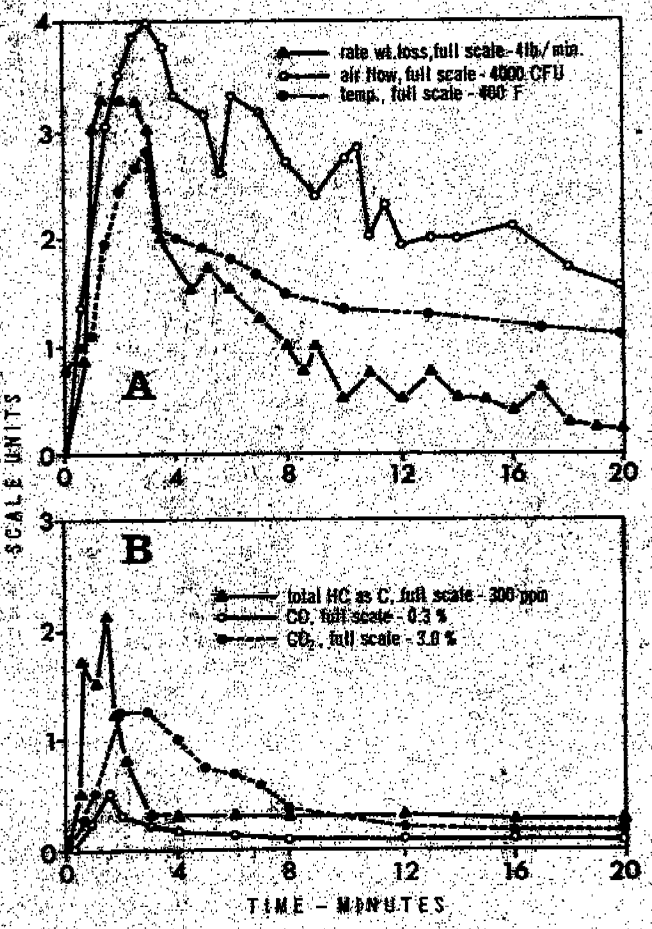

Fig. 2. Various responses with time from the burning of 25 lb of prunings from prune trees. (A) Rate of burning expressed as weight loss in pounds per minute; airflow in cfm; and temperature in °F. (B) Total hydrocarbon expressed in ppm C; CO and CO_2 expressed in per cent.

The remaining saturates, olefins, and acetylenes listed below were analyzed on a second Aerograph equipped with a 36 ft x $^1/_8$ in. column packed with 10% dimethyl sulfolane on C-22 60/80 firebrick.

Saturates	*Olefins*
Propane	Propene
Isobutane	Butene-1
Butane	Isobutene
Isopentane	*Trans*-butene-2
Pentane	*Cis*-butene-2
Hexane	3-methyl butene-1
	Butadiene-1,3
Acetylenes	Pentene-1
Acetylene	2-methyl butene-1
Methyl acetylene	*Trans*-pentene-2
	Cis-pentene-2
	2-methyl butene-2
	2-methyl butadiene-1,3

Grab samples for oxides of nitrogen determination were treated with oxygen for 24 hr, bubbled slowly through Saltzman's reagent, and the color read on a spectrophotometer.

The typical procedure for monitoring a fire was as follows: A given weight of plant material was placed on the burning table. One pound of barley straw was placed under woody and green plant material to assist in starting the fire. The CO, CO_2, and total C analyzers were checked for calibration and all recording instruments were turned on. At a given signal a small amount of alcohol was thrown on the edge of the pile of waste and ignited. Continuous records of CO, CO_2, and total C concentrations and of temperature, airflow, and rate of weight loss were made throughout the fire. Three grab samples for individual hydrocarbon analysis were made, one each being taken as near as possible to the time of the temperature peak, the time of the hydrocarbon peak, and to an arbitrary time designated as "end of fire." This latter period was 5 min for rice and barley straws and 20 min for the woody wastes. Burning was usually conducted in the morning hours when winds were minimum. An example of the records obtained from the burning of 25 lb of prunings from prune is plotted with time in Fig. 2. For rice and barley the events shown in Fig. 2 were compressed into 5 min.

Agricultural Wastes

Agricultural wastes burned in these experiments are listed below and included field crops, fruit and nut crops, native brush, and miscellaneous types.

Common Name	Scientific Name
	Field Crops
Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Rice	*Oryza sativa*
	Fruit and Nut Crops
Almond	*Prunus amygdalus*
Apple	*Malus domestica*
Apricot	*Prunus armeniaca*

Table I—Yield of Hydrocarbon, CO, and CO_2 in Pounds per Ton of Waste Material from the Burning of Various Agricultural Wastes Collected in the San Joaquin Valley and San Francisco Bay Area of California

Waste Material	% Moisture	Total Hydrocarbon as C	CO	CO_2
		San Joaquin Valley		
Rice straw	—	9.1 ± 2.4	73 ± 17	2091 ± 305
Barley straw	—	14.5 ± 3.7	83 ± 23	1708 ± 389
Native brush				
Dry	—	4.7 ± 2.5	70 ± 8	2733 ± 410
Dry and green	—	15.2 ± 4.3	81 ± 6	1990 ± 237
Green	—	27.4 ± 8.8	134 ± 41	1528 ± 464
Cotton	40 ± 14[a]	3.1	73	2532
		Bay Area—1965		
Fruit prunings	11 ± 4[a]	4.2 ± 1.3	46 ± 14	2258 ± 238
Native brush	5 ± 1	4.7 ± 2.1	65 ± 30	2620 ± 204
Fir chips	5	2.8	35	1522
Redwood chips	—	2.2	70	3742
		Bay Area—1966		
Fruit prunings	35 ± 15	9.7 ± 4.2	66 ± 21	1995 ± 347
Native brush	13 ± 7	4.4 ± 2.3	55 ± 19	2374 ± 204

[a] Figures are given with standard deviations. Entries without deviations represent one or two fires only.

Cherry	*Prunus avium*
Grape	*Vitis vinifera*
Peach	*Prunus persica*
Pear	*Pyrus communis*
Prune	*Prunus domestica*
Walnut	*Juglans regia*
Native Brush	
Baccharis	*Baccharis pilularis*
California Blackberry	*Rubus vitifolius*
Chamise (Greasewood)	*Adenostoma fasciculatum*
Coast Sagebrush	*Artemisia californica*
Coffeeberry (Buckhorn)	*Rhamnus californica*
Digger Pine	*Pinus sabiniana*
Interior Live Oak	*Quercus wislizenii*
Manzanita	*Arctostaphylos manzanita*
Squaw Bush	*Rhus trilobata*
Wild Lilac (Deerbrush Ceanothus)	*Ceanothus integerrimus*
Yerba Santa (Mountain Balm)	*Eriodictyon californicum*
Miscellaneous	
Douglas Fir chips	*Pseudotsuga menziesii*
Redwood chips	*Sequoia sempervirens*

Wastes were collected from two general areas of California, (*a*) the San Joaquin and lower Sacramento Valleys, and (*b*) the San Francisco Bay Area. From the first area rice and barley were burned in several lots of 15 lb each and the results averaged for each species; two lots of cotton debris were burned. Dry native brush and dry with some green was picked up at random without regard to species and aliquot lots of 25 lb were burned in several fires and the results averaged for the classes "dry" and "dry and green." Green brush from the San Joaquin Valley was collected by species and two lots of each were burned and the results averaged for the class "green brush." From the Bay Area fruit and nut prunings and native brush were collected by individual species, burned in two lots each, and the results averaged for the two classes "fruit prunings" and "native brush." In total, 123 lots of waste were burned.

Calculations

Since the analyzers for C, CO, and CO_2 gave continuous chart recordings and airflow and temperature were recorded every 5 sec, it was possible to integrate the areas underneath the recorded values and calculate pounds of effluent per charge of material in the fire. Calculations were made for every 20-sec interval throughout a fire, and then the total pounds of all intervals were added to give the pounds of effluent per charge of waste in the fire.

Individual hydrocarbons were determined on two gas chromatographs as noted above. In order to transfer the gas sample to the chromatograph, the sample bottle was usually pressurized with 40 ml of nitrogen. When calculating total ppm C, a small correction factor was applied to account for the change in volume. Percentages of the three classes of hydrocarbons, ethene, olefins, and saturates (except methane) plus acetylenes, were calculated based on the concentration of total C as given by the total C analyzer at the moment of sampling. Since it was not possible to obtain pounds of individual hydrocarbons per charge of waste burned from the chromatographic samples alone, the percentage of the three hydrocarbon classes within each sample period was averaged for a given fuel class and this final percentage applied to the pound yields determined from integrating the total carbon analyzer.

Results

The yield of hydrocarbon, CO, and CO_2 in pounds per ton of waste material burned is presented in Table I. In cases where per cent moisture was determined this information is also included. Pounds of carbon per ton of waste burned varied from approximately two to a high of 27. Carbon yields from barley were consistently higher than those from rice, and this is probably due to the fact that rice fires burned hotter than barley. At the point in the stack where temperature was measured, rice fires were generally over 550°K while those of barley were between 450 and 500°K. It is interesting to note that dry native brush had a relatively low carbon yield, but as green material was added to it the carbon count went up. When totally green native brush was burned, the highest yields of carbon were obtained. While green brush produced more carbon than did dry brush, it should be pointed out that in a natural situation the amount of green brush in a range improvement burn is a relatively smaller portion of the total amount of waste burned. In the field study reported by McElroy in 1959[2] it was shown that on a 1200 acre fire some 1740 tons of fuel were consumed. Of this dry brush represented 940 tons and standing green trees and shrubs represented 267 tons. Fruit prunings were relatively low in carbon yield except that an increase was apparent from the prunings burned in 1966 which had a higher moisture content. It will be noted that there was considerable variation in amount of effluent from a given waste material. It should be emphasized that there was no attempt to make uniform burns other than to provide an open burning situation; variation, therefore, should be expected.

Comparison of yields of hydrocarbon expressed as C between burning of agricultural wastes and the exhausts of gasoline engines will be noted below.

The yield of CO varied from 35 to 134 lb/ton of waste material burned. Again the green native brush produced almost twice as much CO as the dry brush. For other wastes, about 50–80 lb was the usual yield. Using the emission factors compiled by Mayer[5] and those of the Los Angeles County Air Pollution Control District, auto exhausts produce something between 850 and 900 lb of CO per ton of gasoline. In comparison the burning of agricultural wastes yields less than one-tenth the amount of CO.

If one assumes that CH_2O represents the composition of the plant wastes, then approximately 3000 lb of CO_2 would be produced per ton of waste burned. The yields of CO_2 given in Table I indicate that the burning was generally good and that the method of integrating the charts was fairly satisfactory. This is further borne out by the trend of less CO_2 being produced from brush fires as the material became more green, and therefore contained more moisture, and from the prunings as the moisture content increased. One anomaly not explained is the relatively high CO_2 yield from the burning of redwood chips.

The per cent yields of ethene, olefins, and saturates (except methane) plus acetylenes for each class of agricultural waste burned are given in Table II. The ratio of ethene to olefins varied from about 0.4 to 0.7, whereas the ratio of olefins to saturates varied from 2 to 5. Thus among the hydrocarbons measured the photochemically active olefins predominated.

The maximum yield of the three categories of hydrocarbons in pounds per ton of waste material burned is presented in Table III. It will be noted here that the maximum yields of ethene and olefins are again from the green native brush which constitutes a relatively small portion of the native brush that is burned. In general, the pounds of ethene per ton of waste burned was 3 lb or less and that of all olefins 5 lb or less.

The three principal agricultural waste types in the San Francisco Bay Area are fruit prunings, barley straw, and native brush. Using the data obtained from burning Bay Area prunings and brush in 1966 and assuming that barley would have the same value as for the San Joaquin Valley, these three fuels and the maximum yield of tons of hydrocarbons per day for the burning season as well as on a calendar year basis are given in Table IV. These are calculated by multiplying the maximum pounds of hydrocarbon per ton times the tonage of wastes burned per year and dividing by the number of days in the burning season as well as dividing by 365 days. These amounts are generally considerably less than amounts calculated by the Bay Area Air Pollution Control District[4] wherein daily yields of hydrocarbons for an unspecified number of days during given seasons for fruit prunings (fall season), stubble and straw (summer season) and range brush (fall season) are 119, 5, and 11, respectively. It is important to emphasize that the relatively higher yield of 47 tons of hydrocarbon from native brush in the present study is due to the fact that records over the past few years indicate that the burning takes place in two days, whereas the 11 tons reported by the District is for an unspecified number of days in the fall season.

A comparison of the yield of hydrocarbons in pounds per ton of material burned from agricultural wastes and from the exhaust of gasoline engines is shown in Table V. The figures for total hydrocarbons from the gasoline engine are calculated on the basis of 6.5% of supplied fuel as reported by the California Department of Public Health[8]; those for ethene, olefins, and saturates plus acetylenes are based upon the weight per cent of these same compounds presented by Jackson.[9] The yield of total hydrocarbons from the burning of the three principal agricultural wastes in the San Francisco Bay Area are considerably less than those from gasoline engine exhausts. The nearest approach to comparable values is the yield of ethene which is about one-third that of auto exhaust. Olefins as a whole are at least one-fifth that of auto exhaust, and for purposes of photochemical reactions it would appear that the burning of agricultural fuels is much less of a contributor on a fuel rate basis than is the automobile exhaust. Comparatively, agriculture becomes even less of a contributor based on total yields. According to the Bay Area District Report,[7] the automobile contributes about 1014 tons of hydrocarbons per day from the daily consumption of approximately 12,000 tons of gasoline. Thus the total yield of hydrocarbons from agriculture for a year approximates the daily yield from automobiles. The trend of these data varies appreciably from those reported by Feldstein, *et al.*[4] In at least two hydrocarbon categories, ethene and olefins, they indicate that the yields from the burning of plant wastes are greater than from gasoline engine operations. This comparison may not be quite valid because they reported on the burning of land clearing operations, which is not considered agricultural in the present report, and their estimates of effluent yields were projected from incinerator

Table II—Yield of Ethene, Olefins, and Paraffins Plus Acetylenes in Per Cent of Total Carbon from the Burning of Several Agricultural Wastes Collected from the San Joaquin Valley and San Francisco Bay Area of California

Waste Material	Ethene	Olefins	Saturates Plus Acetylenes
	San Joaquin Valley		
Rice straw	9.6 ± 5.4[a]	16.7 ± 4.6	4.2 ± 2.1
Barley straw	9.6 ± 2.5	14.3 ± 4.9	4.5 ± 1.5
Native brush			
Dry	6.9 ± 3.3	10.7 ± 5.6	4.3 ± 2.6
Dry and green	12.6 ± 5.1	19.9 ± 7.0	4.1 ± 1.5
Green	10.3 ± 4.9	16.4 ± 7.6	3.8 ± 1.9
Cotton	9.1	16.0	5.2
	Bay Area—1965		
Fruit prunings	8.8 ± 5.1	15.7 ± 8.0	5.5 ± 2.9
Native brush	10.3 ± 7.3	16.2 ± 10.0	5.7 ± 2.7
Fir chips	7.0	11.7	3.8
Redwood chips	8.0	11.7	3.3
	Bay Area—1966		
Fruit prunings	14.1 ± 5.2	22.4 ± 7.1	6.8 ± 2.7
Native brush	10.2 ± 3.4	16.9 ± 4.9	6.9 ± 2.6

[a] Per cents are given with standard deviations. Entries without deviations represent one or two fires.

Table III—Maximum Yield of Ethene, Olefins, and Paraffins Plus Acetylenes in Pounds per Ton of Waste Material from the Burning of Various Agricultural Wastes Collected from the San Joaquin Valley and San Francisco Bay Area of California

Waste Material	Ethene	Olefins	Saturates Plus Acetylenes
	San Joaquin Valley		
Rice straw	1.7[a]	2.5	0.7
Barley straw	2.2	3.5	1.1
Native brush			
Dry	0.7	1.2	0.5
Dry and green	3.5	5.2	1.1
Green	5.5	8.7	2.1
Cotton	0.3	0.5	0.2
	Bay Area—1965		
Fruit prunings	0.8	1.3	0.5
Native brush	1.2	1.8	0.6
Fir chips	0.2	0.3	0.1
Redwood chips	0.2	0.3	0.1
	Bay Area—1966		
Fruit prunings	2.7	4.1	1.3
Native brush	0.9	1.5	0.6

[a] Pounds/ton are calculated by multiplying the sum of the pounds of total hydrocarbon and its positive deviation (Table I) times the sum of the per cent of the hydrocarbon(s) and its positive deviation (Table II).

Table IV—Maximum Yield of Tons of Hydrocarbon per Day from Burning the Three Principal Types of Agricultural Wastes Occurring in the San Francisco Bay Area

Waste Material	Lbs. HC/ton	Tons Waste Burned/Yr	Tons HC/Yr	Max. tons HC/day—Burning Season	Max. tons HC/day—Calendar Yr 365 Days
Fruit prunings	9.7 ± 4.2	121,115	587 ± 254	5.6[a]	2.30
Barley straw	14.5 ± 3.7	1,632	12 ± 3	0.7[b]	0.04
Native brush	4.4 ± 2.3	28,140	62 ± 32	47.0[c]	0.25

[a] 150 days from December through April.
[b] 120 days November–December, and June–July.
[c] 2 days in August.

studies and were not based on data obtained from open burning.

Determinations of nitrogen oxides as NO_2 were made on a few fruit pruning and native brush wastes burned in 1966. The concentration of NO_2 at temperature peaks of 400°–519°K ranged from 21 to 42 ppm. One minute before or after the temperature peak at temperatures of about 380°K, the concentrations ranged from 11 to 25 ppm. Only 1.5–3.8 ppm of NO_2 were found at the sample period designated as "end of fire." Since the concentration of nitrogen oxides expressed as NO_2 in auto exhausts is reported to be greater than 1000 ppm,[10] it appears that the contribution of this effluent from the burning of agricultural wastes is much less than from the automobile.

Although not originally intended to be a part of this study, it became of interest to determine the nature of the benzene extractable particulates collected on the glass fiber filter in the gas sampling line. Clean filters had been put in the line prior to each fire. These were extracted using standard procedures[11] and absorbances read on a Perkin-Elmer Model 137B Infracord spectrophotometer. The greatest amount of extractable material was obtained from the green native brush. Strong absorbance peaks indicating hydrocarbons were obtained at 3.4, 6.9, and 7.9 microns. A strong carbonyl peak at 5.8 mμ and an OH-stretching band at 3.0 mμ was also obtained. Spectra from dry brush, on the other hand, contained nothing of interest and appeared to be little different from background spectra. Absorbances in all bands but the OH were present in spectra from occasional fruit pruning and barley burns, but the strength was one-third or less than that of green brush. Spectra of rice burns were no different from background.

Discussion

Two field studies[2, 3] on the contributions of open burning of agricultural wastes indicated that such burning did not contribute significantly to the hydrocarbon richness of the atmosphere at any distance away from the fire. The methods used in the study, however, did not permit data to be expressed in terms of units of effluent per unit of material burned. Another report[4] presented estimates in terms of pounds of effluent per ton of debris burned in urban land clearing operations and suggested that such burning was a significant source of hydrocarbons, but the estimates were based on data obtained from single chamber incinerators and not from open burning of such debris.

The burning tower and the associated apparatus and analytical instruments discussed in the present paper offered a technique of determining the pounds of effluent per ton of waste material burned while still retaining the essential features of an open burning situation. The results obtained show that the maximum expected emissions of hydrocarbons (saturates, except methane, olefins, and acetylenes) per ton of waste when burning fruit tree prunings, rice straw, barley straw, and dry native range brush would be approximately 14, 9, 18, and 7 lb, respectively. Green native brush could be expected to produce as much as 36 lb of hydrocarbon per ton but this type of waste constitutes a relatively small portion of the total material burned in a range improvement program. In comparison, the automobile exhaust produces about 130 lb of the same hydrocarbons per ton of fuel. Thus it is evident from the present studies that the contribution of total hydrocarbons from agricultural burning is considerably less than from the automobile. The difference between the two sources, however, is not so great when considering ethene only. Of the four agricultural wastes, fruit tree prunings emitted the most ethene—2.7 lb/ton of waste burned. This compares with about 7.8 lb from auto exhausts. Total olefins from burning of fruit prunings and from auto exhausts were 4.1 and 20.8 lb, respectively, so even in this photochemically active group of hydrocarbons, agricultural burning emits less effluent per ton of material burned. Moreover, if total yields of hydrocarbons are compared in the Bay Area, agriculture contributes considerably less than the automobile as evidenced by the fact that the latter source contributes about 1014 tons of hydrocarbons per day from the daily consumption of about 12,000 tons of gasoline, whereas the annual burning of 151,000 tons of the three principal agricultural wastes produces a maximum of 950 tons of hydrocarbons per year. Thus the annual yield from agriculture approximates the daily yield from automobiles in this area. The trend of these results varies from those of the report[4] noted above which states that the yields of ethene and total olefins were greater from burning plant wastes than from gasoline engine operations. It should be emphasized that the figures presented in the latter study were based on emissions from single chamber incinerators and not from open burning.

The emissions of CO and oxides of nitrogen also indicate that the burning of agricultural wastes is a relatively less important source of photochemically related pollution than is the automobile. Except for green native brush, which emitted up to 170 lb of CO, the emissions of this pollutant from the burning of most wastes was between 50 and 80 lb/ton of material burned. Again, this is considerably less than 850–900 lb of CO per ton of fuel emitted from autoexhausts. The few analyses of oxides of nitrogen did not permit expressing results in pounds of NO_2/ton of waste burned. However, the maximum concentrations during the fires ranged from 21 to 42 ppm which are much less than

Table V—Comparison of Yield of Hydrocarbons in Pounds per Ton of Fuel between the Burning of the Three Principal Types of Agricultural Wastes Occurring in the San Francisco Bay Area and from the Exhaust of Gasoline Engines

Hydrocarbon	Agricultural Wastes: Fruit Prunings	Agricultural Wastes: Barley Straw	Agricultural Wastes: Native Brush	Gasoline Engine
Total	13.9	18.2	6.7	130
Ethene	2.7	2.2	0.9	7.8
Olefins	4.1	3.5	1.5	20.8
Saturates plus acetylenes	1.3	1.1	0.6	14.3

the more than 1000 ppm found in auto exhausts.

Summary

With the objective of determining the relative contribution of agricultural burning to photochemically related air pollution, the residues of the principal fruit, nut, and field crops, and native range brush were burned in a specially designed tower, which permitted adequate sampling of the effluents without sacrificing the essential features of open burning situations. The emissions of hydrocarbons, both total and ethene and olefins, were considerably less than from the exhaust of automobiles, one of the principal sources of such pollutants. The same was true for emissions of CO and oxides of nitrogen expressed as NO_2. The total emissions of hydrocarbons from the annual burning of the three principal agricultural wastes in the San Francisco Bay Area would amount to about 950 tons. This annual yield approximates the daily yield of 1014 tons of hydrocarbons from automobiles in the same area.

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