EPA-450/3-75-071

July 1975

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

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# AIR POLLUTANT EMISSIONS FROM BURNING SUGAR CANE AND PINEAPPLE RESIDUES FROM HAWAII

by

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Grant No. R800711

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Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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July 1975

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Publication No. EPA-450/3-75-071

## Abstract

Whole sugar cane, sugar cane leaf trash, and pineapple leaf trash from Hawaii were burned in an instrumented burning tower to determine the emission factors for particulate matter, carbon monoxide, and hydrocarbons. Analyses of benzo(a)pyrene and the trace metals beryllium, cadmium, chromium, copper, and nickel were made from a few whole cane fires. Particle size distribution of particulate matter was determined in two cane leaf trash fires.

Emissions in terms of pounds per ton of fuel burned and pounds per acre burned are given for sugar cane in the following summary table. Emissions from pineapple trash are given only in terms of pounds per ton of fuel burned since the fuel was not collected on an area plot basis. Yields of benzo(a)pyrene are given on the basis of micrograms per gram of particulate matter and pounds per acre. Yields from the metals are shown on the basis of picograms per cubic meter of air through the sampling probe and also as pounds x $10^{-9}$ per acre.

Yields of pollutants from sugar cane in terms of pounds per ton of fuel burned agree quite well with the yields from a number of agronomic crops that have been burned in the tower. The same is generally true of pineapple trash, except that the CO yields is a little higher than from most other herbaceous fuels of comparable moisture content.

There is little or no data with which to compare the yields of benzo (a)pyrene. Some previous work done in the burning tower by EPA staff indicated a yield of about 0.18 grams per ton of landscape refuse burned. Recalculating the yield from the present study gives a value of about 0.22 grams per ton of fuel burned.

About 90 percent of the particles from sugar cane leaf trash were less than 0.5 μM in diameter.

Emission Factor Summary table.

| | Part | | CO | | HC | |
|---|---|---|---|---|---|---|
| | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre |
| **Sugar Cane** | | | | | | |
| Whole cane 99% conf. level[a] | 6.0-8.4 | 92-133 | 60.1-81.2 | 843-1383 | 4.7-16.0 | 82-222 |
| Leaf trash 99% conf. level[a] | 4.1-6.5 | 33-47 | 47.7-71.2 | 392-562 | 2.3-14.4 | 27-112 |
| **Pineapple** | | | | | | |
| Head fires % moist., dry wt. basis | | | | | | |
| 9.6 | 6.4 | --- | 100.1 | --- | 4.6 | --- |
| 16.9 | 8.5 | --- | 105.4 | --- | 5.9 | --- |
| 26.7 | 23.3 | --- | 129.9 | --- | 12.3 | --- |
| Back fires % moist., dry wt. basis | | | | | | |
| 9.3 | 6.4 | --- | 107.4 | --- | 3.7 | --- |
| 16.5 | 7.7 | --- | 112.5 | --- | 6.0 | --- |
| 24.4 | 9.1 | --- | 116.7 | --- | 7.2 | --- |

| | B(a)P | | Ni | | Cr | | Be | | Cd | | Cu | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | μg/g[c] | lbs/ acre | pg/m$^3$ | lbs/ acre[b] | pg/m$^3$ | lbs/ acre[b] | pg/m$^3$ | lbs/ acre[b] | pg/m$^3$ | lbs/ acre[b] | pg/m$^3$ | lbs/ acre[b] |
| Whole cane | 73.1 | .009 | 1.92 | 4.86 | .60 | 1.62 | .22 | .60 | 1.96 | 5.48 | 6.73 | 17.53 |
| Leaf trash | 79.0 | .003 | 1.02 | 1.94 | .35 | .61 | .32 | .70 | 2.03 | 4.65 | 6.48 | 13.91 |

[a] Figures show range of true mean of population using Student's 't'

[b] Lbs x $10^{-9}$ per acre for each of the five metals shown.

[c] μg/g of particulate

## Introduction

In mid-72, the Emission Factors Unit, National Source Inventory Section, EPA, Durham, North Carolina in response to solicitations for assistance from EPA Region IX and Hawaii Officials, requested that the Center's burning tower be used to determine the emissions from burning sugar cane from Hawaii. The work would be supported through an amendment to an existing EPA Research Grant R800711, "Air Pollution from Forest and Agricultural Burning." This was appropriate because of the unique sampling capabilities available at the University.

A meeting held in North Carolina to discuss feasibility was attended by representatives from the Emission Factors Unit, EPA Region IX (San Francisco), and the University. It was decided that such a study was feasible but would require the close cooperation of the sugar growers and other agencies in Hawaii. The decision was made to proceed to simulate the burning of sugar cane to determine the emissions so decisions could be made regarding the Hawaii State Implementation Plan.

Broad information concerning field burning of sugar cane was solicited as a first step. Replies were received from the Director of Agricultural Extension Service, University of Hawaii, the Chairman, State Board of Agriculture, and the Director, Office of Environmental Control, State of Hawaii. These letters indicated an enthusiastic willingness to cooperate wherever needed, and as a result UCR and EPA representatives met in Honolulu with representatives of the University, Hawaii Departments of Health (DOH) and Agriculture (DOA), Hawaiian Sugar Planter's Association (HSPA), and the Pineapple Growers' Association of Hawaii (PGAH). The burning tower facilities at Riverside were described and several technical challenges countered and satisfactory understanding and agreements achieved. In the discussion that followed, technical questions concerning weight of cane, ratio of cane to leaf and the amount of material burned, cutting sample plots, packaging, shipping, and arrangement of cane on the burning table were considered. Since the burning table is 8 feet in diameter, and the scale on which it rests has a fuel loading limit of 125 pounds, it was suggested that cane from a 5 foot square plot could probably be set on the table. Of prime importance was the need to have the cane arrive in Riverside in as fresh a condition as possible which meant shipping by air freight. Staff of DOA stated that we would probably need an import permit to move cane onto the mainland. This proved to be the case and a permit was subsequently obtained from the USDA Quarantine Office in Hoboken, New Jersey. The principal quarantine requirement was that the cane be fumigated with methyl bromide under a 25 inch vacuum. Riverside county (California) officials required that all residual cane be autoclaved at the conclusion of each experiment.

Following a visit to cane fields during which time burning was observed and sampling methods were again discussed, it was agreed that preliminary work would be done to establish field sampling methods, moisture loss and other possible physical effects of the fumigation, and packaging procedures. Officials of HSPA and DOA would arrange with the growers for cutting cane samples and delivering them to the DOA laboratories. DOA would assume responsibility for the fumigation, packaging and shipping.

While the principal emphasis was to be placed on determining pollution emission factors from sugar cane, it was requested and agreed that pineapple trash also be burned in the tower at Riverside. Since the plant materials from pineapple is dead and fairly dry, freshness was not a factor and the material could be sent to the mainland by ship.

## Experimental Methods

### Collection and Shipping Plant Material

A. Sugar Cane

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 commercial fields on Oahu on the morning that the field was to be burned. Four plots measuring 5' x 5' were selected about 40 feet in from the edge of the field and corner stakes placed 2-1/2 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. As much of this cane was too long and crooked to ship or place on the burning table, it was cut into approximately 5-6 foot sections and segregated into the categories of bottom cane, mid cane and top cane. Some pieces were necessarily much shorter. Each category from each plot was weighed. The bottom cane was stripped of the few leaves it may have had and then discarded because its inclusion generally would have exceeded the weight limit for the burning table. The leaves from the bottom cane were included in the leaf trash. The mid and top cane as well as the loose leaf trash (top trash) and the leaf trash on the ground (bottom trash) from a given plot constituted the plant material for one fire. At the same time, top and bottom leaf trash only were collected from comparably sized plots so that emissions from burning leaves alone without the cane could be compared with burning whole cane. Each category of material was placed in separate polypropylene woven bags and coded alphabetically by collection date. For example, D-1 and D-2 were the two cane plots for the fourth shipment and D-3 was the leaf trash material. All material was taken to the DOA laboratories, fumigated as noted earlier, and then well aerated to remove all methyl bromide. The bags of leaves were sealed in cardboard cartons and the bagged cane was rolled in sheets of corrugated cardboard and bound. The packages were then delivered to an air freight terminal in Honolulu.

A uniform scheduling was adopted to avoid weekend transit and to provide a minimum time lapse between collection and tower burning of material. Cutting was done on Monday or Tuesday, or both days, to provide a maximum of two shipments during any given week. As an example, cane cut early Monday morning was delivered to the freight terminal by late evening, flown to San Francisco that night, arriving about mid-morning on Tuesday. Packages were transferred to another plane which arrived in Ontario about 20 miles from Riverside, by noon or shortly thereafter. We brought them to Riverside, held them overnight, and burned the cane Wednesday morning. Tuesday shipments were burned Thursday morning.

A total of 10 cane shipments (20 plots) and 19 leaf trash samples were received from October through mid-December, 1972, at which time the sugar harvest was stopped because of rains and to permit repair work in the factories. It was intended to resume additional shipments for further burning trials by March, but it was later decided that the immediate needs were satisfied with the data obtained from the first set of fires.

The remaining two plots in each field were cut after the fire. Weights of cane and ashes were obtained by DOA staff and compared with the amount sent to R'verside in order to determine the weight of material consumed in the fire.

B. Pineapple Trash

Pineapple trash consists of the stumps and leaves that remain after the final harvest of fruit from a given planting. Prior to replanting, the stumps are knocked over, allowed to dry and then field burned to reduce residue. DOA and PGAH staff, working with the growers determined average weights and depths of fuel on the ground prior to burning so that fuel densities could be reasonably duplicated in Riverside. Rather than collecting plant material on a plot basis as was done with sugar cane, two large bulk shipments were made, and from these, individual fires were conducted using 16-20 pounds of material arranged in a 4' x 4' bed.

<u>Loading Burning Table and Ignition</u>

A. Sugar Cane

Several methods of loading the burning table were tried with the first shipments of whole cane. A piece of hardware cloth bent in a corrugated fashion to a height of about 2 inches and then cut to 5 feet square was placed on the table. In a preliminary trial, plant materials were placed on the screen at a uniform depth in as loose a pile as possible, intermixing leaves and cane pieces; the cane was essentially horizontal. The pile was ignited with a small propane torch near the bottom, along one 5-foot edge. The material did not burn at all well and some leaves on the bottom of the pile were not consumed even though the screen provided ventilation underneath.

A light weight aluminum rack 5 feet square was built. The corner posts were 3 feet high and the side rails were permanently fastened at 12 inches from the bottom. A vertically adjustable wire mesh frame was fitted to the corner posts; the mesh measured 2 x 4 inches. With the wire mesh in place near the top of the rack, cane pieces could be threaded vertically downward through the mesh so their cut ends rest on the corrugated screen. For the next few fires, the fuel categories were placed on the table in the following order and their cumulative weights noted: (1) bottom trash was placed loosely on the screen; (2) mid-cane pieces were laid at an angle around the inside of the rack with one end resting on the rack rail and the other on the bottom trash; (3) top cane was threaded down through the wire mesh, mid-cane, and bottom trash, care being taken not to compact the bottom trash; and (4) the top trash was worked in loosely between the top cane pieces and on top of the mid-cane and bottom trash. Since cumulative weights were noted, differences between successive values gave the weights of individual fuel categories. The loaded fuel was then ignited by applying the propane torch to the bottom trash along one 5-foot edge.

The next three fires were conducted with the above loading method. They burned very well and all succeeding cane fires were loaded in this manner. In addition, after the fire, weights of top and mid cane were noted as these pieces were removed from the table in order to give an idea of the weight loss within these two categories. In some later experiments, each single cane piece, both top and mid, was individually tagged and the weight recorded before and after the fire.

One important change should be noted that occurred about half way through the program. In the earlier fires, when mid cane pieces were very short and would not stand against the rail easily, attached leaves were removed and added to the fire but the cane was discarded without recording the weight. Some top cane was also discarded if too short to stand in the mesh frame. Later it was decided that all cane shipped to Riverside should be put on the table. When the emission data were analyzed, adjustments were made for the discarded cane by methods discussed latter.

Where leaf trash alone was burned, head firing (with the wind) and back firing (against the wind) was simulated by placing the fuel on a sloped tray and igniting from the bottom or top edges, respectively.

B. Pineapple Trash

No special loading techniques were needed with this fuel except to use the head and back fire tray as noted above. Sufficient trash was shipped to conduct 13 fires at a loading of 16-20 pounds. Since the fuel had dried down while waiting to be burned, in some trials the trash was remoistened with a fine spray and allowed to equilibrate in a large polyethylene bag.

Sampling Procedures

A. Particulate Matter

1) Total Particulate.

Total particulate matter was collected isokinetically on standard Type A glass fiber filters held in a modified HIVOL sampler positioned just just outside the burning tower as described by Darley et al.[1] A pneumatically controlled globe valve in the sample line continuously regulates the rate of air flow through the filter so that approximately 1/776th of the total flow out of the tower is sampled isokinetically. From the weight of particulate matter on the filter, the yield based on weight of plant material burned in a given fire can be calculated easily. From this value, the usual method for all previous studies has been to express yields in terms of particulate per ton of fuel burned. This was done in the present study. In addition, yield was also expressed in terms of pounds of particulate per acre since all of the combustible material on a measured plot was accounted for.

When the particulate sampling system was first installed, efficiency of the single filter was checked by placing two filters back-to-back in the holder. The second filter was always clean. Recently, it was suggested that perhaps some

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[1] Darley, E. F., S. Lerman, G. E. Miller, Jr., and J. E. Thompson. Laboratory testing for gaseous and particulate pollutants from forest and agricultural fuels. Proc. Intern. Symp. "Air Quality and Smoke from Urban and Forest Fires." Nat. Acad. Sci. In press.

condensible materials were passing through the filter because the gases passing through the filter were not yet at ambient temperature. Thus, late in this study, a second HIVOL sampler was placed in the particulate sampling line downstream from the first filter. It was found that additional particulate was collected on the second filter. Since the second filter was not part of the sampling system when the technical aspects of the program were agreed upon in Honolulu, and further, since the two-filter system is still being evaluated, only particulate collected by the single filter is reported in this report.

Several filter papers were supplied to us by EPA. These filters had been treated to permit analysis of benzo(a)pyrene as well as certain trace elements. After collection of particulates from given fires, the filters were returned to EPA for analysis.

2) Particulate sizing

Only a few samples were taken to determine particle size distribution. More detailed work on sizing as well as particle morphology with the scanning electron microscope was scheduled if the cane shipments had been resumed in March, but, as noted above, it was subsequently decided to eliminate the second set of shipments.

The instruments used for particle sizing were the Brink Cascade impactor* loaned by EPA, and the Weathermeasure Cascade impactor, loaned by Agricultural Engineering, University of California, Davis.

The Brink 5-stage impactor used a relatively low air flow rate of 3 liters per minute and the sample cups of each stage are small but relatively heavy. The impactor is essentially designed to collect from a steady-state source over a long period of time in order to obtain sufficient material for accurate

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*Mention of commercial products here and elsewhere does not constitute endorsement thereof by EPA weighing. Since these fires lasted only 5 minutes, it was difficult to obtain adequate samples. In one test, burning only the leaves of sugar cane, we attempted to maintain a stedy-state fire by hand-feeding the leaves onto the fire bed at a given rate over a period of about 25 minutes. To improve the ratio between weight of the collection surface and the weight of particles collected, the bottom of the collection cup of each stage was lined with an aluminum fiol disc held in place with a retention ring. A specially designed cyclone filter preceded the impactor and a Nuclepore membrane filter (0.4μM) followed the last stage to provide a sixth stage for particle sizing. The sampling probe was inserted into the stack at about the same position as the sampling orifice of the isokinetic system.

The Weathermeasure impactor fits a standard HIVOL sampler. This feature make its use much more feasible for sampling in the burning tower because the high flow rate of up to 50 cfm permits an adequate sample in a short time. The impactor was attached to a portable HIVOL sampler and this combined unit was fitted with a suitable sample probe of such length to assure that collection was made at ambient temperatures. The probe was inserted into the stack near the sampling orifice of the isokinetic system. Again, sampling was done only from the burning cane leaf trash.

B. Gases and Water Vapor

Carbon monoxide and carbon dioxide were sampled continuously on separate Beckman Model 15A infrared gas analyzers and concentrations recorded on Esterline-Angus strip chart recorders. Full scale for each gas analyzer was 4000 and 50,000 parts per million, respectively. Total hydrocarbons were analyzed continuously with a Beckman Model 109 hydrogen flame detector hydrocarbon analyzer with concentrations being recorded on a Honeywell Electronic 17 strip chart recorded. The analyzer was calibrated at full scale of 1000 ppm. Integrating these values into calculations with air flow air flow and temperature at the collection site permits expressing results in terms of pounds of pollutants per ton of fuel burned. As was done with the particulate matter, yields were also calculated in terms of pounds per acre.

No attempt was made to determine sulfur dioxide because there is no evidence to date to indicate that this pollutant is significantly involved in agricultural burning.

Discussion of Results

A. Sugar Cane

1. Yields of particulates, carbon monoxide and hydrocarbons.

Whole cane: As noted earlier, when the burning table was loaded with whole cane, some mid and top cane pieces from about the first half of the shipments were discarded because they were too short to place in an erect position. In later fires all cane was used. When emission data on particulates were calculated it was found that there was correlation between particulate yield and weight loss of the tops. Thus, it was possible to adjust the data for the tops that were discarded since the weight of those tops could be fairly well established by taking the difference between the weight cut from each plot in Hawaii and the weight actually put on the table. Because all the leaves from any discarded mid-cane pieces had been placed on the table, and because later experiments demonstrated that weight loss of mid-cane pieces themselves was neligible, it was decided that the discarded mid-cane would not have contributed significantly to the emissions. Therefore the yields of particulate, carbon monoxide and hydrocarbons presented in Table I take into account the probable emissions from the discarded top cane pieces.

Particulate yields averaged 7.2 pounds per ton of fuel burned (112 pounds per acre) with a standard deviation of 1.6 pounds (32 pounds per acre). At the 99 percent confidence level, the true mean of the population would be expected to fall between 6.0 and 8.4 pounds per ton of fuel burned (between 92 and 132 pounds per acre). The yield of particulates in pounds per ton of fuel burned is not excessive and falls within the range of many other herbaceous types of fuel that have been burned in the tower. One might have expected a higher particulate yield because of the presence of the moist, green tissue in the tops. The tops did burn and lose a significant portion of their total weight, the range being from 8 to about 23 percent. One reason the yields

Table 1. Yield of Particulate Matter, Carbon Monoxide, and Hydrocarbon in Pounds of Pollutants per Ton of Fuel Burned and Pounds per Acre when Burning Whole Sugar Cane from Hawaii.

| | | Pollutant emissions | | | | | |
|---|---|---|---|---|---|---|---|
| | | Particulate | | CO | | HC | |
| Plot number | Pounds cane per plot | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre |
| B-2 | 218 | --[a] | -- | 63.8 | 722 | 2.4 | 27 |
| C-1 | 172 | -- | -- | 86.0 | 1573 | 4.6 | 84 |
| C-2 | 184 | -- | -- | 77.8 | 1694 | 4.5 | 98 |
| D-1 | 230 | 4.6 | 95 | 49.4 | 865 | 1.8 | 32 |
| D-2 | 241 | 6.1 | 143 | 81.9 | 1819 | 4.6 | 102 |
| E-1 | 211 | 10.4 | 185 | 106.6 | 1838 | 6.5 | 112 |
| E-2 | 211 | 5.2 | 135 | 64.6 | 1536 | 3.8 | 90 |
| G-1 | 163 | 10.1 | 128 | 73.5 | 832 | 4.1 | 46 |
| G-2 | 193 | 6.7 | 104 | 47.3 | 610 | 1.9 | 24 |
| H-1 | 123 | -- | -- | 36.8 | 497 | 3.4 | 40 |
| H-2 | 139 | 6.3 | 91 | 70.3 | 949 | 14.6 | 197 |
| M-1 | 138 | 8.7 | 113 | 76.0 | 993 | 27.7 | 362 |
| M-2 | 148 | 6.8 | 112 | 76.0 | 1258 | 13.8 | 228 |
| N-1 | 132 | 7.0 | 86 | 58.3 | 711 | -- | -- |
| N-2 | 142 | 8.0 | 156 | 104.3 | 2044 | 23.6 | 462 |
| O-1 | 93 | 7.3 | 76 | 71.4 | 740 | 17.8 | 184 |
| O-2 | 122 | 7.1 | 89 | 70.0 | 878 | 19.6 | 245 |
| P-1 | 122 | 6.5 | 75 | 66.4 | 769 | 15.0 | 174 |
| P-2 | 143 | 7.1 | 94 | 61.6 | 821 | 16.8 | 224 |
| | Mean | 7.2 | 112 | 70.6 | 1113 | 10.4 | 152 |
| | Std. dev. | 1.6 | 32 | 17.3 | 481 | 8.3 | 121 |

| Using Student's 't' values, true mean of population will fall between: | Particulate | | CO | | HC | |
|---|---|---|---|---|---|---|
| at 95% confid. level | 6.3-8.1 | 95-130 | 62.9-78.3 | 881-1345 | 6.2-14.5 | 92-210 |
| at 99% confid. level | 6.0-8.4 | 92-133 | 60.1-81.2 | 843-1383 | 4.7-16.0 | 82-222 |

[a]First three particulate samples intentionally not taken; H-1 was not isokinetic. Hydrocarbon sample line came disconnected while sampling N-1.

yield varied from 1.4 to 21.8 pounds per ton of fuel burned. From J-1 on, samples were burned chronologically as listed and a similar variation is roted. Therefore we can only conclude that the range noted above is normal for sugar cane burned in the tower for the fuel arrangements used. The values themselves are not too different from burning cereal grain straw and are at or below the value of 14 pounds/ton obtained from burning a number of herbaceous and woody agricultural fuels in California.

Leaf trash: The pollutant emission yields, with the expected true mean values at 95 and 99 percent confidence levels, are given in Table 2. The yields of each in terms of pounds of fuel burned are a little less than from whole cane. As noted above, the variation in hydrocarbon yield from leaf trash is about the same as for whole cane.

As noted earlier, several of the leaf samples were burned as head and back fires. Pollutant yields from the back fires were slightly less than from head fires but the difference was not significant. This result agrees with data from cereal grain straws wherein there was little or no difference between head and back firing when the fuels were dry. With straws however, as the fuel moisture level increased, particulate pollution from head firing increased at a much greater rate than that from back firing.

2. Yields of benzo(a)pyrene and some trace metals.

As noted above, special filters had been received from EPA which, after sampling, were returned to the EPA laboratories for analysis of benzo(a)pyrene and the trace metals nickel, chromium, beryllium, cadmium and copper. The results of the analyses of filters used on whole cane fires are given in Table 3; those from trash fires are given in Table 4. Benzo(a) pyrene yields are expressed in micrograms per gram of particulate and pounds per acre. Amounts of metals are expressed as picograms per cubic meter of air going out of the burning tower and as pounds x $10^{-9}$ per acre.

Table 3. Yield of Benzo(a) Pyrene and Certain Trace Metals Contained in the Particulate Matter from Burning Whole Sugar Cane from Hawaii

| Plot number | Rounds cane per plot | B(a)P, ug/g and lbs/acre: μg/g[a] | B(a)P: lbs/acre | Ni: pg/m³ | Ni: lbs/acre | Cr: pg/m³ | Cr: lbs/acre | Be: pg/m³ | Be: lbs/acre | Cd: pg/m³ | Cd: lbs/acre | Cu: pg/m³ | Cu: lbs/acre |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Trace metals, pg/m³ and lbs x 10⁻⁹/ acre | | | | | | | | | |
| C-1 | 172 | 135.4 | .019 | 2.67 | 8.38 | tr | tr | .56 | 1.76 | 2.89 | 9.07 | 5.89 | 18.49 |
| C-2 | 184 | 124.6 | .018 | 1.51 | 4.26 | tr | tr | .42 | 1.18 | 3.69 | 10.41 | 7.53 | 20.73 |
| D-1 | 230 | 35.1 | .003 | 0 | 0 | 0 | 0 | 0 | 0 | 5.23 | 10.17 | 9.68 | 18.83 |
| D-2 | 241 | 87.4 | .012 | 0 | 0 | 0 | 0 | 0 | 0 | .32 | 8.40 | 7.18 | 18.84 |
| E-1 | 211 | 22.3 | .004 | .93 | 2.60 | 2.21 | 6.17 | .34 | .95 | 1.27 | 3.55 | 10.99 | 30.70 |
| E-2 | 211 | 27.3 | .003 | 2.71 | 7.54 | 2.12 | 5.90 | .47 | 1.31 | 1.48 | 4.12 | 9.35 | 26.01 |
| G-1 | 163 | 21.4 | .003 | 2.21 | 5.29 | 1.28 | 3.06 | .29 | .69 | 1.08 | 2.59 | 6.92 | 16.57 |
| G-2 | 193 | 22.7 | .002 | 2.75 | 6.38 | tr | tr | 0 | 0 | 1.32 | 3.06 | 4.05 | 9.40 |
| H-2 | 139 | 181.6 | .015 | 1.47 | 3.48 | 0 | 0 | 0 | 0 | 1.57 | 3.72 | 2.90 | 6.87 |
| M-1 | 138 | -- | -- | 1.00 | 3.06 | 1.15 | 3.52 | 0 | 0 | 1.19 | 3.64 | 11.16 | 34.13 |
| M-2 | 148 | -- | -- | 4.16 | 8.97 | 0 | 0 | .32 | .69 | 2.30 | 4.96 | 3.85 | 8.30 |
| N-1 | 132 | -- | -- | 2.39 | 5.80 | .98 | 2.38 | .29 | .70 | 1.43 | 3.47 | 4.43 | 10.74 |
| N-2 | 142 | -- | -- | 3.22 | 7.45 | 0 | 0 | .20 | .46 | 1.74 | 4.03 | 3.60 | 8.33 |
| | Mean | 73.1 | .009 | 1.92 | 4.86 | .60 | 1.62 | .22 | .60 | 1.96 | 5.48 | 6.73 | 17.53 |
| | Std. dev. | 61.1 | .007 | 1.24 | 2.95 | .85 | 2.35 | .20 | .59 | 1.30 | 2.89 | 2.89 | 8.81 |

[a] μg/g particulate collected

higher than from leaf trash alone (see Table 2) may be done due to the open, loose arrangement of the top leaves. We know from work with cereal grain straws, wherein the fuel bed is much more compacted, that air dry material may yield about 5 pounds of particulate per ton of fuel burned. If the moisture content of these fuels is raised to about 50 percent on a dry weight basis, the particulate yield may be increased by a factor of 3 or 4. A second reason why particulate yields were not much higher may be that with whole cane, quite a bit of large flakes of charred leaf material ("Hawaiian Snow") was easily visible; this material was not produced when burning leaf trash alone.

The carbon monoxide yield averaged 70.6 pounds per ton of fuel burned (1113 pounds per acre) with a standard deviation of 17.3 pounds (419 pounds per acre). At the 99 percent confidence level the true mean of the population would be expected to fall between 60.1 and 81.2 pounds (843-1383 pounds per acre). In terms of pounds per ton of fuel burned, this again is only a moderate amount of CO and is similar to the yield from dry cereal grain straw. As an example of the extreme in yields of CO that can be obtained from other herbaceous fuels that have some green matter in them, asparagus fern and tumbleweed approach 200 and 300 pounds, respectively.

The hydrocarbon yield averaged 10.4 pounds per ton of fuel burned (152 pounds per acre) but the standard deviation of 8.3 pounds is comparatively large. Similarly the range of the expected true mean at the 99 percent confidence level is large, being 4.7 to 16.0 (121 pounds per acre). The fires were run chronologically in the order listed in Table 1. At first glance it would appear that from sample H-2 on, there has been a decided shift in the operation of the analyzing system. This conclusion however, is not borne out by results of the leaf trash fires (see Table 2). Plots D-3, F-3, I-1, and I-2 were burned on the same day and the hydrocarbon

Table 2. Yield of Particulate Matter, Carbon Monoxide, and Hydrocarbon in Pounds of Pollutant per Ton of Fuel Burned and Pounds per Acre when Burning Sugar Cane Leaf Trash from Hawaii.

| | | Pollutant emissions | | | | | |
|---|---|---|---|---|---|---|---|
| | Pounds leaf | Particulate | | CO | | HC | |
| Plot number | trash per plot | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre | lbs/ ton | lbs/ acre |
| A-1 | 6.3 | 6.4 | 34 | --[a] | -- | -- | -- |
| A-2 | 13.0 | 3.8 | 39 | -- | -- | -- | -- |
| A-3 | 12.0 | 8.0 | 62 | -- | -- | -- | -- |
| B-3 | 10.1 | 5.5 | 43 | 64.7 | 507 | 0.8 | 6 |
| D-3 | 11.1 | 3.9 | 32 | 75.1 | 621 | 21.8 | 180 |
| E-3 | 21.3 | 10.4 | --[b] | 75.9 | -- | 4.6 | -- |
| F-1 | 11.5 | 2.7 | 24 | 36.4 | 330 | 2.1 | 19 |
| F-2 | 11.8 | 5.0 | 42 | 96.4 | 798 | 7.1 | 59 |
| F-3 | 11.0 | 3.2 | 27 | 49.2 | 420 | 7.6 | 65 |
| G-3 | 13.0 | 4.1 | 43 | 41.1 | 426 | 0.6 | 6 |
| H-3 | 9.5 | -- | -- | 50.1 | 361 | 5.1 | 37 |
| I-1 | 11.0 | 4.3 | 37 | 53.6 | 458 | 1.4 | 12 |
| I-2 | 10.3 | 3.3 | 26 | 53.8 | 422 | 9.5 | 74 |
| J-1 | 10.5 | 7.3 | 60 | 57.3 | 469 | 6.6 | 54 |
| J-2 | 10.9 | 5.5 | 48 | 64.5 | 567 | 9.0 | 79 |
| K-1 | 9.5 | 6.8 | 54 | 46.2 | 362 | 23.4 | 183 |
| K-2 | 9.5 | 4.8 | 37 | 64.7 | 496 | -- | -- |
| M-3 | 9.3 | 5.3 | 38 | 62.7 | 459 | 17.7 | 130 |
| | Mean | 5.3 | 40 | 59.4 | 477 | 8.4 | 70 |
| | Std. dev. | 2.0 | 11 | 15.3 | 126 | 7.5 | 61 |

| Using Student's 't' values, true mean of population will fall between: | Particulate | | CO | | HC | |
|---|---|---|---|---|---|---|
| at 95% confid. level | 4.3-6.3 | 34-46 | 50.7-68.2 | 401-552 | 4.1-12.7 | 33-106 |
| at 95% confid. level | 4.1-6.5 | 33-47 | 47.7-71.2 | 392-562 | 2.3-14.4 | 27-112 |

[a]First three gas samples intentionally not taken. Particulate from H-3 and hydrocarbon from K-2 were invalid due to equipment maladjustment.

[b]Load was doubled for this fire, therefore, calculation on acre basis is not applicable.

Table 4. Yield of Benzo(a)Pyrene and Certain Trace Metals Contained in the Particulate Matter from Burning Sugar Cane Leaf Trash from Hawaii.

| Plot number | Pounds leaf trash per plot | B(a)P, ug/g and lbs/acre: μg/g[a] | B(a)P, ug/g and lbs/acre: lbs/acre | Ni: pg/$m^3$ | Ni: lbs/acre | Cr: pg/$m^3$ | Cr: lbs/acre | Be: pg/$m^3$ | Be: lbs/acre | Cd: pg/$m^3$ | Cd: lbs/acre | Cu: pg/$m^3$ | Cu: lbs/acre |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Trace metals, pg/$m^3$ and lbs x $10^{-9}$/acre | | | | | | | | | |
| B-3 | 10.1 | 60.9 | .003 | 2.58 | 5.63 | tr | tr | .59 | 1.29 | 3.55 | 7.75 | 8.57 | 19.10 |
| D-3 | 11.0 | 177.0 | .006 | tr | tr | 0 | 0 | .29 | .67 | 1.67 | 3.88 | 4.03 | 9.37 |
| E-3 | 21.3 | 41.8 | --[b] | 1.66 | -- | .96 | -- | .31 | -- | 1.03 | -- | 6.61 | -- |
| F-3 | 11.0 | 76.1 | .002 | 0 | 0 | tr | tr | .36 | .66 | 1.56 | 2.88 | 7.07 | 12.91 |
| G-3 | 13.0 | 32.1 | .001 | 1.03 | 2.36 | 1.85 | 4.24 | .62 | 1.42 | 1.75 | 4.02 | 10.29 | 23.61 |
| I-1 | 11.0 | 112.2 | .004 | .50 | 1.17 | 0 | 0 | .25 | .59 | 1.51 | 3.53 | 4.85 | 10.72 |
| I-2 | 10.3 | 52.9 | .001 | 0 | 0 | 0 | 0 | 0 | 0 | 2.89 | 6.38 | 5.53 | 12.20 |
| M-3 | 9.3 | -- | -- | 2.40 | 4.39 | 0 | 0 | .16 | .29 | 2.27 | 4.15 | 5.16 | 9.44 |
| | Mean | 79.0 | .003 | 1.02 | 1.94 | .35 | .61 | .32 | .70 | 2.03 | 4.65 | 6.48 | 13.91 |
| | Std. Dev. | 50.5 | .002 | 1.08 | 2.30 | .69 | 1.60 | .21 | .51 | .83 | 1.75 | 2.12 | 5.41 |

[a] μg/g of particulate collected

[b] Load was doubled for this fire, therefore, calculation on acre basis is not applicable.

The means and standard deviations of B(a)P and of each metal from each fuel type were about the same. There was, however, a great variation within B(a)P, nickel, chromium, and beryllium. The three metals were completely below detection in some samples and there is no identified explanation for this. It is known that there is some condensation in the probe and this may be a possible explanation; but no analyses have been made of the materials adhering to the probe to determine quantities of metals retained.

There are no comparative data for the yield of metals from fires in the tower so it is not possible to comment on the significanee of the yield figures. There are, however, comparative data for B(a)P. Several years ago staff of the EPA used the tower to burn a variety of materials, one of which was landscape refuse which included lawn clippings, leaves, and other plant trash. From two such fires they obtained 0.31 and 0.13 grams per ton of fuel burned. If the 7 trash fires, for which there are data on both particulate and B(a)P yields, are combined, the yield of B(a)P is 0.18 grams per ton of fuel burned. This is not too different from the mean of 0.22 grams produced in the landscape refuse fires.

3. Particle size distribution

One sample of particulate matter was taken with the Weathermeasure 5-stage cascade impactor using a normal leaf trash fire. A Nuclepore membrane filter (0.4 μm pore diameter) was installed below the 5th stage to assure complete collection. For this impactor, particle cut-off sizes for each stage were determined by calculations based on the theory developed by Marple.[2] A correction was made for a 50 cfm air flow and a mass density of 0.9 g/cc was selected as a reasonable approximation. Particle size distribution is plotted in Figure 1.

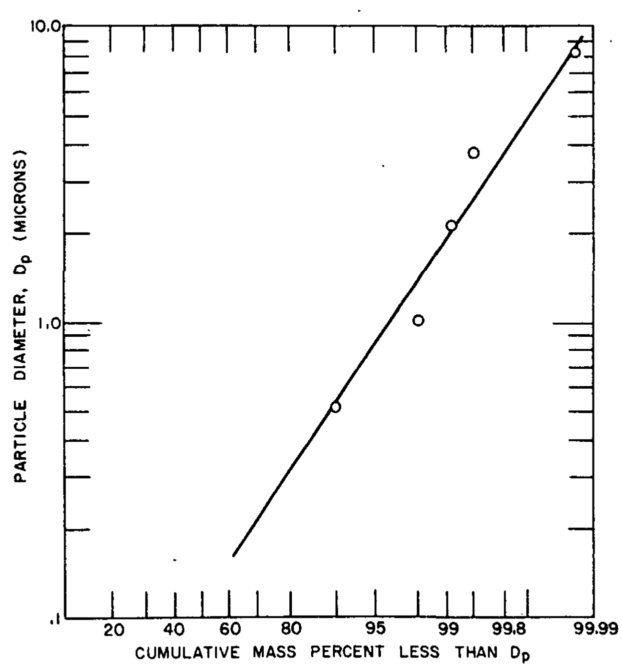


Figure 1. Cumulative particle size distribution of smoke from leaf trash of sugar cane burned at 20 percent moisture (dry wt. basis). Particles collected with the Weathermeasure HIVOL cascade impactor.

Most of the particles were sub-micron and about 90 percent were less than 0.5 μm. Because of the high volume sampling rate, the Weathermeasure collects a large sample so that a measureable amount of larger particles may be collected. Even so a little less than 2 percent of the particles were larger than 2 μm.

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[2] Marple, V. A., A Fundamental Study of Inertial Impactors. Ph.D. Thesis Mech. Eng. Dept. University of Minnesota, Dec. 1970

A second test was made with the Brink 5-stage cascade impactor using leaf trash in a hand-fed steady state fire. Again, a Nuclepore filter was installed below the 5th stage. The Brink collected particles only on the 4th and 5th stages and on the back-up filter. The distribution of the particle size based on these data indicated that 92 percent of the particles were below the 0.5 μm range and 61 percent had a diameter below 0.25 μm. The 92 percent figure agrees with the Weathermeasure impactor data.

1. Yield of particulates, carbon monoxide and hydrocarbons.

As noted in the section on methods, pineapple trash was burned on the sloped tray, either as a head or back fire. Additionally, moisture was added to the trash to raise the fuel moisture content to levels of about 15 and 25 percent, on a dry weight basis. The reason for wetting the fuel was that the trash, including stumps, had become very dry between the date it was received and the dates of actual burning. Whereas the leaves were dry and brittle upon delivery to Riverside, the stumps were quite wet. The overall moisture level of a trash sample would have been higher than that of the leaves alone. It was therefore decided to moisten some of the trash in order to obtain an indication of the effect of moisture on pollutant emissions.

Pollutant emissions from the several fires, Duncan's multiple range test for significance of mean difference for head/back fires and moisture levels are presented in Table 5. Yield data from two groups of fires are shown in the table as a matter of interest but were not included in the analyses. In one group, the fuel was heavily dusted with red soil and was thus atypical of the bulk of trash sent to Riverside. In the other, moisture added to the fuel was higher than intended and the fuel bed was difficult to ingnite.

Table 5. Yield of Particulate Matter, Carbon Monoxide, and Hydrocarbon in Pounds of Pollutant per Ton of Fuel Burned when Burning Pineapple Trash from Hawaii as Head/Back Fires at Three Fuel Moisture Levels.

| Head Fires | | | | Back Fires | | | |
|---|---|---|---|---|---|---|---|
| Fuel | Emissions, lbs/ | | | | | | |
| % | Part. | CO | HC | % | Part. | CO | HC |
| Low-- | | | | | | | |
| 8.8 | 6.3 | 108.7 | 4.3 | 8.1 | 6.2 | 113.9 | 3.2 |
| 10.4 | 6.4 | 102.1 | 4.9 | 10.4 | 6.6 | 100.9 | 4.2 |
| 10.8[1] | 7.0 | 78.0 | 5.7 | 12.3[1] | 7.0 | 78.2 | 4.9 |
| Medium-- | | | | | | | |
| 16.7 | 8.7 | 121.8 | 6.6 | 15.6 | 6.5 | 112.9 | 4.6 |
| 18.4 | 8.1 | 91.0 | 5.7 | 17.9 | 7.4 | 103.1 | 5.3 |
| 15.7 | 8.8 | 87.4 | 5.4 | 16.1 | 9.2 | 121.5 | 8.2 |
| High-- | | | | | | | |
| 25.0 | 24.8 | 131.9 | 11.7 | 25.0 | 8.2 | 110.7 | 6.6 |
| 28.3 | 21.7 | 127.8 | 12.8 | 23.8 | 9.9 | 122.7 | 7.8 |
| 26.9[1] | 10.5 | 99.3 | 8.4 | 28.3[1] | 9.0 | 146.0 | 7.2 |
| 30.6[2] | 45.0 | 166.0 | 26.4 | | | | |
| 30.7[2] | 28.5 | 126.0 | 17.2 | | (no back fires) | | |

Duncan's Multiple Range Test:

Factors -- 1. Head versus back fires
2. Moisture level -- low, medium, high (lo, med, hi)
3. Moisture x (head/back)

Variables -- Particulate, carbon monoxide, and hydrocarbon, lbs/ton

| | Particulate | | | CO | HC | | |
|---|---|---|---|---|---|---|---|
| | | Confidence level | | | | Confidence level | |
| | Means | 95% | 99% | Means | Means | 95% | 99% |
| Head | 12.11 | a[3] | a | 110.1 | 7.343 | a | a |
| Back | 7.71 | b | b | 112.2 | 5.700 | b | a |
| Hi | 16.15 | a | a | 123.3 | 9.725 | a | a |
| Med | 8.12 | b | b | 106.3 | 5.967 | b | b |
| Lo | 6.38 | c | b | 106.4 | 4.150 | c | b |
| Head-hi | 23.23 | a | a | 129.9 | 12.25 | a | a |
| Back-hi | 9.05 | b | b | 116.7 | 7.20 | b | b |
| Head-med | 8.53 | bc | b | 105.4 | 5.90 | bc | b |
| Back-med | 7.70 | bc | b | 112.5 | 6.03 | bc | b |
| Back-lo | 6.40 | bc | b | 107.4 | 3.70 | c | b |
| Head-lo | 6.35 | c | b | 100.1 | 4.60 | bc | b |

[1]Fuel heavily dusted with red soil; data not included in analyses.

[2]Fuel at a higher moisture than intended and data are not included in analyses. Screen inadvertently omitted from first fire.

[3]Different letters within a factor grouping indicates significant difference between factors; same letter indicates no difference.

The particulate yield ranged from 6.2 pounds per ton of fuel burned with a low-moisture back fire to 24.8 pounds with a high-moisture head fire. The means of head and back fires were 12.1 and 7.7 pounds, respectively, and this difference was highly significant. Increasing levels of moisture per se resulted in an increased production of particulate and the differences were significant at the 95 percent confidence level. At the 99 percent confidence level, particulate yield from the high-moisture fuel was significantly higher than that from either the medium- or low-moisture, but yields of the latter two were not different from each other. In the two-way analysis of head/back fires versus moisture level, high-moisture head fires gave significantly higher particulate yield than all other combinations at the 99 percent level; the other combinations were not significantly different from each other. At the 95 percent level, the low-moisture head fires produced less particulate than high-moisture backfires.

It appears from these results that if the moisture level of leafy trash is about 15 percent, the particulate yield should not exceed 9 pounds per ton of material burned and may approach 6 pounds of the fuel moisture were reduced to below 10 percent. These values are not too different from those obtained from sugar cane. If it ever became necessary to burn under higher moisture conditions, backfiring would have a definite benefit over head firing.

One of the two excessively high-moisture head fires demonstrated how high the yield of particulate could be. In this fire, the aerating screen had been left off of the burning table inadvertently. This might somewhat simulate a field condition if the trash had not been fluffed up. Mechanically stirring and fluffing up the trash is the normal practice. Particulate yield was 45 pounds, which was almost double the mean of the high-moisture head fires. When the screen was used on the second fire, particulate yield decreased drastically.

Carbon monoxide yields varied from 87.4 to 131 pounds per ton fuel burned. There was, however, no significant difference between head/back firing, between the three moisture levels, or in the interaction of firing direction and moisture. The overall mean of all fires was 111.1 pounds, which is a little more than 50 percent greater than the mean of 70.6 pounds obtained from burning sugar cane.

The trend in the yield of hydrocarbon followed very closely that of particulates, the least (3.2 pounds) being obtained from a low-moisture back fire and the most (12.8) from a high-moisture head fire. The means of head and back fires were 7.3 and 5.7 pounds, respectively, and the difference was significant only at the 95 percent confidence level. At the same confidence level, hydrocarbon increased with increasing moisture and the difference was significant only at the 95 percent confidence level. At the same confidence level, hydrocarbon increased with increasing moisture and the differences were significant. At the 99 percent level, hydrocarbon yield from the high-moisture fires was significantly different from medium and low-moisture fuels, but the latter were not different from each other. Again, as with the particulate yield, the two-way analysis of head/back fires versus moisture showed that the 99 percent confidence level, only the hydrocarbon yield from the high-moisture head fires was different from all other combinations and none of the latter were different from each other. At the 95 percent level, the yield of hydrocarbon from low-moisture back fires was significantly less than that from high-moisture back fires.

If pineapple trash is burned at moisture levels of 15 percent or less, the hydrocarbon should not exceed about 8 pounds but could approach 4 pounds if the moisture were reduced to 10 percent. At a high moisture level, hydrocarbon yields would be reduced significantly if back firing was used.

The excessively high-moisture fire, wherein the aereating screen was not placed under the fuel, again demonstrated how high the yield of hydrocarbon might be. The 26.4 pounds produced from this fire was more than twice that produced from the high-moisture fires.

No attempt is made to interpret the results obtained from those fires using trash covered with red soil; the data are included for information. Particulate yields were comparable to fuels without soil, except for the high-moisture head fire wherein the yield was reduced by half. Red soil on the fuel resulted in less CO except in the high-moisture back fire.

# TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA-450/3-75-071 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE<br>Air Pollutant Emissions From Burning Sugar Cane and Pineapple Residues From Hawaii | | 5. REPORT DATE<br>July 1975<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Ellis F. Darley and Shimshon L. Lerman | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Statewide Air Pollution Research Center<br>University of California, Riverside | | 10. PROGRAM ELEMENT NO.<br>11. CONTRACT/GRANT NO.<br>R800711 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>U. S. Environmental Protection Agency<br>Office of Air Quality Planning and Standards, MDAD<br>Research Triangle Park, North Carolina 27711 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final<br>14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Whole sugar cane, sugar cane leaf trash, and pineapple leaf trash from Hawaii were burned in an instrumented burning tower to determine the emission factors for particulate matter, carbon monoxide, and hydrocarbons. Analyses of benzo(a) pyrene and the trace metals beryllium, cadmium, chromium, copper, and nickel were made from a few whole cane fires. Particle size distribution of particulate matter was determined in two cane leaf trash fires.

Emissions in terms of pounds per ton of fuel burned and pounds per acre burned are given for sugar cane in the following summary table. Emissions from pineapple trash are given only in terms of pounds per ton of fuel burned since the fuel was not collected on an area plot basis. Yields of benzo(a)pyrene are given on the basis of micrograms per gram of particulate matter and pounds per acre. Yields from the metals are shown in the basis of picograms per cubic meter of air through the sampling probe and also as pounds x $10^{-9}$ per acre.

Yields of pollutants from sugar cane in terms of pounds per ton of fuel burned agree quite well with the yields from a number of agronomic crops that have been burned in the tower. The same is generally true of pineapple trash, except that the CO yields is a little higher than from most other herbaceous fuels of comparable moisture content.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|---|
| Benzo(a)pyrene | Carbon Monoxide | | |
| Hydrocarbon | Particulate matter | | |
| Beryllium | Cadmium | | |
| Chromium | Copper | | |
| Nickel | Emissions | | |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>Release Unlimited | 19. SECURITY CLASS (This Report)<br>Unclassified | 21. NO. OF PAGES<br>30 |
| | 20. SECURITY CLASS (This page)<br>Unclassified | 22. PRICE |

EPA Form 2220-1 (9-73)