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AIR POLLUTION FROM FOREST AND AGRICULTURAL BURNING

ARB PROJECT 2-017-1

UNIVERSITY OF CALIFORNIA

PRINCIPAL INVESTIGATOR:

Ellis F. Darley

CO INVESTIGATORS:

George E. Miller, Jr.
John R. Goss
Harold H. Biswell

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AGRICULTURAL BURNING ABSTRACT

This project was initiated 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, rice, 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 fine 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 down wind edges (backfiring) or using an into-the-wind striplighting technique. Particulates were analyzed for size distribution and percent fraction soluble in chloroform. Residue drying rates were measured to aid in predicting when a particular residue would be dry enough to burn. Costs of various fire management procedures were determined and cultural recommendations to reduce emissions are given.

FOREST BURNING ABSTRACT

All of the experimental work in the forest burning portion of the project has yet to be completed. Emissions from forest fuels collected at Whitiker's forest in the Sierras are still being determined from fuel beds prepared two years ago. The report of the field fuel management study has been prepared by the Berkeley group, but since the emissions portion is not yet complete, it seems better to submit the complete forest fuels portion at a later date as a supplement to the present report.

This report was submitted in fulfillment of ARB Project No. 2-017-1 and ARB 2113 by the University of California at Davis. (Principal Investigator: Ellis F. Darley, Co-investigators: George E. Miller, Jr., John Goss, Harold Biswell) under the partial sponsorship of the California Air Resources Board - work was completed as of April 30, 1974.

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ACKNOWLEDGEMENTS

Davis

During the course of this project many assisted in making it possible to achieve the goals established. Rice, wheat and barley growers, farm advisors, experiment station specialists, development engineers, engineering aids, laboratory mechanicians, laboratory technicians, extension research associates, University Agricultural Services Personnel, and others all worked together to accomplish the task and to provide counsel, guidance, encouragement, and evaluation at various steps along the way.

We wish to give special recognition to Mr. James F. Thompson, Jr. Development Engineer, Department of Agricultural Engineering, University of California, Davis, whose contribution has been outstanding in this study. His enthusiastic and competent effort in the management of field and laboratory data collection, computation, data analysis, data evaluation and report preparation has been appreciated since the time he joined in the study in July of 1971. We also wish to express our thanks to Mr. Jack F. Williams, Farm Advisor, Sutter County who was an important member of the project leadership and field study team on Agricultural Burning. He arranged for field test sites, participated in the planning and data collection of field burning trials on rice, and wheat residues and evaluation of results. He also arranged for areas to conduct large scale trial burns in Sutter County and has worked diligently toward completion of the project.

Growers of cereal crops who made their properties available to us in the field studies covered by this report were: Tom Joaquin, Newhall Land and Farming Co., Morrison Bros., Roy Osterli, Jack Schiedel, and Buz Osterli of Sutter County.

Asparagus Trials

Mr. Adolph Van Maren, County Director of Cooperative Extension in Imperial County, arranged with Dave Schoenemann, and Bob Chan of Fresh Pick Corporation to conduct trial burns in 1972. Portable monitoring equipment was tested.

Mr. G. Neil McRae of Indio, in Riverside County, made contacts with growers in that area and trial burns were conducted and photographed. Growers participating in these trials in 1972 and 1973 and providing their properties were: Stu Schlegel, John Farringer, Lee Anderson, and Bert Covanaugh, Bob Stone, Jack Kitagawa, Foreman, Dick Grant, Head Foreman. Their cooperation, support, interest, and counsel were important in obtaining the necessary field data and evaluations.

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Department of Agricultural Engineering

H. B. Schultz, Professor

J. J. Carroll, Assistant Professor and Assistant Meteorologist

J. B. Dobie, Agricultural Engineer

N. B. Akesson, Professor

S. M. Henderson, Professor

A. A. Arkush, Extension Research Associate, Cooperative Extension

M. E. Engstrom, Extension Research Associate, Cooperative Extension

D. E. Fischer, Extension Research Associate, Cooperative Extension

I. G. Akpan, Senior Engineering Aid

R. E. Cowden, Staff Research Associate

C. R. Page, Trainee Mechanician

R. T. Stormont, Laboratory Technician

J. A. Joy, Principal Mechanician

P. E. Pankratz, Senior Design Draftsman

J. L. Bumgarner, Senior Design Draftsman

P. S. Parsons, Extension Economist - Farm Management Specialist, Cooperative Extension

R. D. Boynton, Graduate Student, Department of Agricultural Economics and Research Assistant, Department of Agricultural Engineering

C. A. Bush, Typist

Riverside

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Special thanks are given to Mrs. Minn Poe, Computer Programer in the Air Pollution Research Center, for constantly supervising our programing needs and making on-the-spot modifications where needed. She also coordinated our very full burning schedule with staff of the computer center to assure that there was no interruption of data polling during fires. We thank the computer center staff for their fine cooperation.

Berkeley

Acknowledgement is made of the efforts of Mr. James K. Agee, Research Assistant, University of California Department of Forestry and Conservation, Berkeley, California, for the substantial part he took in the forest burning studies. We also wish to acknowledge the valuable participation of Mr. Ron Wakimoto, Research Assistant, University of California Department of Forestry and Conservation, Berkeley, California, for his contribution to the forest burning aspects of this project.

We thank all unnamed who contributed time and ideas to the project.

CONCLUSIONS

Management of fuels, fire, and timing of burning agricultural residues can be effective tools in minimizing emissions from agricultural burning. While all field conditions and residues have not been evaluated, a representative number have been and the results and observations developed are as follows:

1. Moisture content of fine fuels [cereal straw and stubble, fine portions of asparagus fern (< 1/4" diameter), leafy portions and small stems (< 1/4" diameter) on orchard prunings, wildland grasses, etc.] is the main factor affecting the level of emissions from agricultural burning. When the moisture content of these fuels is increased above 12% wet basis, there is a definite increase in emissions of: particulate matter, hydrocarbons, and carbon monoxide. In coarser fuels (large orchard prunings, limbs, and stumps) that burn slowly, the moisture content does not appear to be a large factor until it reaches 30-35% or more wet basis.

2. Backfires generally produce about one-half as much particulate emissions as headfires, but backfires do not seem to provide much, if any, reduction in hydrocarbon or CO emissions. The reductions in particulate emissions in backfire burns occur largely when the moisture content of the fine fuels exceeds 12%. The slower burning backfire develops more complete combustion of the volatile organic aerosols which are produced in close proximity to the fire. In the backfire these combustibles are carried into the flame area and consumed. In the headfires these aerosols are also produced on the upwind side of the fire but the flame is moving away from the aerosols and there is essentially no potential for combustion of this airborne material. Other factors that affect combustion and may enhance the quality of burn in a backfire are: longer flame-fuel contact period which can aid in preheating and predrying the fuel, and greater potential for oxygen supply. No attempt has been made to isolate or evaluate the individual effects of these factors. The overall benefits of backfiring are attributed to the combination of these factors and possibly others not recognized in these studies. There may be a reduction of emissions in backfires at less than 12% moisture content (wet basis), but the data are so well grouped at this point and the differences so small that it could not be detected within the precision levels of our instrumentation. In fact, data from rice straw, barley straw, and wheat straw for all management methods of fire and fuel are grouped well together at moisture levels below 12%(wet basis) except pile

burns which generally produced the lowest levels of emissions. Backfires also typically produce much less dense plumes than headfires. This is largely due to greater dilution with a slower rate of fuel consumption and partially due to the reduced emissions in Kg/MT (lb per ton). This effect is most noticeable at higher moisture contents, but the presence of visible white smoke even at very low moisture content makes the headfire appear to have higher emissions even if they cannot be detected in measurements. The less dense plume of the backfire is of definite advantage even on dry fuels when burning in close proximity to airports, highways, or highly populated areas.

3. The SAPRC burning tower studies of particulate matter emissions from rice straw residues showed a significant decrease in particulate emissions with increased fuel loading [Kg/m^2(lbs/ft^2)]. This phenomenon was also observed in some rice field burn trials and a few pile burns of rice straw and barley straw that were measured. However, not enough field trials were conducted to obtain statistical significance for this factor and the effect is relatively small compared to those items reviewed in paragraph 1 and paragraph 2.

There is also a contradiction to this in the SAPRC Trials on barley and wheat straw at .9 Kg(2 lb) and 2.7 Kg(6 lb) per 1.2 m x 2.4 m(4 ft x 8 ft) tray. On these residues the higher fuel loading levels produced higher emission levels. Further studies will have to be done to clarify this point. Higher fuel loadings will aid in producing greater flame residence time and theoretically should improve combustion but it did not work out this way in this one set of trials.

Hydrocarbon emissions were also inversely related to fuel (residue) loading. Carbon monoxide emissions showed no effect from residue loading. In field trials there was so much inherent correlation between residue loading and moisture content that no separate relationships could be found.

4. At the SAPRC burning tower studies of rice residue burns, absolute humidity appeared as a significant variable affecting hydrocarbon emissions. In field studies humidity was so correlated to fuel moisture content that no separate relationship could be detected.

Measured variables that showed no statistically significant effect in field trials were: lapse, windspeed, rate of burn, ambient temperature, and relative humidity. This does not mean that these variables do not produce effects. In fact, with some variables it seems reasonable to expect that they do have some effect, it just could not be measured with these tests. For example, bulk density of fuels appears to be a factor. Very low densities such as Russian thistle produce high emission levels and tightly compacted residues also produce similar results. It is also expected that relationships exist between rate of burn, rate of fuel consumption, or windspeed and particulate emissions. One of the problems in field trials was not being able to get a wide enough range of conditions to fully evaluate certain factors. Normal weather conditions often provided a repetition of results of previous tests. This was not fully recognized until data was analyzed. This problem generally occurred when the moisture content was less than 12%. It was for this reason that additional tests were scheduled and performed at the SAPRC burning tower at Riverside so that controlled variation over a wide range in specific variables, such as moisture content, could be introduced. The result of these simulations has been good and it appears that further tests of the effects of fuel and fire management should be conducted at a burning tower or in a wind tunnel to better define effects of these variables.

Since moisture content was found to be a dominant variable affecting all measured emissions, preliminary studies were made to determine moisture level patterns in some residues in the field. These preliminary studies revealed substantial diurnal variations and different drying characteristics for spread straw than for straw left in windrows. From these data and other information available it is apparent that spreading green or wet straw exposes it to the maximum available solar radiation and convective drying. This is the most effective means of reducing the moisture content during the drying periods of clear days. The increased exposure is beneficial during clear daytime periods but has a negative effect on drying when night time high humidity and dew formation reverses the drying process. Thus, in the early morning hours spread straw will have a larger quantity of dew or moisture associated with it than will straw in windrows and the apparent* moisture content will be higher. This quantity of water that can become re-associated with the residue and can be substantial under

*Apparent moisture content is used in this case to reflect the total moisture (surface and internal) that is associated with the straw at any given time.

heavy dew conditions but it is largely surface moisture and is readily removed on a clear day by solar radiation and convective drying. Usually by 11 a.m. or when the relative humidity reaches 50% or less, spread straw on standing stubble will be 12% or less moisture content. Windrowed straw may not reach that moisture level until later in the day or even several days later depending on the initial moisture level in the morning. All of which indicates that spreading residues and waiting until they are down to 12% moisture or less is a method that can be generally utilized with reasonably low expense and little inconvience to produce minimum emissions.

Particle size distribution of emissions were determined on a number of field and SAPRC laboratory burns. These studies revealed that mass median diameter levels from the line fire burns monitored (headfire, backfire, sidefire) were in the submicron range. This indicates that the majority of the particles would remain in the atmosphere for extended periods of time unless altered by: evaporation, growth through agglomeration and subsequent fallout, precipitation, or through chemical or photochemical reaction with other pollutants. Particles from .4μ to 6μ significantly affect visibility, but only 20-50% (with an average of 30%) are in this range. Therefore, only 30% of the measured emissions affect visibility as measured in a fresh plume. Aged plumes may present a different picture. With evaporation, aged plumes should show a lower percentage larger than .4μ. The only way to evaluate this would be to measure aged plumes with a high-vol cascade impactor for comparison. Very few particles (2-3%) were found to be over 10μ in line fires so little fallout would result from line fire emissions. This would not be true in peripheral lighted fires where fire whirls can carry large amounts of ash, unburned residue, and soil particles hundreds of feet into the atmosphere.

Costs have been developed for different types of burning techniques for field crops. There will be variations in these costs depending on many factors but reasonable estimates for average conditions have been made for comparison as follows:

Headfires	\$ .30-.48/ha (\$.12-.19/ac)
Backfires	\$1.61/ha (\$.65/ac)
Into-the-wind striplighting	\$ .62/ha (\$.25/ac)

The many variables present in field monitoring of burns and the difficulties, if not impossibilities, of making measurements in appropriate locations for some types of open burns makes it almost a necessity to employ laboratory simulations.

Simulations in the SAPRC burning tower have compared favorably on many burns to date and when the simulations are accomplished the results should be comparable. Another potential would be aircraft sampling with a high-volume Cascade impactor in aged plumes. An unknown factor would be the dispersion characteristics of the gases such as CO_2, CO, HC, compared to particulates. We have accepted Boubel's theory that the gases and particulates will essentially disperse at the same rate and this appears to be appropriate for short time and distance comparisons. The theory may have to be re-evaluated for aged plume studies where photochemical or chemical reactions may be taking place. However, aged plume studies may be the only way to examine some fires where the intensity will not permit the type of measuring equipment we were able to utilize.

Drying characteristics vary with crop residues and management methods. It is therefore difficult to make broad classifications that will adequately cover the wide variety of crop residues and conditions that exist in California. The large quantities of certain crop residues that are burned has guided the direction of this research and important information has been developed for these residues. More detailed work is needed on drying characteristics in order to cover more of the conditions that exist particularly in rice straw under the wide variety of weather conditions that may be encountered during that burning season.

Estimates were made of the number of days of drying required for a specific agricultural fuel to be dry enough to burn with minimum emissions. Straw spread on standing stubble where it is not in contact with wet soil or water will dry down in one or two clear or mostly clear days. Windrowed straw in contact with wet soil may require 10 days or more of good drying weather. Asparagus fern that has been severed with a rotary cutter will require 20-30 drying days if it is a mature heavy fern, a young stand not so thick will require less time to dry. It is difficult to ascertain when asparagus fern that has been prepared by knocking down with a roller or bar is dry enough to burn because of the unknown effect of soil moisture, the percent of connected stems and many other factors. Orchard prunings may require 10 to 30 days depending on the fire management technique to be employed. A single pile fire can be best utilized by picking up the prunings on a brush rake, and continuously adding them to the fire. This utilizes the heat of a pre-existing fire to dry, preheat, and gassify combustibles of subsequently applied prunings in the flaming zone of the fire. A clean burn can then be obtained at relatively high moisture levels. Each fuel must be evaluated separately for its drying characteristics and its emission characteristics. A substantial start has been made in this subject.

Emission levels for crop residues vary with the crop and even under optimum conditions of fire and fuel management. Particulate emissions for some crops residues under reasonably good burning conditions are about as follows:

	Kg/MT	(lbs/ton)
1. Orchard prunings: citrus, almond, peach, walnut, grape	2-4	(4-8)
2. Rice, barley, wheat	3-5	(6-10)
3. Russian Thistle	10-13	(20-26)
4. Asparagus	14-20	(28-40)

Fortunately, the quantities of the latter two residues burned are small compared to the first two, but it might be logical to consider limiting the quantities burned per day in a local area based on the potential emissions.

With careful selection of permissive burn periods, more attention to fuel moisture content, proper selection of fire lighting techniques, emissions from agricultural burning can be minimized. Atmospheric visibility can be increased and the local effects of plumes on aesthetics, and air and land traffic can be minimized. This will require a cooperative effort by all concerned but it is possible. The amount of improvement that can be effected is unknown because much of the current burning is being accomplished under good conditions and growers are becoming more aware of the value of burning with a minimum of emissions. Further research and educational programs will be needed to fully utilize the information obtained so far. Some of the basic principles of emission production have been related for fire and fuel management of agricultural residues. For specific crops and conditions not covered by this study additional work may be required.

AGRICULTURAL BURNING
RECOMMENDATIONS

From these studies it has become apparent that all fuels should be burned after a suitable drying period following harvest or rain. Fine fuel moisture appears to have a more dominant roll in emission control than coarse fuel moisture. The fine fuels are more susceptible to diurnal moisture variations and are responsive to the effects of rain or dew and humidity as well as solar radiation and convective drying. In general, internal moisture must be low enough (on fine fuels less than 12% moisture content, on coarse fuels less than 35%) and surface moisture from dew or rain should not be present at the time of burning. Moisture levels can generally be related to the type and condition of a specific residue, the time since harvest or appreciable rain and the atmospheric condition of the previous day and night, together with current conditions and time of day. Rainy days should probably not be burn days "except under unusual conditions".

General recommendations that apply to agricultural burning for minimizing emissions are:

1. Burn on permissive burn days.
2. Burn when fine fuels (<1/4" dia.) have dried to 12% moisture content or less and all dew or other surface moisture has been dissipated.
3. Utilize line back fires and line side fires, and into-the-wind striplight fires (with caution) whenever feasible, for field crops and generally avoiding headfires or peripheral light fires except under conditions where this type of fire is the only feasible means.
4. Utilize backfires near roads, airports and residential areas, where good local visibility and minimum particulate concentration are important.
5. Burn heavy fuels such as orchard prunings after dew or other surface moisture has been dissipated and when moisture content of the wood is less than 35% wet basis. Where practical, burn fuels by adding to an existing fire to benefit from preheating and predrying of fuel with energy in coals and flame.
6. Burning should generally begin at a time of day when relative humidity in the field or at the site of the burn has reached 50% or less. In most areas examined this would generally be from 11 a.m. to 6 p.m. Desert areas, and coastal areas may be somewhat different and if so these times should be adjusted accordingly. Under certain weather regimes, such as north wind in the Sacramento Valley, satisfactory

burning conditions may occur earlier in the morning; if so, the times can be adjusted. When fog occurs in coastal areas in the morning, the relative humidity may not reach 50% all day and if so the fuel should not be burned. There will be other similar type conditions which may preclude the use of time. However, if the residue has once reached a satisfactory moisture level since harvest or the last rain it should reach it again by 11 a.m. on the next clear day.

Specific Recommendations for Crops Examined

Cereal Crops Residues - Spread straw behind the harvester to promote drying following harvest and subsequent rain storms and on the daily diurnal cycle of moisture content. Burn when the moisture content is 12% or less and use backfire and sidefire, or into-the-wind striplight lighting techniques. Vehicle traffic in rice fields should be minimized to limit fuel compaction which results in poor drying, poor combustion, and high emission levels. Raking windrowed or compacted straw can aid in drying if moisture content is a problem. Striplighting should be done with caution with healthy personnel, good supervision, and a buddy system in the event of incapacitation of a fire lighter through injury, seizure, or other cause. Wind changes can also be a problem and this system can best be used under relatively steady wind conditions above 6 Km/hr (4 mi/hr) up to possibly 19-24 Km/hr (12-15 mi/hr). Mow levees in rice fields to promote fire coverage of the entire field. Burn as soon as fuel is sufficiently dry after harvest to minimize emissions. Green regrowth in rice and summer weed growth in other crops increases average moisture content of the fuels and increases emissions. If burning is accomplished soon after harvest and follows the same schedule so that fuels do not accumulate, burning is spread over a longer period. Under these conditions, daily concentrations of emissions from burning in an air basin can be minimized.

Asparagus Fern - Rotary mow asparagus fern allowing three weeks to dry. Burn when fine fuel [< .3 cm (1/8") diameter] is less than 12%. Backfire and sidefire or into-the-wind striplight with the same precautions as listed under cereal crop residues. If material is not drying satisfactorily it may be advantageous to rake and expose shaded material to solar radiation and convection drying. This has not been tested to date in asparagus fern and is not a recommendation but can be a valuable potential.

Orchard Prunings - In those instances where it is feasible and practical leave prunings in small piles or windrows in the orchard to dry to 35% moisture or less. Start a good fire with dry prunings and ignition aids such as dry cellulose and some diesel oil, or some of the materials manufactured for this purpose, when dew is dissipated or relative humidity reaches 50%. Add prunings to the fire as fuel is consumed maintaining a relatively steady state fire. Other similar methods or waiting until prunings reach lower moisture levels can also be utilized. If visible smoke is minimized or non-existent from this type of burn it is a good indication that gaseous emissions are also low.

Russian Thistle - Based upon the limited number of fires, it appears that the material should be burned when dry and that green plants should not be added to the fire because of the increase in hydrocarbon emissions.

Utilization of these recommendations should be a substantial aid in minimizing emissions from agricultural burning of these residues which constitute the majority of contributions to air pollution from prescribed agricultural burning. Further refinements can and undoubtedly will be developed for moisture content predictions, and methods for emission reduction for various crop residues but this study has developed important criteria than can be utilized now.

burn. (See figure 1). The platform contained the following instruments:

1. Gelman Hurricane high volume sampler with 20 cm x 25 cm (8" x 10") type A glass fiber filter.
2. Gelman Hurricane high volume sampler with a six stage Weathermeasure high-volume cascade particulate impactor.
3. Chromel-alumel thermocouples for measuring temperatures at the platform and in the fire.
4. CO_2 gas sample intake.

A 37 meter (120 feet) cable carried the temperature and gas information to a four wheel drive instrument vehicle and supplied power to the sampling equipment(see figures 2&3). The instrument vehicle contained the following:

1. 2 strip chart recorders for temperature recording.
2. A Beckman non-dispersive infra-red gas analyser for CO_2 analysis and a strip chart recorder.
3. Wind speed and direction recording aparatus.
4. Ambient air temperature and relative humidity sensors.

Prior to each cereal crop burn straw* and stubble** quantity and moisture content samples were taken along with stubble height measurements. After the burn, unburned straw and stubble quantity and moisture samples were collected as well as ash samples to determine ash quantity and carbon content. Rate of flame advance measurements were made on a number of the trials. Laboratory analysis of field collections included: chloroform extraction of high volume particulate samples using Soxhlet extraction apparatus; carbon content analysis of straw and post burn ash using an induction oven, dry chemical CO_2 absorption method; and air oven moisture content determinations of the straw and stubble samples. (See Appendix A for sample calculations for particulates). Three residue

*For these trials straw and chaff are defined as the material cut by the combine.

**Stubble is that portion of the plant not cut by the combine.

management techniques and six fire management techniques were studied in the field trials. The straw was left in windrows as it was dropped behind the harvester, spread uniformly over the stubble by a combine straw spreader attachment or two rakewidths of spread straw were raked together after several days of drying. The six fire techniques were: lighting a single line fire perpendicular to the wind on the leeward edge of the plot allowing the flame to progress into the wind (backfire), lighting the windward edge of the plot (headfire), lighting the entire perimeter (peripheral light) on a calm day, spot lighting the center of the plot only (center fire), lighting fields in strips into the wind at 100-200 m (300-600 feet) intervals (into-the-wind striplight) and lighting approximately 400 kg(1000 lbs.) piles of straw (pile burns). Headfires and backfires were not monitored unless the windspeed was greater than 4 miles per hour to avoid the difficulty of defining the fire type under light and variable winds. Despite this precaution, some fires changed type and this undoubtedly contributed to some of the variability of field data results.

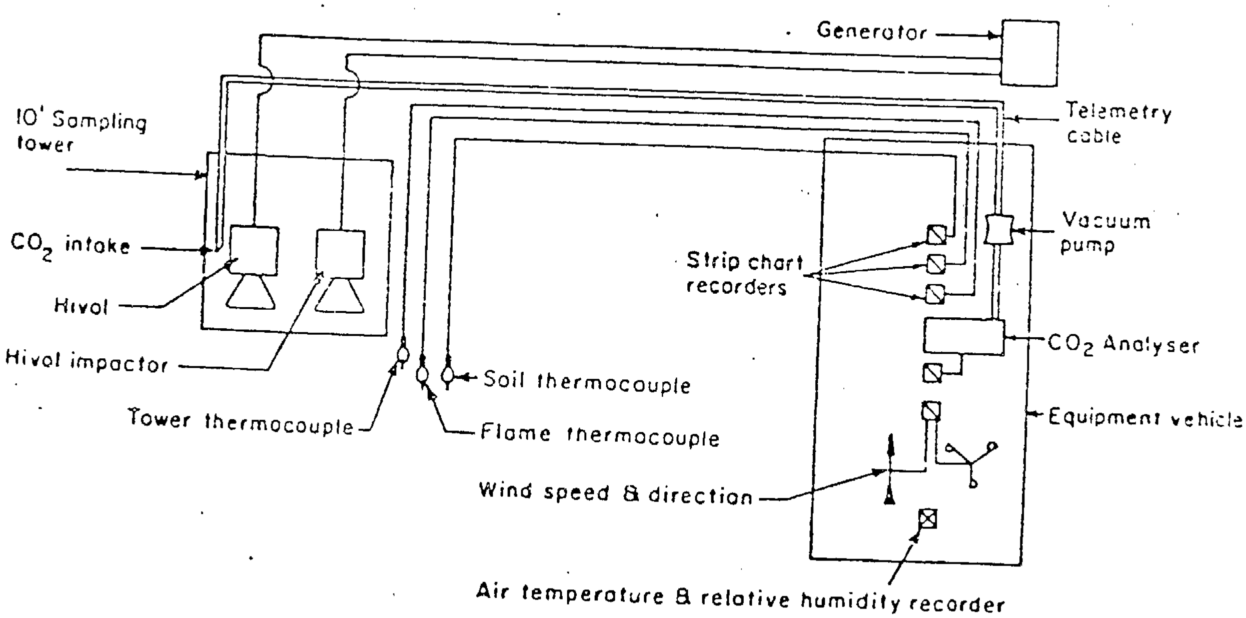


Figure 1. Schematic of Field Sampling Equipment

The cost for open field burning of cereal grains analysis was based primarily on the rate of flame advance for the various fire management techniques. Several average sized fields, approximately 40 ha(100 ac) were burned to verify the total time required to burn a field calculated on the basis of the plot data. The large field trials were also used to evaluate the practicality of the proposed fire and residue management techniques.

Burning Tower Simulations

Experimental procedures for burning fuels and sampling emissions were carried out in an out-of-doors burning tower and adjacent instrument building. The facility simulated open burning but channelled the combustion products so that representative samples of gas and particles could be taken. The tower was in the form of an inverted funnel 4.8 m(16 ft) in diameter at the base, decreasing to 71 cm(28 in.) in a length of 6.1 m(20 ft) and topped with a stack 2.4 m(8 ft) in length. The tower had been erected above a table 2.4 m (8 ft) in diameter, which was positioned on a scale with a maximum capacity of 56 kg(125 lb). The sample site for gases, particulate, and for recording temperature and airflow was in the stack about .6 m(2 ft) from the top. Stack gases for analysis of total hydrocarbon, CO, and CO_2, were drawn through sample lines into the appropriate analyzers in the instrument building to give a continuous millivolt equivalent recording of concentrations. Taps on the gas sampling system led to bottles which could be used to obtain grab samples at any desired time during a fire. Previous studies showed that little NO_x is produced in these types of fires, therefore it was not sampled in this set of burns.[9] Airflow was monitored with a 4-cup anemometer mounted in the stack. A shaft encoder was positioned on the end of the anemometer shaft, just ouside of the stack. The encoder generated a millivolt signal by making and breaking a light beam through an 800-slot disc. One revolution of the shaft created 800 pulses, and 3000 pulses per second generates the full-scale 50 mv signal. The maximum airflow encountered during the peak of the hottest fires was between 40-45 mv, or approximately 283 m^3/min. (10,000 cfm). A transducer was adapted to the actuating mechanism of the scale so that a change in weight generated a millivolt signal; 1 mv is equivalent to .45 kg (1 lb) and full range is 50 mv.

All recording instruments were connected to a data acquisition system, which in turn was connected to the campus computer. The computer polled each recorder every 2.6 seconds and stored the millivolt response of each instrument on tape or discs. A computer program had been written from which the yield of pollutants in kilograms per Metric Ton of fuel burned could be calculated using the data collected on temperature, gas concentration, and airflow.

Particulates were collected isokinetically on standard Type A glass fiber filters held in either one or two modified HIVOL samplers positioned in series in the sample line and outside of the tower. The approximately 2.5 cm (1")

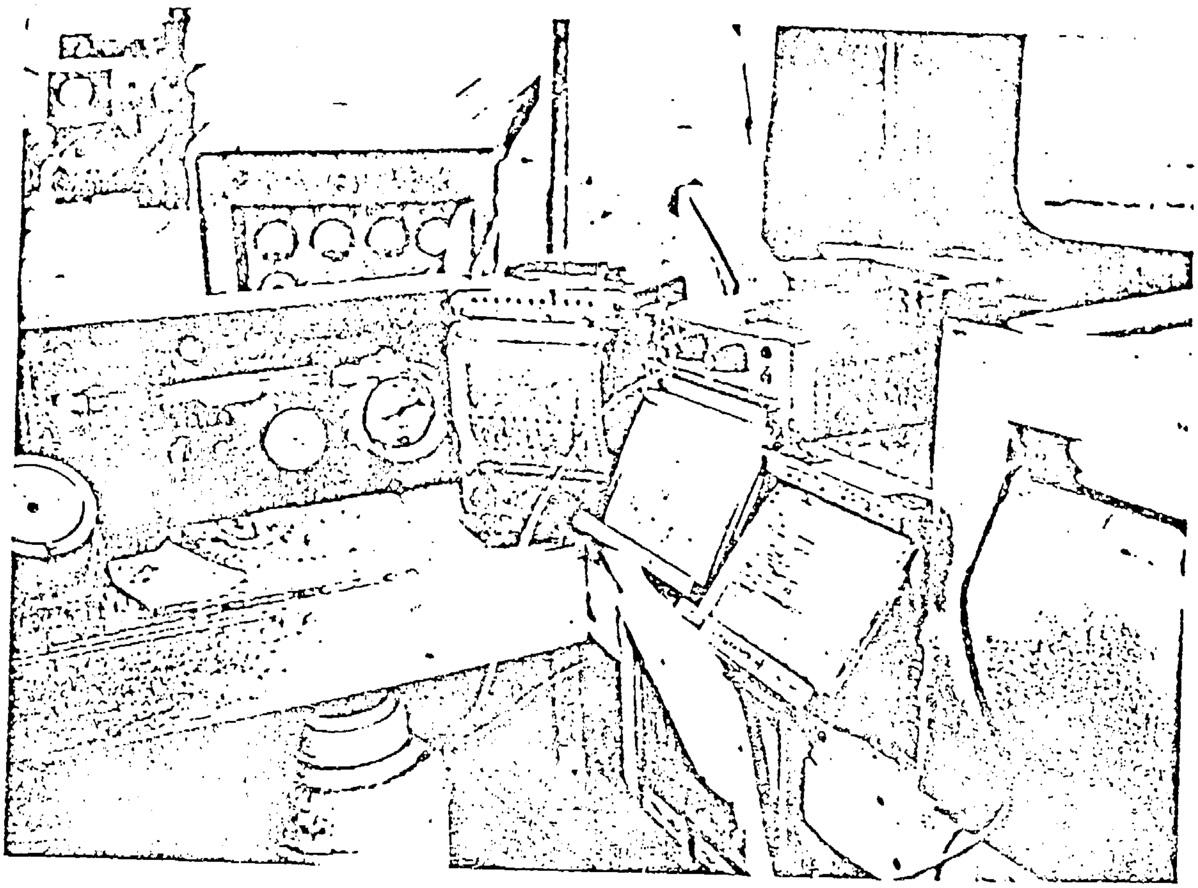


Figure 2. Photograph - Field Instrumentation - Scout

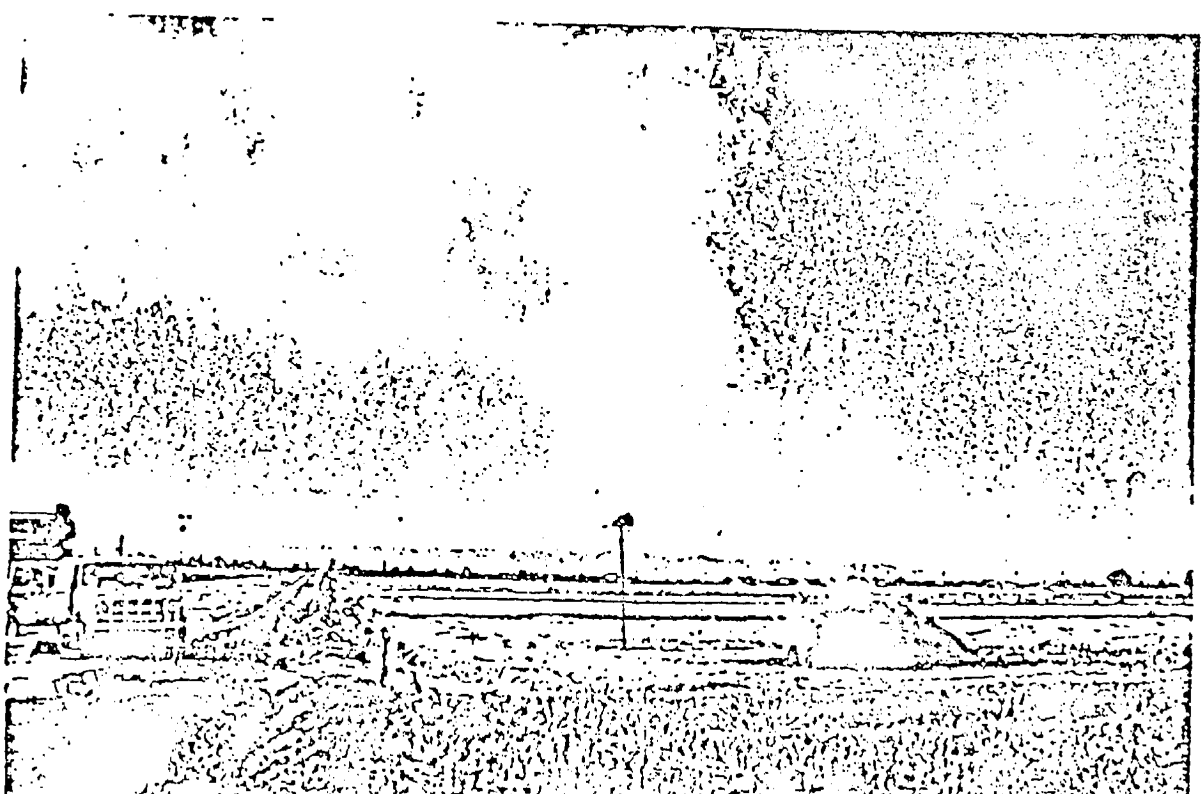
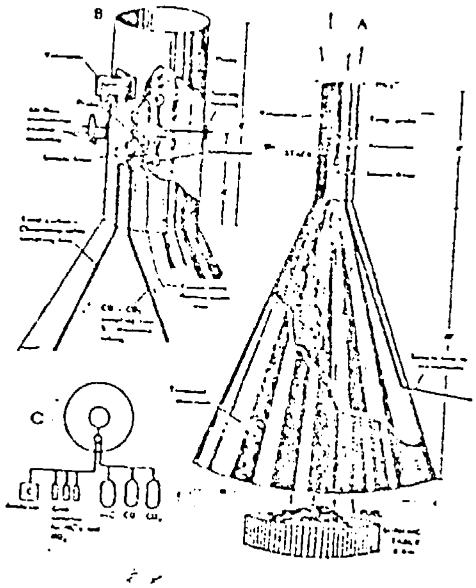
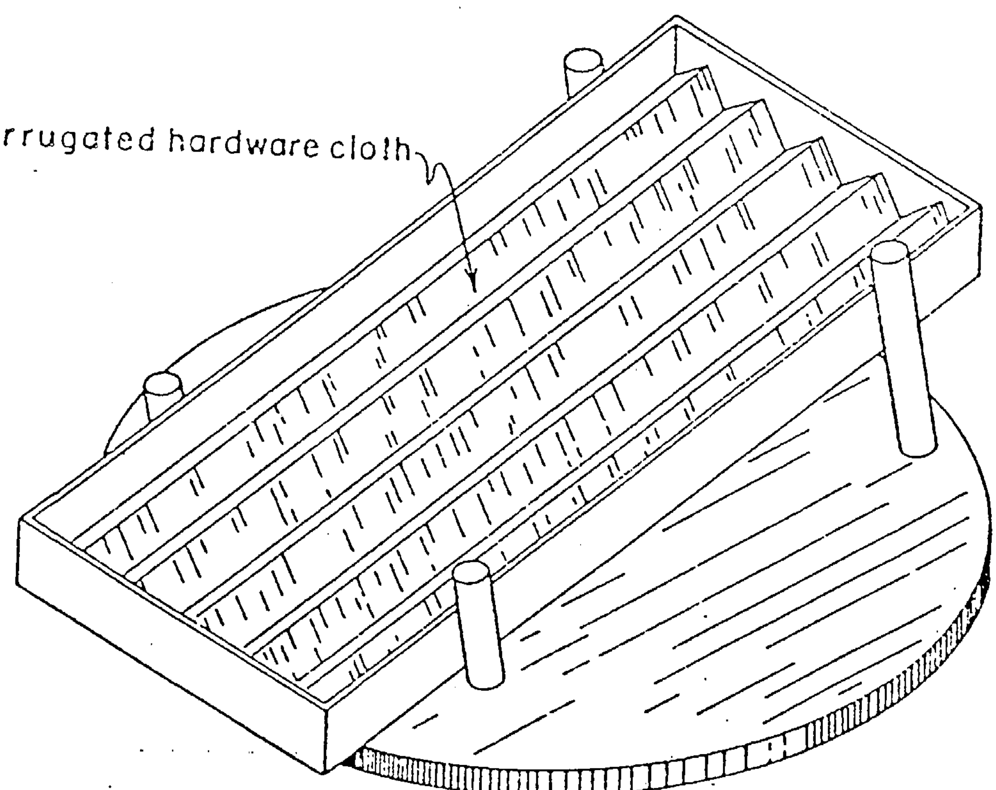


Figure 3. Photograph - Field Instrumentation - Sampling Tower



Drawing of tower used in burning straw. (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 relationships of tower and analytical instruments in shed next to tower.

Figure 4. SAPRC Burning Tower



Inclined tray set on burning table to simulate head and back fires

Figure 5.

diameter particulate sampling orifice in the stack was one of a pair of piezometer rings, the exhaust side of which was connected to the sample line through the filter holders. The sample air flowed sequentially into the sampling orifice and through the filter, a pneumatically controlled globe valve, and a constant speed exhaust blower. The exhaust of the second piezometer ring was open to the atmosphere. The static pressure plenum of each ring was connected with appropriate tubing to a pneumatic controller located in the instrument building. The pneumatic controller sensed any pressure difference between the piezometer rings resulting from airflow rate differences through the rings, and equalized the pressure (and thus the airflow), by opening the globe valve. In a typical fire, the blower was turned on prior to ignition. Since there was no flow up the stack, and thus no pressure difference between the piezometer rings, the controller was already balanced and the globe valve remained closed. As heat generated an airflow through the stack and the open-ended piezometer ring, a pressure difference developed which immediately caused the controller to open the globe valve until the pressure was equalized. This of course, was a continuous response and isokinetic sampling was achieved. The sample volume was calibrated at 1/770th of the total flow through the stack.

With many agricultural fuels, the wastes generated at the end of each growing season are generally loosely arranged on the ground, either from the harvesting process itself or from subsequent spreading, raking, or piling. It is thus less critical as to how such fuels are collected and arranged on the burning table except to duplicate the range in fuel size and weight per unit area that one finds with a given crop.

Fuel moisture is an important factor governing pollutant emissions. Samples of fuel are taken just before ignition and oven dried to constant weight at 105°C. For fuels that are received green and/or fairly moist, fires are run at appropriate intervals as the fuel dries naturally. Where higher moisture levels were studied with fuels that were received dry, calculated amounts of water were sprayed into the fuel contained in a large plastic bag. The bag was sealed and the contents allowed to come to equilibrium.

The simplest fire situation was to place a given weight of fuel [2-20 kg (5-50 pounds), depending on bulk density] either in a pile and ignite from the top or along the edge, or to spread it uniformly in an inclined rectangular 1.2m x 1.8m (4' x 6') tray and ignite along one 1.2m edge. A small propane torch was used for ignition. Prior to ignition filters were placed in the holders and all gas analyzers and other instrumentation were turned on. The analyzers recorded the background levels and indicated completion of the fire when concentrations again return to background. Weather conditions, ambient emperature, and relative humidity were recorded.

Size distribution was determined with the Brink 5-stage cascade impactor and the Weathermeasure cascade impactor. Particulate morphology was examined by light and scanning electron microscopy.

With cascade impactors, particles were sized by their aerodynamic size rather than their geometric size. The method accounted for the three major aerodynamic factors of size, shape, and mass density. With the Brink, calculation of particle size distributions was based on the generalized calibration curve determined by Ranz and Wong[12]. The characteristic diameter for each stage of the impactor was calculated following Brink's calculation[13]. For the Weathermeasure, particle cut-off sizes for each stage are determined by calculations based on the theory developed by Marple[14]. With this impactor, correction was made for a 1.4 m^3/min. (50 cfm) flow and for both impactors a mass density of 0.9 g/cc was selected as a reasonable approximation.

Because the Brink impactor uses relatively low sample flow rates (3000 ml per minute), it was difficult to obtain adequate samples during the short burning period of most tower batch type fires. Reliable samples were obtained from nearly steady-state fires by hand-feeding the fuel at a uniform rate over a 20 minute period onto an existing fire.

A specially designed glass cyclone preceded the Brink impactor and a nuclepore membrane filter followed the last stage to provide an additional cut point. The complete apparatus was mounted in a temperature controlled box as described by Brink[13]. Rather than use the sample cups as the collecting surface, the bottom of the cup of each stage was lined with a pre-weighed aluminum foil disc held in place with a retention ring. This modification reduced the ratio between the weight of the collector and the weight of particles collected and also provided a medium for direct mounting on the specimen holder of the electron microscope. The aluminum foil had been washed previously with $MeCl_2$/acetone, dried in an oven, and held in a dessicator prior to weighing.

The Weathermeasure impactor was used extensively with the batch fires because of its high flow rate (40-60 cfm). Several minutes of sampling provided enough particulate matter on each stage to permit gravimetric analysis. The samples were collected on glass fiber material so chloroform extraction could be performed and a size distribution for both soluble and insoluble particulates could be obtained. The Weathermeasure impactor was also suitable for microscopic analysis with specially prepared aluminum foil used as the collection surface instead of glass fiber filter material.

PART III. DISCUSSION OF RESULTS

CEREAL GRAINS

Field Burning Trials[15]:

Analyses were performed to determine which fire and fuel management variables had a statistically significant effect on particulate emissions. In the analyses of the rice open field burning data, fall and spring open field burning data were combined to give a broader range of some of the independent variables. The following dependent and independent variables were considered.

Dependent variable	Independent variables
particulate emissions	direction of burn: headfires vs. backfires
carbon monoxide emissions	residue moisture content
gaseous hydrocarbon emissions	(residue moisture content)^2*
	(residue moisture content)^3
	fuel loading
	absolute humidity
	(absolute humidity)^2
	relative humidity
	log (relative humidity)
	air temperature
	wind speed

*NOTE: $( )^n$ where n indicates the exponent of the variable enclosed in the parentheses.

The direction of burn variable is discreet, therefore, the correlation and regression analyses were performed separately on headfire burns and backfire burns. No significant difference could be found in particulate production by grouping the data by fuel management technique. The effect of spread, windrowed, and raked straw was represented by the moisture content and fuel loading variables.

The correlation analysis of the fall and spring field data indicated that as fuel loading and moisture content increased particulate production increased but the high positive correlation between fuel loading and moisture content overshadowed the real effect of fuel loading. (Tests at the SAPRC Riverside laboratory, where the field correlation between fuel loading and residue moisture did not exist, indicated that as fuel loading increases, particulate production decreases. The relationship between fuel loading and residue moisture content will be discussed further in the residue drying experiment.)

Table 1

Correlation Analysis*

Field Data

Rice Straw Particulate Emissions

independent variables vs.	particulate emissions Headfire r	Backfire r
residue moisture content	.548	.743
(residue moisture content)^2	.536	.766
(residue moisture content)^3	.503	.776
fuel loading	.538	.675
relative humidity	.275	.417
log (relative humidity)	.281	.405
absolute humidity	.198	.159
(absolute humidity)^2	.174	.143
air temperature	-.103	-.218
wind speed	.066	-.208
significant correlations between independent variables:		
moisture content vs. fuel loading	.649	.748

A regression analysis of the data verified the significance of residue moisture content and showed the difference between headfiring and backfiring. A stepwise regression package developed at the Health Sciences Computing Facility at UCLA was used[3]. Using a 10% significance level the regression chose residue moisture content in headfires and (residue moisture content)^3 in backfires as being the significant variables affecting particulate production. The headfire and backfire regression equations are signficantly different at the 1% level.

*See appendix D for raw data.

Table 2

Regression Analysis

Field Data

Rice Straw Particulate Emissions

	Independent Variable Selected	Coefficient (Metric)	% of Variability Explained
Headfire	residue moisture content	.76 (1.52)	30
	[constant = -3.78 (-7.55)]		
	Multiple r = .548		
Backfire	residue moisture content	.00068 (.00135)	60
	[constant = 1.37 (2.74)]		
	multiple r = .776		

Figure 6 (field data) shows what the statistics imply. Firstly, particulate emissions decrease with decreasing residue moisture in both headfires and backfires. Secondly, backfiring reduces particulate emissions over headfiring.

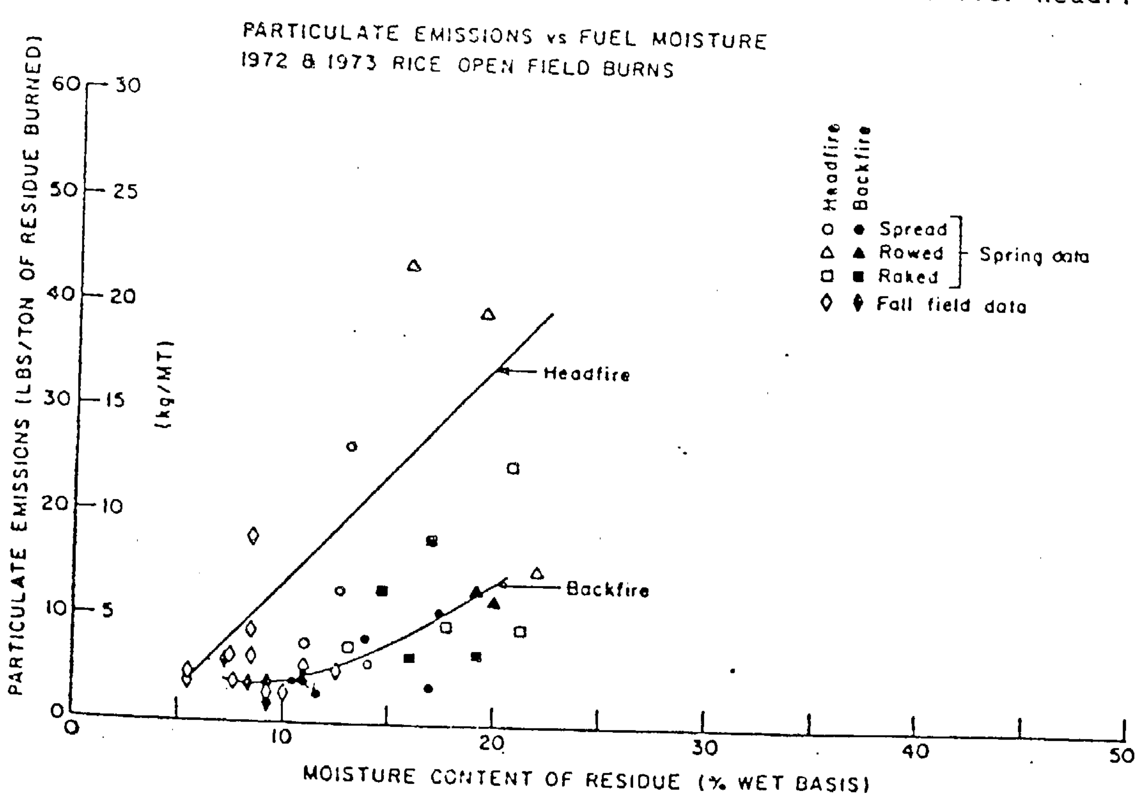


Figure 6. Particulate Emissions vs. Moisture (Rice Field Data)

Although the other independent variables were not found to be statistically significant in determining particulate production this does not imply that they do not have any effect. The variation in the data could easily obscure the effects of these other variables. This variation arises from several sources. 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.

Field tests have also been done with wheat and barley straw. These residues are often burned under different field conditions than rice. These grains are harvested after the plant becomes senescent and consequently the straw residues are usually very dry. Also these residues are burned in the summer when drying conditions are excellent. In the Central Valley and desert regions, barley and wheat residues can reach a moisture content of 4-5% in the mid afternoon of a clear, hot summer day. (Under typical conditions in the fall and spring rice straw will only dry to 8% moisture and can easily be at much higher moisture levels.) Further, wheat and barley usually have a lower residue quantity in the field than rice. Wheat and barley often have 2200-3400 kg/ha (2000-3000 lb/ac) while a rice crop can easily leave over 6700 kg/ha (6000 lbs/ac) of residue after harvest.

50 open field barley and wheat residue burns were monitored in the summer of 1972 and 1973. The burns were done during normal burning hours (9 a.m. - 3 p.m.) on dry surface soil, low relative humidity and high levels of solar radiation. As a result the straw was generally at low moisture content compared to typical rice straw moisture conditions. No statistically significant effects could be found between any of the atmospheric or fuel variables.
A comparison of the fire management techniques showed no difference between head firing, backfiring, center firing on a calm day, or peripheral lighting on a calm day. Tests did show that pile burns [450 kg(1000 lbs) piles] did reduce particulate emissions over the other burning techniques listed above. Three

pile burns produced an average of .8 Kg/MT (7% moisture) and 46 field burns produced 2.5 Kg/MT (6.1% average moisture). The inability to distinguish differences between any of the fire, fuel, or atmospheric parameters is largely due to the level of error in experimental technique. The combined experimental error allows a resolution of about ± 2 Kg/MT (4 lbs/ton). In rice burning trials backfires typically reduce emissions by about one-half over headfire burns. A one-half reduction of a burn that produces 4 Kg/MT (8 lbs/ton) is 2 Kg/MT (4 lbs/ton) which is equal to the "noise" level in the experimental data. Thus it is difficult to determine the difference between a headfire and a backfire burn when a field is dry enough to produce less than 4Kg/MT (8 lbs/ton) with a headfire burn (see figure 7).

Some error also resulted from the hi-vol filter being exposed to different temperatures on different burns. There is some evidence from both field and laboratory tests that a filter that is exposed to a higher temperature will collect less particulate weight than one at a lower temperature. This phenomenon is reasonable in light of the fact that the particulates are formed by condensation. When the particulate levels for the summer burn trials were corrected for average temperature at the filter, the average emission level of rowed and raked headfires was higher than the average emission level for rowed and raked backfires. However, the results were not significantly different.

In any case, a burn that produces less than 3 Kg/MT (6 lbs/ton) of particulates is an efficient open field burn. Open field burning is often charged with producing nearly 8 Kg/MT (16 lbs/ton). It appears that if barley and wheat straw are burned under these dry conditions (e.g. 4%-8% moisture content) an acceptably low particulate emission level will be produced. An example later on in the report will show that barley and wheat straw might be burned in the summer at moisture contents above 8% in the morning hours and that burning in the afternoon hours will minimize emissions.

It should also be pointed out that even though the experimental procedure could not detect a difference between headfiring and backfiring in dry wheat and barley burns there may still be one. The results previously presented from rice straw would tend to indicate that there is a difference between these two lighting techniques even though it may be small at low moisture levels. This difference has also been reported in low intensity prescribed forest management fires.[16] From a safety and public nuisance viewpoint backfiring is always desirable. A backfire is a much slower burning fire and consequently produces low level, low density plume. In fact, in dry barley burns, the plume from a backfire in a summer wheat or barley field is barely visible at a distance of a quarter of a mile. Where visibility is important (i.e. near roads and airports) a backfire has a definite advantage over a headfire. (See figres 8 & 9).

SAPRC Burning Tower Trials:

Recognition of the variability in field data led to the laboratory work at Riverside. It was expected that under the laboratory situation variables could be better controlled and measured with greater reliability. A series of 84 trials was conducted with rice, barley, and wheat straw. A large percentage of the burns were conducted with rice straw. The quantity of fuel burned in most trials was approximately 2.7 Kg (6 lb) of dry material per tray. This corresponded to field fuel loadings in Kg/m^2 commonly found with spread straw. These burns were designed to attempt to isolate the effects of ignition technique: headfire, backfire, sidefire (an attempt to simulate striplighting in the field), residue moisture content, absolute humidity, and relative humidity.

A smaller percentage of burns were conducted on wheat and barley straws. Fuel quantities of 2.7 Kg(6 lb) and .9 Kg(2 lb) per tray were used. The .9 Kg loading simulated spread straw in barley and wheat fields. The 2.7 Kg trials corresponded to rowed straw. The .9 Kg burns had never been tried in the SAPRC tower and it was not known if the tower would accurately measure emissions from such a small quantity of material. Therefore, several .9 Kg trials were done with rice straw to compare the emission levels of these fires with the emission levels from the relatively large number of 2.7 Kg rice straw burns. The same statistical analyses used on the field trial data were performed on the laboratory test data. The correlation analysis (see table 3) showed that in the 2.7 Kg rice straw trials, moisture content and fuel loading were the most significant variables affecting particulate emissions. There was not a significant correlation between straw loading and residue moisture content because the residue samples were not allowed to be affected by meteorological factors before ignition. Straw loading showed a negative correlation with particulate production. This result was in agreement with trends observed in piled straw burns. The stepwise regression (table 4), using a 10% significance level, chose residue moisture content and fuel loading in headfires and (residue moisture content)^2 in backfires as being the significant variables affecting particulate production.

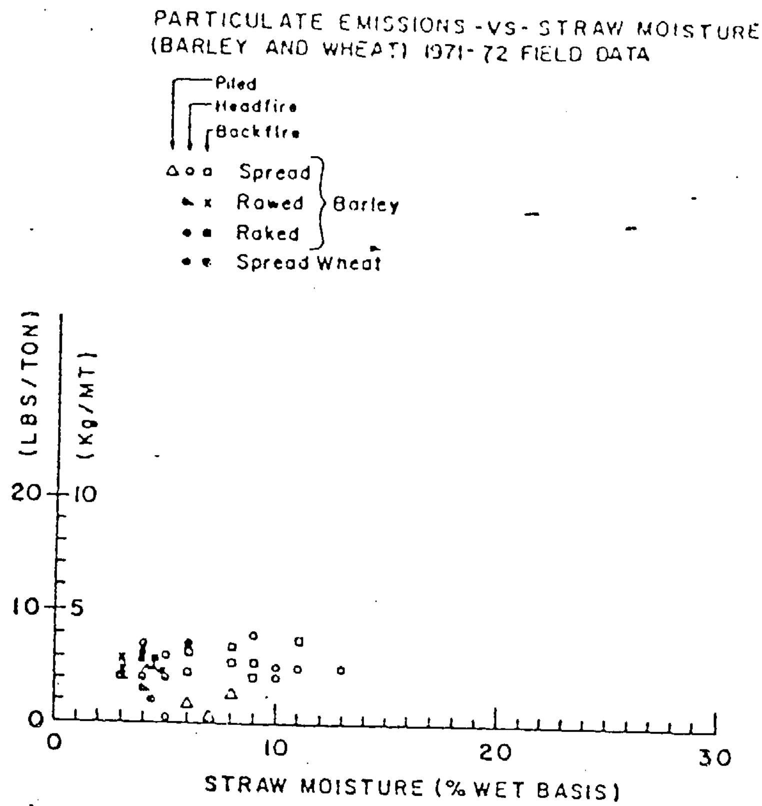


Figure 7. Particulate Emissions vs. Moisture (Barley Field Data)

Table 3

Correlation Analysis for Particulate Emissions

SAPRC Riverside Laboratory Rice Straw Data

Independent variable	Headfire r	Backfire r
residue moisture content	.785	.726
(residue moisture content)^2	.779	.738
(residue moisture content)^3	.745	.738
fuel loading	-.248	-.242
air temperature	-.202	-.096
(absolute humidity)^2	-.153	-.226
log (relative humidity)	.137	.122
absolute humidity	-.133	-.200
relative humidity	.087	.068
windspeed	held constant in trials	

No significant correlations between independent variables.

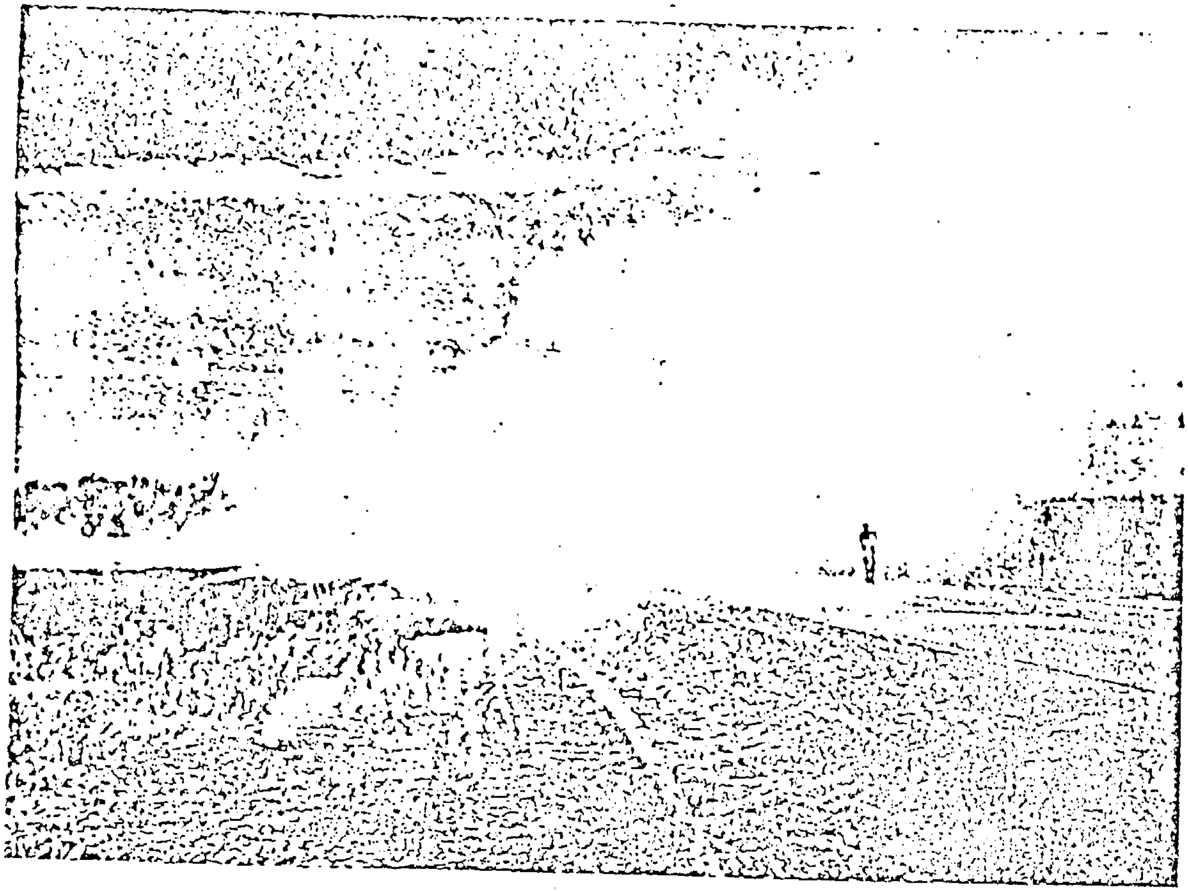


Figure 8. Photograph - Headfire Burn in Barley Straw

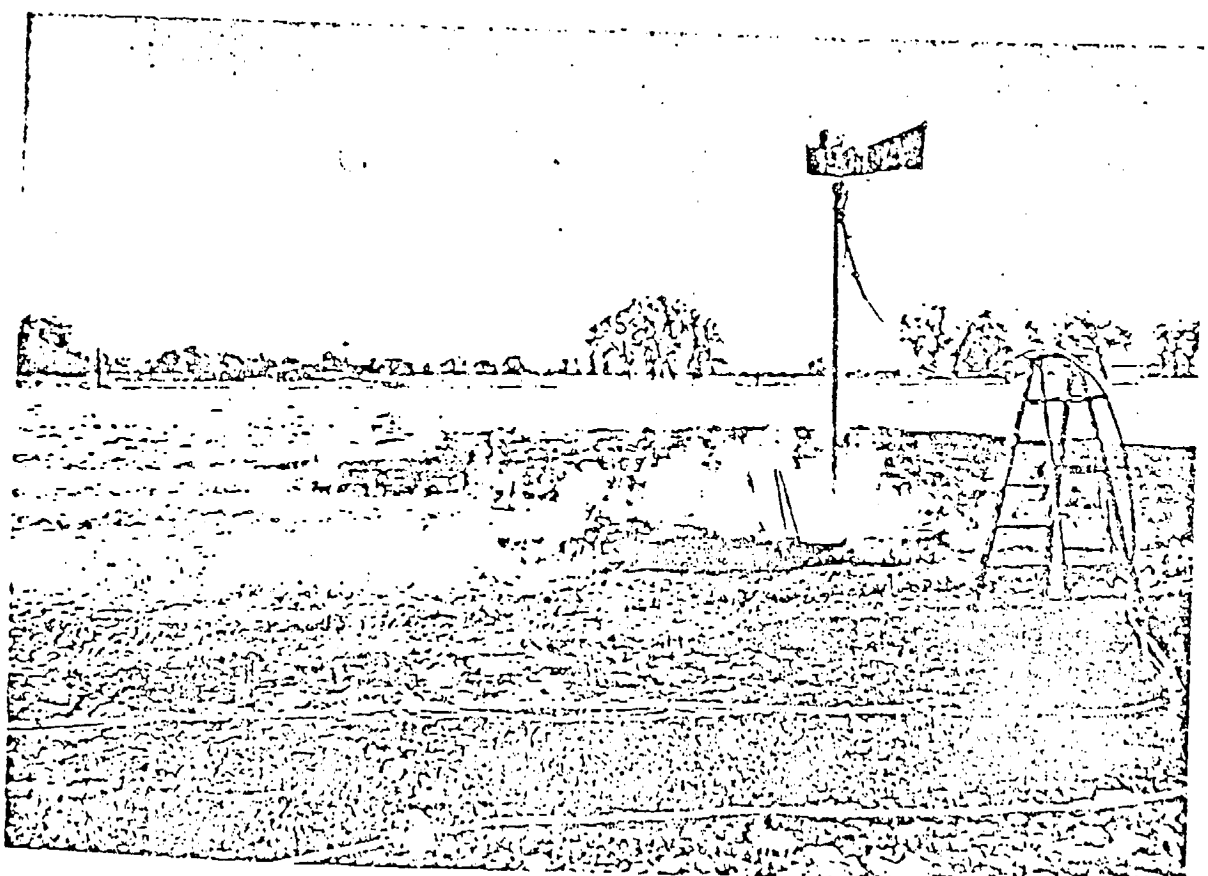


Figure 9. Photograph - Backfire Burn in Barley Straw

Table 4

Regression Analysis for Particulate Emissions

SAPRC Riverside Laboratory Rice Straw Data

	Independent Variable Selected	Coefficent Metric	% of Variability Explained
Headfire	residue moisture content	.87 (1.74)	61
	Straw loading [constant .51 (1.02)]	-3.66 (-35.6)	7
	multiple r = .826		
Backfire	[residue moisture content]^2	.013 (.026)	55
	[constant 1.54 (3.08)]		
	multiple r = .738		

The headfire data were significantly different from the backfire data at the 5% level.

Riverside and field 2.7 Kg rice straw particulate emission data were statistically compared to determine the correlation between laboratory and field tests. Field and Riverside data were segregated according to moisture content and type of burn and then the difference between laboratory and field particulate emission data was calculated at each moisture level and for each type of burn. The following table was calculated using a significance level of 5% and 2.5 Kg/MT (5 lbs/ton) was selected as the minimum detectable difference between means.

Table 5

Comparison of Riverside and Field Rice Straw Data

Particulate Emissions

	average of differences	std. deviation of differences	d	probability of accepting false hypothesis
Headfire	1.52	7.85	.64	7%
Backfire	-.04	4.40	1.1	2%

Table 5 indicates that there is only a 7% chance of erroneously concluding that the Riverside headfire data is the same as the field headfire data. Similarly, there is only a 2% chance of erroneously concluding that the Riverside backfire data is the same as the field data. Thus it is reasonable to conclude that the Riverside laboratory rice straw trials accurately simulated field rice straw trials.

The Riverside data confirmed the effects of direction of burn and residue moisture content (see figure 10). A reduction in residue moisture content from 25% (wet basis) to 10% can reduce particulate emissions from 18 Kg/MT(36 lb/ton) to 5 Kg/MT (10 lb/ton) in headfires. Backfire burning additionally reduces particulate production nearly 50% over headfire burning at moisture levels between 10% and 25%. Increased straw loadings tended to reduce emissions in headfires but not in backfires.

The SAPRC Riverside Tower trials also provided data on gaseous hydrocarbon and carbon monoxide emissions from rice straw burning. The same statistical analyses used on the particulate emission data was used on carbon monoxide and hydrocarbon data. Tables 6 and 8 show the results of the correlation analysis. Tables 7 and 9 show the results of the regression analysis. No significant statistical difference could be detected between headfires and backfires for these emissions, therefore the tables show correlation and regression results for data from headfires and backfires combined.

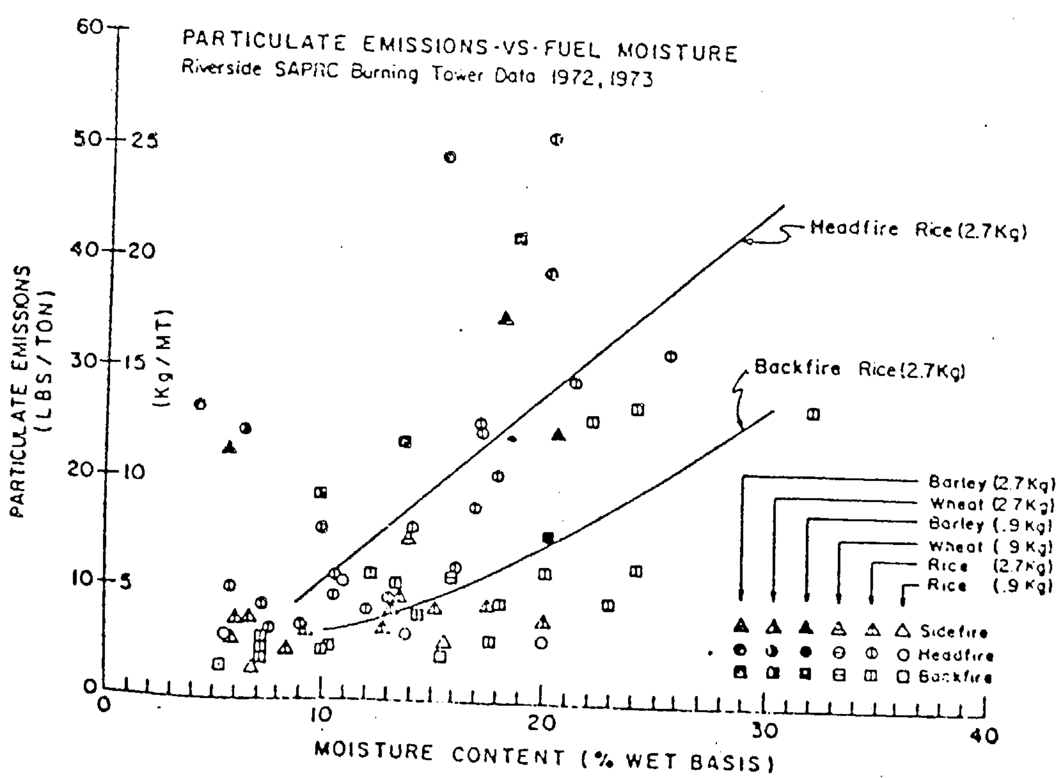


Figure 10. Particulate Emissions vs. Moisture (Laboratory Data)

Table 6

Correlation Analysis

SAPRC Riverside Laboratory Rice Straw Data

Independent Variables	vs. Gaseous Hydrocarbon Emissions
residue moisture	.822
$(\text{residue moisture})^2$	.794
$(\text{residue moistura})^3$	.729
residue loading	-.343
log (relative humidity)	.249
relative humidity	.230
air temperature	-.230
absolute humidity	.198
$(\text{absolute humidity})^2$	.191
wind speed held constant in trials	

No significant correlations between independent variables.

Table 7

Regression Analysis

SAPRC Riverside Laboratory Rice Straw Data

Gaseous Hydrocarbon Emissions

Independent Variable Selected	Coefficient (Metric)	% of Variability Explained
Moisture	.79 (.40)	68
$[\text{Absolute Humidity}]^2$	.00086 (.00043)	8
Residue Loading	-18.8 (-.397)	6

[constant = -2.57 (-1.29)]

multiple r = .904

Table 8

Correlation Analysis

SAPRC Riverside Laboratory Rice Straw Data

Independent Variables	vs.	CO Emission
residue moisture		.796
(residue moisture)^2		.777
(residue moisture)^3		.728
(absolute humidity)^2		-.233
absolute humidity		-.213
air temperature		-.196
log (humidity)		.116
residue loading		-.092
relative humidity		.062
wind speed		held constant in trials

No significant correlations between independent variables.

Table 9

Regression Analysis

SAPRC Riverside Laboratory Rice Straw Data

Carbon Monoxide Emissions

Independent Variable Selected	Coefficient (Metric)	% of Variability Explained
Moisture	6.09 (3.05)	64

[constant = 29.2 (14.6)]

multiple r = .809

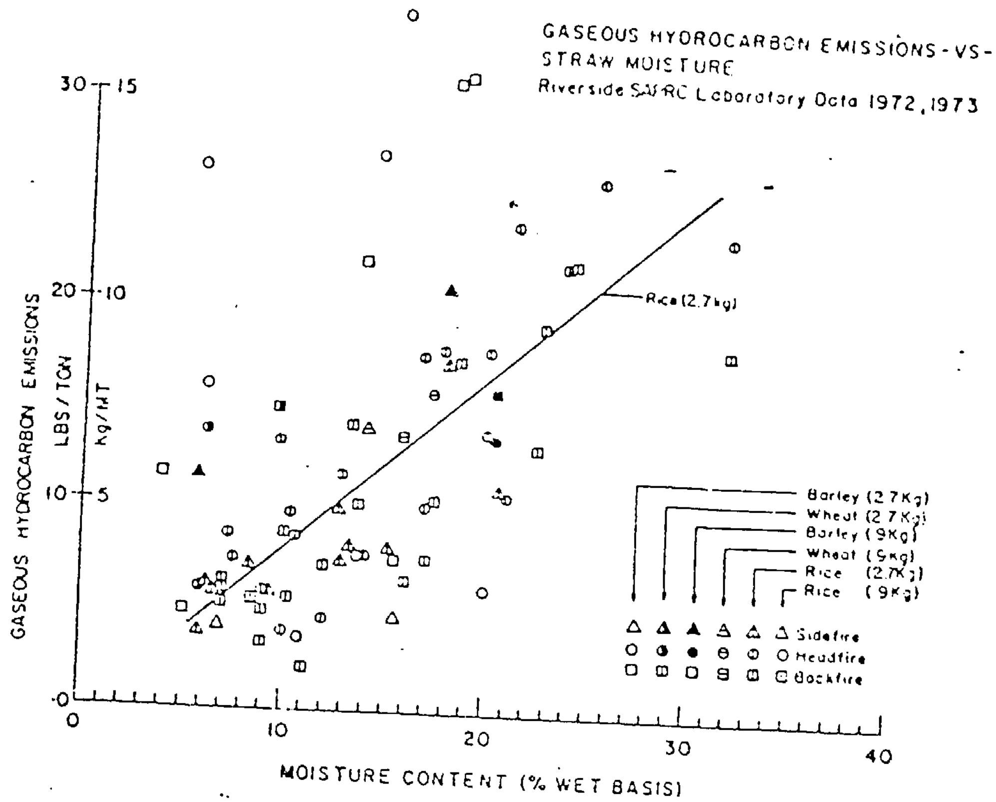


Figure 11. Gaseous Hydrocarbon Emissions vs. Moisture (Laboratory Data)

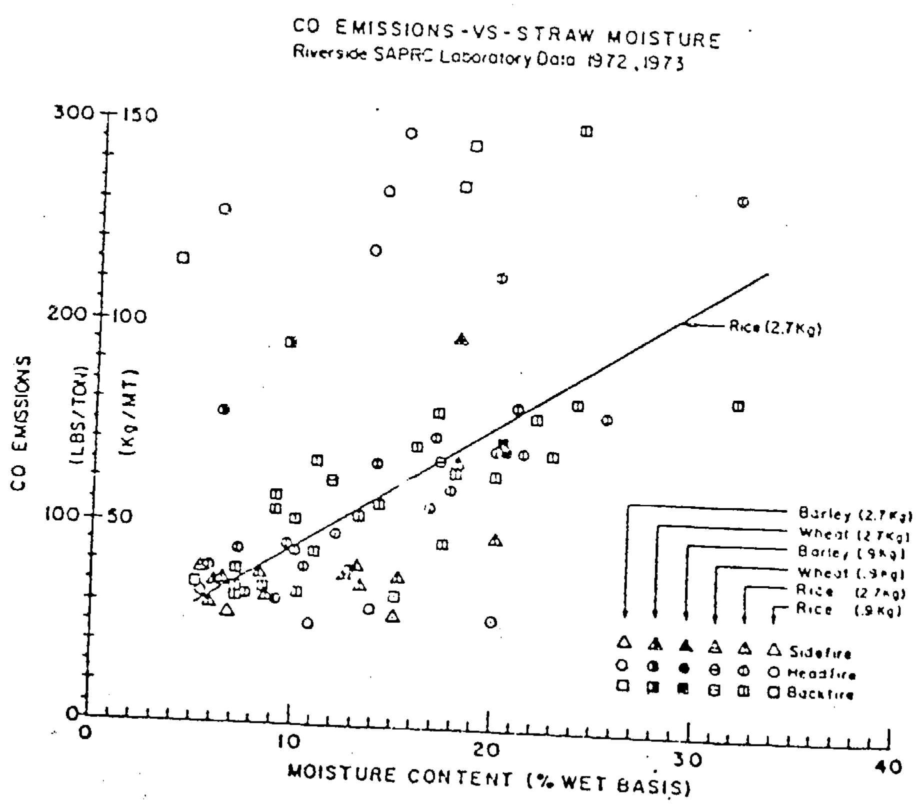


Figure 12. Carbon Monoxide Emissions vs. Moisture (Laboratory Data)

Air flows on the .9 Kg (2 lb) burns were determined to be within the range of calibration of air flow instrumentation of the tower. This would indicate that the tower is capable of accurately measuring emission levels of this low fuel quantity. However, we are still not completely sure of why there were typically lower readings on .9 Kg burns. Possible explanations may be as follows:

1. .9 Kg trials were more susceptiable to significant air drying between moisture sampling and ignition than 2.7 Kg burns because of the greater exposure to convection and radiation drying to the thin .9 Kg layer. This is because of the greater surface area of exposure per unit of weight of straw in these trials.
2. It is possible that 2.7 Kg barley and wheat straw are more compacted than .9 Kg. Compaction has been shown to increase particulate emissions in forest fuels.[16]
3. Light fuel loadings. .9 Kg requires a lower rate of oxygen supply which should produce more complete combustion, hence lower emissions.

Barley and wheat straw fires have shown higher emissions at the SAPRC burning tower than rice straw at both residue loading. A corresponding relationship does not show up in field data. The reason for this difference is not apparent at this point. A possible reason may be differences in the chemical constituents of the fuels burned at SAPRC from the L.A. area compared to field conditions in the Sacramento Valley. Chemical analyses of the fuels were not made or anticipated to be needed for this purpose at the time of the burns. Another possible difference might be in physical characteristics of barley and wheat straw which were baled for handling and storage at SAPRC until the burns could be conducted. While rice straw was baled similarly, it does not generally break up as much as barley and wheat straw when taken from the bale in preparation for hydration or burning. The slick character of barley and wheat straw compared to rice straw produces a potential for more compaction of the material on the burning tray. Compaction again may have added to the emission levels.

Another factor that may be a consideration is that in field burning a composite moisture content was used based on a weighted average of the individual moisture contents of straw and stubble. In some cases there is a substantial difference in moisture content between straw that has been severed and stubble that is still rooted in the soil. At the SAPRC burning tower only straw materials were used and it was hydrated uniformly to one moisture content. This would not account for the high emission levels of low moisture straw since it was not hydrated at all.

At this point nothing definite can be said about these unexplained differences in the level of results, and additional trials will be required to determine the causes, and to make appropriate burning procedure recommendations. These trials should be designed to evaluate the possible explanations suggested.

Greater residue moisture tends to increase particulate production for two reasons. The water vapor coming out of the residue tends to smother the fire. For higher moisture contents, especially associated with wet pockets of straw, the vapor pressure of the water may almost equal the atmospheric pressure.[5] Under this extreme condition oxygen is nearly excluded from the area near the fire. With insufficient oxygen the residue will not flame but will only smolder. Increased moisture in the residue also requires a greater heat energy flux to dry the residue enough to burn. As the moisture increases more of the residue will not be dry enough to burn while the flame is nearby. However, there will still be enough residual heat to cause smoldering of the incompletely burned residue.

The effectiveness of a backfire in reducing particulate emissions can be inferred from the nature of the fire. A backfire burn is characterized by a low flame which progresses across the field at a slow rate. The slow rate of burn results in a longer local flame residence time as the flame front advances into unburned residue. Thermocouple recordings of a backfire flame front show that a typical backfire maintains a high temperature two to three times longer than a headfire and that the peak temperature in a backfire is usually slightly higher than a headfire peak temperature (see figure 13). The longer residence time and the higher flame temperature in a backfire exposes the unburned fuel adjacent to the flame front to greater heating and drying as the front progresses toward this fuel. As a result of this, more fuel burns without smoldering. The higher peak temperature in a backfire is probably due to the greater oxygen supply and drier fuel in the slow speed front moving against the wind. The relative velocity of the wind (oxygen supply) to the flame front on a backfire is the sum of the wind velocity plus the rate of flame spread. The relative velocity of the wind (oxygen supply) to the flame front on a headfire is the difference between the wind velocity and the rate of flame spread. A backfire also has the property of consuming substantial quantities of the combustibles contained in the white smoke associated with smoldering combustion. The slow rate of flame spread in a backfire causes most of the distilled volatile organic compounds and gaseous hydrocarbons to be released upwind from the flame. These are then carried by the wind into the flame area of the fire and largely consumed. The flame area of a headfire passes quickly over the surface of the residue heating unburned or partially burned material enough to drive off volatile compounds and gases. With a wind of 4 miles per hour or more the flame of a headfire does not remain in contact with the ignited fuel and volatiles long enough to consume as much of these combustibles. As the unburned volatiles leave the heat source (flaming and smoldering combustion areas), they are cooled and some condense forming thick white or brown smoke behind the flame front.

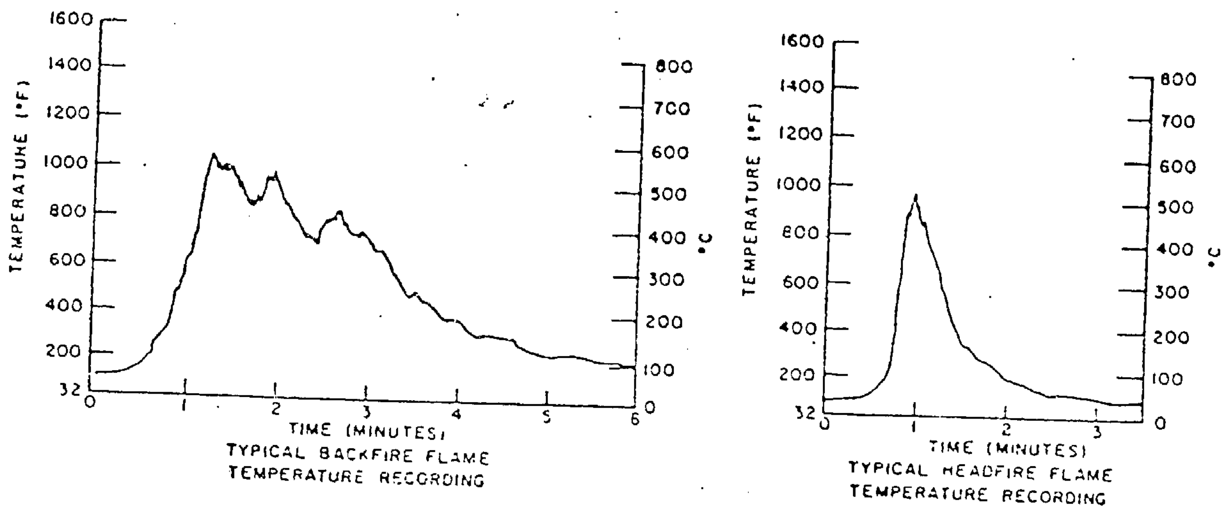


Figure 13. Typical Flame Temperature Recordings

Particulate Characteristics:

Extensive particulate size distribution measurements were performed at the SAPRC burning tower. The particle size distribution of smoke particles was determined with the aid of various cascade impactors and microscopes. The impactors were the Brink, Lundgren, and High Volume (Weathermeasure Corp.). The following table compares data on particle size distribution in smoke from the burning of citrus leaves and twigs using the Brink 5-stage impactor. The conditions under which the samples were obtained are indicated by the words "pre" and "post". The term "pre" means sampling of undisturbed smoke at a location slightly above the second filter holder without any filter being placed in the first filter holder whereas "post" indicates sampling at the same location but with a filter in the first holder. Consequently, the collected particles under the "post" conditions are the uncondensed gases which traveled through the first filter.

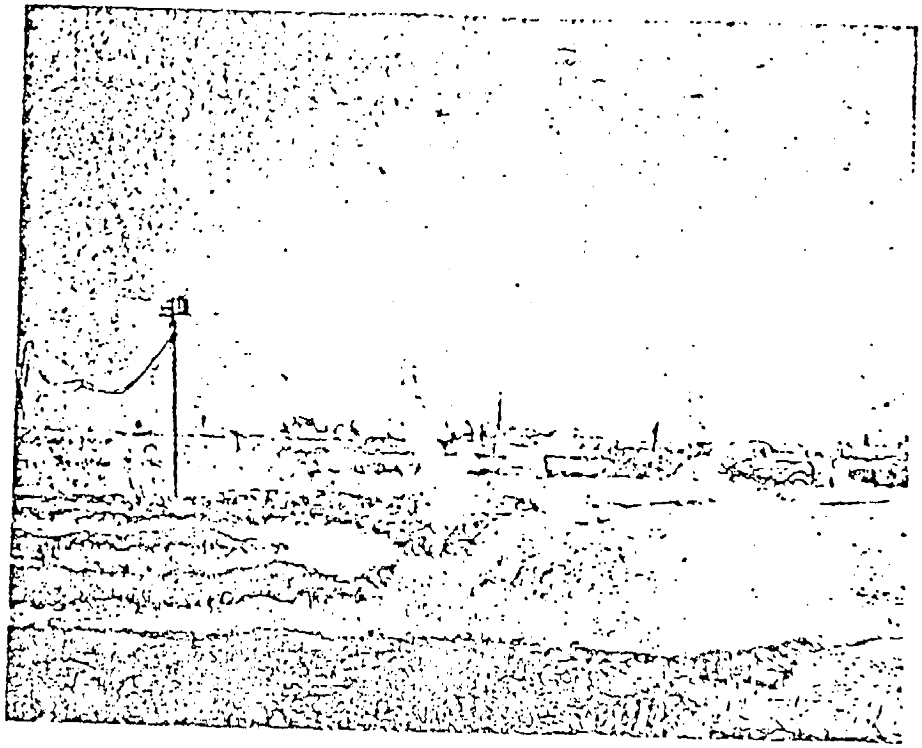


Figure 14. Photograph of Spring Backfire Burn

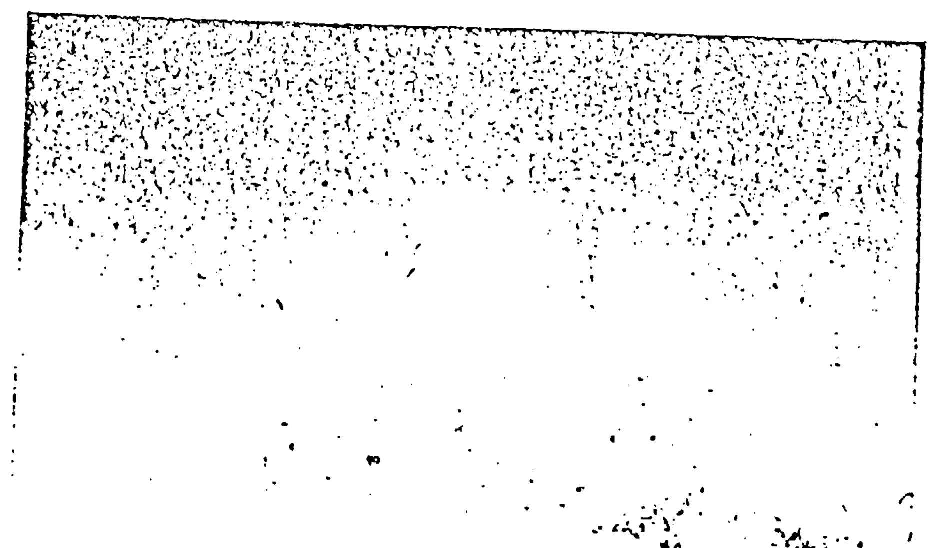


Figure 15. Photograph of Spring Headfire Burn

Table 10

Particle Size Distribution in the Smoke of Citrus Leaves and Twigs Expressed on a Weight Percent Basis, Using a Brink Model B, Five-Stage Impactor

Stage	Particle Size μ	Weight Percent Distribution Pre	Post
1	<2.5	0.19	0
2	1.5 - 2.5	0.97	0
3	1.0 - 1.5	5.53	0
4	0.5 - 1.0	18.04	9.12
5	.25 - 0.5	22.90	13.05
Filter	<.25	52.38	77.82

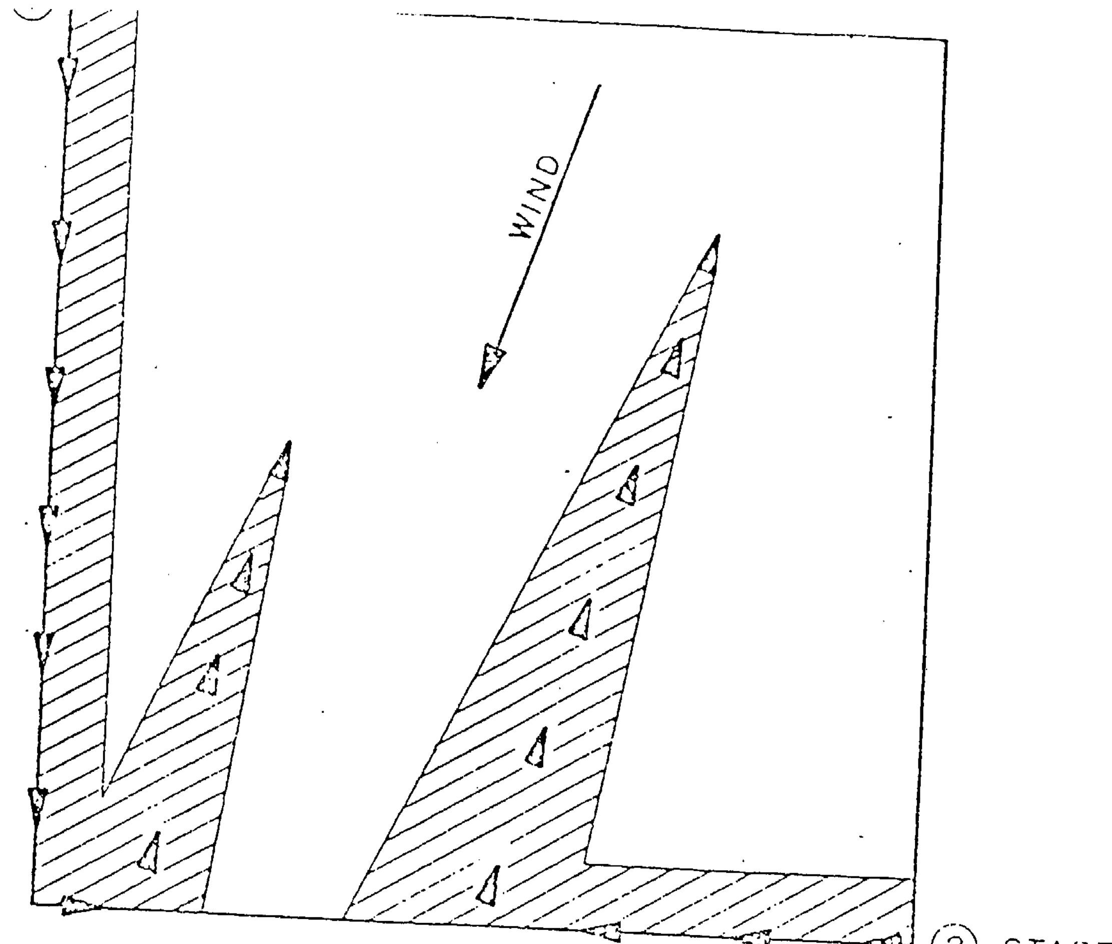
In this fuel the proportions of particles below the .25 micron range is higher under the "post" conditions. The majority of the particles fall in the range below 0.5 micron.

A series of 27 cereal straw fires were sampled for particulate size distribution with the hi-vol cascade impactor. (See appendix D for complete data). Assuming a log normal particle size distribution the average mass median diameter for the 27 fires was .17μ. This compares quite well with the mass median diameters obtained in the spring rice field trials. See figures 16, 17, and 18. The Riverside Trials revealed that there was a tendency for fires with higher particulate emissions to have larger mass median diameters than fires with lower particulate emissions. This is undoubtedly due to the fact that most of the particles formed in open field burning are formed by condensation. The denser smoke associated with fires that have higher particulate emission levels allow particles to grow through condensation and agglomeration to a larger size. The average mass median diameter for the soluble particulates was .23μ and the mass median diameter for the insoluble particulates was .16μ. The small size of the insoluble particulates indicates that these particles were also formed by condensation and not cominution and are perhaps condensed carbon. This would also imply that only a small amount of fly ash is being collected at the sampler and it is not a significant portion of the particulate matter that travels any distance. This observation is valid only for single line headfires and backfires. Peripherally lighted fields can cause large fire whirls which will :rain large amounts of ash charred plant material and elevate them hundreds of feet in the air.

The fact that all mass median diameters are small shows that very few of the particulates will fall out of the plume. Figure 19 indicates that particles less than 10μ in size cannot be expected to fall more than 210 meters per day (700 feet per day). Except on windy days open field burn plumes will rise at least 210 meters. The size distribution indicates that only 1-2% of the particles are larger than 10μ. Thus, most of the particles have the potential to remain in the atmosphere for an extended period of time unless removed by one of the other removal processes such as precipitation, or coagulation and subsequent gravitational settling.

Although most of the particulates have the potential to remain in the atmosphere for extended periods of time, not all are going to affect visibility. Visibility degradation is associated primarily with particles larger than .4μ. 70% of the particulates in open field burning emissions are smaller than .4μ. This means that only 30% of the total mass of particulates will contribute significantly to visibility degradation.

The preceding statement demonstrates that merely measuring the quantity of particulate emissions without considering their nature can lead to an incorrect evaluation of the magnitude of their effect. A further example of this can be seen in the chloroform extraction data. It showed that about half the particulate production is soluble in chloroform. It is probable that a substantial portion of the soluble particles are organic liquids which can be expected to evaporate at atmospheric temperatures. It has been shown that organic compounds with vapor pressures as low as 10^{-5} Torr(mm of Hg) can evaporate quite rapidly when they are in an aerosol form with a large surface to volume ratio[8]. Aircraft sampling of particulates by Carrol[7] confirms the fact that some of the particulates evaporate. Carrol's data leads to the conclusion that within a few hours enough evaporation has taken place to significantly decrease the size of many of the particles. Thus, within a few hours the chloroform soluble particulate fraction (approximately one-half of total mass) may be small enough to have significantly different physical characteristics than they had when initially emitted from the fire. The data in this report can reveal only glimpses of the picture of the fate of open field burning particulates. More work needs to be done to discover the processes that effect the particulates in the atmosphere.



LIGHTING PATTERN FOR INTO-THE-WIND-STRIPLIGHT
(TWO MEN LIGHTING FIELD)

Figure 30.

Some field sampling of particulate emissions from open field burning of asparagus burning was done with a portable air sampler in 1972. The sampler was only able to take µg/m³ measurements. Headfires and backfires were sampled in areas where operators were able to withstand the heat. This typically resulted in monitoring fires with relative low flame intensity. A comparison of low intensity headfire and backfire burns at similar moisture contents is summarized in Table 11. These data show that the particulate emissions for a low intensity headfire produces a plume that has approximately the same µg/m³ as a backfire burn. In barley and rice straw field burns, the relationship showed headfires to be about 2 to 3 times greater in particulate density than backfires. These had been taken generally in the center of the fire front as it progressed across the field. It would appear from this that a substantially different combustion condition was taking place at the points sampled in asparagus with the portable sampler. Results are therefore not necessarily considered to be representative of the main fire front in these tests.

Table 11
Particulate Levels and Percent Chloroform Extractables
for Head and Backfire Burns - Rotary Mowed Asparagus Fern

Backfire	Particulate Level ug/m³ x 10³ (1)	% Chloroform Extractables	Headfire	Particulate Level ug/m³ x 10³ (1)	% Chloroform Extractables
11/29 #4	185	25	Flaming Portion		
11/30 #1	83	25	11/29 #2	190	36
11/30 #2	125	25	11/30 #3	211	32
			11/30 #7	450	13
11/30 #5	373	10	average	289	27
11/30 #6	466	18	Smoldering Portion		
			11/29/#3	182	87
			11/30 #4	244	49
			11/30 #8	265	61
			average	231	66
Backfire Average:	246	21	Headfire Average:	260	44

1. Values corrected for dilution and temperature.

Two series of asparagus burns with different fuel management techniques were observed in the South Desert area in 1973. The fern was knocked over with a tool bar, mounted on a tractor, or mowed with a rotary brush mower. Headfires in the asparagus that had only been knocked over produced very dense plumes. Even backfire burns appeared to have high particulate emissions. However, when the ferns were cut with a rotary mower, the backfire burns produced only a faint plume. It may be that backfires in asparagus fern that has been only knocked over burns poorly because of lack of oxygen. The SAPRC tower data noted below show that asparagus fern burns have high carbon monoxide levels which indicate a lack of oxygen. The backfires in the knocked down asparagus produce large flames indicative of a fire requiring large amounts of oxygen. The backfires in the rotary mowed fern produce only small flames which require less oxygen at any given time.

At the request of staff of the Regional Anti-Pollution Authority of the Coachella Valley and the Agricultural Extension Service of Riverside County, a few fires were conducted at the SAPRC Riverside Laboratory using asparagus fern collected in the Indio area in December, 1972. Most of the fern was burned immediately in order to determine emissions at the fuel moisture level at which the fern was currently being burned. Sufficient material for two fires was held for 4 months to allow the fern to come to air dry conditions.

All of the fern from field plots of 2.3 m^2 (25 ft^2) were included in each fire and held in a standing position within 1.5 m x 1.5 m (5 ft x 5 ft) rack on the burning table. In the December fires, the weights of each fuel loading ranged from 8.6 kg - 11 kg (19 to 22 lbs) for the April fires the fuel weighed about 6.4 kg (14 lbs) due to loss of moisture. Fuel moisture of the fern and stem and the emissions of particulates, carbon monoxide, and hydrocarbons are given in Table 12.

Table 12
Emissions from Burning Asparagus Fern
in SAPRC Burning Tower

Fuel Moisture Wet Basis			Emissions, Kg/MT (lbs per ton) of Fuel Weight Loss		
Fern	Stem		Part.	CO	HC
		December Fires			
18	46		18 (35)	52 (103)	33 (66)
33	61		16 (32)	54 (107)	24 (48)
29	50		27 (53)	136 (171)	44 (87)
18	63		---1/	111 (221)	31 (61)
		April Fires			
12	12		14 (27)	83 (165)	4.7 (9.3)
9	10		14 (28)	73 (145)	3.6 (7.1)

1/ Particulate sampler inoperative.

Light microscope photomicrographs of particles collected on the second stage of the Brink in the pre- and post-filter samples of the citrus fires are shown in figures 20 and 21. The large dark clusters of particles in the pre-filter sample probably represent the soot component in the smoke. These clusters appear to be an agglomeration of smaller particles and to have a spongy structure. Most of the single particles are transparent, yellowish brown in color and may be the tar fraction. There are a few greyish angular particles of various sizes which may represent ash. In the post-filter sample, the large clusters are missing, having been removed by the filter in the first holder. Most of the particles are of the transparent, yellowish-brown tar fraction which passed the first filter and condensed as liquid aerosols.

Scanning electron microscope (SEM) photomicrographs of two collection stages of the pre-filter sample are shown in figures 22 and 23. The same aluminum disc from stage 2 of the impactor as shown in figures 20 and 21 was used in making the upper photograph. The large clusters appear more clearly to consist of spongy substance unlike the individual rounded and angular small particles. A comparison of the light and SEM micrographs also indicates that there is no significant alteration in the morphology of particles from the vacuum imposed in the SEM column. The micrograph in figure 23 shows particles collected on the nuclepore membrane filter which followed the last state of the impactor. These are all below 0.4 μm and represent 52 mass percent of the particles collected. Many particles are in the 0.1 μm range and appear to agglomerate somewhat.

Many of the high volume filter samples were extracted with chloroform. (Benzene was also tested as a solvent but typically dissolved less material). The chloroform extraction data from the SAPRC Tower burns showed that rice straw burns had about 60% extractable material in the hivol filter collection. Head-fires and backfire burns were similar and moisture content of the straw had little effect on the relative amount of chloroform soluble material. The second filter in the two filter system consistently had a slightly smaller amount of chloroform soluble particulates. This fact tends to reinforce the idea that the insoluble particulate emissions collected from open field burning are primarily condensed particles, not entrained charred plant material or fly ash.

The summer wheat and barley burns had a smaller quantity of chloroform soluble particulates. In the 1972 barley trials, headfires averaged 30% extractables and backfires averaged 19% extractables. The difference between the headfire and backfire burns is statistically significant and is perhaps an indication that backfire burns even at low moisture contents produce less particulate emissions than headfires.

The extract from the filters is a thick brown liquid which has led to the speculation that the soluble particles are liquid aerosols of organic compounds. These compounds are the major constituents of the thick white (or brownish-yellow) smoke often seen in open field burns. Work done by Darley et al[9] partially identified some of the hydrocarbon compounds. Darley indicated that rice and barley gaseous hydrocarbon emissions contained about 10% ethene, 15% olefins and 4% saturates and acetylenes. Work done by Tebbins et al indicates that the soluble particulates from the combustion of cellulosic fuels are a complex mixture of perhaps hundreds of organic species[4]. These particles are associated with the pungent odor of the smoke from some open field burning.

Residue Moisture Studies:

Some preliminary work has been done to determine the drying characteristics of agricultural residues. Report ARB 1-101-1[15] Spring Burns indicated that under good residue management techniques and clear weather rice straw can dry to an acceptably low moisture content for reduced emission burning in two to three days after a rain. (See figure 24.) Figure 25 shows similar results for rice residue following harvest in the fall. In the fall example the rowed straw dried almost as quickly as the spread straw. This rapid rate of drying for rowed straw occurred because the straw was placed on top of 33 cm (13 in.) tall standing stubble. If the rice had been cut close to the ground and the straw placed on top of the wet soil, as in the spring field conditions the rowed straw may have taken ten days or longer to dry. It is important to notice in figures 24 and 25 that each afternoon the moisture content begins to increase and that dew during the night can raise the moisture content above 35% (wet basis) moisture. This implies that even though the residue may have dried to an acceptably low moisture content on one day, it may not be dry enough to burn until 11 or 12 o'clock the following day. This same moisture pattern has been seen in barley and wheat residues in the summer. Even on summer nights with little or no dew the residue can absorb enough moisture because of increased relative humidity and may reach 15% moisture content. (See appendix C Equilibrium Moisture Relationship.) The residue will begin to dry as soon as the sun comes up at about 7 a.m. and may have dried to near 7% moisture by 9 a.m. However, the residue will be even drier at noon and produce less emissions than if it were

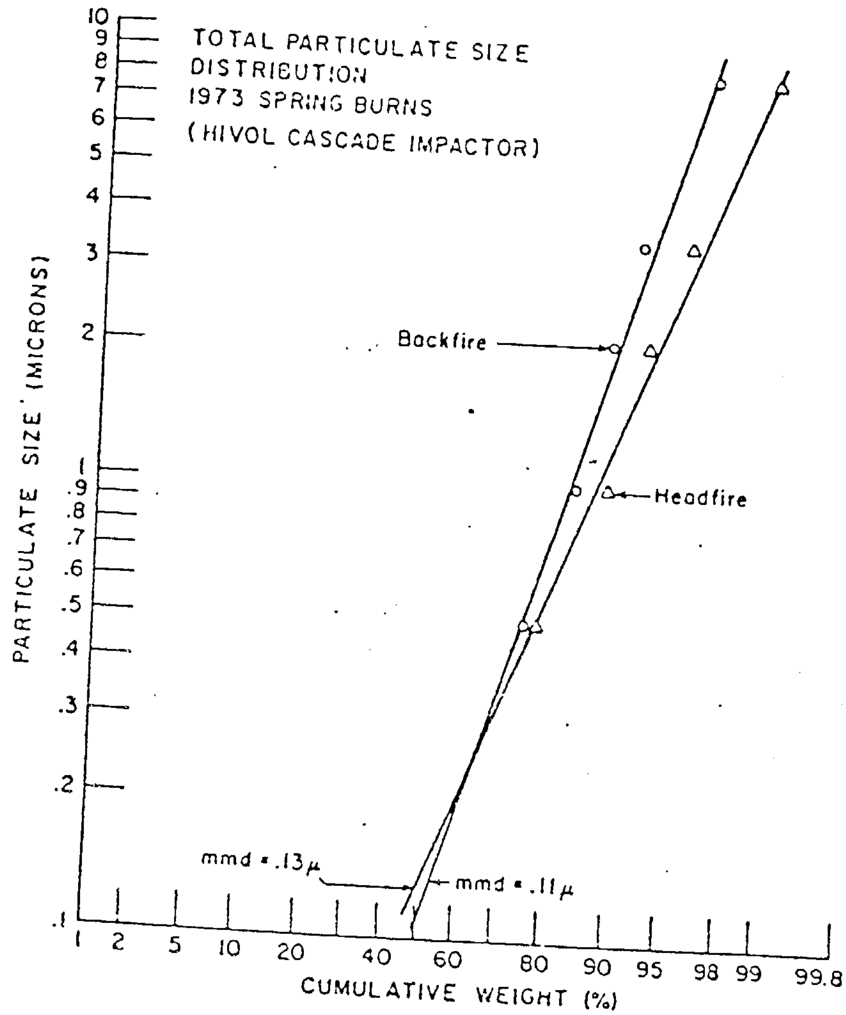


Figure 16. Particulate Size Distribution, Head and Backfires

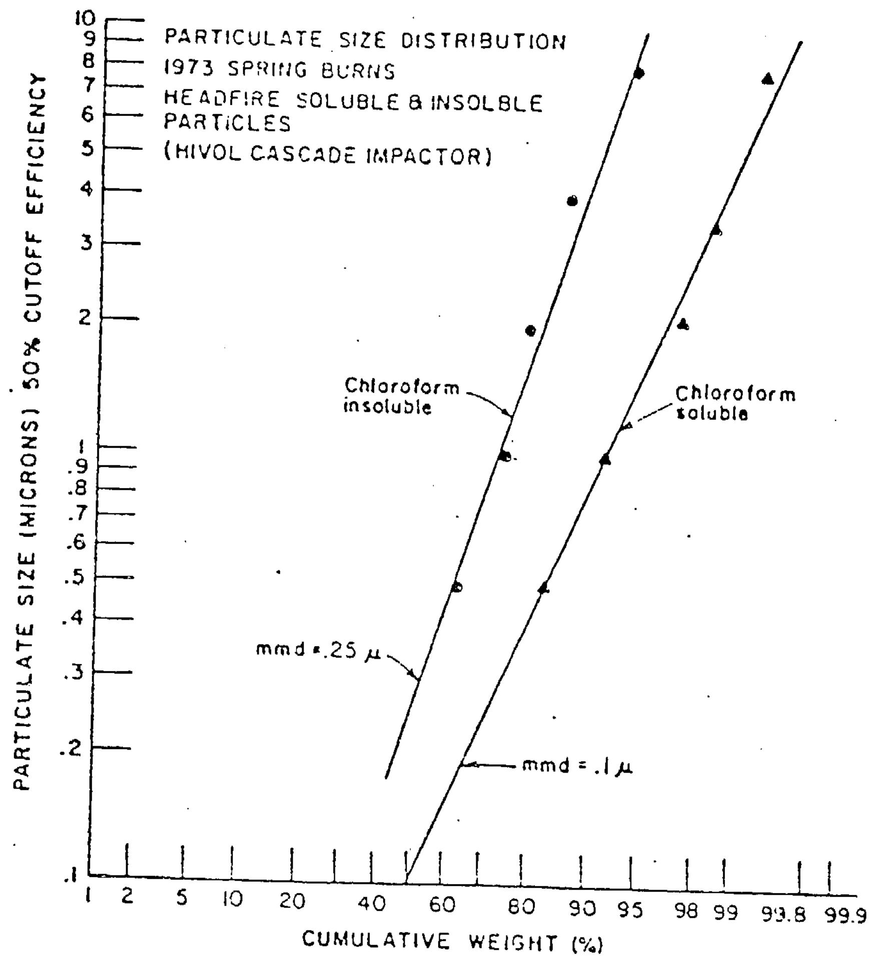


Figure 17. Particulate Size Distribution, Headfires

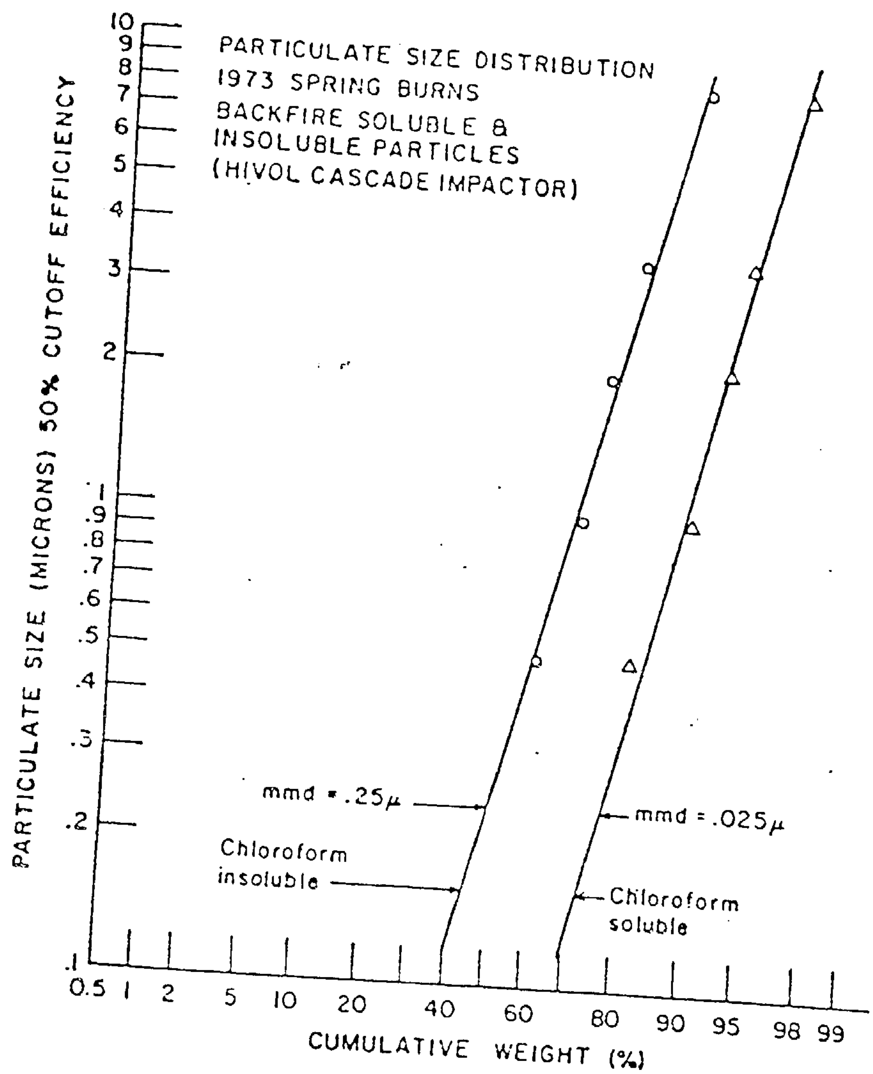


Figure 18. Particulate Size Distribution, Backfires

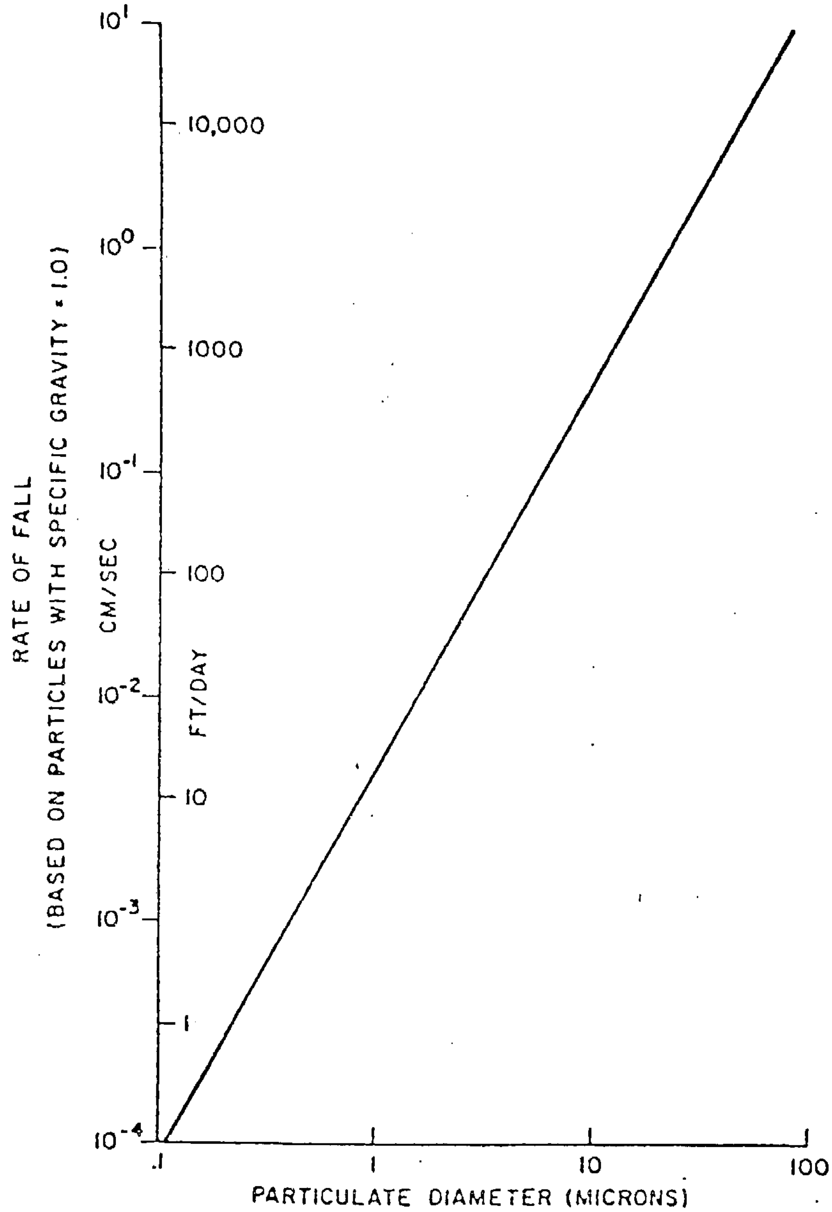


Figure 19. Rate of Particulate Fall vs. Size

Figure 20. Light microscope photomicrograph (400x) - particulates from citrus prunings, pre-filter sample - second stage of Brink impactor.

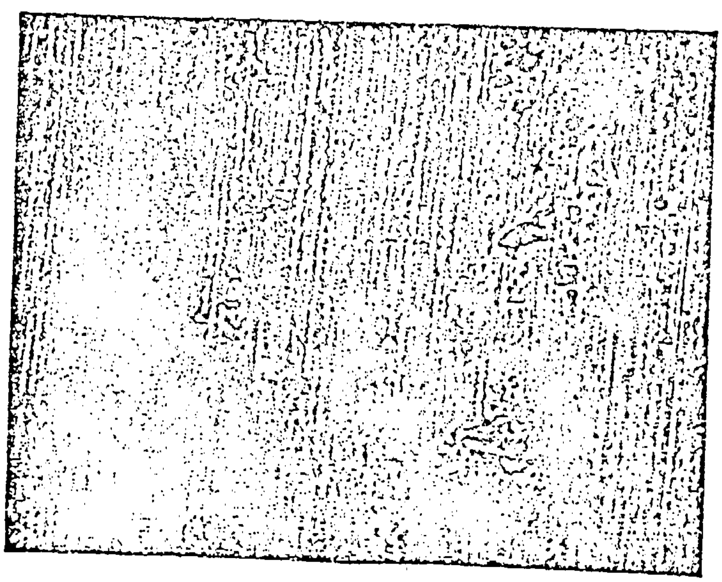


Figure 21. Light microscope photomicrograph (400x) - particulates from citrus prunings, post-filter sample - second stage of Brink impactor.

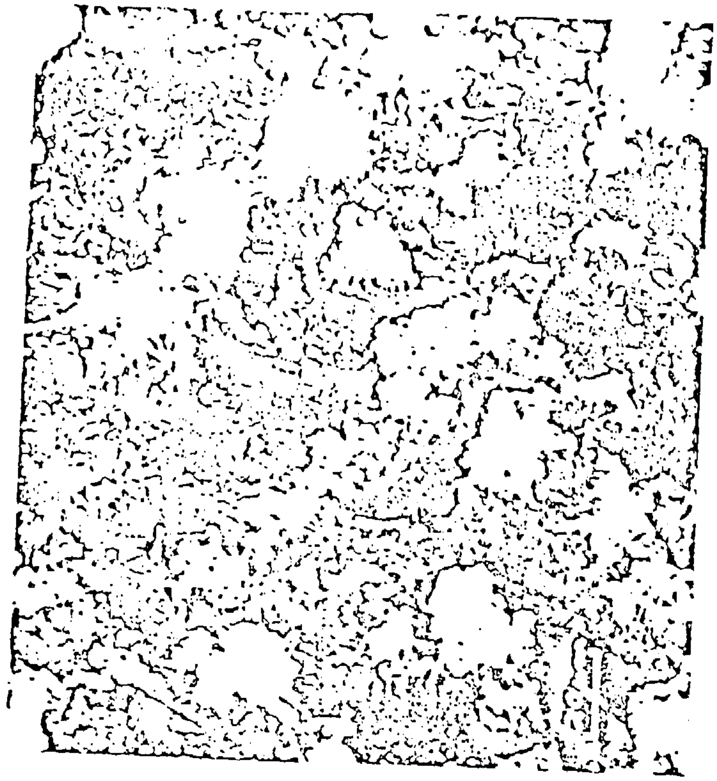


Figure 22. Scanning electron microscope photomicrograph (400x) particulates from citrus prunings, pre-filter sample, last stage of Brink impactor

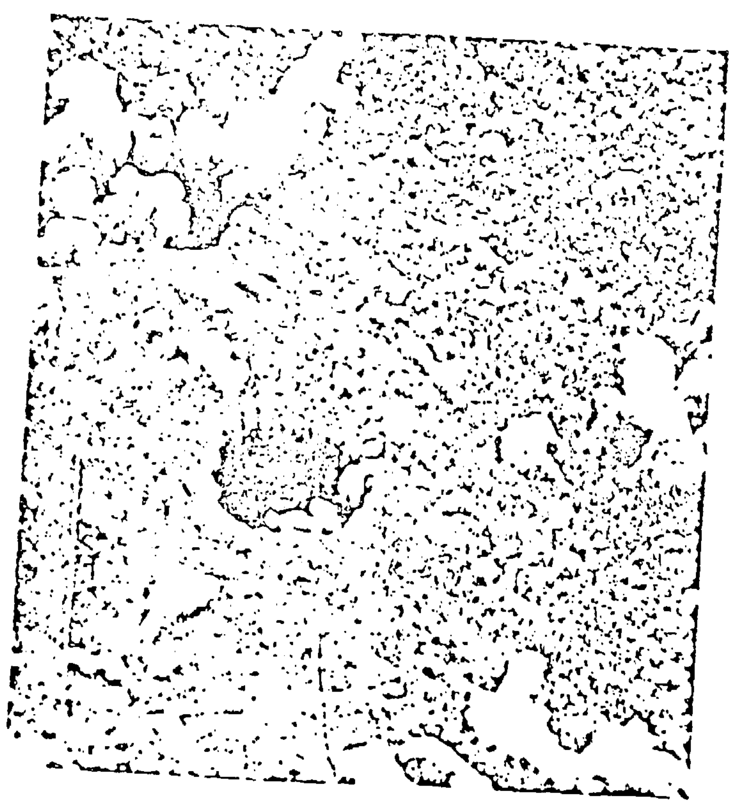


Figure 23. Scanning electron microscope photomicrograph (30,000x) particles collected from citrus prunings, nuclepore filter (0.4 μm pore size) following the last stage of the impactor.

burned at nine a.m. (see figure 26). It is important to note that moisture contents follow equilibrium moistures fairly closely for given relative humidities with spread straw. This phenomena does not exist with rowed straw necessarily. It has been determined that the straw does not follow equilibrium moisture because of the rapid response of straw to ambient relative humidity but responds rapidly because of the drying effect of solar radiation during the daytime and the humidifying effect of dew at night. Equalization of straw residues to ambient air relative humidities without solar radiation and dew is very slow even at substantial air velocities. It takes days instead of minutes to reach equilibrium. See figure 27 developed from laboratory studies at various air velocities under this project. Rowed straw is less effected by solar radiation and dew because of the thickness of the straw mat. Therefore rowed straw will not follow an equilibrium relationship as closely as spread straw.

Emission levels have been related to time of day, relative humidity levels and corresponding moisture content of residues in the field. ARB Report 1-101-1 Spring Burns related emissions calculated for two field conditions of rice straw on March 24, 1973. They are included for information purposes here. See figures 28 and 29.

Work was begun in the spring of 1974 at the University of California on developing a method to predict straw moisture content on the basis of atmospheric and residue conditions. The work shows promise and may well be able to aid in predicting when residue is dry enough to be burned or used in other ways.

Cost Analysis:

The difference in cost between headfires and backfires is due mainly to the length of time each method requires to burn an entire field. Rate of flame propagation was used to estimate total burn time. Backfires consistently progressed across the field at a rate of about 1 meter/min (3 ft/min). The rate of flame propagation for headfire burns was more dependent on wind speed, residue moisture and residue conditions, and type of residue. Propagation ranged from 7 to 21 m/min (29 to 70 ft/min). A rate of 15.3 m/min (50 ft/min) was an average for rice straw headfires under fall burning conditions and is representative of summer barley and wheat burns. A rate of 5 m/min (16 ft/min) is typical for rice straw under spring field conditions. Backfire burning would cost \$1.61/ha (\$.65/ac), headfire burning would cost \$.30-.48/ha(\$.12-.19/ac), and into-the-wind striplighting would cost \$.62/ha(\$.25/ac). (For complete cost analysis see appendix B). Raking the straw to facilitate drying would add approximately \$ .94/ha (\$2.00/acre) to both fire management techniques.

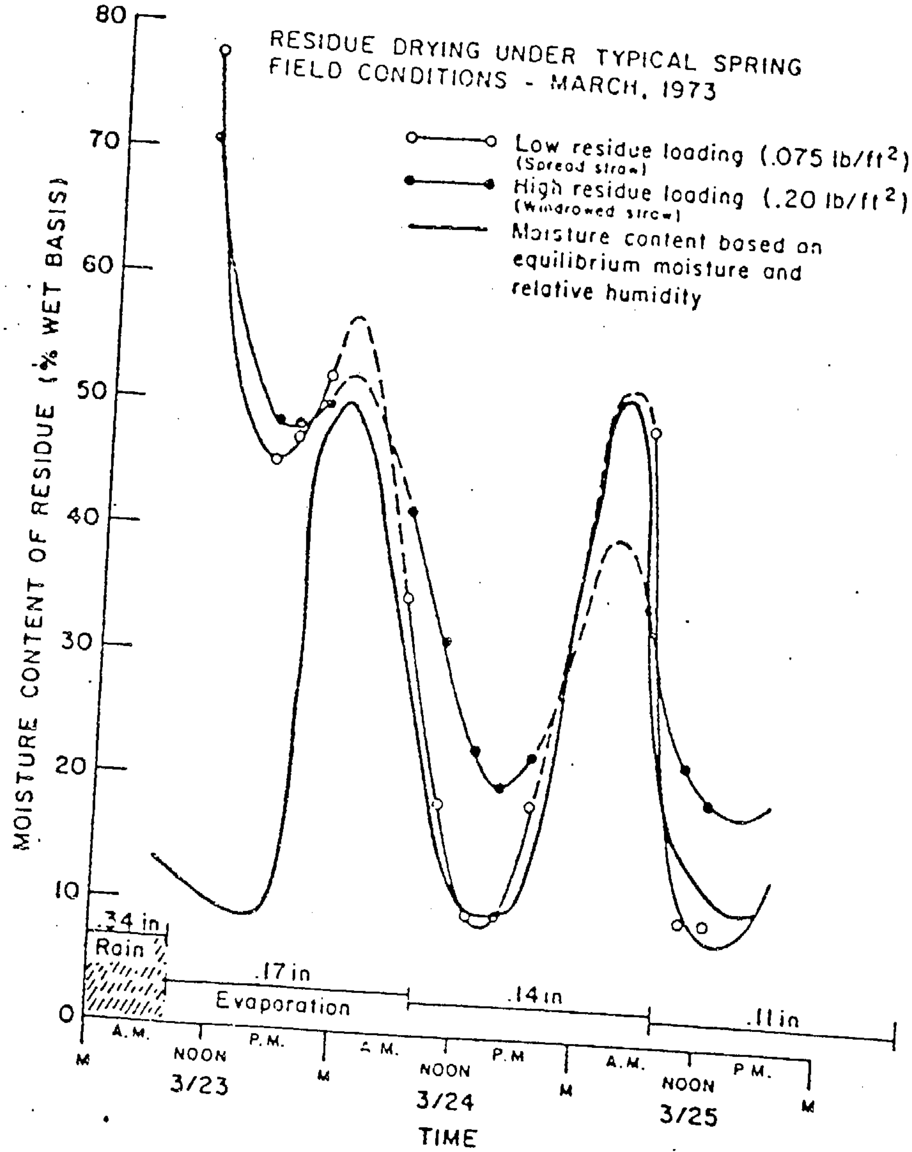


Figure 24. Rice Residue Drying on a Typical Spring Day

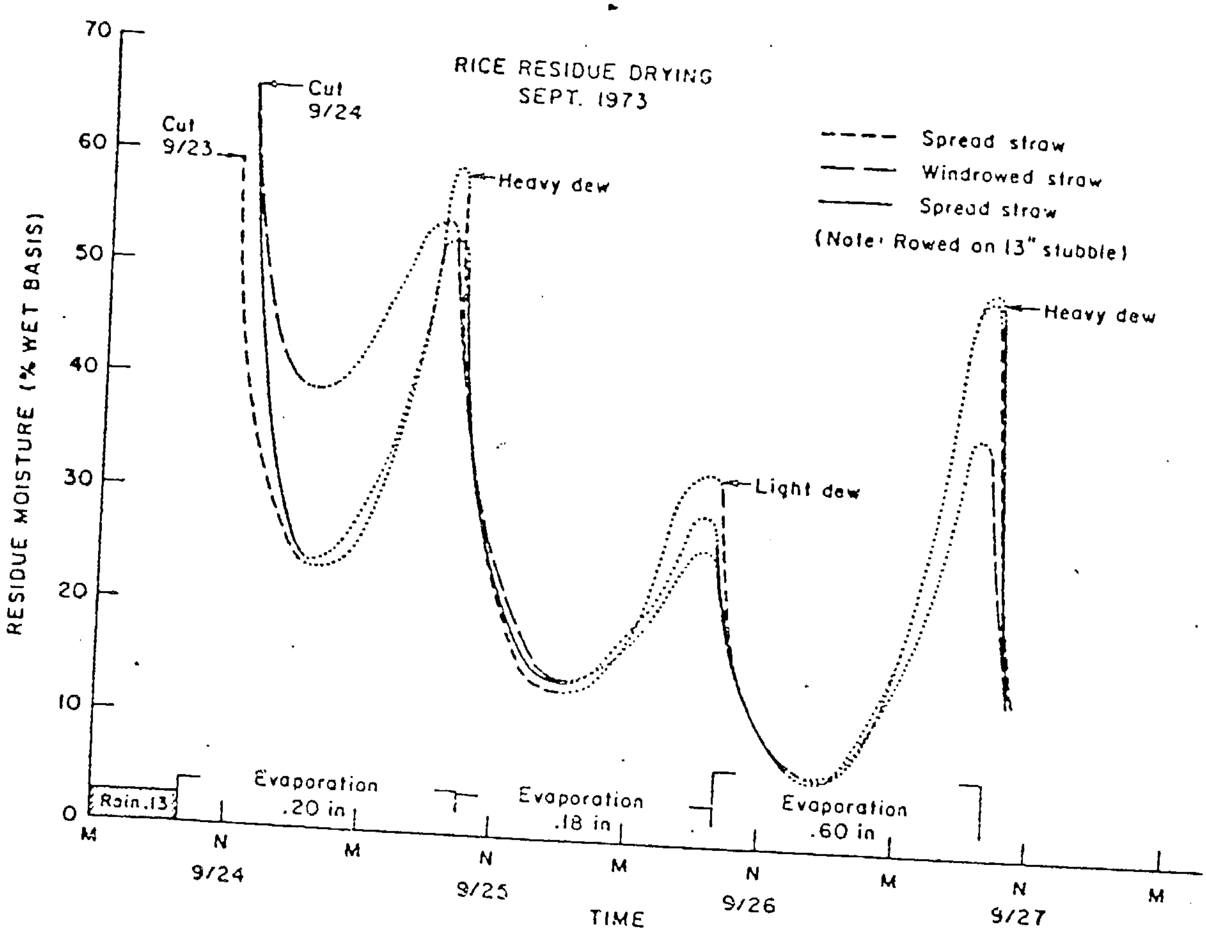


Figure 25. Rice Residue Drying on a Typical Fall Day

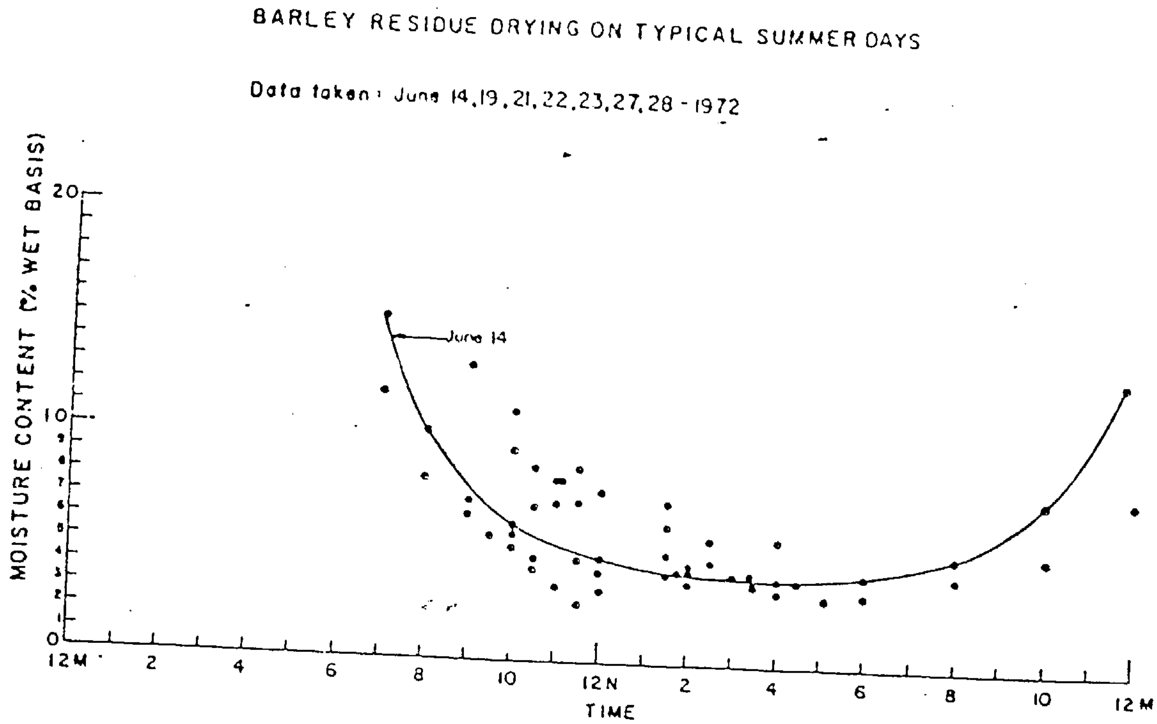


Figure 26. Barley Residue Drying on a Typical Summer Day

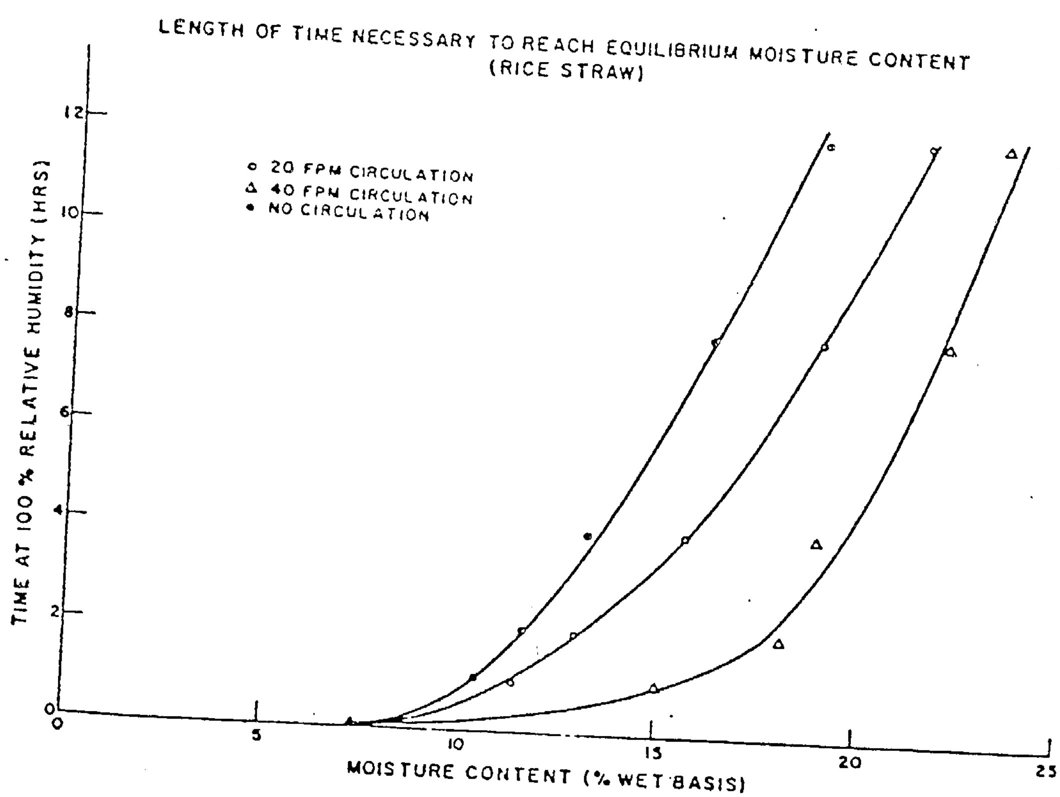


Figure 27. Air Flow vs. Time to Reach Equilibrium Moisture

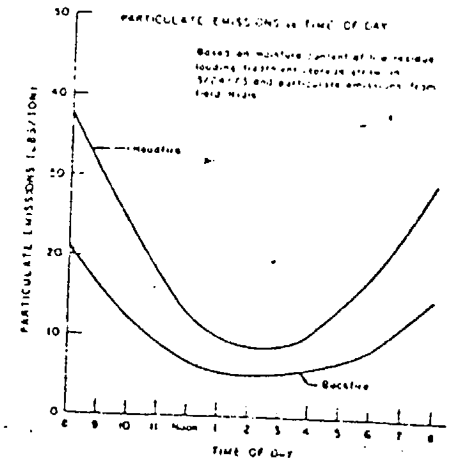


Figure 28. Particulate Emsisions vs. Time of Day (Spread Straw)

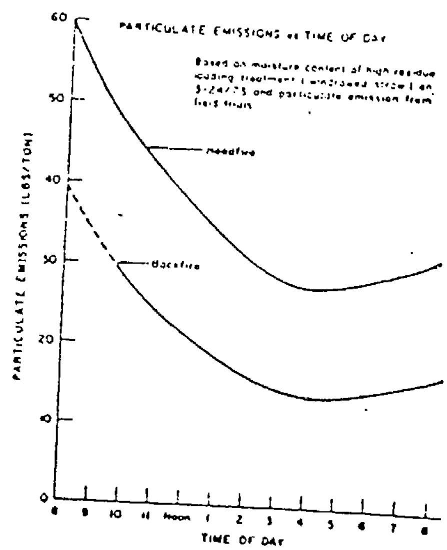


Figure 29. Particulate Emissions vs. Time of Day (Windrowed Straw)

FIELD BURN OBSERVATIONS AND EVALUATION OF MANAGEMENT TECHNIQUES

The evaluation of the practicality of the fire management techniques showed that backfiring cannot be used under as broad a range of conditions as headfires. The low intensity flame (in terms of cal/m^2/min, not temperature) of a backfire has poorer fire propagation potential than a headfire flame. For example, a backfire burn requires a higher fuel density to maintain a fire front than a headfire and headfires will continue to propagate under higher residue moisture conditions than backfires. The lower residue moisture content requirement should not effect the usefulness of backfiring. If a backfire will not stay lighted because of high residue moisture, the residue is too wet to burn and neither a backfire nor a headfire should be used. The field should be given more time to dry, or if straw is in windrows raked to shorten drying time, if urgency requires it.

The evaluation of the practicality of residue management techniques under favorable harvesting conditions showed that straw spreading is superior to leaving the straw in windrows. Straw spreading reduces emission production by enhancing the drying rate and generally providing for drier straw after solar radiation removes free water. Straw spreading places a continuous bed of fuel over the field providing good fire coverage and consequently better disease control. Straw left in rows behind the combine has no advantage over spread straw, from an emission standpoint. Rowed straw offers an advantage where it consolidates fuel and provides for fire spread where residue loading otherwise would be too light, preventing good fire spread. Raking straw rows can be of use in the spring rice burns to turn and fluff the straw. This causes faster drying and allows the residue to be burned sooner, but with substantial additional cost and poor overall field sanitation. There is no recognized value of raking barley or wheat straw.

Several methods for moisture determination suitable for field use have been investigated. A common test used in hay baling operations is the "crackle test". This test is performed by gathering a handful of straw and while holding the straw in both hands bending it sharply. If rice straw makes a crackling or popping noise, it has dried to less than 10-12% moisture content. If the straw makes a "shhush" sound, or no sound at all, it has not dried to 10-12% moisture content. Variability of moisture content in the field requires that several representative samples must be taken to determine if the field as a whole is sufficiently dry.

Laboratory studies of straw have shown that there is a relationship between relative humidity and straw moisture. Given enough time and drying energy, wet straw will dry to a moisture content determined by relative humidity. With little energy from the sun (i.e. cloudy conditions), straw may take days to reach equilibrium. It has been observed that spread rice straw will reach the equilibrium moisture at 10-12% after two or three clear days following a rain or harvest. Heavier straw loadings (straw left in windrows) may take longer. A method of determining that straw is dry enough to be burned with minimum emissions can be related to the above facts. If the straw has been exposed to one or two clear days of drying, it may well be dry enough to burn when the relative humidity is less than 50%. A good way to check this test, especially necessary in heavier straw loadings, is to sample the field to determine if moisture content is uniform. An indication that the moisture content is not represented by the relative humidity is when there are clumps of straw that are much damper than the general field condition. Note that if only 10% of the straw feels wet to the touch, a burn would produce twice as much particulate emissions than if no wet clumps could be found. Hand held wood moisture meters have also been used to determine the moisture content of the straw. They can be calibrated for straw, but have the inherent limitation of measuring the moisture of only a very few stems at one time. Higher moisture contents may require extensive sampling to get a representative level. As with the previous test, the moisture meter determination works best when the straw is uniform in moisture content.

In addition to head and backfiring during the summer of 1973, a fire management technique called "into-the-wind striplighting" was developed. This technique consists of backfiring the downwind side of the field and having several men spaced 100 m (300 ft) to 200 m (600 ft) apart, igniting the residue as they walk toward the windward side of the field directly into the wind. An observer in the air sees long adjacent wedges of flame front progressing across the field into the wind (see figure 30). This technique combines the slow movement of the fire front of the backfire with a greatly increased length of flame front. Optimally, this will combine the low particulate emissions of a backfire with the speed of headfire burns. Field particulate emission tests are difficult to perform with this technique but limited laboratory simulations on barley, wheat and rice straw indicate that the emission levels will be somewhere between backfires and headfires, generally approaching backfire levels. Changes in wind direction have a tendency to make portions of the flame front into headfires.

With normal variation in wind direction, approximately 20-30% of the area of a field would be burned with a headfire type burn. The remaining portion of the field would be burned with a fire that is similar to a backfire. However, before this ignition technique can be recommended, a personnel safety scheme must be devised. If a person lighting a fire through the field were immobilized (i.e. by a broken leg, heart attack, seizure, etc.), he would be subject to further injury by the oncoming fire. Personnel for this work should be selected for good health to minimize the potential for accidents. A buddy system or special supervision with an all-purpose vehicle with water tank and pump have been suggested as possible solutions, however, at this point no completely satisfactory method has been developed and thoroughly investigated.

A personnel hazzard noticed on all burns was the use of orchard heater lighters to light the open field burns. The lighters often leak fuel around joints and potentially allow for the outside of the lighter to catch fire. The fuel for the lighters is a mixture of three parts diesel fuel and one part gasoline. If too great a proportion of gasoline is used, the flame from the lighter becomes dangerously large. Safer lighters are sold for forestry use. The use of this type of lighter should be encouraged.

ASPARAGUS FERN BURNING STUDIES

In the irrigated southern California deserts 2400-3200 ha (6000-8000 ac) of asparagus are grown each year. The asparagus plant goes into dormancy during the late fall months. During November and December, the senescent fern is burned to remove it to aid in soil preparation for harvest of the new crop in January and February. There are several methods of preparing the fern for burning. Some growers knock the fern down with a tool bar mounted on a tractor. Others sever the fern from the crown with a rotary mower. A few then go back over the field with a flail chopper and further reduce the size of the fern. Fields are allowed to dry for varying lengths of time and are burned when the residue will support combustion.

Field observations indicated that backfiring rotary mowed ferns produced a much less dense plume than headfiring the same material. The asparagus fern that was only knocked over produced a dense plume whether it was backfired or head-fired. A field lighted around the entire periphery produces a large, very dense plume with tremendous verticle lift.

From these limited tests, it appears that at the relatively high fuel moisture at which asparagus fern is burned, the yield of all three pollutants reported is fairly high. After the fuel dried, hydrocarbon yield dropped rather dramatically. There was no real change in CO and only a moderate drop in particulate yield. More tests will be required to determine the variation in particulate yield and if the present small difference is significant.

When compared to other fuels at low moisture levels, asparagus yields the highest in particulate of any materials burned to date. Other crops seldom exceed 8 kilograms of particulate per metric ton of fuel burned and are often less than this. Carbon monoxide emission from dry asparagus is also relatively high, but hydrocarbon is at or below the yield of several other crop materials. It is apparent that asparagus should be burned as dry as possible and perhaps some other fuel modification or fire management technique would result in lower particulate yield.

Some preliminary drying studies were performed on asparagus fern. The data indicate that if the asparagus fern is green when it is cut, it will take about three weeks to dry to a reasonably low moisture content (see figure 31). Although all the methods for cutting the straw were combined, this does not imply that all produce similar drying rates. It may well be that flail chopping after mowing reduces drying time by breaking up the thick stalks which are the slowest part of the plant to dry. Knocking the fern over with a tool bar will undoubtedly result in a longer drying time than the mowing methods because the fern is often not separated from the living crown.

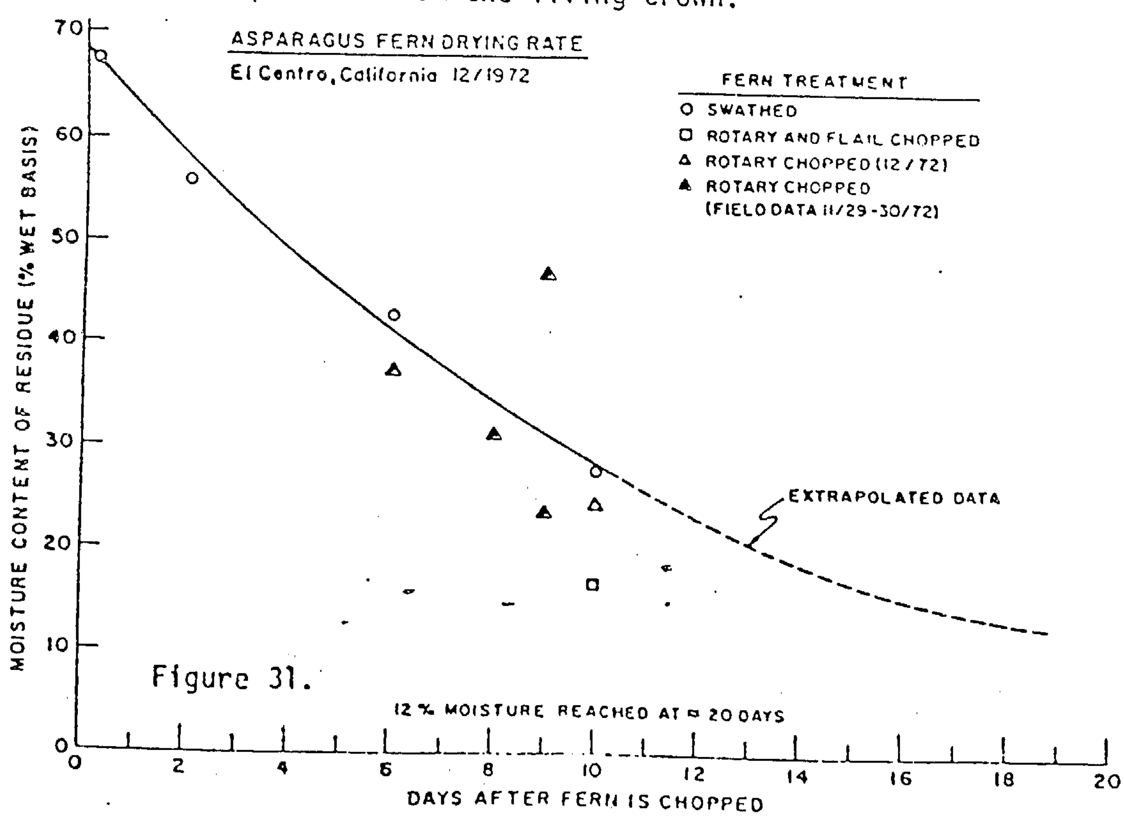


Figure 31.

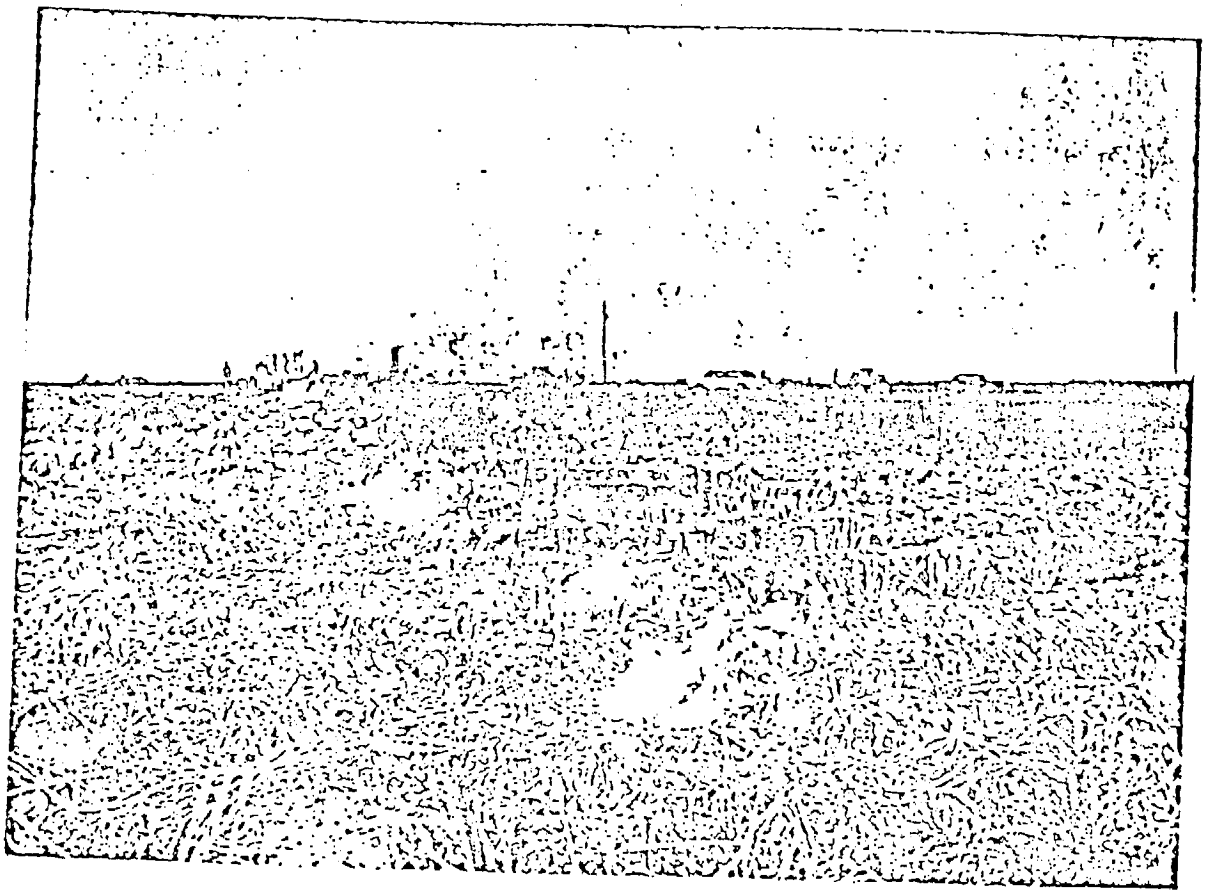


Figure 32. Photograph - Mowed Asparagus Backfire

Figure 33. Photograph - Asparagus Headfire

CITRUS STUDIES

At the request of the staff of the Agricultural Extension Service of Ventura County and the Fruit Grower's Laboratory of Santa Paula, a series of fires were conducted at SAPRC wherein pollutants were determined in relation to drying time after trees are pulled. This was done to help the appropriate officials establish guide lines for burning citrus.

Using orange trees growing at the Riverside campus, the general procedure was to pull trees on a given day, conduct two fires on the following day and then two fires each at weekly intervals for 4 to 6 weeks. Approximately 13.4 - 17.9kg (30-40 lbs) of branch material up to 6.4 cm - 7.6 cm (2-1/2 to 3 in.) in diameter and attached twigs and leaves were burned in each fire. Percent moisture of leaves and small twigs 1.3 cm (1/2 in.) branches, and of branches ranging in diameter from 3.8 - 7.6 cm (1-1/2 to 3 in.) were determined at the time of each fire.

In addition, three samples of lemon branches from trees in Ventura that had been pulled several weeks earlier, were brought to Riverside and burned.

The orange fires were conducted in two series, one with trees pulled December 20, 1972 and a second with trees pulled April 11, 1973. Considerable difficulty was experienced in igniting the fuels the day after and one week after pulling. Whereas growers may use diesel fuel to ignite large piles in the field, we normally use a small laboratory propane torch with the majority of fairly dry agricultural fuels under study. Adding diesel would contaminate our system. In the first series of orange fires, kindling wood and/or barley straw was placed at the base of the pile to aid ignition, but even this practice was not satisfactory and no attempt was made to account for any contribution of the non-citrus fuel. The second series, a uniform 6.7 kg (15 lbs) charge of small citrus branches that had dried approximately 25 weeks, was placed underneath each pile being burned and this was ignited with a larger propane burner in a 1-3 second period. We had previously determined that the burner did not contribute to the hydrocarbon emissions.

The results of the citrus experiments are given in Table 13. The emissions for the relatively greener fuels of the 6 weeks fires in April - May, 1973, are adjusted to account for the contribution of the base fuel.

The moisture level of the leaves drops very rapidly in the first two weeks and this is accompanied by a decrease in emissions. The heavier woods, on the other hand, do not lose moisture as rapidly. It seems safe to conclude, therefore, that most of the emissions due to burning relatively green materials is from leaves and twigs. There are two other pieces of evidence that support this conclusion. First, on the day after the trees were pulled, about 14 Kg(30 lb) material were prepared as for a normal fire, and then all of the leaves were stripped off and the remaining twigs and branches burned with the usual base fuel. This fire was immediately followed by the leaves being burned with another charge of base fuel. The leaves produced from two to three times the emissions than the twigs and branches did. Secondly, the rate of emission yield is quite high during the initial part of the fire when the leaves and twigs are being consumed and fall to a low, relatively steady-state value during the burning of the heavier pieces of wood. If just a few of the green twigs and leaves are added to the fuel bed during the steady-state period, emissions increase rapidly for a few seconds and then fall off to the steady-state situation again.

In spite of the fact that the first orange series was done in the late fall when one would expect slower drying rates, there were some relatively warm days with Santa Ana winds and moisture levels at 4 weeks are not too different than in the April - May series. The higher emissions values with time in the earlier series may be due to experimental variation within a fuel type or may be due to the barley straw that was used to aid in ignition. The fluctuation of the hydrocarbon in this series and in lemon is not understood, although during February, during the course of other trials, we found a rubber-like obstruction in the hydrocarbon sample line which could have varied the flow rate from fire to fire and caused erroneous readings.

Although the particulate level is a little higher in lemon than in orange (no straw was used with the lemon), it is not possible from these limited tests to say there is a species difference. For citrus that is reasonably dry (4-6 weeks), the emission factors are considerably lower than for several other agricultural fuels that have been studied and well below the factors for open burning published by EPA of 8.5 Kg/MT (17 lb/ton) particulate, 50 Kg/MT (100 lb/ton) carbon monoxide, and 10 Kg/MT (20 lb/ton) hydrocarbon. However, our experiments do not take into account all of the dirt, dust, and ash that is thrown into the air of a field fire of whole trees during those periods when the fuel bed is stirred with a tractor blade to increase the rate of burning and shorten the period of time the fire has to be watched for safety reasons. Prior to stirring, these fires appear to be very clean. Thus, it may be of interest to consider the advantages of cleaner fires with minimum stirring against the disadvantage of prolonging the burning period and associated fire danger.

Table 13 Yield of particulates, carbon monoxide, and hydrocarbon from burning leaves, twigs, and small branches of citrus trees that have dried for various periods of time from date of pulling.

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)	6.8 (13.7)
1	20	32	32	3.8 (7.6)	43 (86)	3.8 (7.6)
2	(skipped due to bad weather)					
3	19	29	30	3.0 (6.0)	38 (76)	7.6 (15.2)
4	13	26	27	3.1 (6.2)	37 (73)	8.3 (16.5)
			Orange, April-May, 1973			
0	48	33	37	5.1 (10.1)	64 (123)	8.1 (16.1)
1	29	37	34	2.4 (4.8)	60 (120)	3.8 (7.6)
2	18	32	32	2.0 (4.0)	43 (85)	3.5 (6.9)
3	14	32	33	1.7 (3.4)	36 (71)	2.3 (4.5)
4	15	29	32	1.5 (2.9)	39 (77)	2.3 (4.5)
6	16	14	22	1.7 (3.3)	23 (46)	2.1 (4.2)
25	(base fuel)	13 1/		1.2 (2.4)	12 (23)	.5 (0.9)
			Lemon, December, 1972			
7	11	27 1/		4.1 (8.1)	40 (80)	7.2 (14.4)
8	12	19	27	2.4 (4.3)	43 (85)	3.0 (6.0)

1/ Diameter classes combined.

RUSSIAN THISTLE STUDIES

At the request of the staff of the San Bernardino Air Pollution Control District, eight fires were conducted at the SAPRC Burning Tower using thistle plants collected near San Bernardino. Six of the fires were with naturally dried dead material and two were with approximately equal weights of dead and green plants; the green plants were from the Riverside campus. The thistle was arranged in a loose pile on the burning table over .22 Kg (0.5 lb) of barley straw. The straw was used to aid in carrying the fire through the pile. Ignition was from one side near the bottom of the pile.

Total loading (thistle and straw) was started at 4.5 Kg (10 lbs) but this caused the carbon monoxide recorder to go off scale at 4000 ppm. Loading was gradually reduced to about 2.9 Kg (6.5 lbs) before the CO recorder stayed on scale. The mixed dry and green fuel was run at 3.3 Kg (7.5 lbs). Moisture content on a wet weight basis was 12 percent for dry thistle and 38 percent for the green material.

Beginning with this study, we are reporting the particulate yield from the two filters that are in series in the particulate sampling line. Collection conditions of the first filter were the same as in all previous work so that yields can be compared with other fuels. But since the second filter is collecting particulate at near ambient temperatures, we believe that it is not unreasonable to assume that data from the first filter alone gives a low emission value and that the two filters together indicate more nearly the true particulate emissions. Experiments presently underway are designed to clarify collection techniques.

The particulate yield as indicated by the first filter is about twice that of several types of agricultural fuels of comparable dryness. One exception is the yield from standing asparagus fern which exceeds that of the Russian Thistle. The two fuels are somewhat similar in that when burned in a relatively undisturbed condition from that in which they were growing, the bulk density of the fuel is very low. The combined filters increase the emission factor by about 17 percent to give an overall average of about 11 Kg/MT (22 lbs) particulate per ton of fuel burned. It is interesting to note that there appears to be no influence of green plants on particulate emissions.

The carbon monoxide yield is the highest of any fuel yet burned. An average of many other dry fuels is about 50 Kg/MT (100 lbs/ton) of fuel burned. Here again, there appeared to be no real influence from adding green fuel to the fire.

The hydrocarbon yield is also higher by a factor of about 2 when compared to a variety of fuels of the same moisture content. The addition of green fuel did appear to significantly increase hydrocarbon yield and would indicate that if thistle is to be burned, it should be dry.

In comparing yields of thistle with agricultural crop residues, it should be pointed out that while these results certainly show that thistle produces more emissions than agricultural fuels on a ton for ton basis, the yield from thistle might be much less on an acre basis, assuming that the weight of thistle may be considerably less than one ton per acre.

Table 14

Yield of Particulates, Carbon Monoxide, and Hydrocarbon from Burning Eight Samples of Dry or Mixed Dry and Green Russian Thistle

	Emissions, Kg/MT (lb/ton) of Fuel Burned				
	Particulate				
Fuel	1st Filter	2nd Filter	Total	CO	HC
Dry	10 (20)	1.6 (3.2)	12 (24)	<129 (<258[1/])	4.7 (9.3)
Dry	10 (20)	2.0 (4.0)	13 (25)	<165 (<330[2/])	7.5 (15)
Dry	10 (20)	1.9 (2.7)	11 (22)	<164 (<328[3/])	7.5 (15)
Dry	12 (23)	1.5 (2.9)	13 (26)	168 (336)	9.5 (19)
Dry	9 (17)	1.7 (3.3)	10 (20)	182 (361)	12 (24)
Dry/Green	8 (16)	1.8 (3.5)	10 (19)	115 (230)	17 (34)
Dry	9 (17)	1.5 (3.0)	10 (20)	154 (308)	9.0 (18)
Dry/Green	9 (18)	1.7 (3.4)	11 (21)	155 (310)	16 (32)

1/, 2/, and 3/. Off scale 35 sec., 28 sec., and 10 sec., respectively.

ORCHARD PRUNING STUDIES

At the request of the California Air Resources Board, Division of Implementation and Enforcement, simulated open field burns of several varieties of prunings were monitored.

During the first week in February, 1974, prunings of almond, grape, peach, and walnut were delivered to Riverside. The material had been cut a few days before it was collected. An attempt was made to burn grape prunings on the day of delivery to determine the emission production of fairly green material compared with that of the same material after it had dried for period specified by the

APCD involved. The grape prunings could not be ignited and other materials were not tried; the moisture content of the grape was 48 percent on a wet weight basis. The procedure then followed was to burn the almond at approximately 3 and 6 weeks after collection and the other materials at 30 days after collection. Soon after the first almond was burned, 2.5 cm (1 in.) of rain fell and it was decided to delay the grape, peach, and walnut fires for about 10 days; further delays were occasioned by windy weather which prevented us from burning.

The results of the fires giving average emissions and moisture content of the fuel are presented in table 15. Where fuels are of uniform size, only one moisture value is given. The limbs noted for almond and walnut did not exceed 6.4 cm (2-1/2 in.) in diameter. The particulates are reported for each of the two filters that have been installed in series in the sample system.

Table 15

Emissions of Particulate, Carbon Monoxide and Hydrocarbons from Burning Prunings of Four Orchard Crops

Crop and Number of Fires	Days from Cut to Burn	% Fuel Moisture Wet Wt. Basis	Average Emissions, Kg/MT (lbs/ton)				
			Particulate				
			Filter #1	Filter #2	Total	CO	HC
Almond (3)	23	twigs-31 limbs-35	2.8(5.6)	1.3(2.5)	4.1(8.1)	38(75)	5.6(11.1)
(4)	45	twigs-26 limbs-31	3.1(6.2)	1.2(2.3)	4.3(8.5)	32(64)	4.6(9.2)
Grape (4)	38	30	2.2(4.4)	.7(1.3)	2.9(5.7)	31(62)	3.0(5.9)
Peach (4)	44	28	1.5(2.9)	.5(.9)	1.9(3.8)	16(31)	1.7(3.3)
Walnut (1)	49	twigs-30 limbs-35	1.8(3.5)	.6(1.1)	2.3(4.6)	20(40)	2.3(4.6)

The prunings burned fairly well at the drying times indicated although a large propane torch had to be used to ignite the first fires of almond. Even at the relatively high moisture levels (many other agricultural fuels are burned at 12 to 17 percent moisture on a wet weight basis) the emissions from these woody fuels were not particularly high. The greatest yield of particulate was from almond, and the extra drying period did not alter the yield. The CO yields appear to be lower than we have obtained for other woody fuels and the hydrocarbon is at or below the range we have obtained. Based on work with dry woody fuels, it is fairly safe to assume that if the fuels were drier, the emissions would be lower.

In the fall of 1967. L. B. McNelly[10] conducted some drying studies on prunings from six species of orchard crops. A summary of the results are presented in figure 34. Figure 34 shows that the tree fruit and nut prunings dried at similar rates and that the fastest rate of drying occurred in the first 10 days of drying. On an average basis, most prunings had dried to 35% moisture (wet basis) after 10 days. The drying rate decreased steadily after 10 days. McNelly's data also showed that even heavy rainfall will not increase the moisture content of the prunings drastically. In fact, several inches of rain rarely brought the moisture up to its original level. If tree prunings needed to be at 10%-12% moisture content to burn with minimum emissions, as straw residue must, months of drying would be required.

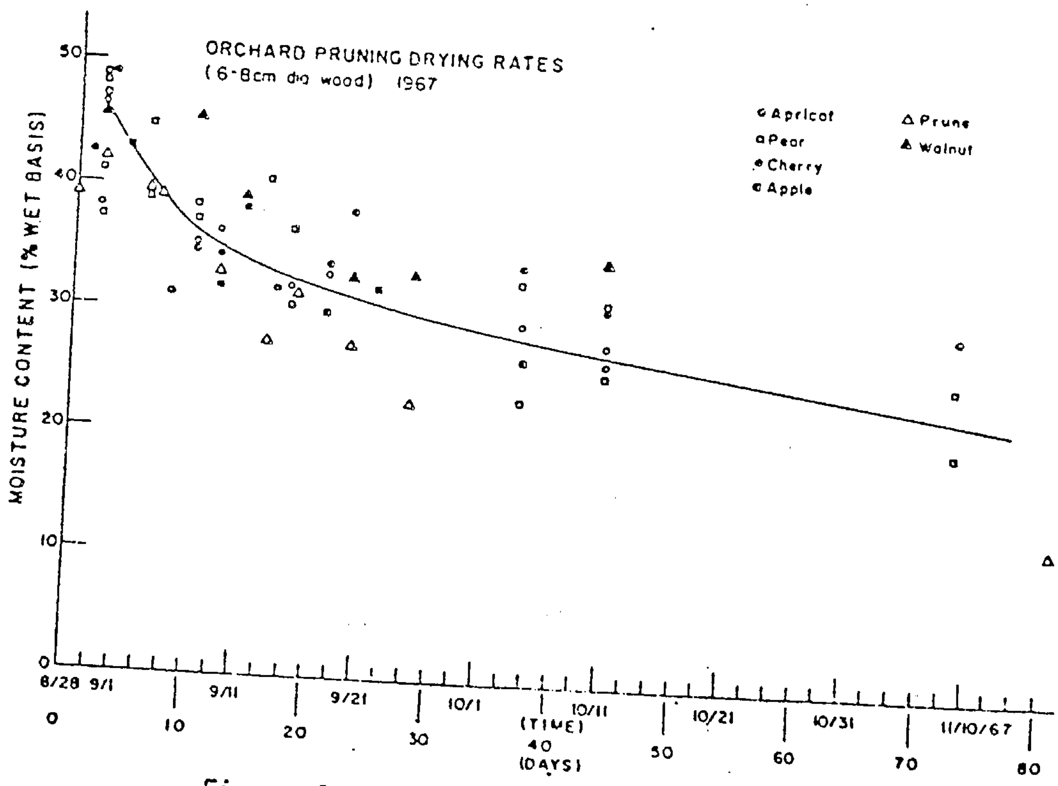


Figure 34. Orchard Pruning Drying Rates

The SAPRC prunings fires showed that minimum emissions (1.5 - 3 Kg/MT) are obtained when the prunings have dried less than 35% (the Riverside data also shows that, like McNelly's data, the prunings reach this moisture level in about 10 days). The pruning fires at the SAPRC Tower were conducted with a pre-existing fire. From the above facts, it appears that orchard prunings can be burned with low emission levels if the prunings are allowed to dry to about 35% moisture content, (approximately 10 days of drying after pruning) and are burned by adding the prunings to a pre-existing fire. Visible smoke levels may be higher during startup when there is no pre-existing fire and coal bed but various ignition aids may be used to minimize this problem.

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Appendix A

PARTICULATE LEVEL CALCULATIONS

Theory of Calculation -

A high volume air sampler measures basically the weight of particulates in a known volume of air, usually expressed as μg of particulates per m^3 of air. This figure can be converted into lbs. of particulates produced per ton of fuel burned if the CO_2 level is measured at the high volume air sampler. The conversion is made by calculating the amount of fuel that was burned to produce the particles in the sample volume. The fuel amount is assumed to be directly proportional to the CO_2 level in the sample volume (eg. 100 lbs. of residue @36% C willprodu produce 132 lbs. of CO_2 if completely burned).

Sample Calculation - using typical field data:

A. Assumptions made in the calculation:

1. Negligible amount of CO produced
2. Negligible amount of hydrocarbons produced
3. Insignificant amount of carbon in particulates

B. Carbon balance:

Carbon content of residue = 36%

Carbon content of ash = 15%

Lbs. of ash produced per lb. of fuel burned = .25

Carbon consumed per lb. of fuel =

(1 lb fuel) (.36) - (1 lb fuel) (.25) (.15) =

.36 - .038 = .322 lbs C/lb fuel

C. Fuel burned to produce CO_2 level in sample volume:

cfm = average hi-vol flow rate = 80 cfm[a]

temp = average temperature of sampled air = 180°F[b]

CO_2 = average CO_2 level of sampled air =.50%

time = duration of sampling = 3 minutes

$$(\text{cfm}) \cdot \left(\frac{\text{std. temp.}^{c}}{\text{temp.}}\right) \cdot (\text{time}) \cdot \left(\frac{CO_2}{100}\right) \cdot (K_1)^{d} = \text{liters } CO_2$$

$$\left(\frac{80\ ft^3}{min.}\right) \left(\frac{530°R}{640°R}\right) \cdot \left(\frac{3\ min.}{1}\right) \cdot \left(\frac{.005\ ft^3\ CO_2}{ft^3\ air}\right) \cdot \left(\frac{28.32\ liters}{ft^3}\right) = 28.2 \text{ liters of } CO_2$$

then: $(\text{liters } CO_2) \cdot (K_2) \cdot (K_3) \cdot (K_4) \cdot (\frac{1}{\text{lbs C/lb fuel}}) = \text{g fuel burned}$

$$\left(\frac{282 \text{ liter } CO_2}{1}\right) \cdot \left(\frac{1 \text{ mol } CO_2}{22.4 \text{ liter } CO_2}\right) \cdot \left(\frac{44 \text{ g } CO_2}{\text{mole } CO_2}\right) \cdot \left(\frac{12 \text{ g C}}{44 \text{ g } CO_2}\right) \cdot$$

$$\left(\frac{1\text{g fuel}}{322\text{g C}}\right) = 46.8 \text{ g fuel burned}$$

D. Particulate Level:

amount of particulates collected = .1400 g

$$\left(\frac{\text{g particulate collected}}{\text{g fuel burned}}\right) \cdot (K_5) = \text{lbs/ton}$$

$$\left(\frac{.1400\text{g particulate}}{46.8 \text{ g fuel}}\right) \left(\frac{2000 \text{ lb}}{\text{ton}}\right) = 5.98 \text{ lb/ton}$$

NOTES:

a The calibration curve for the hi-vol sampler must be used in determining the average flow rate.

b The time base for the CO_2 average is the sum of the periods where the CO_2 level is above the ambient level. This time base is the duration of sampling and is also used in the average temperature calculation.

c Standard conditions: 70°F or 530°R and 29.92" Hg barometric pressure

d Conversion Factors:

K_1 = 1 ft³ = 28.32 liters @ S.T.P.

K_2 = 1 gram mole of a gas = 22.4 liters

K_3 = 1 gram mole of CO_2 = 44 g

K_4 = 1 gram mole of CO_2 has 12 g of C

K_5 = 1 ton = 2000 lbs.

Appendix B

COST ANALYSIS (1973)

Spring and Fall Rice Straw Burns

Rates of burn in feet per minute.

RICE HEADFIRE

Fall 1972, 1971	Spring 1973	
37.5	18.0	24.0
66.4	13.0	24.0
70.0	14.0	11.0
50.0	22.0	8.0
29.0	12.0	8.0
50.0	18.0	8.0
50.0	26.0	11.0
50.0	17.0	8.0
40.0	26.0	9.0
49.2 average	22.0	
	15.7 average	

RICE BACKFIRE

Spring 1973, 1972
4.75
2.3
3.1
10.0*
2.7
2.9
3.3
4.15 average

*3.2 without 10.0

WHEAT HEADFIRE

Summer, 1971
20
86
156
87 average

WHEAT BACKFIRE

Summer, 1971
4.3
3.9
3.7
4.0 average

BARLEY HEADFIRE

Summer, 1972
152
138
138
71
145
125 average

BARLEY BACKFIRE

Summer, 1972
3.9
3.9
3.9
3.0
3.7 average

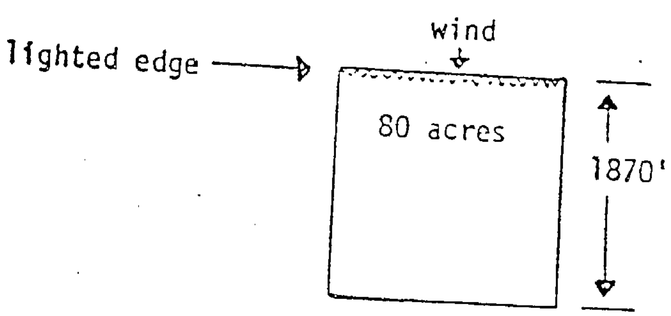
COST ANALYSIS

A. Headfire Burning:

The speed of the flame front in headfire burns varies signficantly with wind speed, moisture content and fuel loading. Rates have been recorded as high as 70 fpm on a field with little residue compaction and dry straw and stubble. (Note: summer barley may reach rates as high as 150 fpm). On the other hand, rates as low as 8 fpm have been recorded on fields where the residue is severely compacted as a result of a long winter with much flooding and animal traffic. This analysis will use two flame front speeds: (1) 50 fpm; corresponding to a spring burn on a field with dry straw and stubble (10% wb), moderate wind speeds (8 to 12 mph) and little fuel compaction, (2) 16 fpm: corresponding to a spring burn on a field with wet stubble (20% wb), dry straw (10% wb), compacted fuel and low wind speeds (4 to 5 mph).

A square 80-acre field would burn in:

1. (1,870 ft) · [1/(50 ft/min)] · [1/(60min/hr)] = .6 hrs
2. (1,870 ft) · [1/(16 ft/min)] · [1/(60 min/hr)] = 1.9 hrs



COST ANALYSIS

A. Headfire (cont'd)

1. Headfire (speed of flame front = 50 fpm)
Equipment cost based on 400 acres in rice per year. Fire is lighted along one edge only and requires no relighting.

	cost	use	total
field labor (1 man operation)	2.25/hr.	.6 hr.	1.35
equipment:			
pickup	2.00/hr.	.6 hr.	1.20
small tools, drip can, etc. $50/2 years			
lighting fuel	.0375/acre	80 acres	5.00
	.0005/ft.	1,870 ft.	.94
overhead and supervision (10% of subtotal)			8.49
TOTAL COST PER 80 ACRES			.85
cost per acre			$9.34
cost per hectare			$ .12
			$ .30

2. Headfire (speed of flame front = 16 fpm)
Based on 400 acres in rice per year

	cost	use	total
field labor (1 man operation)	2.25/hr.	1.9 hr.	4.28
equipment:			
pickup	2.00/hr.	1.9 hr.	3.80
small tools, drip can, etc. $50/2 years			
lighting fuel	.0375/ac.	80 acres	5.00
TOTAL COST PER 80 ACRES	.0005 ft.	1,870 ft.	.94
cost per acre			$15.42
cost per hectare			$ .19
			$ .47

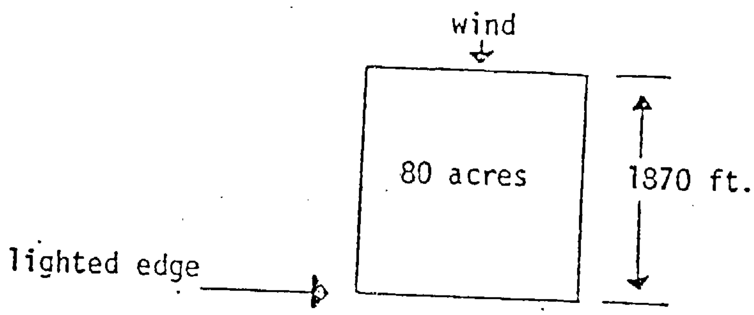
COST ANALYSIS

B. Backfire Burning:

Data from rice residue burning consistently indicates a rate (speed of flame front) of flame advance (progression) between 2.7 to 4.8 ft/minute. An average rate of 3.25 fpm will be used in the cost analysis.

A square, 80-acre field would completely burn in:

(1,870 ft.) (1/3.25 ft/min) (1/60 min/hr) = 9.6 hr



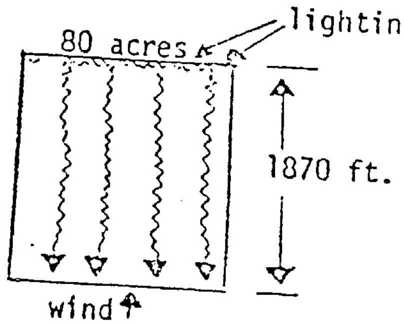
Equipment cost based on 400 acres in rice per year and field tended throughout entire time of burn.

	cost	use	total
field labor (1 man operation)	2.25/hr.	9.6 hr.	21.60
equipment:			
pickup	2.00/hr.	9.6 hr.	19.20
small tools, drip can, etc. $50/2 years	.0375/ac	80 acres	5.00
lighting fuel	.0005/ft.	1,870 ft.	.94
			46.74
overhead and supervision	(10% of subtotal)		4.67
TOTAL COST/80 ACRES			$51.41
cost per acre			$ .65
cost per hectare			$ 1.61

C. Into-the-Wind Striplighting

The rate of flame front advance with the into-the-wind striplight technique is comparable to backfire burning. The advantage of this technique is that more than just one edge of the field can be ignited. Although the rate of flame front advance is the same as a backfire burn, the fire front is much longer, and is moving in two directions at once plus the rate of lighting is equivalent to a fast headfire (@ 2 mph = 176 fpm), thereby covering the field faster.

Using the following lighting pattern:



lighting $\frac{2290}{176} \times \frac{1}{60} =$ .22 hrs x 4 men = .88 (Man Hrs.)

standby $\frac{1870}{8} \cdot \frac{1}{200} =$ 1.13 hrs x 1 man = 1.12

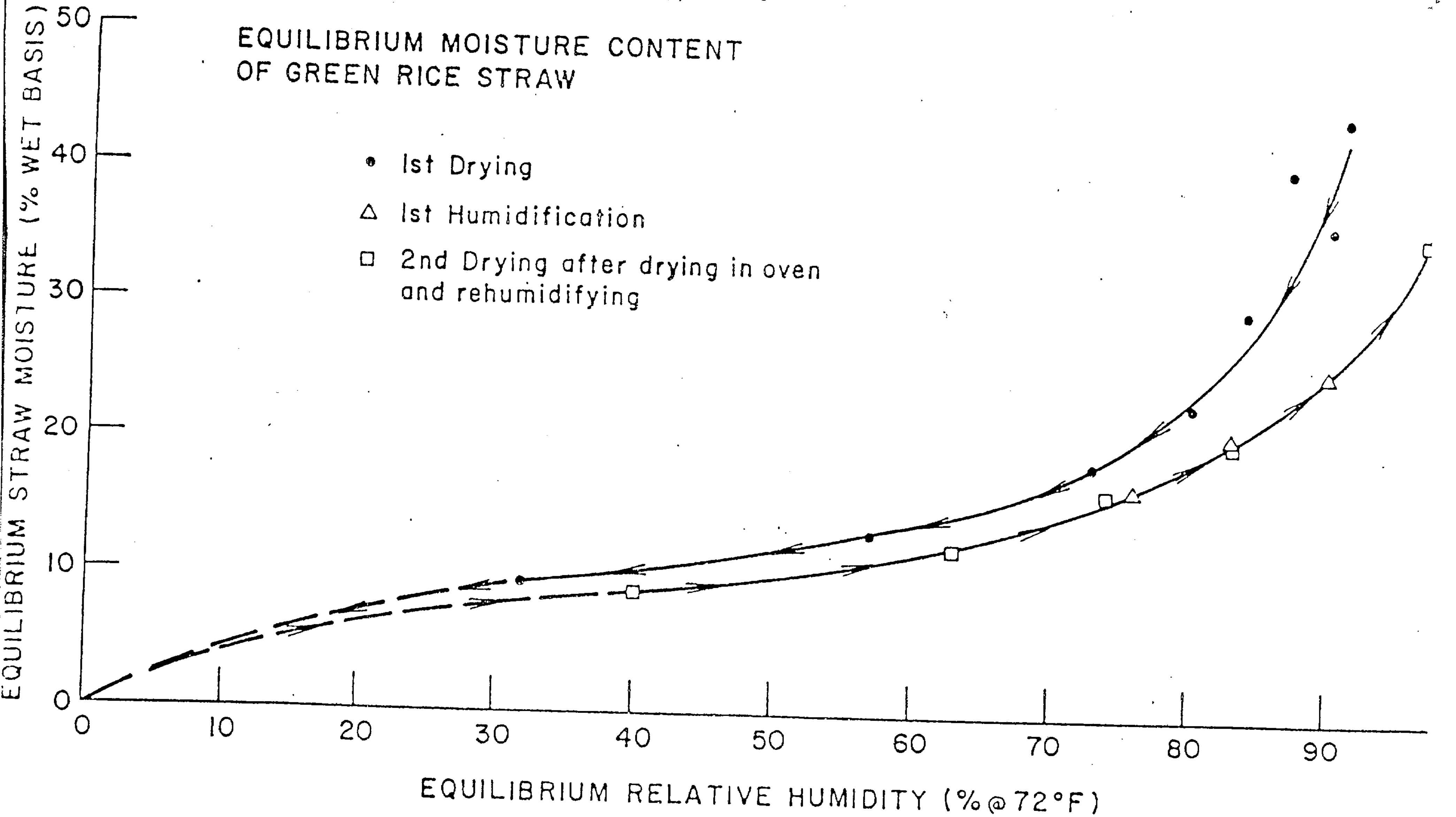
2.00 hrs.

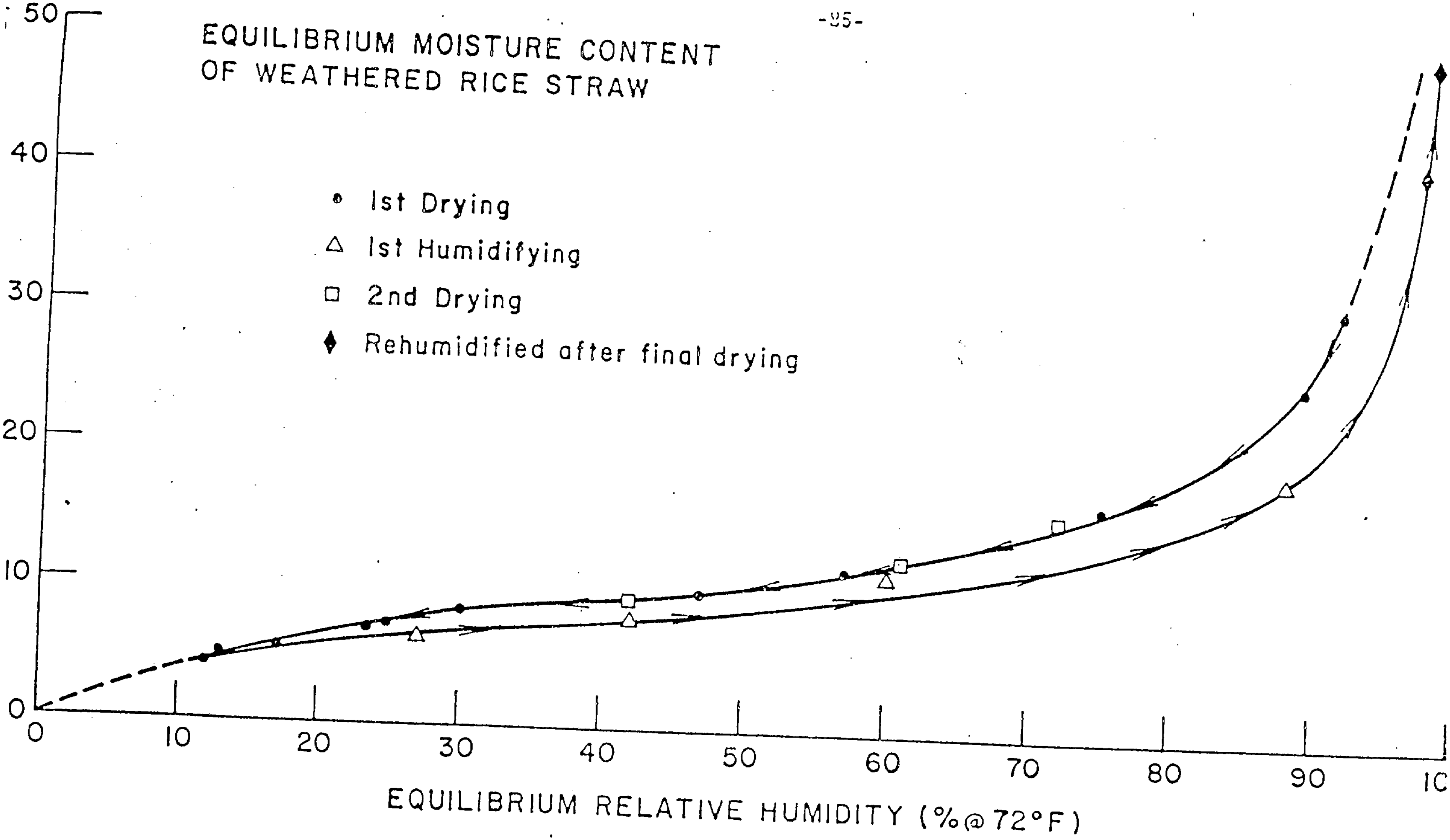
1/4 hour at two miles per hour and fire advances 200 ft/hr.

Equipment cost based on 400 acres in rice per year:

	cost	use	total
field labor (4 men operation)	2.25/hr.	2 hrs.	4.50
equipment:			
pickup	2.00/hr.	2 hrs.	4.00
small tools, drip can, etc. $50/2 years	.0375/ac	80 acres	5.00
lighting fuel	.0005/ft.	9,350 ft.	4.70
			$18.20
overhead and supervision (10% of subtotal)			$ 1.82
TOTAL COST/80 ACRES			$20.02
cost per acre			$ .25
cost per hectare			$ .62

Appendix C


EQUILIBRIUM MOISTURE CONTENT
OF GREEN RICE STRAW
Ist Drying
Ist Humidification
2nd Drying after drying in oven and rehumidifying
EQUILIBRIUM STRAW MOISTURE (% WET BASIS)
0
10
20
30
40
50
0
10
20
30
40
50
60
70
80
90
EQUILIBRIUM RELATIVE HUMIDITY (%@72°F)


EQUILIBRIUM MOISTURE CONTENT
OF WEATHERED RICE STRAW
Ist Drying
Ist Humidifying
2nd Drying
Rehumidified after final drying
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
EQUILIBRIUM RELATIVE HUMIDITY (%@72°F)

Appendix D

Data Sheets

Fall 1970 (Rice)

Summer 1971 (Wheat)

Fall 1971 (Rice)

Summer 1972 (Barley)

SAPRC Tower 1972 (Rice)

SAPRC Tower 1973 (Rice, Wheat, Barley)

Asparagus Trials 1972

Particulate Size Distribution Studies 1973

1975 RICE BURN DATA

Metric

Date	Treatment	Wt. of individual straw samples (g) #1	#2	#3	Straw sample area (m²)	Wt. of individual stubble samples (g) #1	#2	#3	Stubble sample area (m²)	Straw (kg/ha)	Moisture content (%)	Stubble (kg/ha)	Moisture content (%)	Straw & stubble total (kg/ha)	Stubble in burn area (kg/ha)	Straw & stubble in burn area (kg/ha)	Soil moisture under straw before burn (%)	Soil moisture under straw after burn (%)	Soil moisture between rows (%)	Ambient temp. (°C)	Wind speed (km/hr)	Wind direction	Relative humidity (%)	Lapse rate
10-2	Spread Straw	732	347	877	1.49	417	917	502	1.49	3,579	8.5	4,746	52.5	12,332	4,744	10,127	15.1	(2)	(2)	34	4.4	NW	23	.6
10-2	"	751	517	772	1.49	372	592	437	1.49	4,551	8.3	4,091	57.5	8,632	4,041	8,633	16.9	(2)	(2)	35	0.0	W	23	.6
10-7	"	547	377	732	1.49	677	712	632	1.49	2,904	5.5	4,647	52.3	8,453	4,647	8,453	16.6	(2)	(2)	36	3.2	W	17	.6
10-14	"	611	1187	(2)	1.49	134	660	(2)	1.49	7,062	8.6	1,353	56.5	9,021	1,959	9,021	18.8	11.7	(2)	22	4.4	NW	46	1.9
10-15	"	767	1298	(2)	1.49	288	272	(2)	1.49	6,275	12.0	1,757	69.5	8,325	1,757	8,036	21.9	12.1	(2)	22	2.1	NW	48	.6
10-15	"	514	798	(2)	1.49	264	440	(2)	1.49	4,293	8.8	2,354	60.9	6,745	2,364	6,745	8.4	21.3	(2)	23	5.6	N	48	.6
Average	"									5,246	10.9	3,249	53.8	8,136	3,249	8,136	16.8	21.0	(2)	25	4.2		35	.8
10-6	Straw Rows	578	375	1373	5.57	472	575	640	1.49	3,213	8.5	4,647	51.8	6,360	1,009	2,214	11.3	10.7	(2)	30	7.2	N	30	.6
10-6	"	836	1462	2153	5.57	815	845	710	1.49	2,443	7.9	5,318	46.1	7,961	1,420	4,063	11.3	10.5	(2)	26	7.2	N	37	1.2
10-6	"	1379	2215	1786	5.57	735	640	785	1.49	1,826	9.1	8,832	67.5	10,654	1,624	5,041	12.5	13.3	(2)	25	10.5	W	37	1.8
10-14	"	3659	2494	(2)	5.57	122	72	(2)	1.49	3,524	8.5	652	52.8	4,176	175	5,699	17.0	22.7	8.5	23	4.0	SSW	41	.5
10-15	"	2196	1372	(2)	5.57	230	196	(2)	1.49	3,658	35.3	1,332	72.0	4,990	356	4,011	16.0	20.3	7.9	22	3.2	SW	44	.5
10-16	"	2995	2911	(2)	5.57	135	75	(2)	1.49	3,296	12.1	1,347	47.4	4,339	335	5,637	20.8	19.1	12.6	23	4.8	N	47	.8
Average	"									3,394	13.0	3,173	59.5	7,272	1,632	4,445	15.0	16.1	9.6	24	6.0		43	
10-15	Raked Straw	(2)	(2)	(2)		344	(2)	(2)	1.49	2,026	8.8	2,316	57.0	4,342	324	2,351	11.1	10.7	18.4	22	6.4	S	43	.6
10-15	"	2519	2348	(2)		180	60	(2)	1.49	2,241	20.8	1,461	74.9	3,774	290	2,443	11.8	19.6	23.5	22	5.6	SSW	47	.7
10-16	"	3225	1622	(2)		135	105	(2)	1.49	2,065	4.8	727	54.1	2,792	94	2,379	22.6	19.7	11.9	24	4.2	NNW	43	.6
Average	"									2,118	12.5	1,502	58.1	3,620	236	2,324	15.6	23.4	14.1	23	5.4		44	.6

Date	Wt. of individual post burn stubble samples (g)(3) #1	#2	#3	Post burn stubble sample area (m²)	Post stubble in burn area (kg/ha)	Stubble burned (kg/ha)	Straw equivalent in ash (kg/ha)	Stubble equivalent in ash (kg/ha)	Straw and stubble burned (kg/ha)	Straw and stubble burned (%)	Straw and stubble burned % of total field	Maximum temperature (°C)	Average temperature (°C)	Degree/Sec. above 127°C	Field notes
10-2	252	227	367	1.49	1,739	3,007	340	142	6,063	78	78	682	241	3.01	18" to top of straw
10-2	477	312	67	1.49	2,353	1,986	279	121	6,177	71	71	516	218	1.27	"
10-7	442	502	337	1.49	2,963	1,643	232	102	5,157	78	70	(2)	(2)	(2)	"
10-14	(2)	(2)	(2)	1.49	235	1,723	1,251	335	7,293	80	80	495	153	.33	10" to top of straw + unusual whirlwind
10-15	57*	(2)	(2)	1.49	376	1,360	341	150	6,010	75	75	582	201	.66	"
10-15	(2)	(2)	(2)	1.49	235	2,120	77	374	5,951	66	66	564	214	.99	"
Average					1,266	1,984	421	213	6,427	77	77	564	204	1.15	
10-6	60	196	348	1.49	1,163	1,165	118	11	1,661	64	27	582	162	.73	22" to top of straw (backfire)
10-6	275	255	606	1.49	327	1,197	26	63	2,379	73	37	538	223	2.91	"
10-6	1625*	262	286	1.49	542	929	277	90	3,141	91	35	647	(2)	1.56	
10-14	36*	(2)	(2)	1.49	177	64	277	26	3,303	92	86	749	236	2.38	14" to top of straw
10-15	25*	(2)	(2)	1.49	56	445	443	38	2,186	87	70	699	(2)	3.01	"
10-16	(2)	(2)	(2)	1.49	125	291	63	16	3,403	96	85	641	222	1.96	"
Average					678	687	236	52	3,715	85	57	644	(2)	1.97	
10-14	[illegible]	(2)	(2)	1.49	34	448	224	31	2,043	38	67	449	(2)	27.6	22" to top of straw
10-15	121*	(2)	(2)	1.49	184	37	236	79	2,077	85	86	553	(2)	4.55	
10-16	131*	(2)	(2)	1.49	82	318	137	24	1,896	92	72	549	(2)	38	Aborted run
Average					95	278	199	14	2,043	88	54	642	(2)	17.5	

Date	Part. wt. (g)	Sampler rate (m³/min)	Duration of sampling (min)	Part. level at tower (g/m³)	CO_2 level (%)	Total CO_2 (%)	Particulate level at 12% CO_2 (g/m³)	Part. Amt. (kg/Mt)	Part. Amt. (kg/ha)	Initial Hivol filter wt. (g)	Final Hivol filter wt. (g)	Net wt. (g)	Hivol flow reading (m³/min)	Rate of flame advance (m/min)	Filter color Bacharach scale	CO_2 area	Tower height (m)	Average temp. (fire) plus ambient temp. (°C)	Average temp. (tower) less ambient temp. (°C)	Average temp. (tower) plus ambient temp. (°C)
10-2	.1606	2.64	3	.016	.463	13.1	.363	2.20	17.7	4.9056	4.7969	.1087	2.64	16	9+	17.27	4.5	171	---	---
10-2	.0156	2.49	5	.001	.126	6.06	.125	2.37	18.4	4.5461	4.5615	.0439	2.19	(2)	5	7.87¹	4.5	126	18	53
10-7	.0476	2.52	2.75	.007	.263	6.96	.318	1.91	8.9	4.8141	4.7671	.0468	2.52	31	9+	8.13¹	4.5	164	52	46
10-14	.0962	2.65	.78	.027	.383	7.72	.906	.57	4.1	4.6402	4.6034	.0563	2.65	(2)	6	7.51¹	4.5	276	24	46
10-14	.0480	2.67	1.5	.012	.735	10.6	.196	1.25	8.7	4.6406	4.5327	.0473	2.67	(2)	8	13.72	3.0	255	21	43
10-15	.1195	2.60	4.3	.012	.246	10.7	.535	3.04	16.1	4.9534	4.8303	.1190	2.60	(2)	1	13.37	3.0	309	19	43
Average	.0661	2.59	2.86	.012	.376	10.3	.401	1.63	10.7						7.6	13.21		221	27	54
10-6	.1166	2.64	2.8	.018	.261	7.37	.644	6.03	7.3	4.7715	(2)	.1146	2.64	(2)	8	9.91	4.5	136	32	61
10-6	.1161	2.46	3.3	.014	.354	11.18	.480	3.00	8.9	4.7742	(2)	.1161	2.46	3.5	9	14.48	4.5	397	31	56
10-6	.3437	2.52	3.0	.006	.393	11.30	.147	.96	3.8	4.6535	(2)	.0437	2.52	(2)	7	14.73	4.5	339	30	54
10-14	.2172	2.51	3.3	.025	.324	7.11	1.40	8.90	47.3	4.9947	4.7774	.2173	2.52	(2)	5-1/2	9.16¹	4.5	314	29	62
10-15	.1363	2.32	2.89	.010	.615	17.0	.367	2.38	8.1	4.9304	4.7944	.1360	2.52	(2)	6-1/2	22.10	3.0	172	11	36
10-16	.1616	2.31	1.2	.043	.874	6.13	900	3.73	31.0	4.8465	4.8446	.1119	(2)	(2)	9	8.64¹	3.0	243	26	49
Average	.1566	2.43	2.75	.022	.410	10.80	.579	4.22	17.7						7.4	13.07		245	25	53
10-14	.0963	2.52	3.3	.011	.344	14.4	.396	2.23	6.6	4.7361	4.6446	.0963	2.52	3.7	7	11.22	4.5	579	3	25
10-15	.1260	2.54	3.45	.015	.435	15.1	.384	2.38	6.9	4.762	4.6345	.1780	2.54	(2)	8	19.56	3.0	216	4	26
10-16	.0423	2.53	1.3	.013	.397	6.96	.367	2.38	6.7	4.8778	4.8355	.0423	2.53	(2)	6	8.35¹	3.0	259	11	36
Average	.1366	2.53	2.66	.013	.408	10.2	.398	2.28	6.7						7.3	11.20		376	21	49

(1) Cutoff for CO_2 = 33.8 cm²

(2) Data not taken in field

(3) Post burn ash and stubble were collected and weighed together. Stubble portion estimated on the basis of some laboratory comparisons.

(4) Doubtful data, not used

1979 Rice Burn Data
English

Date	Treatment	Wt. of Individual Straw Samples, dry weight (g) 1	2	3	Straw Sample Area (ft²)	Wt. of Individual Stubble Samples, dry weight (g) 1	2	3	Stubble Sample Area (ft²)	Straw (lb/ac)	Moisture (percent)(1)	Stubble (lb/ac)	Moisture (percent)(1)	Straw & Stubble Total (lb/ac)	Stubble in Burn Area (lb/ac)	Straw & Stubble in Burn Area (lb/ac)	Soil Moisture Under Straw Before Burn (%)	Soil Moisture Under Straw After Burn (%)	Soil Moisture Between Rows (% wt)	Ambient Temp. (°F)	Wind Speed (mph)	Wind Direction	Relative Humidity (%)	Lodge
10-2	Spread Straw	732	477	427	16	492	917	568	16	4,372	5.5	4,232	52.5	9,204	4,232	9,204	15.1	(2)	(2)	93	2.5	[illegible]	21	1
10-2	"	757	517	771	16	572	592	637	16	4,092	1.1	3,602	52.5	7,194	3,602	7,194	18.5	(2)	(2)	95	3	[illegible]	23	1
10-3	"	542	317	732	16	677	762	632	16	3,391	5.5	4,142	52.5	7,534	4,142	7,534	19.4	(2)	(2)	97	2	[illegible]	17	1
10-14	"	941	1182	(2)	16	162	400	(2)	16	6,219	8.6	3,796	55.5	8,042	1,746	6,040	18.4	19.7	(2)	71	3	[illegible]	46	2
10-15	"	767	1298	(2)	16	291	233	(2)	16	3,395	12.0	3,564	69.1	7,161	1,564	7,111	21.9	12.1	(2)	71	1.3	[illegible]	44	.2
10-16	"	515	790	(2)	16	260	440	(2)	16	3,915	6.5	2,100	60.9	6,015	2,100	6,015	8.4	31.3	(2)	74	3.5	[illegible]	46	1
Average										4,710	10.9	2,896	53.0	7,608	1,896	7,608	16.5	21.0	(2)	84	2.4		35	1.5
10-4	Strip Burn	370	373	1073	64	470	375	640	16	2,064	5.3	4,320	35.8	7,154	900	1,974	13.2	16.2	(2)	86	4.5	[illegible]	30	1
10-5	"	175	1065	2194	64	615	645	778	16	2,323	7.4	4,740	66.1	7,113	1,756	3,439	12.3	16.5	(2)	75	4.5	[illegible]	37	2
10-6	"	1179	2215	1195	64	735	440	765	16	2,275	9.1	2,405	63.5	4,954	1,629	4,491	12.1	11.3	(2)	78	6.5	[illegible]	37	1
10-14	"	3659	2134	(2)	64	122	78	(2)	16	4,923	6.5	542	52.3	5,535	354	5,279	17.0	22.7	5.4	73	5.0	[illegible]	43	1
10-15	"	2196	1577	(2)	64	200	196	(2)	16	3,260	15.3	1,164	77.0	4,444	317	3,327	14.8	20.3	7.9	71	2.0	[illegible]	44	1
10-16	"	2995	2511	(2)	64	136	75	(2)	16	4,729	12.3	930	47.4	3,650	299	3,019	20.6	19.1	10.8	73	3.0	[illegible]	47	1.5
Average										3,263	13.0	3,278	51.5	6,441	1,470	3,562	15.6	16.9	9.4	76	6.0		40	
10-14	Raked Straw	(2)	(2)	(2)		344	111	(2)	16	1,406	6.8	2,364	57.8	3,870	283	2,095	11.1	10.7	13.4	72	4.5	S	41	2
10-15	"	2579	2366	(2)		120	40	(2)	16	1,999	23.8	1,373	76.9	3,359	178	2,177	13.8	15.8	21.5	72	3.5	[illegible]	47	1.3
10-16	"	3225	1478	(2)		135	126	(2)	16	1,254	8.1	930	54.1	2,444	64	1,342	12.6	15.7	11.9	74	1.0	[illegible]	41	1
Average										1,644	12.5	1,338	58.1	1,724	184	2,371	15.0	12.4	11.2	73	3.5		44	1

Date	Wt. of Individual Post Burn Stubble Samples (g)(3) 1	2	3	Post Burn Stubble Sample Area (ft²)	Post Burn Stubble in Burn Area (lb/ac)	Stubble Burned (lb/ac)	Straw Emissions to Air (lb/ac)	Stubble Emissions to Air (lb/ac)	Straw and Stubble Burned (lb/ac)	Straw and Stubble Burned (%)	Straw and Stubble Burned % of Total Field	Maximum Temperature (°F)	Average Temperature (°F)	Degrees/Sec. Above 600°F	Field Notes
10-2	241	227	307	16	1,512	2,640	348	463	7,186	76	76	1,250	445	5.42	10" to top of straw
10-2	477	372	67	16	1,832	1,778	293	106	5,305	71	71	960	410	2.78	"
10-3	442	402	337	16	2,547	1,508	707	11	4,536	70	70	(2)	(2)	(2)	"
10-14	(2)	(2)	(2)	16	215	1,536	1,115	275	8,120	80	86	930	315	.06	10" to top of straw - ambient whirlwind
10-15	[illegible]	(2)	(2)	16	336	1,738	308	134	5,757	75	75	1,080	351	1.16	"
10-16	(2)	(2)	(2)	16	210	1,890	59	332	5,304	64	68	1,040	418	1.70	"
Average					1,130	1,754	375	167	5,779	77	77	1,054	399	2.14	"
10-4	40	130	380	16	1,238	1,838	106	54	3,470	68	27	1,080	341	1.40	22" to top of straw (backfire)
10-5	175	754	625	16	620	1,067	23	56	2,455	73	37	1,000	433	5.23	"
10-6	1025	287	255	16	175	420	217	80	3,411	91	39	1,200	(2)	2.32	"
10-14	136	(2)	(2)	16	158	75	217	23	4,725	93	86	1,380	437	4.28	14" to top of straw
10-15	75	(2)	(2)	16	41	614	195	34	3,705	87	79	1,290	(2)	1.41	"
10-16	(2)	(2)	(2)	16	112	768	34	11	4,821	96	85	1,200	412	3.52	"
Average					361	512	117	44.1	3,373	86	57	1,132	(2)	3.54	"
10-14	(2)	(2)	(2)	16	34	399	200	23	1,821	84	47	1,560	(2)	49.6	22" to top of straw
10-15	121	(2)	(2)	16	165	51	319	70	1,051	85	56	1,100	(2)	8.27	
10-16	131	(2)	(2)	16	56	132	122	21	1,781	92	72	1,020	(2)	.32	Aborted run
Average					85	194	177	12.4	1,818	88	130	1,227	(2)	31.58	

Date	Pass (?)	Sampler Rate	Duration of Sampling (min)	Part. Level at Tower (g/m³)	CO_2 Level (%)	Total CO (%)	Particulate Level (g/m³)	Part. Em. (lb/ton)	Part. Em. (lb/ac)	Initial Filter Wt. (g)	Final Filter Wt. (g)	Net Wt. (g)	Total Flow Sampling (CF)	Rate of Flame Spread (ft/min)	Filter Color	Wind Area	Tower Height (ft)	Average Temp. (°F)	Average Temp. Less Ambient Temp.	Average Temp.
10-2	1000	91.3	3	.016	.063	13.3	.363	4.68	12.40	4.9954	4.7968	.1967	93.3	33	9+	4.8	13	166		
10-2	3150	90.0	3	.001	.116	9.00	.133	5.90	15.88	4.3361	4.1435	.0639	90.0	(2)	3	3.1	13	133	33	144
10-3	[illegible]	89.6	1.33	.007	.113	6.96	.316	3.42	8.78	4.8141	4.7673	.0464	89.0	33	9+	3.3	13	119	96	191
10-14	3560	93.3	.18	.017	.063	1.73	.000	1.16	1.60	4.6602	4.6934	.0344	93.1	(2)	6	1.39	13	129	43	144
10-15	4400	96.3	1.5	.017	.733	10.6	.390	3.30	8.10	4.6666	4.1127	.0473	94.1	(2)	6	3.4	14	195	36	129
10-16	4109	91.0	4.0	.412	.100	16.7	.395	6.06	14.18	4.9936	4.2301	.1196	91.1	(2)	6	1.3	14	133	31	149
Average	3661	91.4	1.96	.011	.170	10.3	.391	3.33	1.30						1.1	3.1		138	42	132
10-4	3150	93.3	1.6	.016	.201	7.33	.368	6.71	6.36	4.7713	(2)	.1156	91.3	(2)	6	3.9	13	121	33	144
10-5	3163	87.0	3.3	.014	.354	11.18	.469	6.30	7.37	4.7767	(2)	.1116	87.0	4.13	9	3.7	13	313	56	111
10-6	[illegible]	86.9	3.0	.005	.293	11.30	.447	1.96	3.39	4.5311	(2)	.3637	90.3	(2)	7	5.8	13	641	56	130
10-14	4173	86.0	1.3	.376	.316	7.11	1.46	17.84	41.60	4.9967	4.7776	.2172	86.0	(2)	3 1/2	3.6	13	418	76	141
10-15	1364	11.9	2.89	.019	.455	37.0	.307	4.60	7.11	4.9304	4.7166	.1304	80.5	(2)	4 1/2	2.7	14	361	75	96
10-16	.010	41.6	1.3	.061	.376	6.33	.960	11.53	27.60	4.8443	4.0644	.1313	(2)	(2)	8	1.6	14	449	67	341
Average	3169	88.1	1.72	.011	.319	10.19	.479	8.44	11.77						7.4	3.1		433	71	133
10-14	2960	89.3	1.3	.061	.146	10.6	.396	4.66	6.96		6.3469	.0961	81.1	37.3						
10-15	[illegible]	89.6	1.45	.063	.655	13.1	.304	4.76	4.40	4.7309	4.6363	.1789	89.6	(2)	7	1.6	13	1,003	5	77
10-16	[illegible]	88.6	1.3	.013	.367	6.75	.347	4.33	6.11	4.7[illegible]	4.8315	.0613	89.6	(2)	8	7.7	14	420	7	79
Average	[illegible]	89.6	1.39	.313	.196	15.7	.379	4.39	3.13	4.5118					6	1.8	14	416	10	96
															7.1	1.1		334	11	114

(1) Cutoff for CO_2 [illegible]
(2) Data not taken in field
(3) Post burn straw and stubble were collected and weighed together. Stubble portion estimated on the basis of some laboratory separations.
(4) Shortfall noted, not used.

1971 SUMMER WHEAT STRAW BURNS Metric

Field No.	Residue Sample Weight (g)	Moisture (%)	Net Wt. (g)	Residue Quantity (kg/ha)	Ash Sample (g)	Ash Sample (kg/ha)	Residue Quantity (kg/ac)	Ash Quantity (kg/ha)	Relative Humidity %	Average % CO_2	g of Fuel Burned to Produce Part. Sample Collected (g)	Rate of Burn: Time	Rate of Burn: m	Rate of Burn: Speed (m/min)
1	450	3.8	640		151.19	1015								
	340	4.0	330		163.77	1102	4883	1270	39	.181	16	2.45	15	6.1
	790	4.1	760	5116	253.97	1694								
	680	4.2	650	4398										
2	770	4.4	730	4925	144.36	964								
	460	4.3	460	3119	363.16	2513	4532	1739	44	.229	32	.58	15	26
	510	4.0	490	3309										
3	620	4.4	600	4016	286.18	1930								
	450	4.0	440	2939	257.65	1795	3391	1862	38	.242	13	.32	15	43
	480	3.0	470	3152										
	540	4.8	510	3464										
4	1100	4.7	1080	7281	340.34	2289								
	1270	4.2	1220	8245	246.59	2333	7045	2311	37	.0944	23	11.55	15	1.3
	830	5.3	830	5609										
5	570	4.5	540	3646	200.70	1346								
	520	4.3	600	4016	209.19	1402	3968	1374	39	.0387	18	10.32	12	1.2
	650	3.6	630	3241										
6	950	4.4	930	6226	329.47	2221								
	600	6.0	560	3769	261.43	1750	5209	1986	38	.0716	11	13.45	15	1.1
	990	3.8	960	6439										
	680	4.2	650	4398										

Field No.	Burn No.	HiVol Filter: Initial Wt. (g)	HiVol Filter: Final Wt. (g)	HiVol Filter: Difference (g)	Ambient Temp. °C	Lapse °C	Wind Direction	Wind Velocity (km/hr)	Duration (minutes)	Flow Reading (m^3/m): Initial	Flow Reading (m^3/m): Final	Flow m^3/min	Average Tower Temp. (°C) (m^3/m Correction)	Soil Temp. °C	Maximum Tower Temp. (°C)	Corrected m^3/min	kg/MT	$g/m^3 \times 10^3$	g/m^3 @ 12% CO_2 $\times 10^3$
1	1	4.7570	4.8095	.0525	32	2.0	SW	9.3 5.1*	3	2.97	2.49	2.43	47	(1)	76	2.4	3.3	8.0	.529
2	4	4.7392	4.7614	.0422	38	1.2	W	7.1	4.10	3.06	3.03	2.66	43	91	43	2.7	1.32	4.2	.222
3	6	4.6314	4.6721	.0407	43	2.1	W	5.1	1.53	2.94	(1)	2.58	43	(1)	43	2.7	3.10	11.3	.561
4	*2	4.6914	4.7437	.0573	32	2.9	SW	7.7	8	2.86	(1)	2.52	52	24	137	2.4	2.46	3.2	.407
5	*3	4.6969	4.7253	.0284	32	.9	S	(1)	4.85	3.06	2.91	2.63	52	(1)	62	2.5	2.52	2.5	.420
6	*5	4.6912	4.7357	.0445	41	1.2	SW	5.1	5.85	3.03	2.86	2.63	76	98	137	2.4	2.51	3.5	.425

(1) No data available.

* Backfire burn.

1971 SUMMER WHEAT STRAW BURNS English

Field No.	Residue Sample Weight (oz)	Moisture (%)	Wet Wt. (oz)	Residue Quantity (lb/ac)	Ash Sample (g)	Ash Sample (lb/ac)	Residue Quantity (lb/ac)	Ash Quantity (lb/ac)	Relative Humidity %	Average % CO_2	Lbs. of Fuel Burned to Produce Part. Sample Collected (lb x 10^{-2})	Rate of Burn: Time	Rate of Burn: Feet	Rate of Burn: Speed (fpm)
1	16	3.3	15.4		151.19	905								
	12	4.0	11.5	4580	163.77	982	4353	1132	39	.181	3.504	2.45	50	20
	28	4.1	26.8	4560	253.97	1510								
	24	4.2	23.0	3920										
2	27	4.4	25.8	4390	144.36	860								
	17	4.3	16.3	2730	363.16	2240	4040	1550	44	.229	7.096	.58	50	86
	18	4.0	17.3	2950										
3	22	4.4	21.0	3580	205.18	172								
	16	4.0	15.4	2620	267.65	1609	3023	1660	38	.242	2.896	.32	50	156
	17	3.9	16.5	2819										
	19	4.0	10.1	3088										
4	40	4.7	33.1	6490	340.34	2040								
	45	4.2	43.1	7350	246.59	2060	6200	2060	37	.0944	5.130	11.55	50	4.3
	31	5.3	29.4	5000										
5	29	4.5	19.1	3250	200.70	1290								
	22	4.3	21.0	3580	209.19	1250	3537	1225	39	.0987	3.905	10.32	40	3.9
	23	3.6	22.2	3780										
6	34	4.4	32.6	5550	329.47	1980								
	21	6.0	19.7	3350	261.43	1560	4643	1770	38	.0716	2.482	18.45	50	3.7
	35	3.8	33.7	5740										
	24	4.2	23.0	3920										

Field No.	Burn No.	HiVol Filter: Initial Wt. (g)	HiVol Filter: Final Wt. (g)	HiVol Filter: Difference (g)	Ambient Temp. °F	Lapse °F	Wind Direction	Wind Velocity (mph)	Duration (minutes)	Flow Reading (CFM): Initial	Flow Reading (CFM): Final	Flow CFM	Average Tower Temp. (°F) (CFM Correction)	Soil Temp. (°F)	Maximum Tower Temp. (°F)	Corrected CFM	Lb/Ton	µg/m³ x 10^3	µg/m³ @ 12% CO_2 x 10^3
1	1	4.7570	4.8095	.0525	90	3.6	SW	5.8 3.2*	3	105	88	86	117	(1)	169	85	6.6	8.0	.529
2	4	4.7392	4.7814	.0422	100	2.2	W	4.4	6.10	108	107	94	110	195	110	94	2.62	4.2	.222
3	6	4.6314	4.6721	.0407	109	3.8	W	3.2	1.53	104	(1)	91	110	(1)	110	94	6.19	11.3	.561
4	*2	4.6914	4.7487	.0573	90	4.3	SW	4.8	8	101	(1)	89	126	76	278	86.5	4.92	3.2	.407
5	*3	4.6969	4.7253	.0284	90	1.6	S	(1)	4.85	103	103	93	126	(1)	143	88	5.04	2.5	.420
6	*5	4.6912	4.735[illegible]	.0445	105	2.2	SW	3.2	5.85	107	101	93	169	208	278	84	5.02	3.5	.425

(1) No data available.

* Backfire burn.

[illegible]

[illegible]	Moisture Content of Straw [illegible]	Center to Center Distances [illegible]	Height of Stubble Sample [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] FALL [illegible]

[illegible]	WEIGHT OF STRAW SAMPLES [illegible]	MOISTURE CONTENT OF STRAW [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible] CENTER TO CENTER DISTANCES [illegible] — WEIGHT OF STUBBLE SAMPLE [illegible] — POST BURNED STUBBLE [illegible] — MOISTURE CONTENT OF STUBBLE [illegible]

[illegible]

(1) no data available [illegible] (2) estimated from other burns [illegible]

(3) data estimated from burns [illegible] (4) [illegible] samples [illegible] of windrow

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Ambient Temp	Relative Humidity	Wind Speed	[illegible]	Particulates	[illegible]	[illegible]	Maximum Fire Temp	Average Fire Temp	Area Under Fire Temp Curve	CO_2 Area	Particulate [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(1) [illegible]
(2) No data

Date	Burn No.	Moisture Content of Straw	Moisture Content of Stubble	Cumulative Moisture Content	Ambient Temp. °F	Relative Humidity	Wind Speed mph	Time (sec)	Particulates (lb/ton)	Chloroform Soluble Organics (%)	Rate of Fire (ft/min)	Maximum Fire Temp. °F	Average Fire Temp. °F	Area Under Fire Temp. Curve (sq. in.)	CO_2 Area (sq in.)	Particulate Density
Spread Head																
6-19	1	(2)	(2)	(2)	89	38	(2)	102		48.0	(2)	1015	518	.66	1.43	5.57
	1	4	6	5	93	35	10	176	5.99	(2)	(2)	1053	637	.66	2.11	
6-21	3	4	14	11	91	32	(2)	145	4.97	5.6	(2)	1095	574	.75	1.09	1.32
6-22	3	7	15	9	78	46	15	174	7.92	(2)	152	1405	730	.77	1.87	14.70
6-22	2	9	11	10	64	55	10	(2)	3.71	(2)	1.30	1370	413	1.05	1.78	15.44
	3	9	15	13	66	56	10	(2)	5.07	(2)	1.38	991	559	.66	1.54	8.00
	5	9	10	10	70	53	6	(2)	1.10	5.9	71	1075	690	.66	1.66	9.40
6-23	4	6	5	5	90	33	6	45	.71	(2)	146	432	114	4.60	3.15	(2)
Average		7	11	10	79	47	10	154	5.5	19.8	125	1129	623	.75	1.64	9.41
Spread Back																
6-19	2	4	9	7	91	40	(2)	134	5.40	20.1	(2)	1106	640	2.47	3.09	2.27
6-21	1	8	13	11	88	34	(2)	510	7.28	11.8	(2)	426	454	.77	1.50	3.76
6-22	2	7	9	8	48	57	12	441	7.10	(2)	(2)	410	310	1.13	1.60	2.91
	4	7	10	8	68	56	17	709	5.23	(2)	(2)	769	517	.94	1.51	1.72
6-23	6	7	10	9	70	52	6	(2)	3.35	12.0	(2)	817	497	1.08	1.18	1.30
6-30	1	5	7	6	103	26	8	(2)	4.54	(2)	.4	960	641	1.90	1.07	1.88
	2	5	6	6	106	26	8	(2)	6.80	(2)	(2)	774	611	1.20	3.21	3.34
Average		6	11	9	85	42	10	530	5.70	14.6	.4	781	527	1.36	1.80	2.47
Spread Peripheral																
6-29	3	4	7	6	84	30	2	(2)	4.78	33.0	(2)	887	418	.40	1.44	18.00
	5	3	6	5	90	30	6	(2)	2.22	29.4	(2)	(2)	(2)	(2)	1.29	6.09
7-1	2	6	6	6	76	52	4	(2)	2.98	29.3	(2)	(2)	(2)	(2)	3.22	10.22
	4	5	11	9	83	42	3.5	(2)	4.51	24.8	(2)	942	421	2.44	1.67	14.39
Average		5	8	7	83	39	3.8	(2)	3.62	29.1	(2)	915	420	1.52	1.81	14.17
Spread Center																
6-29	7	6	9	6	78	40	4.0	(2)	6.93	16.8	(2)	398	325	1.07	1.67	7.09
	4	3	8	6	66	30	3.0	(2)	6.36	15.5	(2)	(2)	(2)	(2)	2.41	4.04
	6	3	8	6	90	29	3.5	(2)	6.25	13.2	(2)	(2)	(2)	(2)	1.93	3.63
7-3	1	7	9	6	70	64	3.0	(2)	5.66	16.7	(2)	231	117	1.46	2.42	5.54
	3	4	7	6	78	50	3.5	(2)	5.00	20.4	(2)	459	301	2.06	1.63	3.58
Average		5	8	7	81	45	3.4	(2)	6.04	16.5	(2)	529	314	1.52	2.03	4.76
Round Head																
6-20	1	4	(1)	4	84	38	6	(2)	3.79	5.9	(2)	(2)	(2)	(2)	2.38	8.38
7-3	5	4	(1)	4	91	36	8	(2)	5.39	44.2	(2)	1004	332	2.76	1.49	6.29
7-4	7	3	(1)	3	72	55	4	(2)	4.50	46.5	(2)	818	305	2.20	1.93	5.90
Average		4	(1)	4	83	43	6	(2)	4.33	32.9	(2)	911	319	2.40	1.93	6.62
Round Back																
6-28	2	4	(1)	4	93	32	5	(2)	3.97	(2)	(2)	1346	714	3.40	3.89	3.91
	3	3	(1)	3	94	38	6	(2)	4.79	(2)	(2)	1404	714	2.00	2.97	(2)
6-30	3	4	(1)	4	105	25	4	(2)	4.99	14.7	4	1267	735	6.00	3.10	(2)
	4	3	(1)	3	106	25	8	(2)	5.33	18.34	4	1518	765	3.90	2.73	9.75
7-3	6	4	(1)	4	90	35	12	(2)	4.72	22.25	3	1254	346	2.60	1.89	1.87
Average		4	(1)	4	98	31	7	(2)	4.76	18.43	4	1359	659	3.58	2.92	4.91
Raked Head																
7-4	2	5	(1)	5	75	54	5	(2)	3.97	30.09	46	1054	369	3.40	4.88	9.58
	4	6	(1)	6	83	43	6	(2)	7.43	57.58	(2)	918	350	2.06	1.89	12.30
	5	4	(1)	4	93	34	4	(2)	6.93	26.31	(2)	1256	360	6.00	1.71	5.34
7-5	6	4	(1)	4	87	35	8	(2)	3.69	28.11	(2)	1295	782	3.00	3.28	12.96
	7	4	(1)	4	87	32	12	(2)	3.49	41.24	(2)	1160	444	2.60	1.35	11.24
Average		5	(1)	5	85	40	7	(2)	5.10	36.70	46	1137	440	3.58	2.62	10.30
Raked Back																
7-4	3	6	(1)	4	77	51	9	(2)	5.51	25.65	(2)	1290	515	5.85	2.27	6.64
	7	4	(1)	4	94	32	9	(2)	5.05	20.37	(2)	1290	490	4.60	2.26	2.61
7-5	6	4	(1)	4	84	33	9	(2)	4.28	26.84	(2)	1122	549	5.64	1.44	1.98
	8	4	(1)	4	86	34	13	(2)	3.34	23.74	(2)	818	427	3.92	2.49	1.07
Average		4	(1)	4	86	30	9	(2)	4.55	24.15	(2)	1130	494	5.00	2.13	3.13
Piled Peripheral																
7-5	3	6	(1)	6	78	40	6	(2)	1.86	29.61	(2)	1295	935	7.22	1.57	4.71
Piled Peripheral																
7-5	2	7	(1)	7	74	50	6	(2)	.50	52.86	(2)	1180	580	20.82	3.04	1.04
Piled Center																
7-6		8	(1)	8	70	56	5	(2)	2.38	26.99	(2)	1295	915	37.30	8.12	8.11

(1) Negligible amount of stubble in field

(2) No data

Riverside Burning Tower Data - 1972 Metric

Riverside Burning Tower Data - September, 1972

Metric

Mival Filter No.	Date	Burn No.	Fuel (Rice Straw): Type of Burn*	Fuel (Rice Straw): Charge Dry Wt. (Kg)	Fuel (Rice Straw): Moisture Content	Ambient Air: Temp. °C	Ambient Air: Relative Humidity %	Fuel Concentration Kg/m²	Particulate Emissions: Total Kg/MT	Particulate Emissions: % Chloroform Soluble	Particulate Emissions: Soluble Kg/MT	Particulate Emissions: µg/m³ x 10³	Maximum Fire °C	Average Fire °C	Duration Sampling Min.	Ave. Temp. x Time °K x Sec.	Gaseous Emissions (Kg/MT): CO_2	Gaseous Emissions (Kg/MT): CO	Gaseous Emissions (Kg/MT): HC
152	9-12-72	1	F	3.6	40	16	72	.939	44.7	72	32.2	214.41	738	377	2.00	754	805.0	---	9.3
153	9-12-72	2	B	3.5	32	20	57	.978	13.5	65	9.8	23.47	702	414	1.90	787	1093.5	134.6	9.0
154	9-12-72	3	B	2.9	24	22	40	.802	13.6	47	6.4	77.19	616	348	1.80	626	1132.4	150.4	11.3
155	9-12-72	4	F	3.1	20	24	41	.856	25.6	68	17.4	215.38	561	250	.77	193	974.9	113.6	8.6
156	9-12-72	5	F	3.1	12	27	25	.855	4.0	48	1.9	48.14	(1)	(1)	(1)	(1)	1123.8	48.2	2.2
157	9-12-72	6	B	3.3	9	27	25	.914	3.3	14	1.0	24.58	876	554	1.82	1,008	1531.8	54.0	1.6
158	9-12-72	7	F(M)	3.1	10	27	25	.875	5.4	57	3.1	58.69	629	330	1.00	330	949.1	79.9	4.5
159	9-12-72	8	B(M)	3.3	9	23	20	.914	3.8	41	1.9	29.43	800	445	1.50	669	1277.4	57.4	2.5
160	9-13-72	1	F	3.2	32	13	71	.900	32.9	66	21.7	279.87	(1)	(1)	(1)	(1)	845.3	32.1	11.7
161	9-13-72	2	F	3.1	20	17	60	.856	19.5	64	13.0	184.78	357	176	1.5	264	1044.9	63.7	6.9
162	9-13-72	3	B	3.2	22	19	53	.830	12.9	65	8.8	73.39	665	374	1.78	656	1051.0	76.0	6.5
163	9-13-72	4	F	4.3	17	21	48	1.19	12.5	53	7.3	136.07	361	141	2.5	356	943.2	72.7	5.0
164	9-13-72	5	B	3.8	16	22	45	1.07	6.1	33	2.0	48.71	586	333	2.57	856	1348.5	70.2	3.2
165	9-13-72	6	F	6.6	10	24	40	2.40	3.2	27	.9	36.44	620	348	1.30	452	1116.3	41.2	1.3
166	9-13-72	7	B	8.1	11	27	25	2.25	1.4	38	.6	13.07	851	408	4.0	1,632	1500.1	42.3	1.0
167	9-13-72	8	P	19.9	9	30	25	5.57	2.9	70	2.1	27.71	851	671	1.5	1,007	1111.4	52.1	3.6
168	9-14-72	1	P	16.8	23	16	64	.471	7.4	45	3.6	104.30	733	502	5.5	2,761	924.8	41.5	6.2
169	9-14-72	2	F	7.4	21	19	56	2.08	8.7	49	4.3	113.12	523	216	2.50	540	987.7	80.0	5.3
170	9-14-72	3	B	7.6	17	21	48	2.14	5.8	38	2.2	54.05	766	427	5.30	2,263	1363.7	79.0	3.7
171	9-14-72	4	F	3.6	14	23	44	1.00	7.8	48	3.7	85.37	629	299	1.5	343	---	65.1	3.0
172	9-14-72	5	B	2.5	12	25	42	.655	5.8	58	3.4	39.97	503	216	2.09	451	560.5	66.1	3.5

Mival Filter No.	Date	Burn No.	Fuel (Rice Straw): Type of Burn*	Fuel (Rice Straw): Charge Dry Wt. (lbs)	Fuel (Rice Straw): Moisture Content	Ambient Air: Temp. °F	Ambient Air: Relative Humidity %	Fuel Concentration lb/ft²	Total lbs/ton	% Chloroform Soluble	Soluble lbs/ton	µg/m³ x 10³	Maximum Fire °F	Average Fire °F	Duration Sampling Min.	Temp. x Time	Gaseous Emissions (lbs/ton): CO_2	Gaseous Emissions (lbs/ton): CO	Gaseous Emissions (lbs/ton): HC
152	9-12-72	1	F	7.4	40	60	72	.192	89.4	72	64.4	214.41	1,361	715	2.00	1,430	1610.0	---	18.5
153	9-12-72	2	B	7.7	32	68	57	.200	27.0	65	17.6	23.47	1,296	778	1.90	1,478	2187.2	269.2	18.0
154	9-12-72	3	B	6.3	24	71	40	.164	27.2	47	12.8	77.19	1,161	659	1.80	1,185	2384.8	300.7	22.1
155	9-12-72	4	F	6.8	20	76	41	.177	51.2	68	34.8	215.38	1,041	482	.77	372	1949.7	227.1	17.2
156	9-12-72	5	F	6.8	12	80	25	.177	8.0	68	3.8	48.14	—	1	—	—	2247.6	96.3	4.4
157	9-12-72	6	B	7.2	9	80	25	.147	6.6	14	.9	24.58	1,608	1,029	1.82	1,870	3063.6	107.9	3.2
158	9-12-72	7	F(M)	6.9	10	81	25	.179	10.8	37	6.1	58.69	1,165	626	1.00	626	1899.1	159.7	8.9
159	9-12-72	8	B(M)	7.2	9	82	20	.187	7.5	41	3.8	29.43	1,472	833	1.50	1,250	2554.7	114.3	4.9
160	9-13-72	1	F	7.1	32	55	71	.186	65.7	66	43.4	279.87					1770.6	164.2	23.4
161	9-13-72	2	F	6.8	20	62	60	.177	38.9	64	26.9	184.78	675	348	1.5	323	2089.7	137.3	13.7
162	9-13-72	3	B	7.0	22	66	53	.192	25.7	66	17.0	73.39	1,229	705	1.78	1,254	2102.0	155.9	13.0
163	9-13-72	4	F	9.4	17	70	48	.244	24.9	58	14.5	136.07	682	286	2.5	715	1886.4	145.3	10.0
164	9-13-72	5	B	8.4	16	72	45	.218	12.2	33	4.0	48.71	1,087	632	2.57	1,620	2699.0	140.3	6.4
165	9-13-72	6	F	18.9	10	76	40	.49	6.3	27	1.7	36.44	1,148	659	1.30	856	2232.5	86.3	3.7
166	9-13-72	7	B	17.9	11	80	25	.46	2.8	38	1.1	13.07	1,563	767	4.0	3,070	3014.1	84.5	2.0
167	9-13-72	8	P	43.8	9	86	25	1.139	5.8	70	4.1	27.71	1,563	1,239	1.5	1,354	2222.7	104.1	7.6
168	9-14-72	1	P	37.1	23	61	64	.963	14.8	48	7.1	104.30	1,361	935	5.5	5,150	1849.6	163.0	16.4
169	9-14-72	2	F	16.4	21	66	56	.426	17.3	49	8.5	113.12	937	421	2.50	1,053	1975.4	159.9	10.6
170	9-14-72	3	B	16.8	17	70.5	48	.437	11.5	38	4.4	54.05	1,411	801	5.30	4,250	2727.4	158.0	7.4
171	9-14-72	4	F	7.9	14	74	44	.205	15.5	46	7.4	85.37	1,195	570	1.5	955		132.2	7.6
172	9-14-72	5	B	5.6	12	77	42	.140	11.5	58	6.7	39.97	937	421	2.09	842	1121.1	132.1	7.0

* F Indicates Front or Headfire burn

B Indicates Backfire burn

P Indicates Pile burn

M Indicates Simulated Mud under fuel

FIELD BURNING SMOKE DATA - 1973
Metric

Test	Date	Zone No.	Type of Burn	Charge dry	Moisture Content	Absolute Humidity	(1) Relative Humidity	Temperature °C	Fuel Concentration	Particulates Measured: Filter A (grams)	Filter A % Soluble	Filter B (grams)	Filter B % Soluble	Total (grams)	Rate of Burn	Gaseous Emissions: CO_2	CO	
[illegible]	6-4-73	1	F (8)	2.58	5.2	.0048	60	18	.867	5.0	(2)	3.1	(2)	8.1	3.3	1364.0	35.2	7.9
[illegible]	6-4-73	2	F (5)	2.58	6.1	.0060	62	19	.867	20.3	(2)	5.5	(2)	26.0	2.1	1355.5	129.5	7.9
[illegible]	6-4-73	3	B (4)	2.35	7.1	.0046	54	20	.960	2.8	(2)	.7	(2)	3.5	.8	1326.0	38.5	2.5
[illegible]	6-4-73	4	B (3)	3.54	4.0	.0051	54	22	1.034	13.2	49.6	2.7	37.4	15.9	.5	1462.6	115.2	5.1
[illegible]	6-4-73	5	C (4)	2.47	4.5	.0063	49.5	23	.596	4.8	57.1	.8	55.9	5.6	.4	1324.2	34.4	3.1
[illegible]	6-4-73	6	S (9)	2.47	7.1	.0056	43	24	.896	3.7	64.5	.7	63.7	4.4	1.2	1303.4	32.9	3.0
[illegible]	6-4-73	7	S (3)	.36	5.7	.0064	40.5	24	.237	11.2	48.9	2.1	48.3	13.3	.4	1472.0	71.3	5.7
[illegible]	6-4-73	8	S (9)	2.72	5.6	.0063	39	27	.916	2.3	65.3	.6	57.5	3.5	1.2	1262.8	29.3	3.9
[illegible]	6-4-73	9	S (9)	2.61	6.3	.0011	33	30	.562	3.8	67.8	.9	58.6	4.5	1.0	1319.7	36.0	2.6
[illegible]	6-5-73	1	F (8)	2.56	10.5	.0054	78	17	.867	5.8	61.0	1.7	50.7	7.5	1.1	1441.4	39.6	4.2
[illegible]	6-5-73	2	C (8)	2.58	10.2	.0011	49.5	18	.867	7.3	63.9	.9	49.2	3.2	.6	1194.2	33.3	2.7
[illegible]	6-5-73	3	S (4)	2.61	9.2	.0102	60.0	22	.882	3.9	61.6	.9	40.8	4.6	1.0	1464.1	32.8	2.4
[illegible]	6-5-73	4	F (9)	2.55	10.2	.0102	54.0	24	.963	6.5	66.5	1.0	48.3	5.6	2.4	1356.2	44.1	4.4
[illegible]	6-5-73	5	B (4)	2.72	14.1	.0101	47	26	.914	7.8	75.8	1.0	52.1	4.9	.7	1462.9	53.6	5.9
[illegible]	6-5-73	6	F (4)	2.63	12.6	.0099	39	29	.662	10.2	65.7	2.3	55.0	12.4	2.0	1233.7	59.2	4.3
[illegible]	6-5-73	7	B (4)	2.76	13.2	.0096	29	31	.925	5.1	78.1	1.1	55.0	6.4	.5	1423.2	52.6	7.0
[illegible]	6-5-73	8	F (8)	2.51	16.8	.0097	26	34	.915	4.1	54.6	2.2	49.3	11.0	2.0	1363.4	54.7	6.7
[illegible]	6-5-73	4	C (8)	2.72	20.9	.0092	26	36	.916	5.5	42.0	1.6	57.4	7.5	.7	1334.2	63.1	7.3
[illegible]	6-5-73	12	F (4)	2.72	14.3	.0103	24	36	.916	12.3	40.0	.4	34.2	17.7	1.6	1535.5	133.4	13.7
[illegible]	6-6-73	11	B (8)	2.76	11.6	.0037	25	36	.930	11.7	51.1	2.3	29.7	14.1	.5	1516.4	116.7	11.1
[illegible]	6-6-73	1	F (8)	.35	20.4	.0100	65	21	.413	12.2	82.5	3.0	75.8	15.3	1.8	965.0	64.9	6.7
[illegible]	6-6-73	2	B (8)	.35	21.1	.0099	62	22	.419	7.5	83.2	2.2	32.7	9.7	.5	1713.6	73.1	7.4
[illegible]	6-6-73	3	S (3)	1.13	17.9	.0101	46	27	.330	16.4	40.0	.1	37.1	21.0	.6	1491.9	87.7	10.4
[illegible]	6-6-73	4	F (3)	2.49	15.2	.0100	38	29	.374	24.7	42.3	.1	33.7	29.4	1.8	1256.6	149.3	12.0
[illegible]	6-6-73	5	B (3)	2.72	14.0	.0097	42	30	.314	12.0	65.0	3.0	33.1	15.0	.3	1272.5	135.7	15.4
[illegible]	6-6-73	6	[illegible]	2.72	13.4	.0031	27.5	33	.915	21.0	43.0	1.7	33.0	24.4	.5	1340.8	144.7	13.5
[illegible]	6-6-73	7	[illegible]	2.36	6.2	.0032	23.5	34	.334	12.3	86.6	2.4	55.7	14.7	.5	1361.7	30.5	5.6
[illegible]	6-6-73	2	B (4)	2.27	9.6	.0071	18.0	37	.750	9.3	55.4	1.7	52.6	11.0	.4	1235.1	33.3	7.3
[illegible]	6-6-73	10	[illegible]	.42	11.9	.0063	20	39	.273	5.5	68.6	.3	54.1	5.9	5.9	1252.5	24.0	5.9
[illegible]	6-6-73	11	F (4)	.42	11.1	.0061	23	38	.273	3.0	76.1	1.2	48.3	4.2	5.9	1251.5	29.1	3.5
[illegible]	6-7-73	1	S (9)	1.54	14.5	.0017	53.5	15	.351	1.6	68.1	.5	46.3	2.2	.4	1456.7	38.6	3.3
[illegible]	6-7-73	2	F (4)	2.49	7.2	.0037	58	22	.836	4.0	65.1	.8	50.2	4.9	1.6	1453.6	43.4	4.2
[illegible]	6-7-73	3	B (4)	2.34	7.2	.0037	36	28	.867	2.2	79.1	.6	41.8	2.6	1.0	1427.3	33.5	3.0
[illegible]	6-7-73	4	[illegible]	1.85	7.2	.0050	39	30	.838	1.8	63.2	.5	49.1	2.4	.7	1404.3	32.1	2.9
[illegible]	6-7-73	5	[illegible]	.34	7.3	.0061	33.5	30	.052	2.2	58.7	.5	55.5	2.8	.7	1547.5	38.5	3.5
[illegible]	6-7-73	6	F (3)	.46	5.3	.0084	29	33	.253	2.5	74.2	.4	33.3	2.9	4.9	1352.6	30.9	13.3
[illegible]	6-7-73	7	B (8)	.41	5.1	.0077	21	35	.307	1.6	67.0	.1	55.2	1.7	.5	1445.6	38.0	2.4
[illegible]	6-7-73	8	S (4)	.91	6.9	.0073	23	37	.307	1.5	64.1	.4	64.7	1.9	.8	1242.6	25.7	2.0
[illegible]	6-7-73	10	F (4)	.56	20.3	.0073	15.5	36	.237	2.7	72.6	.5	34.5	3.2	3.3	1189.9	27.0	3.0
[illegible]	6-7-73	11	S (8)	.72	1.3	.0073	15.5	32	.273	2.0	71.3	.4	42.1	2.4	.5	1295.0	32.4	3.7
[illegible]	6-7-73	1	S (3)	.56	1.5	.0073	15.5	32	.327	[illegible]	(2)	.5	52.0	2.5	.9	1344.8	29.3	2.2
[illegible]	[illegible]	2	S (4)	[illegible]	13.4	.0074	43.5	20	.316	2.6	57.4	1.0	43.6	3.8	.5	1634.1	46.2	5.1
[illegible]	[illegible]	3	S (4)	2.12	14.9	.0074	43	22	.916	4.3	35.5	1.3	44.3	5.8	.6	1515.0	63.9	4.6
[illegible]	[illegible]	4	S (3)	2.27	29.6	.0077	35	27	.916	3.9	53.1	1.1		5.1	.5	1334.3	39.7	5.3
[illegible]	[illegible]	5	S (8)	2.5	11.1	.0077	31	31	.760	3.7	63.1	1.1	37.2	4.4	.5	1295.5	36.8	4.9
[illegible]	[illegible]	6	S (3)	2.91	15	.0077	25	32	.445	4.3	72.6	.9	31.7	4.9	.5	1434.6	34.4	3.5
[illegible]	[illegible]	7	[illegible]	2.15	11.7	.0051	17	34	.760	4.3	86.4	.7	41.7	4.7	.5	1336.1	36.2	4.9
[illegible]	[illegible]	8	S (8)	2.30	12	.0072	20	34	.474	4.5	54.3	2.5	41.0	7.0	2.0	1198.3	39.2	5.4
[illegible]	[illegible]	1	F (3)	[illegible]	9.1	.0091	56	22	1.667	1.6	68.7	.6	64.6	2.5	1.2	1355.3	33.5	2.8
[illegible]	6-11-73	2	[illegible]	[illegible]	6.6	.0093	51	23	1.672	1.4	63.3	.4	62.4	1.9	.7	1121.8	34.5	2.5
[illegible]	6-11-73	3	S (3)	5.02	6.5	.0092	42	23	1.730	1.2	48.0	.5	33.2	2.3	.7	1332.9	32.2	3.5
[illegible]	6-11-73	4	F (3)	.36	12.2	.0093	41	25	.297	12.4	63.3	2.3	58.3	15.7	2.0	1051.0	67.2	7.8
[illegible]	6-11-73	5	B (3)	.32	16.7	.0081	40.3	27	.273	5.9	60.1	2.3	40.2	8.2	.6	1347.5	61.7	6.9
[illegible]	6-11-73	6	S (8)	.41	14.0	.0102	40	29	.327	7.6	52.7	2.4	46.3	10.1	.6	965.7	49.5	6.3
[illegible]	6-12-73	7	F (4)	2.49	7.6	.0092	34	26	.23	2.9	51.5	.9	41.8	3.9	1.2	1267.9	32.2	3.6
[illegible]	6-12-73	1	F (4)	2.52	9.7	.0066	34	31	.581	7.6	51.2	2.4	47.3	10.1	2.0	1235.6	44.7	4.4
[illegible]	6-12-73	2	[illegible]	2.16	12.7	.0090	31	31	.525	5.7	64.8	1.6	60.7	7.5	.5	1221.6	32.8	5.4
[illegible]	6-12-73	3	[illegible]	2.49	12.2	.0015	75.5	17	.413	3.1	74.2	1.2	50.6	4.5	.5	1574.2	34.8	3.6
[illegible]	6-12-73	4	B (8)	2.72	19.0	.0091	23	17	.906	2.3	72.3	.8	42.9	3.1	.6	1429.8	51.8	4.2
[illegible]	6-12-73	5	F (8)	2.76	25.5	.0090	65	33	.835	15.4	55.5	4.7	37.5	15.8	1.2	1296.8	76.2	13.1
[illegible]	6-12-73	6	F (8)	2.95	21.3	.0090	54	21	.974	14.6	55.0	3.6	39.4	18.1	1.1	1145.0	60.3	12.2
[illegible]	6-12-73	7	B (8)	2.31	24.2	.0091	15	27	.325	[illegible]	76.7	[illegible]	51.2	7.4	.6	1222.4	90.4	2.2
[illegible]	6-12-73	[illegible]	[illegible]	[illegible]	22.3	.0096	47.5	26	.443	2.6	73.2	1.4	53.3	4.0	.5	1144.4	64.8	9.5

(1) Estimates
(2) No data available

F Indicates Front or Head Fire Burn
B Indicates Backfiring Burn
C Indicates Center Fire Burn
S Indicates Strip Fire Burn

(8) Indicates [illegible] Straw
(3) Indicates Barley Straw
(4) Indicates Wheat Straw

Riverside Burning Range Data - 1973
English

Test Filter No.	Date	Burn No.	Type of Burn*	Charge Dry Wt. (lbs)	Moisture Content	Absolute Humidity	(%) Relative Humidity	Temperature	Fuel Concentration (lbs/ft²)	Particulates Measured Filter 1	Filter 2	Total (lbs/ton)	(fpm) Rate of Burn	Gaseous Emissions (lbs/ton) CO_2	CO	HC
334-335	6-4-73	1	F (R)	5.7	6.7	.0088	49	64	.178	10.0	6.2	16.2	10.7	2,750.6	78.4	5.8
336-337	6-4-72	2	F (R)	5.7	6.0	.0063	62	67	.178	40.7	11.3	52.0	5.6	2,774.2	237.3	15.6
338-339	6-4-73	3	B (R)	6.3	7.1	.0066	56	66	.187	5.6	1.4	7.0	2.5	2,614.8	77.0	5.7
340-341	6-4-73	4	B (R)	6.8	6.0	.0071	56	71	.213	25.5	5.4	31.9	1.8	2,364.6	130.7	11.5
342-343	5-4-73	5	C (R)	5.9	6.5	.0068	41.5	73	.188	9.6	1.6	11.2	2.7	2,611.2	76.5	6.3
344-345	6-4-73	6	S (R)	5.8	6.1	.0065	43	78	.104	7.4	1.4	8.8	4.0	2,629.6	47.8	6.3
346-347	6-4-73	7	S (R)	5.8	5.7	.0068	40.5	79.5	.059	22.4	4.2	26.6	2.7	2,547.2	159.9	11.5
348-349	6-4-72	8	S (R)	6.0	5.8	.0093	39	61	.184	5.7	1.3	7.0	4.0	2,556.1	58.2	3.9
350-351	6-4-73	9	S (R)	5.8	6.3	.0091	33	56	.181	7.2	1.9	9.1	3.6	2,642.4	72.1	5.7
352-353	6-5-73	1	F (R)	5.7	10.5	.0094	78	62	.173	11.6	3.5	15.1	3.6	2,920.1	79.2	8.5
354-355	6-5-73	2	B (R)	5.7	10.2	.0093	69.5	65	.178	4.7	1.8	6.5	2.1	2,591.7	66.1	5.4
356-357	6-5-73	3	S (R)	5.8	9.2	.0102	60.0	72	.181	7.6	1.5	9.4	3.2	2,322.5	65.6	5.7
358-359	6-5-73	4	F (R)	6.3	10.2	.0102	54.0	75	.197	9.1	2.1	11.2	8.0	2,737.5	95.3	9.6
360-361	6-5-73	5	B (R)	6.0	14.1	.0101	47	78.5	.158	7.7	2.1	9.8	2.2	2,529.1	111.4	11.1
362-363	6-5-73	6	F (R)	5.8	17.8	.0099	39	64	.161	20.5	4.3	24.8	6.4	2,793.5	118.6	17.9
364-365	6-5-73	7	B (R)	6.1	11.2	.0074	39	87	.190	10.6	2.3	12.9	1.8	2,849.6	104.1	14.1
366-367	6-5-73	8	F (R)	6.2	16.8	.0097	26	54	.194	17.7	4.4	22.1	4.4	2,729.8	109.5	17.5
368-369	6-5-73	9	B (R)	6.0	20.0	.0092	26	76	.188	11.9	3.2	15.1	2.2	2,638.9	125.4	15.7
370-371	6-5-73	10	F (R)	6.0	14.3	.0103	26	57	.188	54.6	10.9	75.5	5.3	2,073.2	267.0	27.5
372-373	6-5-73	11	B (R)	6.1	13.6	.0097	25	96	.131	23.5	4.7	28.2	1.6	3,037.0	237.6	22.3
374-375	6-6-73	1	F (R)	2.1	20.4	.0100	65	69	.066	24.5	6.1	30.6	6.3	1,972.2	138.0	13.4
376-377	6-6-73	2	B (R)	2.1	23.3	.0099	60	71	.066	15.0	4.4	19.4	1.8	3,425.0	142.0	15.6
378-379	6-6-73	3	S (R)	2.5	17.9	.0101	46	50	.078	32.8	10.2	42.0	1.9	2,957.0	135.6	20.3
380-381	6-6-73	4	F (R)	6.4	15.2	.0100	38	65	.200	49.4	10.2	59.6	6.0	2,536.3	235.0	28.1
382-383	6-6-73	5	B (R)	6.0	15.0	.0097	42	86	.134	24.1	6.0	30.1	.97	3,544.9	271.74	30.9
384-385	6-6-73	6	B (R)	6.0	18.4	.0091	27.5	91	.188	42.1	7.5	49.6	1.6	2,684.6	297.4	31.12
386-387	6-6-73	7	F (W)	5.2	6.2	.0082	23.5	93	.153	24.6	4.9	29.5	1.6	2,725.4	157.[illegible]	13.6
388-389	6-6-73	8	B (W)	5.0	9.6	.0071	18.0	95	.156	18.6	3.5	22.1	1.2	2,475.0	166.2	14.5
392-393	6-6-73	10	F (W)	1.6	10.9	.0080	20	102	.056	11.1	.7	11.8	19.2	2,567.8	43.0	3.7
394-395	6-6-73	11	F (R)	1.8	13.8	.0103	23	100	.056	6.0	2.4	19.2	19.2	2,520.0	58.5	6.3
396-397	6-7-73	1	B (R)	2.3	14.8	.0087	59.5	47.5	.072	7.3	1.1	9.8	1.4	3,721.5	76.0	6.6
398-399	6-7-73	2	F (R)	5.5	7.2	.0087	58	71	.172	8.1	1.7	9.8	5.1	2,520.5	86.8	8.5
400-401	6-7-73	3	B (R)	5.7	7.2	.0087	36	82	.178	4.5	1.2	5.7	3.2	2,612.2	67.9	6.1
402-403	6-7-73	4	B (R)	5.5	7.2	.0090	39	66	.172	3.7	1.1	4.8	2.3	2,311.7	64.7	5.4
404-405	6-7-73	5	S (R)	5.6	6.3	.0093	33.5	86.5	.175	4.5	1.4	5.6	2.2	3,097.7	77.3	7.1
406-407	6-7-73	6	F (R)	1.9	5.3	.0094	29	91	.052	5.0	.9	5.9	14.0	2,708.1	61.6	26.7
408-409	6-7-73	7	B (R)	2.0	5.1	.0077	21	95	.061	3.2	.2	3.4	1.8	2,902.5	72.0	4.8
410-411	6-7-73	8	S (R)	2.0	6.3	.0073	23	99	.063	3.0	6.1	11.1	2.7	2,467.9	51.6	4.0
412-413	6-7-73	9	F (R)	1.9	20.0	.0073	15.5	100	.059	5.5	1.0	6.5	10.7	2,322.4	54.0	6.1
414-415	6-7-73	10	B (R)	1.8	15.3	.0073	15.5	100	.054	4.0	.9	4.9	1.5	2,592.8	64.1	7.5
416-417	6-7-73	11	S (R)	2.1	15.5	.0073	15.5	100	.066	4.1	1.0	5.1	3.0	2,735.6	54.0	4.6
418-419	6-8-73	1	B (R)	6.0	17.4	.0074	49.5	64	.144	5.2	2.1	7.3	1.78	3,277.9	92.5	10.3
420-421	6-8-73	2	S (R)	6.0	16.0	.0078	49	71	.188	8.6	2.8	11.2	1.33	3,233.6	127.7	17.2
422-423	6-8-73	3	S (R)	6.0	20.8	.0077	35	80	.184	7.9	2.3	10.2	1.6	2,671.6	79.5	10.6
424-425	6-8-73	4	S (R)	6.3	13.1	.0077	31	86	.137	7.5	2.2	9.7	1.6	2,601.8	77.5	9.4
426-427	6-8-73	5	S (R)	6.2	15	.0077	25	89	.154	8.1	1.8	9.9	1.65	2,812.3	72.8	7.8
428-429	6-8-73	6	S (R)	6.3	13.2	.0056	17	92.5	.167	8.0	1.5	9.5	1.78	2,679.1	72.4	8.0
430-431	6-8-73	7	F (R)	6.4	12.8	.0072	20	94	.200	9.1	1.0	14.1	8.4	2,399.3	78.4	11.8
434-435	6-11-73	1	F (R)	10.9	9.1	.0091	56	71	.343	2.9	1.2	5.7	4	2,713.5	43.0	5.7
436-437	6-11-73	2	B (R)	10.6	8.8	.0093	51	73.5	.331	2.9	.9	3.8	2.18	2,845.2	69.0	5.1
438-439	6-11-73	3	S (R)	11.1	8.5	.0103	62	71.5	.349	3.6	1.0	4.6	2.29	2,664.8	64.5	7.1
440-441	6-11-73	4	F (W)	1.9	17.2	.0093	47	77	.059	24.9	6.6	31.5	6.4	2,104.3	134.8	15.6
442-443	6-11-73	5	B (W)	1.8	15.7	.0091	40.8	80	.054	11.8	4.7	16.5	1.23	2,734.0	123.6	13.4
444-445	6-11-73	6	S (W)	2.0	14.0	.0102	40	84	.063	15.3	4.9	20.2	1.41	1,833.5	99.1	13.9
446-447	6-11-73	7	F (R)	5.5	7.6	.0092	38	82.5	.172	5.9	1.9	7.8	4.36	2,538.6	64.5	7.3
448-449	6-12-73	1	F (R)	5.7	9.7	.0066	64	58	.183	15.3	4.9	20.3	6.4	2,474.0	89.5	13.2
450-451	6-12-73	2	C (R)	6.1	12.7	.0090	71	61	.190	11.5	3.6	15.1	1.5	2,545.7	105.7	11.9
452-453	6-12-73	3	S (R)	5.3	12.8	.0054	72.5	52	.167	6.6	2.5	9.1	1.5	3,151.8	77.6	7.3
454-455	6-12-73	4	B (R)	6.0	10.5	.0071	75	63	.126	4465	1.6	6.2	1.85	2,862.7	103.4	8.6
456-457	6-12-73	5	F (R)	6.1	25.5	.0090	65	95	.192	31.6	8.2	39.8	4.0	2,420.2	156.5	26.2
458-459	6-12-73	6	F (R)	6.4	21.3	.0090	58	89	.200	29.3	6.9	36.2	3.56	2,292.5	137.8	24.0
460-461	6-12-73	7	B (R)	6.1	24.2	.0091	56	71	.190	12.1	3.6	15.7	1.26	2,465.5	161.0	22.1
462-463	6-12-73	8	B (R)	6.2	22.4	.0074	62.5	74	.133	9.3	2.5	12.1	1.44	2,431.5	137.4	19.2

*F indicates front of head fire burn
B indicates backfire burn
C indicates center fire burn
S indicates side fire burn

(R) indicates rice straw
(B) indicates barley straw
(W) indicates wheat straw

1972 Fall Asparagus Burns

English

Burn	Type	Field	Notes and Observations	Moisture Content (% wet basis)	Final Filter Wt. (g)	Initial Filter Wt. (g)	Net Particulates Collected (g)	Sample Time (sec)	Average Temperature at Sampler (°F)	Initial Air Flow (in H_2O)	Final Air Flow (in H_2O)	Average Air Flow (in H_2O)	Average Air Flow (CFM)	μg/m³ x 10³	Corrected for Temp. μg/m³ x 10³	Temperature of Fire (°F)	Ambient Temp. (°F)	Relative Humidity (%)	Wind Speed (MPH)	% Chloroform-soluble particles	μg/m³ of Chloroform extractable [illegible]	μg/m³ x 10³ [illegible]	Rate of Mass [illegible]
11/27 #1	Sidefire	2nd field burned on 11/29/72	60% green material, 6 days after cutting	38%	3.5418	3.4172	.1244	33	125	.70	.40	.55	52.5	152	168	T (4) 1200	(3)	(3)	4-7	24	[illegible]	124	(3)
#2	Headfire		10% green material	31%	3.6090	3.5278	.0812	19.5	140	.70	.40	.55	52.5	168	190	"				36	[illegible]	[illegible]	47.4
#3	Smolder Headfire		Burned in late afternoon		3.9640	3.4158	.5482	120.5	115	.70	.40	.65	57.5	165	182	"			"	87	154	74	47.4
#4	Backfire		Ferns cut only once, 8 days after cutting		3.6590	3.5140	.0359	22.2	170	.70	.40	.55	52.5	156	185				"	25	46	119	1.9
11/30 #1	Field Backfire	1st field burned on 11/30/72	9 days after cutting, Ferns cut only once	23 = fern	3.4546	3.4200	0346	23	165	.70	.40	.55	52.5	70	83	(P)(4) 1100	75	26	3-4	25	21	62	(3)
#2	Field Backfire		3 beds raked together & placed on top of bed	62 = stalks	3.6113	3.5600	.0513	20	175	.70	.40	.55	52.5	104	125		"	"		15	19	116	
#3	Swath Headfire			Composite: 42%	3.4813	3.4234	.0579	13	150	.70	.35	.53	51.5	183	211	"	"	"	"	15	32	[illegible]	
#4	Swath Smolder				4.0503	3.4182	.6321	120	165	.70	.55	.56	54.0	207	244		"	"		49	[illegible]	[illegible]	
#5	Swath Backfire	2nd field burned on 11/30/72	9 days after cutting	16 = fern	3.5260	3.4391	.3.62	11	165	.70	.40	.55	52.5	316	373	(3)	75	25	0-1	10	37	136	8
#6	Backfire		3 beds raked together & placed on top of bed	10 = stalks	3.6862	3.5862	.0970	11	(2) 200	.70	.30	.53	50.0	374	466		"	"		18	44	162	8
#7	Headfire			Composite: 23%	3.5416	3.4312	.1104	11	100	.70	.30	.50	50.0	425	450		"	"	"	13	54	[illegible]	11.6
#8	Smolder				4.1160	3.4047	.7114	120	100	.70	.30	.50	50.0	251	265		"	"		46	122	143	(3)
#9	Background				3.5767	3.5714	0051	300	70	.70	.70	.70	60.0	.6	.6								

1972 Fall Asparagus Burns

Metric

Burn	Type	Field	Notes and Observations	Moisture Content (% wet basis)	Final Filter Wt. (g)	Initial Filter Wt. (g)	Net Particulates Collected (g)	Sample Time (sec)	Average Temperature at Sampler (°C)	Initial Air Flow (mm H_2O)	Final Air Flow (mm H_2O)	Average Air Flow (mm H_2O)	Average Air Flow (m³/min)	μg/m³ x 10³	Corrected for Temp. μg/m³ x 10³	Temperature of Fire (°C)	Ambient Temp. (°C)	Relative Humidity	Wind Speed [illegible]	% Chloroform-soluble particles	μg/m³ of chloroform [illegible]	μg/m³ x 10³ [illegible]	Rate of Mass [illegible]
11/29 #1	Sidefire	2nd field burned on 11/29/72	60% green material, 6 days after cutting	38%	3.5418	3.4172	.1246	33	52	.70	102	140	1.49	152	168	T (4) 649	(3)	(3)	6-11	24	[illegible]	[illegible]	(3)
#2	Headfire		10% green material	31%	3.6090	3.5278	0812	19.5	60	.70	102	140	1.49	168	190	"			"	36	69	122	12.9
#3	Smolder Headfire		Burned in late afternoon		3.9640	3.4158	.5482	120.5	46	.70	152	165	1.53	168	192	"			"	87	154	74	12.9
#4	Backfire		Ferns cut only once, 8 days after cutting		3.6590	3.5140	.0850	22.2	77	.70	102	140	1.49	156	185					25	46	119	[illegible]
11/30 #1	Field Backfire	1st field burned on 11/30/72	9 days after cutting, Ferns cut only once	23 = fern	3.4546	3.4200	.0346	20	74	.70	102	140	1.49	70	83	(P)(4) 593	75	26	5-6	25	21	62	(3)
#2	Field Backfire		3 beds raked together & placed on top of bed	62 = stalks	3.6113	3.5600	0513	20	79	.70	102	140	1.49	104	125	"	"	"		15	19	116	
#3	Swath Headfire			Composite: 42%	3.4813	3.4234	.0579	13	66	.70	89	135	1.46	183	211	"	"	"	"	15	32	179	
#4	Swath Smolder				4.0503	3.4182	.6321	120	74	.70	140	147	1.53	207	244	"	"	"	"	49	120	174	
#5	Swath Backfire	2nd field burned on 11/30/72	9 days after cutting	16 = fern	3.5260	3.4391	.3862	11	74	.70	102	140	1.49	316	373	(3)	75	26	0-2	17	37	136	2.4
#6	Backfire		3 beds raked together & placed on top of bed	10 = stalks	3.6862	3.5862	.0970	11	(2) 93	.70	76	127	1.42	376	466			"	"	18	44	162	2.4
#7	Headfire			Composite: 23%	3.5416	3.4312	.1104	11	38	.70	76	127	1.42	426	250		"	"	"	13	54	141	3.5
#8	Smolder				4.1160	3.4047	.7114	120	38	.70	76	127	1.42	251	265		"	"	"	44	122	143	(3)
#9	Background				3.5767	3.5714	.0051	300	21	.70	178	178	1.70	.6	.6		"	"	"				

(1) This data is for the second burn of the day. First burn data: moisture content = green material: 49%, dry: 23% (50% of the fuel was green).

(2) Filter brittle and cracked in center (perhaps glass fused on filter) (+ 316 °C)

(T)- thermocouple pole (P)- optical pyrometer

(3) [illegible] data taken

(4) Temperatures are representative values for head and backfire burn, respectively.