Agricultural Field Burning In the Willamette Valley

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Air Resources Center
Oregon State University
Corvallis

FOREWORD

One of the responsibilities assigned to the Air Resources Center, when it was established in September 1968, was to make the research findings and scientific expertise of the University available to assist in the development of public policy related to the air environment. This report is a contribution in fulfilling this responsibility.

Substantial research programs as well as training activities are under way at Oregon State University on aspects of field burning. This report draws heavily on these programs. Nearly all of the research on agronomic and disease factors, in utilization, and in meteorological areas has been conducted through the Agricultural Experiment Station in the School of Agriculture. Aspects related to assessing the contribution of this practice to air pollution has been handled principally through the School of Engineering. The programs have been closely coordinated. A contribution is also being made by the School of Forestry through research on utilization of straw in paper making.

The material contained in the "Summary and Outlook" and in the initial eight pages of the text is essentially the same as that contained in the previous report published in January 1969. The balance of the report, covering University research activities and accomplishments, presents additional material to that contained in the original report. The individual papers by staff members covering their research programs, contained in the original report, have been omitted from this draft in that most of them are no longer current. This material has been prepared by R. M. Alexander of the Air Resources Center at Oregon State University with assistance from R. W. Boubel, professor of Mechanical Engineering; D. O. Chilcote, associate professor of Crop Physiology; and J. R. Hardison, professor of Plant Pathology.

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SUMMARY AND OUTLOOK

* Field burning in the production of grass seed and cereal grain crops is a highly effective agricultural practice to accomplish residue disposal, field sanitation, seedbed preparation, and yield maintenance.

* Field burning involves major side effects in the form of air pollution. Like pollution generally, these side effects are passed on to others--in this instance, in the form of visibility loss, soiling and other damage to property, and a possible factor in harm to health.

* The field-burning practice is currently used in the Willamette Valley with an estimated 140,000 acres of perennial grass seed crops, 90,000 acres of annual ryegrass, and 85,000 acres of small grain crops. An estimated 700,000 tons of material is burned annually.

* From the standpoint of benefits to agriculture, the field sanitation provided to certain perennial grass seed crops is of prime importance. There are, at present, no satisfactory alternative control measures for certain diseases of these perennial crops. No chemical control alternatives are yet available; however, several promising chemicals are being tested.

* Field burning associated with annual crops--annual ryegrass and cereal grains--is beneficial from an agricultural standpoint primarily as a management practice which contributes to lower production costs. Disease control is not the important consideration that it is with perennials. However, certain annual ryegrass varieties are vulnerable to disease now controlled through field burning. Also, there are currently no suitable weed control herbicides for this crop. These annual crops represent an estimated 55 percent of the Willamette Valley field-burning acreage and two thirds of the tonnage of residue burned. With these crops, the main issue is one of removing large tonnages of residue economically.

* Because of the established benefits of burning in seed production, research is underway to find methods of controlled burning with minimum smoke emissions. Initial work was on propane flaming. This work demonstrated that this practice has application in providing sanitation after mechanical removal of most of the residue. Smoke emissions can still constitute a problem. Attention has now shifted to development of a portable field incinerator. The objective here will be to develop a machine that will burn the residue with a minimum smoke emission, while providing the necessary high temperature to the soil surface to destroy disease pathogens and weed seeds.

* Research to date indicates that straw removal in some form is critical with both perennial and annual crops. With perennials, it appears essential in effective production of all species. With annuals, the most feasible removal alternatives to burning are soil incorporation and mechanical removal. Large residue tonnages and heavy, wet-type soils pose problems with incorporation. It is important that a use be found

for mechanically removed material. Otherwise, it becomes a "solid waste" pollutant. Thus, straw utilization methods are being explored.

* One immediately available and promising utilization method with these crop residues would appear to be as a feed for livestock. Supplementation and pelleting are required. Gains of around 1.75 lbs/day were obtained in a test with beef heifers on a ryegrass straw ration. The use of pesticides could pose a problem in utilization of residues from certain species. Other potential problem areas in feed utilization would be the extent of market outlets for this material and how costs and animal performance would compare with other available feeds.

* Utilization of straw for industrial purposes is feasible, but technical and economic problems are involved. Straw can be used in producing pulp for paper, for example, but superior raw material sources from wood are available. An odorless kraft process could be used. Trials to date with annual ryegrass straw indicate that pulp yields at least as high as those from Douglas fir (45-50%) can be obtained. The paper produced from this pulp appears of high quality for certain uses, such as corrugating medium. High-grade cellulose, cellulose products, and plastics can also be made from straw. Industrial utilization for these purposes, particularly if geared to incorporating other waste products, appears promising. Other products, including chemical intermediates capitalizing on the energy stored in the carbon bonding of the straw, and pressed boards, have also been produced from this straw.

* Extensive research is underway on alternative crops for the heavy, wet type of soils now in grass seed production in the mid-Willamette Valley. Drainage, soil amendments, and irrigation will permit the production of higher value crops. Irrigation developments currently planned will have an impact in fostering a shift to other crops.

THE PRACTICE OF FIELD BURNING

This report summarizes available information on agricultural field burning in the Willamette Valley. Such information should be useful to all concerned with this practice and with the contribution it makes to air pollution in the State. The areas covered include background and basis for field burning; acreages, volumes, and emissions involved; programs underway at Oregon State University; and an assessment of certain alternatives to field burning.

At present, field burning (post-harvest burning of straw and stubble) is practiced with both perennial and annual grass seed crops and with a portion of the small grain cereal crops. The volume of smoke emissions during the late summer and fall when the now substantial acreages of these residues are burned has become a significant public issue.

This report is intended only to summarize relevant information and provide an outlook. No policy recommendations are made. The fact that the basis for and benefits of field burning from an agricultural standpoint are indicated, for example, should not be construed to mean that a continuation of this practice is thus recommended or not recommended in this report. This decision must be made through the political process--through group action with participation by all interests. The benefits of field burning as an agricultural practice must be weighed against harmful effects or "costs" in air pollution. It is hoped that the information provided will assist in this social decision.

Historical Background and Basis for Field Burning

Field burning as a cultural practice in the production of grass seed crops in Oregon dates from the mid 1940's. The practice was recommended at that time as a field sanitation measure for the control of the blind-seed disease fungus (*Gloeotinia temulenta*) which was then infecting some 90 percent of the perennial ryegrass crop in Western Oregon. Since then, nearly all fields producing perennial ryegrass have been burned following harvest. These burns have effectively destroyed the inoculum of the blind-seed disease, thus providing excellent control. At the time the practice was initiated, perennial ryegrass production in Western Oregon totaled some 50,000 acres, all in the Mid-Willamette Valley. As other crops have been added to the list of those on which post-harvest burning is practiced, more than 300,000 acres are now involved annually.

Post-harvest burning of straw and stubble is important for the control of other diseases of perennial grass seed crops. The most significant are ergot and grass-seed nematode. Climatic conditions in Western Oregon are favorable for the development of the ergot fungus. Most perennial grasses, including perennial ryegrass, are susceptible to this disease and heavy infections would result without adequate control programs. At the present time, field burning is the only effective method available for ergot control.

Grass-seed nematode, of importance with the fine-leaved fescues and the bentgrasses, is also controlled through post-harvest burning. At present, it is the only known method of satisfactory control in established fields.

The heat produced through burning straw and stubble following harvest is effective in providing at least partial control of a number of other grass diseases or disorders. Among these are the disorder, silver top, and a portion of the 125 grass rusts, 140 grass smuts, and 400 leaf and stem diseases of grasses, a number of which occur in Oregon. An added factor in disease control is that through residue removal, disease inoculum is reduced and a better base is provided for application and action of fungicides.

In addition to disease control, other important benefits now recognized from field burning include 1) removing residues effectively and inexpensively--with perennials, such residues shade and otherwise cause problems if not removed and, with annuals, subsequent crops are planted without cost of plowing or other seedbed preparation; 2) destroying weeds and weed seeds and providing a clean surface for better herbicide application and activity; 3) lowering the cost of nitrogen fertilization by eliminating residues that would otherwise require nitrogen in their decomposition; and 4) maintaining yields in perennial crops--thinning is provided and the "sod-bound" effect is at least partially overcome. Other benefits sometimes cited include fire hazard reduction as a result of early burned blocks stopping the spread of accidental fires, partial control of such pests as insects and rodents, and the release of minerals to the soil.

The extent of benefits from insect and rodent control has been questioned. Entomologists note, for example, that many serious pests of grass seed crops in Oregon are root or crown feeders. Observations indicate that field burning has little effect on this type of insect--cut worms, sod web worms, and bill bug larvae, for example. Also, field burning may foster the increase of certain harmful insects by destroying exposed insect parasites and predators, insectivorous birds, and small rodents which would have provided natural controls.

A recognized detrimental effect of field burning, in addition to air pollution, is harm to wildlife, including the destruction of habitat. An exception would be Canada geese which feed on ryegrass fields during the winter period.

Another area, apart from air pollution, in which the benefits vs. detrimental effects are not clear is the value of incorporation of these residues into the soil. Agronomic research generally has shown a beneficial long-term effect from "plowing under" such organic material. Obviously, incorporation is only employed with perennials when the planting is being abandoned. However, considerable organic matter is added to the soil throughout the life of the stand from breakdown of root material.

Incorporation can pose a problem with annual ryegrass and grain crops due to the large volumes of residue often involved. With the present heavy use of nitrogen fertilizer, straw and stubble volumes of five to six tons per acre are not uncommon in the Willamette Valley. Incorporation of volumes of this magnitude is often not feasible with present tillage methods. Some combination of mechanical removal and incorporation would be required.

Where residue volumes are lower and incorporation is feasible, particularly when the detrimental effects of air pollution are considered, the benefits of incorporation surely exceed the "costs." An even stronger case can be made where such problems as soil erosion or low water infiltration rates may be involved.

With perennial grass seed crops, recommendations to producers are that the straw and stubble be burned to provide disease control (and other benefits) as soon after harvest as possible--consistent with fire hazard conditions. Perennial grass seed is produced largely for out-of-state (including foreign) markets. Rigid quality standards, including high germination and freedom from seed-borne disease and noxious weeds, are imposed. The primary method now available to obtain these quality standards is through field burning. Effective and inexpensive residue removal and stimulation of production also have been recognized as important added benefits but they were not the original basis for recommending the practice of field burning with perennial grass seed crops.

Fields of annual (common) ryegrass are also burned following harvest. Most of this production is in one county--Linn. While some justification for this practice from a plant-disease control standpoint exists, it is not the clear-cut factor that it is with perennial grasses. Certain of the newer, early flowering annual varieties are vulnerable to blind-seed disease. There is also a danger of harboring disease which, in turn, could infect a perennial grass seed crop planted later on this same land. From the standpoint of the producers, higher costs of alternative methods of residue removal, the need for more fertilizer if the material is incorporated in the soil, and weed control are other key factors which lead them to practice field burning with annual grass seed crops. The practice with much of the annual ryegrass production is to reseed with a grassland drill without plowing or other seedbed preparation.

During the past several years, an increasing number of fields in cereal (small grain) production in Western Oregon have been burned to remove straw and stubble. This practice is most extensive with winter wheat. Acreages of this crop have increased markedly in Western Oregon in recent years. The basis for burning of grain-crop fields is that it provides a low-cost method of residue removal and contributes to weed control. Disease control through burning has not been established as an important factor with small-grain crops. However, certain growers have expressed concern that such disease problems as foot-rot could become serious if continuous wheat production was practiced without field burning. In the North Willamette

Valley counties, burning is fairly well restricted to fields that have been in grain and are being seeded to crimson clover and other small seeded legumes following burning (and without mechanical tillage). In the southern portion of the Valley, the practice of burning grain fields is much more prevalent, with low (or no) cost of tillage, less nitrogen fertilizer required, and weed control as the principal justifications.

Acreage and Residue Tonnage Involved in Field Burning

Grass seed is produced for harvest on approximately 260,000 acres in Oregon. All but about 15,000 acres of this production is in the Willamette Valley. The breakdown of this grass seed acreage by crop is as follows:

Crop		Acreage
Perennial Grasses:		
Perennial ryegrass		42,000
Bluegrasses		36,500
Fine fescues		33,500
Tall fescue		16,000
Orchard grass		10,000
Bentgrass		32,000
Annual (common) ryegrass		90,000
	Total	260,000

In a normal year nearly all of the fields making up the 260,000 acres in grass seed production are burned following harvest. The exceptions are certain old seedings to be plowed under and the creeping bentgrasses. Thus, excluding this acreage (assumed to be 15,000 acres) and the 15,000 acres produced outside of the Valley, an estimated 230,000 acres of grass seed fields are burned annually at present in the Willamette Valley.

Small grains are currently produced in the Willamette Valley on some 300,000 acres. For the Valley as a whole, it is estimated that weather conditions permitting, from 25 to 30 percent of this acreage has been post-harvest burned in past years. The highest percentage of burning took place in the mid-Valley counties. The percentage of small grain residue burned in the northern Valley counties has been much lower, with essentially no burning on lands adjacent to the Portland metropolitan area.

The volume of straw and stubble residue remaining following harvest of grass seed and small grain crops varies from around one-and-a-half to as much as six tons per acre, air-dry weight. Assuming that 230,000 acres of grass seed crops and 85,000 acres of cereals are burned annually in the Willamette Valley, the volume of residue burned would total some 700,000 tons. This assumes a one-and-a-half ton per acre average residue with bentgrass, the fine fescues, and bluegrass, and two-and-a-half tons per acre for the balance of the grass seed crops and the cereals. These estimates are conservative, particularly for annual ryegrass which has heavy straw volumes.

The largest and most concentrated grass seed production area in the Willamette Valley lies between Albany and Eugene. Over three quarters of the annual and perennial ryegrass acreage is in this area. The soils are heavy and poorly drained, and the range of crops that can be produced on these soils is limited. Installation of drainage and application of soil amendments would be required to increase the range of crops that could be produced. Irrigation would also be required with certain alternative crops.

Emission Content and Volumes from Field Burning

Emissions into the atmosphere from the burning of straw and stubble is characteristic of vegetative plant sources generally. Cellulose and lignin are the primary constituents. Emissions consist of smoke, made up of carbon particles of varying sizes, ash, and certain gases. Most of the carbon particles are minute in size and indistinguishable without visual aid, while others are readily visible. The former, characterized as aerosols and constituting "suspended particulates," are a major factor in reduced visibility, while the larger particles, which settle out more readily, are factors in soiling and deposits on property. The principal gases emitted are the organic hydrocarbons, carbon dioxide, carbon monoxide, and oxides of nitrogen.

On the basis of controlled burning tests, indications are that carbon particulate (larger soot particles and smaller suspended material) emissions from grass seed and cereal straw are in the 10 to 20-pound range per ton of material burned. Assuming an average figure of 15 pounds per ton with 700,000 tons burned, the total particulate material released into the ambient air of the Willamette Valley each year from field burning would total 5,250 tons. This does not include ash particles, including those remaining on the ground following burning, which may later be picked up by the wind to become air borne.

Tests by the University of California Air Pollution Research Laboratory at Riverside have shown that the level of total hydrocarbons (organic gases) in emissions from straw burning is in the same range as particulates--around 15 pounds per ton. These levels of particulates and hydrocarbons are based on favorable conditions both with the straw and the weather. Both particulate and hydrocarbon levels would increase with higher moisture content of the straw, presence of green regrowth, and weather conditions that would lower combustion efficiency.

Carbon monoxide levels in the California tests ranged from 80 to 120 pounds per ton of residue burned. Analyses for oxides of nitrogen were limited in these tests and did not permit expressing results in pounds per ton of waste burned. Concentrations during burnings, however, were reported as ranging from 21 to 42 parts per million.

Harmful Effects of Field Burning

Certain harmful effects of field burning are obvious and clearly defined, such as loss of visibility and soiling and other damage to property. Other effects, such as possible harm to human health, are not clearly established. However, because of recent public statements and press releases on the subject of possible health effects from smoke emissions from burning agricultural and forestry residues (straw and slash), some background on the subject appears important. It must be stressed that there has been no research at Oregon State University on this subject. Nor are there any research results from other sources, known to the authors of this report, that relate specifically to health effects from the particulates released through burning the type of plant residues involved here.

The concern, from a health standpoint, is that it is now being recognized that smoke particulates can play a role in making other pollutants more harmful. Scientifically, this is referred to as a "synergistic" effect--the combined effect from two or more pollutants exceeds the total of their individual effects. The carbon particulates in the smoke, it is being found, both adsorb and absorb gases and mists, which may be toxic. The particulates, it is believed, can then carry these toxic pollutants deeper into the lungs and hold them longer. Sulfur oxides, nitrogen oxides, and certain of the hydrocarbons are the air pollution gases with toxic properties that are present in most urban environments.

Particulates from field burning sources, during the fall period when this burning is underway, add to the particulates from other sources to provide the smoke ingredient for this possible combined (synergistic) effect. These other sources include furnaces, fireplaces, and stoves; backyard burning; industrial and commercial activities; automobiles and other transportation devices; and forestry practices. It must be noted, however, that in areas downwind from fields being burned, this source is recognized as the major contributor during the field burning period.

There are various areas of concern regarding the contribution of smoke from field burning to visibility reduction. These include the nuisance and property value effects on Oregon residents; the impact on the tourist industry; and hazards imposed (and possible economic loss) on such activities as air and road transportation. Research is being undertaken at Oregon State University on certain aspects of this visibility reduction problem.

RESEARCH AND SERVICE PROGRAMS AT OSU ON FIELD BURNING

Research has been conducted and is currently underway at Oregon State University in a number of areas relating directly and indirectly to the practice of agricultural field burning. The work concerns both reducing harm from field burning and providing a basis for alternatives leading to the reduction or elimination of field burning. Extension educational activities complement the research efforts.

Initial activities related to field burning (in addition to the work in the late 1940's that led to the development of the practice) began in the early 1960's on a cooperative basis between the seed industry, the University, and the United States Weather Bureau. The over-all objective of the program was smoke abatement. Areas investigated included timing of burns with weather conditions favorable to smoke dispersal and preventing concentrations of burns in the late fall.

Further efforts in research relating to field burning were undertaken in 1965 by the Schools of Engineering and Agriculture. In Engineering, a study was initiated by B. R. Meland and R. W. Boubel, supported through a federal training grant in air pollution. Objectives of this study were to determine "...the effect of environmental variables on grass field burning and...if conditions exist under which significant air pollution reduction can be achieved..." Companion studies were initiated by the Agricultural Experiment Station, under the supervision of D. O. Chilcote, on agronomic effects of various burning practices and by meteorologists W. P. Lowry and R. M. Black on weather relationships. Attention centered on meteorological timing of burning and estimating variation on a day-to-day basis of atmospheric volume available for dispersal of pollutants.

The cooperative program between the Agricultural and Engineering Stations was expanded in 1966 with the establishment of extensive field plots. Such factors as the effects of time and intensity of burning on smoke volumes and crop production were included. Both time of day and season of the year when fields were burned were related to smoke emissions and dispersion and subsequent seed yields. The agronomic phases of the work were fostered through a $10,000 grant from the seed industry.

Also, in 1966, J. R. Hardison, USDA Plant Pathologist, expanded his research on methods of eradication of seed infections. The diseases, now controlled by field burning, which are of prime concern in perennial grass seed crops affect the seed. Thus, this work had a close relation to field burning. Federal and seed industry funds, totalling $6,500 provided through the State Department of Agriculture, helped support Dr. Hardison's work.

With the biennium starting July 1, 1967, an appropriation at the rate of $50,000 per year was made available for expanded research. This was reduced in the 1967-69 biennium because of a cutback in State support resulting from defeat of the tax measure, but the appropriation level was restored for the current biennium, 1969-71. Then in November 1969 an additional appropriation of $75,000 was made through the State Emergency Board to develop and test a portable field incinerator. In addition to the increased State support, certain redirection of existing programs, including staff time, has added additional support in the Agricultural Experiment Station to the field burning program. Elsewhere in the University, strengthened work in the area of atmospheric science or meteorology is helping to provide basic knowledge on atmospheric conditions and pollutant dispersal. Also, several grants from Federal and State agencies are supporting research that relates to the field burning problem.

The balance of this section is devoted to a summary of current research programs and accomplishments. They are covered under the three principal phases underway. These are 1) agronomic relationships and alternative pest control and residue removal methods; 2) pollution emissions and meteorological relationships; and 3) straw utilization.

Agronomic Relationships and Alternate Pest Control and Residue Removal Methods

A major project underway in the Agricultural Experiment Station, under the leadership of Dr. David O. Chilcote, associate professor of Crop Physiology in the Department of Farm Crops, is concerned with agronomic aspects of the field burning practice and with alternative field sanitation and residue removal methods. Extensive field tests with both perennial and annual seed crops are continuing. Information on perennials being obtained here includes the effect of burning methods on subsequent seed yields and quality, and on smoke emissions. Burning pattern variations include season of the year, time of day, amount of residue and heat intensity. Other techniques of supplying high-temperature sanitation with perennial grasses (controlled incineration and flaming) are being studied. Other work involves experimental burning under different meteorological conditions to determine effectiveness of the burn both culturally and in minimizing air pollution. The engineering group, under Dr. R.W. Boubel, has determined types and quantities of emissions from the experimental burns and provided aerial surveillance during this burning season on such factors as smoke dispersion and drift. Atmospheric conditions have also been recorded during these flights.

Experiments have also been conducted on different ways of handling the residue resulting from annual crop production. This work has covered both annual ryegrass and small grain crops. Practices studied have included soil incorporation (plowing under) under several different conditions, physical removal through baling and field chopping, and using alternative incineration techniques such as field flaming with a propane burner. Much of the latter work has been under the direct supervision of Glen E. Page, associate professor of agricultural engineering.

Other studies in the agronomic area have involved assessing the effectiveness of weed and plant disease control with different burning methods or alternatives to burning. Extensive trials, for example, are underway in seeking satisfactory methods for weed control.

Considerable effort was devoted during the summer of 1969 to exploring the feasibility of mobile incineration equipment. The results of the plot work and other relevant research have been provided to possible manufacturers of such equipment to assist them in their feasibility studies.

In November 1969 a project, financed with the $75,000 Emergency Board appropriation, was undertaken by the Agricultural Experiment Station to develop and test a mobile field incinerator. Plans are for a proto-type model for testing in 1970 that will cover one and a half acres, with a 5-ton residue level per hour. Less residue will permit a faster operating speed.

In studies in Agricultural Economics, the results of the agronomic and related research are being utilized in economic analyses of various practices and alternatives.

With the addition made to State appropriations in 1967, an allocation of $8,000 per year was made to Dr. John R. Hardison, professor of plant pathology and USDA pathologist, to permit expansion of his efforts in seeking chemical control methods for the diseases involved in the perennial grass seed crops. Extensive screening trials of all available new chemicals were initiated. In addition, certain basic work on the nature of the disease organisms involved was undertaken. This type of information will be of value in providing guidance as alternative methods to open field burning are considered with perennial crops.

Resume of Accomplishments on Agronomic, Pest Control and Alternative Residue Removal Research

Research conducted on this phase was cooperative between the Departments of Farm Crops, Botany and Plant Pathology, Agricultural Engineering, Mechanical Engineering, Agricultural Economics, the United States Weather Bureau's Agricultural Meteorology Program at Oregon State University, and the University of California Air Pollution Laboratory at Riverside.

* Determined for six different grass species at five different locations in the Willamette Valley, the optimum time for incineration for favorable smoke transport and dispersal. Experimental plots were burned at different times of day and year, and under different climatic and straw conditions, to elaborate effects on smoke emission and dispersal.

* Investigated the effect of acreage burned, location of the burns, and varying meteorological conditions on the air quality at Eugene. Computer analysis of acreages burned on various days throughout the year led to the development of a formula for predicting acreages which can be burned under certain environmental conditions consistent with good air quality at a prescribed location.

* Evaluated removal of part of the residue from grass seed fields (six different species) prior to incineration as a means of reducing pollutant emission. Although disease control could not be fully evaluated, this method was effective in reducing the total amount of residue burned with little adverse effect on seed yield and quality. However, conditions for burning must be favorable (low moisture and high temperature) for uniform residue incineration.

* Investigated burning of fields on other than an annual (every year) basis for several grass seed species grown in the Willamette Valley. One pattern, alternate-year burning, results indicate, could be used to reduce total residue burned with such perennial grass species as orchard grass and bluegrass. However, other species, especially the fine fescues, showed a severe reduction in yield (some as low as 25% of the yield of early burned plots) when not burned annually. Mechanical removal of residue in the alternate year was found necessary to maintain seed yields.

* Evaluated the reduction in smoke emission and effect on seed crop stand and yield by firing of fields into the wind (backfiring). Combustion, in most cases, was improved, pollutant emission levels were reduced, and no excessive damage to the crop stand was detected; however, the operation is quite time consuming and subject to the hazard of wind change. Different backfiring techniques are being explored to find solutions to some of the problems of the backfiring methods used in these tests.

* Tested disposal of straw residue by pile burning after removal from the field to determine if this method would reduce smoke emissions. Firing of straw piles from the top down accomplished disposal with appreciably lower pollutant emissions than result from open burning. Removal costs would cast some question on the practicality of this approach.

* Established the emission characteristics of various grass seed crop residues when straw was of different moisture contents. Results showed little variation between the various grass seed species studied. Throughout, however, higher pollutant emissions were associated with higher moisture levels.

* Evaluated various mechanical methods of removing residue from grass seed fields after harvest in extensive tests at several locations of six different grass seed species. Removal of residue by raking, and flail chopping of the residue were compared to leaving the residue intact following combine harvesting. Effects on seed yields as compared to field burning were determined. Results show that mechanical residue removal may be feasible on a short-term basis for certain of the crops (orchard grass), while in others, very substantial reduction in yields will result (fine fescue). Yields were highest with methods which removed maximum residue.

* Determined the possibilities for increased decomposition of residue and effects on seed yield in the various grass seed species where residue was chopped and spread. The chopping and spreading operation was found to be little better than allowing the residue to remain intact on the field after the harvest operation.

* Investigated, for annual crops, various methods of residue incorporation into the soil. Results indicate that the crop residue must be chopped to allow incorporation with existing equipment. Plowing was found to be the most feasible method for efficiently preparing a seedbed where

large volumes of residue were incorporated. Decomposition of the incorporated straw in the soil was found to be extremely slow with a high percentage of the residue remaining after two years. Incorporation methods which mix the straw and soil more intimately are being evaluated.

* Studied need for supplemental amounts of fertilizer where residue is incorporated or allowed to remain on the soil surface. Results show essentially no yield increases with added increments of fertilizer, and often yield reduction was noted with higher rates of fertilizer use. Studies are underway to relate fertilizer levels to residue decomposition rates in the soil.

* Investigated methods for controlling weeds where burning was not practiced. One benefit of field burning is providing a clean surface to enhance herbicide effectiveness. All results indicated increased effectiveness through some method of residue removal (most effective with burning or flaming). In annual ryegrass where burning has constituted the main weed control method, tests were established utilizing contact herbicides for destroying weed seedlings prior to seeding. Paraquat was found to be a promising herbicide for such a weed-control process; however, it is necessary to wait until weed seeds have germinated before chemical application, thus delaying seeding of the annual crops until later in the fall when precipitation patterns may jeopardize establishment.

* Determined possibilities for establishment of annual ryegrass without tillage, with or without removal of the crop residue. Two experimental drills designed for such operations were tested extensively. Removal of straw facilitated the drilling operations. If satisfactory weed control could be obtained through methods other than burning, non-tillage seeding would appear to be a promising establishment technique. Where the soil is not tilled, seeding can be accomplished much later in the fall and ground applications of fertilizer and pesticides can be made under wetter soil conditions.

* Evaluated propane flaming as a sanitation measure where most of the residue has been removed from the grass seed fields. Subsequent yield of the grass seed crops show this to be a very effective alternative to open field burning. Although substantial reduction in smoke emission can be envisioned by this method, the remaining residue (80-90% of residue is removed) still constitutes a smoke-emission source during the flaming operation. Various modifications of flamer design and application were tested in attempting to improve the flaming operation. Another problem facing this alternative method is the need for removal of a percentage of crop residue before flaming, a time consuming and expensive procedure at present. There is concern that disease control will be less effective than under open burning.

*Initiated a program to develop and test a portable field incinerator. Data relative to critical temperatures needed for field sanitation and to provide the physiological stimulation to certain of the perennials was assembled as criteria for this equipment. A plan for a prototype machine for testing with the 1970 harvest season has been developed.

* Applied monetary values to physical data obtained in various trials covered above in an economic study to assess the added production costs that would be imposed with alternative burning methods or with cultural practices other than burning. Work has now been initiated on comparing present and possible costs (with different production methods) to those existing in other grass seed producing areas.

* Assessed effectiveness of field burning for control of major diseases: blind-seed disease, ergot, and grass seed nematode. Burning gave excellent control of blind-seed disease in perennial ryegrass and tall fescue with no disease found in 98% of fields in 1967, 99% in 1968, and 99% in 1969, with the remainder having only a trace infestation. Ergot control in 1967 in perennial ryegrass showed 59% no ergot, 41% trace; for 1968, 35% none, 61% trace, 4% very light; for 1969, 54% no ergot, 28% trace, 9% light, 2% moderate, and 7% heavy. In tall fescue, 82% of fields showed no ergot in 1969. A sharp increase in ergot during 1969 in turf-type perennial ryegrasses which were not burned in 1968 points to the rapid increase that can result if burning is not done. Grass seed nematode was found in significant amounts only in fields that had not been burned in recent years.

* Conducted extensive tests on chemicals as an alternate method for control of blind-seed disease and ergot. Two approaches are being studied; 1) prevention of seed infection by systemic chemicals applied to soil with root uptake or applied to leaves and inflorescences; and 2) elimination of the primary (ascosporic) inoculum by preventing formation of spore cups (apothecia) in blind seed and of perithecia in ergot. Some 40 chemicals were intensively evaluated and tested at three to five-dosage levels. Only one chemical has shown chemotherapeutic control in preventing seed infection, but heavy dosage rates were required that would make the practice too costly for commercial use. Several chemicals have prevented formation of blind seed apothecia, and one is considered promising for field plot tests. Results on elimination of the ergot primary inoculum have been much less promising. No chemicals appear promising for control of grass seed nematode at present. However, prospects for development of effective chemicals are improving. Over 50 new systemic chemicals will be evaluated during winter-spring 1969-70 for control of ergot, blind seed, stripe smut, flag smut, and stripe rust. This number of systemic chemicals is greater than the total previously available.

* Tested aerated steam as a heat source on various grass disease pathogens. Aerated steam shows promise for disinfecting seeds. The critical point is the extent to which moist heat would be more effective than dry heat in killing pathogens.

* Determined soil, atmosphere and residue conditions for experimental burns at various times of the day and year. Collected information on the amount of residue, its moisture content, wind speed and direction, air temperature and humidity and soil temperature and moisture. In addition, the temperature conditions at various points above and below the soil level were determined during incineration. Data was also collected on CO_2 and CO levels, particulate emissions, and meteorological variables with varying heights in atmosphere during burning of the test plots.

* Studied temperature effects on weed seed viability to determine the level and duration of temperature exposure necessary for thermal destruction of the embryo. Several different weed species were examined in tests which were conducted both in the laboratory and in the field. The temperature level and duration necessary for destruction of the seed was established. Germination levels of the seeds of economically important weed species were determined prior to burning and following burning. Limited tests are also underway on certain of the disease pathogens involved in grass seed production.

* Evaluated the effects of field burning on perennial grass plants in order to ascertain specific responses to high temperature regarding plant mortality, tiller development and stand density as these relate to maintenance of high yields through burning. A number of tests concerned with plant response to burning and other thermal applications are underway.

Pollutant Emission and Meteorological Relationships

In early 1967, a grant was received by the School of Engineering from the national air pollution agency for a three-year study on "Air Pollution from Agriculture and Forestry Burning." Dr. R. W. Boubel was project leader. The study is concerned with the "atmospheric emissions from open burns to determine their contribution to the air pollution burden of the area." This grant has supported the engineering phase of the cooperative program described earlier in which emissions from plots and experimental burns in the agronomy project are determined. Support under this grant has also provided for the observation of smoke plumes and for meteorological measurements made from airplanes while the burning is underway.

In addition to the support provided to the field burning effort from Dr. Boubel's research grant, several of the students who are trainees under the air pollution training grant, under his leadership, have thesis problems relating at least indirectly to field burning.

Several activities in the meteorological field relate to agricultural field burning. The Agricultural Weather Bureau Office on the campus, with Earl M. Bates as agricultural meteorologist, devotes considerable attention to applied research and service activities concerned with field burning.

For example, considerable consulting is provided to the Department of Environmental Quality on meteorological factors. In addition, a limited research project under the leadership of Mr. Bates and Dr. Chilcote has been concerned with relating acreages burned on specific days to visibility and meteorological data on those same days. As part of this project, financed in 1969 through a $2,500 grant from the Department of Environmental Quality, a University employee has obtained data through rural fire districts, extension offices and directly from growers on acreages for which permits were issued for burning each day by species and location. The same data was obtained for the two previous years. Analyses, utilizing the Oregon State University computer, are made to identify the important meteorological parameters related to "good" or "bad" burning days.

Several studies under the direction of Doctors E.W. Hewson, W.P. Lowry, and Lars Olsson, concerned with basic meteorological conditions prevailing in the Willamette Basin, have contributed materially to the general understanding of these conditions. They have clearly pointed to the high air pollution potential in this basin with its restricted lateral and horizontal air movement.

Several reports have been released summarizing the results of research on emissions and meteorological relationships. These reflect the accomplishments from this phase of the total field burning research effort. Those which either report results directly concerned with field burning or which contribute information of importance in understanding meteorological conditions that relate to the air pollution problem from field burning are listed below:

Azarbaijani, Masoud, "Agricultural Field Burning Plume Rise," Unpublished Masters Thesis, Oregon State University, June 1970.

Berg, N., and W.P. Lowry, "Trends in Visibility at Salem, Oregon, 1958-67," presented at Annual Meeting, Pacific Northwest International Section, APCA, Vancouver, B.C., November 21, 1968.

Boubel, R.W., E.F. Darley, and E.A. Schuck, "Emissions from Burning Grass Stubble and Straw," J. APCA, v. 19, no. 7:497-500 (July 1969).

Boubel, R., "Gaseous Emissions from Agricultural Burning," presented at Annual Meeting, Pacific Northwest International Section, Air Pollution Control Association, November 1969, Portland, Oregon.

Lowry, W.P., "A Basic Atmospheric Model for Air Pollution Climatology," presented at Fifth Annual Meeting, Pacific Northwest International Section, Air Pollution Control Association, Salem, Oregon, November 9, 1967.

Lowry, W.P., and H.E. Reiquam, "An Index for Analysis of the Buildup of Air Pollution Potential," presented at Fifth Annual Meeting, Pacific Northwest International Section, APCA, Salem, Oregon, November 9, 1967.

Lowry, W.P., "A Tentative Model to Estimate Requirements for Rise of Large Smoke Plumes from Prescribed Burning," presented at Fifth Annual Meeting, Pacific Northwest International Section, APCA, Salem, Oregon, November 9, 1967.

Lowry, W.P., James L. McElroy, and B.R. Pavelka, "Recent Studies of Air Pollution Meteorology in Oregon," presented at the Annual Meeting, Pacific Northwest International Section, APCA, Vancouver, B.C., November 2-4, 1965.

Meland, B., and R. Boubel, "A Study of Field Burning under Varying Environmental Conditions," J. APCA, 16:481-484 (September 1966).

Olsson, Lars E., and E.W. Hewson, "Study of the Natural Ventilation Near Portland, Oregon," presented at the Seventh Annual Meeting, Pacific Northwest Section, APCA, November 24-25, 1969.

Prodehl, V.H., and W.P. Lowry, "The Development and Application of an Air Pollution Potential Advisory Index as an Aid to Controlling Open Burning," presented to Seventh Annual Meeting, Pacific Northwest International Section, APCA, Portland, Oregon, November 25, 1969.

Roach, M.D., and E.W. Hewson, "Meteorology as a Tool in Air Pollution Control in the Willamette Valley, Oregon," presented at the 62nd Annual Meeting of APCA, New York, New York, June 22-26, 1969.

Crop Residue Utilization

In 1968 and 1969 considerable emphasis was placed on research related to utilization of the straw residue. As noted above, an OSU survey had indicated that more than 300,000 acres in the Willamette Valley were currently being burned, and that residue volumes involved would exceed 700,000 tons. An estimated two thirds of this residue is from annual crops. An important reason for the burning of annual crops is low-cost residue removal to facilitate the seeding of the subsequent crop. It was, therefore, determined that increased attention should be placed on utilization research with emphasis on the annual crop residues.

This research explored the use of grass straws as livestock feed, as pulp for paper making, and as raw material for production of such industrial products as plastics. Other exploratory work was done on microbiological breakdown employing high energy sources to enhance the process.

Studies were conducted in the livestock feed area. One involved a feeding trial for wintering replacement beef heifers on supplemented ryegrass-straw pellets. Three different rations were tested. Straw content in the rations was 67.1, 77 and 84.2 percent. Supplements, including molasses, urea, cottonseed meal and barley were utilized to increase palatability and the energy and protein content of the feed. Average daily gains during the winter feeding period were 1.53, 1.74, and 1.77 pounds per day. Volatile fatty acid production was measured. Pelleting cost at a well-equipped commercial plant in the State is $10 per ton. As a "rule of thumb," livestock feeders and animal nutritionists figure animals of the type used in this study will gain approximately one pound per day when fed a standard ration of loose alfalfa hay.

The second effort in livestock feeding was an *in vitro* digestibility study on unsupplemented ryegrass straw using the artificial-rumen technique. Digestibilities comparable to medium quality hays were obtained (50 to 54 percent).

A number of analyses were run to obtain information on the chemical composition of the various straw residues. In other tests, additives were evaluated for use in pre-ingestion fermentation. These tests were conducted at the USDA Utilization Laboratory in Albany, California and by the OSU Departments of Animal Science and Agricultural Chemistry. Data from these analyses will be of value to all of the research activities related to straw utilization.

Research in chemical extraction of components having potential value as industrial raw materials was handled in conjunction with a research project financed by the Office of Solid Waste entitled "Chemical Transformation of Solid Waste." Industrial raw materials which were extracted and studied included cellulose, lignins, pentosans, and waxes. The purified cellulose was used to make cellulose acetate plastic on a laboratory scale. The pentosans were converted to furfural. A study of potential uses for the waxes and lignins was initiated.

In another study concerned with industrial utilization, certain of the grass seed straws, principally annual ryegrass, were tested for use in paper making. Preliminary tests demonstrate that a satisfactory pulp can be produced which, in turn, can be manufactured into certain grades of paper. The paper produced is of superior quality for certain uses, e.g., corrugating medium. One process utilized sodium hydroxide for pulping, thus eliminating the problem of malodorous organic sulfur gas emission, typical of the kraft process. Yields of pulp from annual ryegrass straw were found comparable to those typically obtained from wood (range of 45 to 50 percent).

Studies in microbiology were conducted in conjunction with a research project supported through a Solid Waste grant. Under this study--"Laser Mediated Solid Waste Fermentation"--organic material including grass-seed straw was subjected to stresses from lasers and other high energy sources to facilitate efficient microbial degradation in both animal digestion and soil breakdown processes. This process has been designated as "photofermentation." Primary attention in the broader project has been devoted to lignin, which is extremely resistant to microbial action. Under ideal conditions, ligninolytic fungi, for example, are capable of transforming only 30 to 40 percent of lignin carbon into carbon dioxide in a six-month period. Through use of the photo-fermentation process, it has been found that the lignin molecule can be broken to yield fragments more readily utilizable as microbial substrates. The preliminary studies on grass-seed straw indicate a similar effect--that through photolytic treatment microbial utilization of both lignin and cellulose in the straw is improved.

Economic aspects of certain of the foregoing alternative utilization methods were studied. Physical data obtained in the tests described will be subjected to economic analysis to assess possibilities for commercial application.