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Petroleum fungicides, herbicides and insecticides for increasing food crop production — C. Loyal W. Swanson

Food is the single most important item in man's life. If he has little or no food, he cannot build houses or machines, write books or songs, propagate his race, praise his Creator, attempt moon journeys, fight wars, or just plain live and enjoy life.

We know that relatively huge increases in food must be produced in the near future in order to meet the food needs of the world. One way to get greater increases in available foods is to reduce current losses from insects, diseases, weeds, harvesting, processing, storage and marketing losses. Many petroleum products are now used as pesticides and adjuvants in curtailing still further losses of crops and animals.

During their various stages of growth during production, crops and animals are exposed to numerous diseases, insect infestations, weed competition, weather hazards and the like. After production, these products are subjected to losses from harvesting, storage, transportation, marketing, and processing into fiber for human consumption and use.

Protecting our food during and after its production is vital to our lives — to a healthy, prosperous living. This paper is a review of the use of various petroleum products used in the growing and protection of food crops.

PETROLEUM-DERIVED PESTICIDES

Pesticides are generally the most effective and oftentimes the only weapons available to fight pests that damage or destroy crops, livestock, and forests, or endanger human health and our natural resources. A pesticide is defined as a chemical used to kill or suppress an organism that in a specific situation is a pest.¹ Petrochemical products used as pesticides in this paper are considered as chemicals.

Although the insecticidal activity of petroleum products was known in 1787, it was not until 1865 that petroleum products were used commercially in the production of crops (34). Modern refining techniques now produce highly refined petrochemical products which can be used separately or as herbicides, insecticides, fungicides, parasiticides and as adjuvants in crop and animal production.

The development since 1945 of modern pesticides, together with other technical advances, has increased, for example, farm output per acre in the United States in past two decades by at least a third (6), helping us keep pace with the needs of an exploding population at home and growing markets abroad.

Petrochemical products, such as herbicidal, insecticidal and fungicidal oils, in view of their rapid chemical and biological degradation, non-resistance to leaching and volatilization characteristics, form no persistent residues (44) in the sense described by the U.S. National Academy of Sciences. Therefore, such petrochemical products are exempt from the Federal Food, Drug and Cosmetic Act and are so designed in the United States Department of Agriculture Summary of Registered Agricultural Pesticide Chemical Uses (5).

¹ Definition source : The Food Protection Committee of the Food and Nutrition National Board.

EARLY USE OF OILS AS CROP PROTECTANTS

Early attempts at using oils as pesticides included the application of unmodified petroleum, turpentine and kerosine (22, 56). Although effective as a pesticide, they were highly toxic to foliage and killed or injured the treated plants. About 1870, a method was discovered for emulsifying oil in water to overcome the phytotoxic effects and the first commercial emulsion was marketed in 1904.

In using spray oils for controlling insects and diseases of plants, a major consideration is the phytotoxic action of the oil on the plant. Phytotoxicity is the tendency of an oil to harm the plant. This may vary from no damage to the foliage to complete killing of the plant.

In early use of oils, they were applied during the dormant stage of plant growth before the foliage began to grow in the spring. Summer, or verdant oils, were applied to plants after the foliage had emerged. These oils differed in their phytotoxicity as related to their physical-chemical composition. Although these terms are still used, highly refined oils have been developed so that they may be applied at any time to plant growth without damaging plant tissues. These new oils may be considered, in a sense "Fool-proof oils" since their phytotoxicity is practically nil whenever they are applied at optimum dosages. Chapman (20) has used the term "general purpose plant spray oil" to describe these oils.

OIL, PLANT, ANIMAL AND PESTICIDAL CONSIDERATIONS

In the use of oils such as in herbicides they may be proficient in killing plant tissues (non-selective) or kill tissues of only certain plants (selective); or the nonphytotoxic oils used as spray oils on fruits may be used as carriers for herbicidal chemicals on such crops as corn. The nonphytotoxic oils facilitate the entry of the herbicidal chemical into the weed leaf, increasing the efficiency of the chemical but not being injurious to the corn.

Thus oils may be used to kill or cure, but one needs to know the characteristics of oils which produce kill or cure effects. One needs to know, too, the characteristics of the plant, insect, disease or animal life in question to accomplish this purpose. A recent review by Calpouzos (17) on the use of oils as fungicides, discusses some of these aspects on such crops as bananas, citrus, sugar beets, tung oil trees, celery, wheat and tobacco.

OIL SPRAYS FOR SIGATOKA DISEASE CONTROL ON BANANAS

Pesticidal oils are being extensively used for the control of Sigatoka disease in bananas. This important leafspot disease (*Mycosphaerella musicola* Leach) was originally recorded in Java in 1902 (8). In Fiji, it became notorious in 1913 in the Sigatoka Valley hence the name "Sigatoka Leafspot Disease", "Sigatoka Disease", or simply "Sigatoka". It is also known as *Cercospora* leaf spot or *Cercospora musae* Zimm. The disease has since spread, being first reported in Trinidad in 1934, in Central America and Jamaica in 1937, now covering all banana producing areas.

Effect of Disease on Bananas — Initially, small brown spots of dead tissue appear on the banana leaves. The leaf tissue around them turns yellow and dies. Before long there are extensive dead areas on the leaf, the whole leaf dying in several weeks. The successive stages

of infection and growth of this disease have been published in color by Klein (47).

The effect of the disease on fruit production is indirect resulting from a reduction of the functional leaf surface of the plant, slowing plant growth, reducing banana yields. If the leaves are badly infected there may be only four to five good leaves left to carry the fruit to maturity. Fruit bunches from heavily infected plants may fail to ripen. If the fruit is nearly mature the flesh ripens unevenly and the fingers appear undersized and angular. The flavor of the fruit may be normal but its small size makes them unmarketable, especially in the United States. Control of the disease is essential if a marketable crop of bananas is to be produced.

Initial Use of Oils For Sigatoka Control — It was found that by spraying at short intervals with Bordeaux Mixture and other copper-containing preparations, a considerable measure of protection against the disease could be achieved (80), but this method was expensive. Bordeaux Mixture, applied as high-volume sprays (at 200 gallons per acre application), requires large volumes of water not always available in banana growing areas. Heavy expenditures for spraying equipment and extensive and costly pipeline systems to the banana fields from the mixing facilities were required.

Many different fungicides have now been tested and in varying degrees have been found to possess some practical value. But for the advent of the new and considerably less expensive control by oil spraying now in general use, some of these fungicides might well in time have displaced Bordeaux Mixture.

From research seeking a low cost and effective low-volume application of fungicide, Guyot (35) learned that oil with a copper or zinc fungicide applied as a mist gave excellent control of Sigatoka. The control obtained was superior to that of Bordeaux Mixture alone, being brought under control quicker with oil-based fungicides. When it was discovered that some oils were equally effective when applied alone (37), the emphasis changed to a search for inexpensive fungicidal oils of low phytotoxicity (15, 29, 36, 37, 38, 48, 80).

Phytotoxic Characteristics Of Oils — A number of studies have been conducted to explain the phytotoxicity of oils used for controlling Sigatoka Disease. Guyot (35) in his initial research, incorporated copper or zinc fungicide in an expensive detergent dispersant motor oil (80) diluted with an inexpensive gas oil to decrease its viscosity and to reduce cost of the final product. This spray oil was applied at a high dosage about $4\frac{1}{2}$ gallons per acre. He reports some scorching of the banana leaves and fruit but better control of Sigatoka than with the fungicidal chemical alone. It may be expected that the oil applied at this rate when compared with the present rate of one gallon per acre, that it would be phytotoxic. A gas oil is high in aromatics and is used as a weed killer in sugar cane in the Caribbean (25).

Cuille and Blanchet (29) realizing that all the oils used in low-volume spraying were not equally good, and that some are more harmful than others, devised a greenhouse test using corn as the test plant for determining the phytotoxicity of oils. Eighty-four different oils were used in 42 tests. They concluded that there are three distinct factors related to phytotoxicity of oils on plants as follows:

1. The quantity of oil applied.
2. The ambient conditions.
3. The physical and chemical properties of the oils.

The Quantity of Oil Applied — The amount of oil remaining on the leaves can vary greatly according to the type of sprayer and the properties of oil used. With an air-pressure sprayer adjusted to a given discharge rate, the weight of the deposit will vary inversely with the viscosity of the oils used (29, 30). In low volume sprayers, a reduction in viscosity means a greater rate of discharge or an increase in droplet size, and either will give a poor distribution of the spray.

On banana plants, it is possible to have too much oil over the whole leaf area. The whole leaf may then become yellow or black, depending on the oil.

Ambient Conditions — Changes in temperature may affect the appearance of phytotoxic symptoms. An increase in temperature reduces the viscosity of the oil allowing it to penetrate the leaf easier. The increase in temperature may also have some effect on the permeability of the leaf membranes and on the vapor pressure of the oil.

During very sunny or very hot weather, the risk of phytotoxicity is believed to be greater. Under these conditions, a highly refined oil with low viscosity should be used.

High humidity or moist conditions are conducive to Sigatoka infection; low humidity or dry conditions curtail the disease (80).

In Jamaica (80), low night temperatures in the cooler months retard Sigatoka infection.

Physical and Chemical Composition of Spray Oils — When the aromatic content rises above 10 per cent, the oil has a serious effect on the growth of the plant. Cuille and Blanchet (29) found that when the aromatic content was 33 per cent, the growth was reduced 31 per cent.

For the oils tested, Cuille and Blanchet found no correlation between phytotoxicity and naphthenic or paraffinic oils on corn. Calpouzos and Colberg (18) confirmed this on bananas in later studies.

Cuille and Blanchet (29) concluded that only oils in the viscosity range of 60—75 and 70—85 SSU at 100°F. should be used. The oils should have a maximum distillation of 50 per cent distilled between 617°F. and 644°F. The unsulphonated residue (UR) should be 85 to 90 per cent minimum and free of sulphur compounds or traces of other elements. Actually, 92 per cent is the minimum UR now used with some spray oils reaching a UR as high as 96 per cent.

Action of Oil on Sigatoka Disease — Oils do not kill the fungus. The oil enters the leaf through the stomata but is not translocated within the tissues to any great extent (80). It is thought that the oils possibly inhibit the fungus inside the leaf at some developmental stage after stomatal penetration (19). Most of the infection occurs on the three youngest leaves of the banana plant. Leaves tend to become more resistant to disease as they grow older. Since it usually takes 4 to 5 weeks for the disease to make its appearance, spraying is done about every two to three weeks to prevent disease formation on new leaves being produced at the rate of one leaf every 7 to 10 days. Calpouzos et al (19) have shown that only the upper leaf surfaces need be sprayed thoroughly to insure disease control.

Action of Oil on Banana Plant — It has been suggested that application of oil to leaves depresses respiration as measured by oxygen intake. Corke and Jordan (24) on the other hand, showed that oil on banana leaves increased respiration. Riehl and Wedding (67) believe that inhibition results from interference with gaseous exchange by the oil. Riedhard (66) in using a Warburg apparatus, showed that application

of oil to banana leaves inhibited photosynthesis. The magnitude of the inhibition appeared to depend on the amount of oil deposited on the leaf.

Some have reported that long-term chronic phytotoxicity from some oils might result in lowered fruit weights. However, others such as Leach (50) have reported that bunches taken from oil-sprayed and Bourdeaux-sprayed plots did not differ appreciably in weight.

Spraying Apparatus Used — Initially, knapsack mist blowers and heavy-duty portable sprayers were used (30) in applying oil-based fungicides and oil alone. Various degrees of leaf-scorching were obtained from this ground application since sometimes too much oil was applied to a plant (80). On the smaller plantations and in very hilly terrain these sprayers are still used, but the larger plantations use fixed-wing airplanes or helicopters equipped with Micronair rotary atomizer or boom-type sprayers. Better distribution of the oil on the banana plant and lower cost of application are achieved by air spraying (17).

Application rates for oil alone range from 0.7 to 2 gallons per acre either applied by air or ground sprayers (17).

Pertinent details of a field testing procedure for banana spray oil field tests as used in Jamaica are summarized as follows:¹

1. Twelve month trial.
2. Application of oil by fixed wing single motor aircraft equipped with 4 Micronair sprayers — one gallon per acre per application.
3. Minimum of 17 spraying cycles — once every three weeks depending principally on weather. Higher precipitation more favorable to Sigatoka disease so more frequent spraying required.
4. Plot size for aerial application about 30 acres.
5. Test replicated three times.
6. Data collected :
 - a. Sigatoka disease scoring of 50 plants in center of plot.
 - b. Scale used for scoring Sigatoka disease on banana leaf.

Code No.

Description

- | | |
|-----|---|
| (0) | Absence of yellow streaks per 100 sq. cm. |
| (1) | 1 — 25 yellow streaks per 100 sq. cm. |
| (2) | 26 — 50 yellow streaks per 100 sq. cm. |
| (3) | 50+ yellow streaks per 100 sq. cm. |
- c. First reading made on day of spray oil application.
Next reading made 4 to 7 days before next application.
 - d. Readings are made on the distal quarter of the right half of 4th fully opened leaf.

7. Droplet size — 80 microns optimum size with range 50 — 100 micron. Desirable density 32 droplets/cm².
8. Observations made on phytotoxicity, plant growth, etc.
9. Fruit yield and maturity dates of the banana plants recorded. Yields sometimes are not taken.

Spraying is done in the early morning hours when the weather is calm in order to minimize drifting of the oil spray.

¹ Courtesy of Dr. J. R. Sessing, Director of Research, Banana Board Research Department, Kingston, Jamaica.

ACCELERATION OF SUGAR CANE RIPENING

Few problems are more serious in sugar production than the processing of canes of low sucrose content. The problem is most severe during harvest where the environment favors vegetative growth at the expense of sucrose storage. Field experiments were carried out by Vlitos and Lawrie (77) in Trinidad over a five-year period using several potential chemical ripeners of sugarcane.

Accelerated ripening in several experiments was induced by pre-harvest treatments of a highly refined oil applied to small plots at 1½ U.S. gallons per acre, and also to entire fields by helicopter equipped with a low-volume Micronair sprayer. The results obtained were compared with a number of other sugarcane ripening chemicals such as 2, 3, 6-trichlorobenzoic acid plus 2-methyl-4-chlorophenoxyacetic acid at 4 pounds per acre and monopotassium phosphate at 50 pounds per acre.

Samples taken at 22 and 28 days after treatment from the oil sprayed plots showed a marked improvement in juice quality. Differences between treatments and controls were highly significant. At 28 and 16 days after treatment, there was a highly significant difference between controls and treated fields in the acceleration of ripening for the respective chemicals mentioned above. No improvement in juice quality was obtained from some other chemicals such as maleic hydrazide used in these trials.

HERBICIDAL OILS

Oils contain four major types of hydrocarbon molecules : paraffins, naphthenes, olefins and aromatics. Havis (39) showed that by spraying pure hydrocarbons on plants, that aromatics rank highest in phytotoxicity, naphthenes and olefins next, while straight paraffins were least toxic.

Herbicidal oils are of two types — selective and nonselective. Selective herbicides kill the weeds but not the crop. Nonselective herbicides kill all types of plants. Oils wet plant surfaces readily, tending to spread over the leaf surfaces as thin films.

Herbicidal activity of oils increase with increasing aromatic content and boiling range (40), but are limited by viscosity. In a low boiling range, herbicidal oils have high boiling ranges.

The boiling range should be high enough so that the oil does not evaporate from plant surfaces too rapidly. The viscosity should be such as to aid smooth film formation on the leaf.

Specifications aid in the manufacture and marketing of herbicidal oils, but they never predict precisely how good a particular herbicidal oil may be. This can be determined only by field test spraying of plants. Weeds are best killed when they are still young and tender.

Dallyn (31) believes that the entrance and movement of an oil in plants is conditioned by the degree of toxicity of the oil to the plant in question. A highly toxic oil enters indiscriminately from the point of contact, its spread within or through the plant being negligible. Non-toxic oils enter through the stomata and usually spread widely through the plant. Chlorophyll destruction is one of the most obvious symptoms of oil injury. There is evidence that oils cause an interruption of photosynthesis (59). They penetrate the crown of grasses where the growing tissues are located (26). Minshall and Helson (59) have demonstrated that in dandelions and carrots, oils spread from the leaves to the roots.

The most important specification for any herbicidal oil is its aromatic content. For a selective herbicidal oil such as is used in a directed postemergence spray (32) for the control of seedling annual grasses and broadleaved weeds in cotton, the aromatic content ranges from 18 to 24 per cent. Five to seven gallons of oil per acre are applied laterally in 8 — 10 inch strips in the cotton row.

Herbicidal oil is considered one of the most effective and economical means of postemergence weed control in cotton. It is used extensively in the the cotton growing areas of the southern United States as shown in Table I.

TABLE I
HERBICIDAL OIL APPLIED TO COTTON

<i>State</i>	<i>Acres</i>
Arkansas ¹	200,000 — 250,000
Louisiana ²	90,000 — 120,000
Missouri ³	21,000
Texas ⁴	208,204
Mississippi ⁵	65,650

¹ 1966 Use. Courtesy W. E. Woodall, University of Arkansas.

² Estimate for 1966. Courtesy T. A. Burch, Louisiana State University.

³ 1966 Use. Courtesy of J. H. Scott, University of Missouri.

⁴ 1965 Use. Courtesy of F. C. Elliott, Texas A&M Univeristy.

⁵ 1966 Use. Courtesy of J. W. McKie, Mississippi State University.

An herbicidal oil similar to that used in cotton is used for killing weeds in soybeans (12, 53). Five gallons of herbicidal oil are applied in a 10-inch band centered on the row 12 to 16 days after soybean emergence and when weeds are one to three inches tall. The oil is directed to cover the weeds and to strike the soybean stem about one inch above the ground. A second oiling may be applied five to seven days later. Oil should not be applied on cool mornings when dew is on the crop.

The extent of the use of herbicidal oil for soybeans is given in data for representative southern states in the Untied States as shown in Table 2.

TABLE 2.

HERBICIDAL OIL APPLIED TO SOYBEANS

<i>State</i>	<i>Acres</i>
Louisiana ¹	30,000 — 40,000
Missouri ²	5,000
Mississippi ³	28,700

¹ 1966 Use. Courtesy L. L. McCormick, Louisiana State University.

² 1966 Use. Courtesy J. H. Scott, University of Missouri.

³ 1966 Use. Courtesy J. W. McKie, Mississippi State University.

For non-selective contact herbicides (33) such as is used to kill weeds in brushland, along roadsides, railways and the like, the aromatic content is 50 per cent or more. From 30 gallons per acre in sugar cane to as much as 300 gallons per acre of diesel fuel along railway banks (33) are used.

Herbicidal oils are employed for killing weeds in a number of crops, in forest nurseries, in range and brushland, in ponds, lakes and waterways, in non-cropland areas and in industrial areas. Detailed information relative to kinds of oils to use and recommended application rates are available in U.S. Dept. of Agriculture, State Agriculture Extension Services, and other publications (1, 5, 12, 27, 32, 33, 40).

Oil sprays usually are more effective than water sprays in wetting leaf surfaces and in penetrating waxy leafy surfaces. Each kind of plant has its own particular mixture of water repellent waxes. Oilwater emulsions fortified with dinitrophenols or chlorophenols are used rather extensively for control of annual weeds on ditchbanks and other non-crop areas (32).

Oils also are used as carriers for other herbicidal chemicals. One new use (45) is Atrazine in an oil-water emulsion for post-emergent application on corn within three weeks after planting for the control of quackgrass and annual weeds before they are 1½ inches tall. One to two pounds of actual Atrazine is added to an oil-water emulsion containing 1.5 gallons of a nonphytotoxic oil plus water made up to 20 gallons total volume. A suitable emulsifier for oil-water emulsions is used. From 15 to 20 gallons per acre are applied. The nonphytotoxic oil has a 95 to 105 viscosity at 100°F. with 92 per cent or more unsulfonated residue. The oil facilitates the entry of Atrazine into the weed leaf requiring less Atrazine and reduces the hazard of Atrazine residues on succeeding crops such as small grains, soybeans, tobacco, sugar beets, tomatoes and other Atrazine-susceptible crops. Nonphytotoxic oils with a UR of 90 or more and a viscosity ranging from 70 to 110 seconds at 100°F. have also been used successfully (51).

Vlitos (76) has reported that nonphytotoxic oils definitely increased the post-emergence activity of Atrazine when applied to weeds in sugar cane. No harmful effects were observed on the foliage of the cane.

HERBICIDAL CHEMICALS IN WAX

Research has shown (54, 55) that a wax bar impregnated with the amine form of 2,4-D can be used for the control of the sesbania weed (*Sesbania exalta* (Ref.) Cory) in soybeans. The wax bars are suspended

from a boom mounted on the rear of the tractor with height adjusted so that the bars travel 2 to 3 inches above the soybean plants. Treatments are made at a speed of 4 m.p.h. after the weeds are about two feet above the soybean plants. The soybean plant is not injured by the 2,4-D. The wax bars weight 6 pounds, are 22 inches long, contain one pound of 2,4-D, and have a melting point of 170°F. The cost of a single treatment varies from \$0.75 to \$1.50 per acre.

THERMAL AGRICULTURE

A new term has been coined — Thermal Agriculture — the use of heat (64) for killing weeds in cotton, corn and other crops, defoliating cotton, control of alfalfa weevil and similar uses. According to the Natural Gas Processors Association, the use of liquefied petroleum gas (LPG) for flame cultivation in the United States doubled in 1964 to 120 million gallons.

The idea of flame cultivation is to kill the plant by preventing the normal metabolism to continue. The plant is usually a weed, but it can also be the crop itself in the case of clearing fields before harvest e.g. potato haulm burning.

Flame cultivation does not entail the complete combustion of weeds as in a brush fire; such large applications of heat would not only tend to damage the crop, but would turn out to be uneconomic. It is a more refined technique requiring a smaller amount of heat.

Every plant is built up of cells and each cell contains water and dissolved nutrients. While the cells are intact, the normal metabolism of the plant can take place. By the application of heat, it is believed the cells located on the outside of the main stem are disrupted due to boiling of the liquid inside each cell. The dead cells act as an impregnable barrier effectively isolating the foliage from the roots, so that plant nutrients and water cannot move from the leaves. The products of the assimilation process taking place under the influence of sunshine and chlorophyll in the leaves, cannot move down to the roots. As a result the metabolism of the plant is interrupted, causing the plant to wither and die.

Flame Cultivation Techniques — Propane and butane have been used extensively as fuel for flame cultivation since 1945 (4, 7, 11, 23, 52, 52, 60). The need to fully mechanize and reduce production costs on the farm has increased the use of flame to control harmful weeds in row crops. The successful use of flame in weed control depends mainly on the flame tolerance of certain crops to heat and the intolerance of weeds to heat. Flaming generally is most successful when weeds are small and just emerging (1—2 inches) although larger weeds are also susceptible to flaming. Flaming's effectiveness depends on how precisely it is applied. Accurate control of the flame path must be maintained at all times, and the speed of travel must be adjusted according to the heat intensity of the flame and the heat tolerance of the row crop.

The use of flame in crop cultivation has tended to increase as the use of chemicals for weed control has increased. The reason for this is that flaming is an effective supplement to chemical and other forms of weed control. Holstun et al (42) found that flame cultivation used alone saved only \$0.83 per acre in weed-control costs for cotton in 1958. However, when used in conjunction with pre-emergence and post-emergence herbicides, flame cultivation saved \$5.66 per acre in total weed costs.

Advantages of flame cultivation include: (a) no residue left on soil or plant, (b) no drifting effects on adjacent crops, (c) does not require incorporation into moist soil for herbicidal activation, (d) not affected by soil type or fertilization program (e) not subjected to sunlight activity, (f) produces immediate effect on weeds, and (g) can be repeated as often as necessary. Apparently, the heat from the flame causes the plant cell sap to expand bursting the cell, causing death to the weed.

Additional information, both theoretical and practical, on the techniques of flaming and results to be expected on several crops are published in detail elsewhere (3, 23, 41, 42, 43, 60, 62, 63, 64, 65, 78). Crops that have been flamed successfully for weed control include cotton, corn, soybeans, potatoes, grapes, onions, peppermint, cabbage, Brussels sprouts, broccoli, cauliflower, sorghum, blueberries, castor beans, and chick weed and dodder in alfalfa. Flaming also is used for flaming weeds in ditches, railroad and highway rights-of-way, along irrigation canals, and in non-crop areas.

Under testing (9) is a flame cultivator using distillate as a fuel source for flaming. Although promising, conclusive data on its effectiveness and workability are not yet available.

Alfalfa Weevil Control — Flaming of alfalfa for the control of the alfalfa weevil (*Hypera postica*) is a new use of flaming and is proving to be effective (65, 73, 75). Flaming during January to early March kills the weevil eggs deposited in alfalfa stems during fall and winter (the time of flaming will vary with local weather conditions). The treatment may combine both insect and weed control. Chickweed and alfalfa weevil are both susceptible to winter burning. Approximately 15 to 30 gallons per acre of LPG used for flaming is an effective treatment for first crop control, reducing the number of insecticidal sprays for controlling the weevil. The Food and Drug Administration has ruled that certain insecticidal chemicals cannot be used on alfalfa fed to dairy cattle for the chemicals carry over into the milk.

Thermal Defoliation of Cotton — The use of heat produced by LPG has been shown to be effective (46, 65). Thermal defoliation involves the transfer of heat to the plant leaf in order to raise the leaf temperature to a lethal level. An exposure time of two seconds at 500°F. gave maximum defoliation. Proper application results in defoliation one to two weeks following treatment. Thermal defoliation has a distinct advantage over chemicals for no potentially dangerous residue is left on the leaves or fiber.

CARBON DIOXIDE FOR GREENHOUSE PLANTS, FRUIT STORAGE INSECT CONTROL IN STORED CROPS

A new use for LPG is the production of carbon dioxide (8) (10) for use in greenhouses as a source of carbon dioxide for plants. Plants consume tremendous quantities of CO₂ (79) in their photosynthesis. It is the most limiting factor in plant growth in greenhouses. The CO₂ is produced with a CO₂ generator using LPG as the fuel source.

The carbon dioxide level of outside air is about 300 ppm, but the level in greenhouses, especially in the winter, reaches a critical level of 150 ppm. Lettuce yields, for example, have been increased 100 per cent by increasing the carbon dioxide level to 1000 ppm. Roses have produced longer and stronger stems with flowers of better quality.

Natural gas or LPG also is used as a source of carbon dioxide for

controlling the atmosphere in the storage of fruits (13, 71). By lowering the level of oxygen from the normal 21 per cent in the atmosphere to about 3 per cent and increasing the percentage of carbon dioxide 2 to 5 per cent in the atmosphere under fruit storage conditions, the ripening process of fruit is slowed. This enables fruit growers to hold their fruit such as apples, peaches, pears and nectarines at harvest when prices are lowest, marketing them later when prices advance.

Recent research by U.S. Department of Agriculture entomologists (61) show that carbon dioxide may someday supplement pesticides and fumigation chemicals for killing insects in stored crops. In carbon dioxide atmospheres red flour beetles lived for about 12 hours and Indian-meal moth larvae, about 24 hours. Carbon dioxide would not be hazardous to the operator and would leave no residue. Carbon dioxide could be produced from burning LPG in a CO₂ generator similar to that used for producing CO₂ for plants in greenhouses.

INSECTICIDAL OILS

Oils are used as carriers of insecticidal chemicals for the control of insects, for example, flies on livestock (49). They are applied as sprays, fogs and as backrubbers or oilers. Generally, oils used as carriers for insecticidal chemicals are commercially prepared formulations. Number 2 Diesel or fuel oils are used in backrubbers.

Oils are also used as carriers for insecticidal chemicals for controlling crop insects. For example, aldrin, heptachlor, malathion and toxaphene are formulated in oil and applied as sprays for the control of grasshoppers on pasture and ranges. There are restrictions on the grazing of these areas by livestock in view of the nature of the chemicals used. Oil is also used as a carrier of DDT for the control of corn ear worm and corn borers (57). Information on insecticidal chemicals using oils as carriers, their use and application rates are published in detail elsewhere (49), (72).

Information on the use of oils in the control of pests in deciduous and citrus fruits have been published by Chapman (21), and by Simanton and Trammel (70), respectively.

The coffee leaf minor, *Leucoptera coffeella* (Guerin-Meneville) has been the major insect pest of coffee in Guatemala for the past 10 years (68). Oil-insecticide spray combinations utilized oil as a penetrant of the larval mine. Dosage rates of insecticides could be reduced to 50 per cent of the normal concentration when the insecticide was used in combination with oil at one per cent by volume. The combinations also lengthened the residual activity of the treatment. No evidence of significant differences in effectiveness between paraffinic and naphthenic-based oils having superior oil ratings in the 58 — 70 second viscosity range were obtained.

WAX COATING OF PLANT MATERIALS

Waxes are used by nurserymen for the coating of roses, trees, shrubs, etc., for preventing them from drying out during winter dormancy and shipment. Emulsified wax is used for wax itself coats the plants with a very thick coating unless the wax was hot enough which would then kill the plants (58).

Waxes are also used for coating citrus, apples, pears and various vegetables to enhance their keeping qualities and appearance (14, 57).

The appearance of oranges, lemons, limes and grapefruit is very much improved when wax coated and polished. These coatings aid materially in preventing the drying out of these fruits.

EFFECT OF ETHYLENE ON PLANTS

Ethylene, a derivative of petroleum, causes leaves to abscise, chlorophyll to blanch, and flowers to fade (16). In seedlings it induces leaf petioles to overgrow (a condition known as epinasty), reduces the rate of elongation of the stem, and causes the stem to swell. In its presence plants lose their ability to orient normally with respect to gravity, the stem assuming a horizontal position, as do the secondary roots, and normal growth movements cease. It inhibits the growth of roots and the formation of lateral roots, inducing roots to form on cuttings. Dormancy in bulbs and cuttings are broken by ethylene.

Industrially (28) ethylene is used to stimulate the ripening of fruits such as oranges, lemons, apples, and bananas (2).

CONTROL OF RUST

Control of rust damage on wheat by maneb and nickel sulfate formulations applied in two gallons per acre of oil with a mist blower was slightly better than those in 30 gallons per acre of water applied with a hydraulic sprayer (69).

Characteristics of the oils used as carriers for chemicals to control wheat rusts are as follows :

Oil Sample No.	Oil		
	2	5	150
Viscosity, SUS/100°F.	74	69.8	75
Unsulphonated Residue, %	92	94	96
A.P.I. Gravity, °F.	34.8	30.0	35
Distillation at 760 mm.			
50% Boiling Point, °F.	705	658	715
Boiling Range 5 to 95, °F.	82	28	83
Type Oil	Paraffinic	Naphthenic	Paraffinic

PETROLEUM PRODUCTS IN FERTILIZERS

Oil, diesel oil and petrolatum have been used as binders and rust inhibitors in granular fertilizers (74). Although used motor oil proved superior to diesel oil as a binder, caution is suggested in using used motor oil indiscriminately as a binder in fertilizers. This is because most motor oils contain certain additives, such as metals, which may or may not be deleterious to plant growth depending on how much is used and the element and plant in question. No. 2 Diesel Fuel would be safer to use generally they contain little or no additives. Those which are used are usually organic products which decompose quite readily ; also, the amount of additives used are in parts per million.

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