

AERIAL SPRAY ADJUVANTS for Herbicidal Drift Control

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ABSTRACT

Increased public concern about pesticides requires that foresters reduce drift and insure precise application of herbicides to the areas requiring treatment. Drift control is necessary near waterways and other ecologically sensitive areas. This publication discusses available drift control adjuvants for herbicidal sprays. These include invert emulsions, thickening agents, particulating agents, and foam sprays. Commercially available adjuvants are described and their use, advantages, and disadvantages are discussed. Thickening agents and foam sprays show special promise **for** drift reduction in aerial application of herbicides on forest lands.

KEYWORDS: Silviculture, brush control, herbicides, aerial sprays,

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children **and** animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly. Spills of herbicides or spray adjuvants should immediately be cleaned from work surfaces and mixing platforms. Spray adjuvants such **as** Vistik, Dacagin, Norbak, and foaming agents are especially slippery and should be immediately flushed off **with** water.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.



Use Pesticides Safely
FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

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GLOSSARY

acid equivalent	The amount of parent acid that has been chemically converted into esters, amines, or other salts.
additive	A substance added to a herbicidal formulation or spray mixture to increase effectiveness of the active ingredient: i. e. , emulsifiers, solvents or co-solvents, wetting agents, buffering agents, penetrants, etc.
adjuvant	Synonymous with additive.
gel	A jellylike, coagulated colloidal dispersion of fine particles in a liquid; in this case, Dacagin in water.
micron	A unit of length equal to 1/1000th of 1 millimeter.
polymer	Compounds consisting of the same elements in the same proportion by weight, but differing in molecular weight.
p. s. i.	Pounds per square inch.
surfactant	A material added to a herbicidal formulation to aid and improve emulsification, dispersion, spreading, wetting, and other surface-modifying properties.
viscosity	Resistance of a liquid to change in form or flow due to internal forces and friction within the liquid.

INTRODUCTION

During the past 20 years, herbicidal sprays have become an indispensable tool in silviculture of Pacific Northwest conifers. Chemicals are widely used to release young conifers from competition of tree, shrub, and herbaceous species, to control vegetation along roads and utility rights-of-way, and to prepare sites for reforestation. In all applications, herbicides have proved a valuable time-, labor-, and money-saving tool for foresters.

Although foresters have compiled an impressive record in safe use of herbicides during this period, increased concern about the effect of pesticides on our environment requires that we become even more selective in our choice of herbicides and more precise in restricting application of chemicals to the desired area. If a site requires treatment, we must make every effort to prevent drift onto adjacent areas.

Drift and volatility are sometimes confused, for both may cause damage to untreated vegetation on adjacent areas. **VOLATILITY** refers to the ability of a herbicide to vaporize and change from a liquid to a gas in air. In contrast, **DRIFT** refers to the actual airborne movement of pesticides from the site of application to adjacent areas. This movement may be in the form of vapors, droplets, mists, aerosols, dusts, or other fine spray particles. Drift may occur with any herbicidal formulation—acid, ester, salt, or dust; but volatility is usually a problem only when using esters.

Many techniques and restrictions are already used by foresters to control drift and other spray losses. Volatilization is minimized by use of low volatile esters and spraying only when air temperature is below 75° F. and relative humidity above 50 percent. To minimize drift, aerial spraying is stopped when windspeeds exceed 6 miles per hour and

when weather conditions are not suitable. Flying speed is limited to a maximum of 40 to 50 miles per hour and flying height is generally 30 to 45 feet above the vegetation. With conventional spray booms, drift is also controlled by use of a nozzle and orifice size that will produce the largest droplet compatible with coverage and desired effect upon vegetation. Larger and heavier droplets fall more directly, strike the vegetation more quickly, and drift less than small droplets or mists (fig. 1).

In the future, this will not be enough. For the past 2 years, the U.S. Forest Service has required use of particulating agents, spray thickeners, invert emulsions, or special spray equipment when applying aerial sprays near ecologically sensitive areas. In the future, *all* foresters **will** probably be forced to use such materials when applying herbicides near sensitive areas. This report was prepared to acquaint foresters with available drift reduction adjuvants, their use and limitations, and experience with such materials in field trials.



Figure 1.—Fine droplets may be lifted high above the helicopter in large whorls from the end of conventional booms. These fine droplets can drift with the wind or evaporate and drift in vapor form.

MATERIALS AVAILABLE

Chemicals now available to reduce drift of aerial sprays may be classified as: (1) invert emulsions, (2) spray thickeners, (3) particulating agents, or (4) foaming agents. All are designed to reduce drift by increasing droplet size by increasing viscosity of the spray solution or by producing a larger particle or globule that contains the herbicide.

Invert Emulsions

Invert emulsions are thick, white, water-in-oil emulsions that have a creamy or mayonnaiselike consistency. These

emulsions, produced by special herbicidal formulations, are widely used to reduce drift in aerial application of herbicides on utility rights-of-way. They are also effective and useful in reducing drift during aerial application of herbicides on forest land.

In invert emulsions, small water droplets are dispersed within a continuous oil phase. In contrast, the more commonly used oil-in-water emulsions have oil droplets dispersed throughout the water phase (fig. 2). Many commercial formulations that produce invert emulsions are available. Most contain phenoxy-acetic herbicides in the form of low volatile

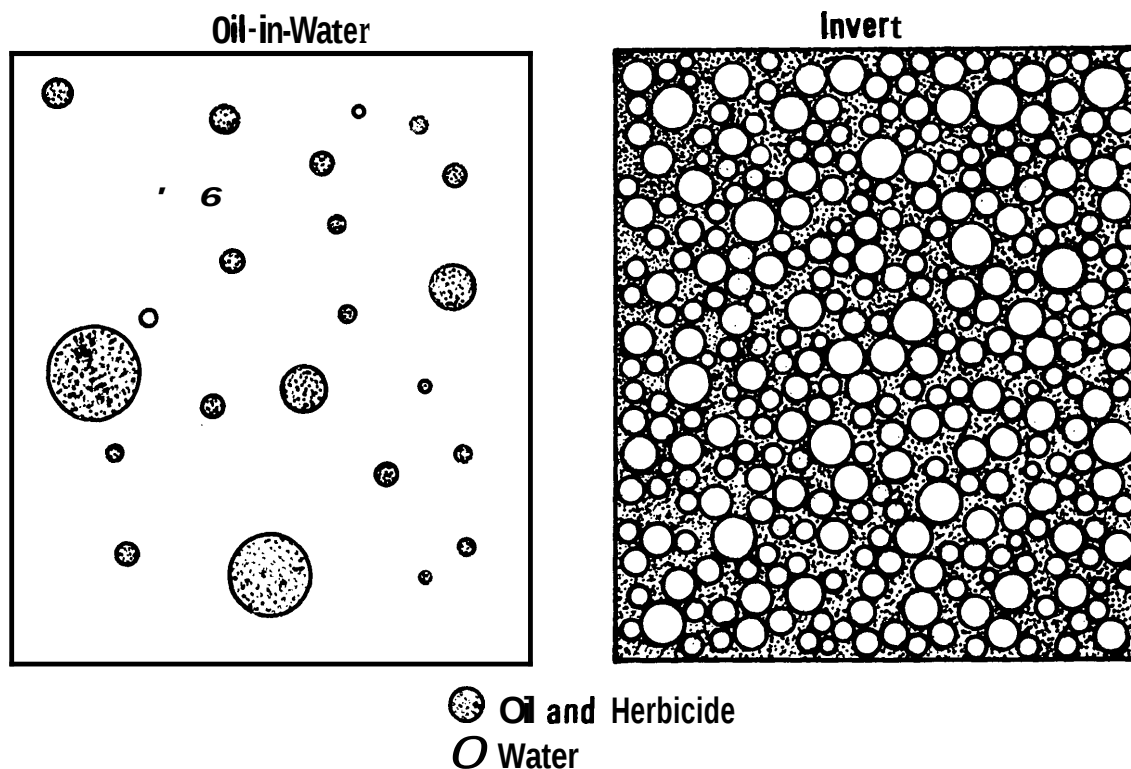


Figure 2.—Illustration of normal oil-in-water and invert emulsions with esters of 2,4-D or 2,4,5-T.

esters, oil soluble amines, or solubilized acids. In addition, Stull Chemical Company produces a series of inverting agents (trade name "Bivert") that produce invert emulsions when added to normal ester or water-soluble amine formulations of phenoxy herbicides. Similar Bivert agents are available for other herbicides.

Invert emulsions reduce spray drift by increasing the number of large droplets (fig. 3). Spray drift is not entirely eliminated, however, for some small droplets are produced during aerial application of any spray formulation. As with conventional sprays, the percentage



Figure 3.—Spray droplets on thimbleberry leaves after aerial application of an invert emulsion of phenoxy herbicides at 10 gallons of spray per acre.

of small droplets produced with invert emulsions is affected by such factors as nozzle tip design, orifice size, and nozzle orientation on the spray boom, all of which affect the degree of spray atomization. Emulsion thickness will **also** affect drift control. Thin emulsions produce more small, drift-susceptible droplets during aerial application.

Viscosity of invert emulsions depends upon the ratio of oil to water and upon the size of the water droplets produced by agitation. Some invert formulations become thicker as they are agitated and pumped, for agitation increases the number of small water droplets. In the field, viscosity may be adjusted by varying the ratio of oil to water. As more oil is added, an invert emulsion becomes thinner and more fluid. Very thin invert emulsions can be applied through conventional aerial spray systems.

In invert emulsions of phenoxyacetic esters, the herbicide is contained in the layer of oil that surrounds each water droplet. Since oil vaporizes much more slowly than water, evaporation of water from the droplets is reduced, droplets striking the plant are larger, and on impact the oil-herbicide layer is immediately in close contact with plant foliage.

However, invert emulsions of phenoxyacetic esters are usually less effective in killing woody plants than equal amounts of similar esters applied in normal oil-in-water emulsions or in oil carriers. In part, the reduced effectiveness of invert emulsions, as compared to normal sprays is probably due to less complete coverage. As Kirch (1967) stated, the larger the droplet, the less there are per gallon of spray. In applying 8 gallons of spray per acre with a droplet size of 200 microns, deposition would average 1,150 droplets per square inch. Increasing droplet size to 1,000 microns would decrease coverage to 9.2 droplets per square inch. Kirch concluded that application of invert emulsions, particulated sprays, or thickened sprays would require two to three times more volume than conventional sprays to obtain a coverage that would insure an equal kill of woody plants.

Mixing techniques and proportions of oil and water are extremely important in preparing invert emulsions. The required amount of commercial herbicidal formulation is added to a specified amount of diesel oil or No. 2 fuel oil and premixed in a clean, dry spray tank equipped with good mechanical agitation. Herbicide and oil **are** agitated until thoroughly mixed. Then, with continued vigorous agitation, water is added to produce the amount of spray needed. The spray mixture is then recycled through the spray pump system and back into the tank for approximately 20 minutes to develop the desired **viscosity** (thickness). Mixing instructions on the herbicide label should be followed very carefully. The most important point to remember, however, is that **WATER IS ALWAYS ADDED TO THE OIL AND HERBICIDE MIXTURE**. The oil-herbicide mix is **NEVER** added to water.

Oil must be used in cleaning equipment after applying invert emulsions. As with other formulations, the oil used in cleaning equipment will contain an appreciable amount of herbicide. It should be placed in the spray tanks of the aircraft and sprayed on the last area treated. Final cleaning is then accomplished with a water and detergent solution **as** usual. This also should be applied on the treated area.

Special aerial spray equipment is required to apply thick invert emulsions. Suitable equipment includes Amchem Products' Spra-Disk apparatus, the Stull bifluid spray system, and the Hercules Pump Invert spray system. Invert emulsions can also be applied with the **R-511** spray system developed by The Dow Chemical Company.

Both the Hercules **and** Stull bifluid systems require different herbicidal formulations than those suitable for

application with the Spra-Disk or **R-511**. The bifluid system depends upon instantaneous or "flash" formation of the invert emulsion in a special mixing and metering chamber immediately before the pump. In flight, the oil and water phases of the spray are carried in separate tanks and pumped through separate lines to the mixing chamber. Formation of the invert emulsion takes place just before the spray leaves the aircraft.

When conventional spray booms, Amchem's Spra-Disk, or Dow's **R-511** are used, the invert emulsion is premixed in a separate spray tank and then pumped into tanks on the helicopter. Elwell (1959) found that early invert emulsions were not stable and that separation occurred after 8 hours, but more stable formulations are now available. If separation does occur, inverts are readily re-emulsified by agitation. Flash emulsified formulations can also be premixed in a nurse tank and applied with the Spra-Disk or **R-511** but may not be as stable **as** normal invert formulations marketed by major chemical companies.

Spray Thickening Agents

Thickening agents are natural or synthetic polymers that are soluble in water. They increase the viscosity of the water phase of spray solutions, thus increasing the size of droplets during spray application. Many thickening agents also function as stickers, increasing spray adhesion to leaves and reducing bounce and runoff from stems and leaves during spraying. Vistik (Hercules Inc.) and Dacagin (Diamond Shamrock Chemical Co.) are **two** spray thickeners that have been used successfully in aerial spraying on the west coast.

Thickened spray solutions were initially developed to decrease spray drift

by converting water-based herbicidal solutions or emulsions into viscous formulations. Water thickeners used in the paint and adhesive industries were first screened during 1962 by the Hydro-Electric Power Commission of Ontario (Suggitt 1965). Among these were colloidal clays, alginates, acrylates, vinyl ethers, and substituted cellulose derivatives. Most effective was a high-viscosity, water-soluble, cellulose polymer, hydroxyethylcellulose (HEC). This material, now formulated as Vistik, satisfactorily stabilized an aerial spray mixture of TCA (trichloroacetic acid) and a phenoxy ester for 100 hours. Dacagin was developed later.

Although the primary function of thickened spray solutions is to decrease spray drift by increasing droplet size, increased viscosity is also claimed to slow evaporation of water from spray droplets and improve adhesion of spray to wet **and** dry foliage. Unfortunately, the higher viscosity may also reduce spread and coverage of the spray solution on leaf surfaces.

VISTIK

Vistik is a chemically inert, water-soluble hydroxyethylcellulose compound marketed as a fine white powder (fig. 4). When mixed with water, Vistik increases the viscosity of herbicidal sprays to improve drift control. It is readily soluble in water and in the water phase of oil-in-water emulsions. **It cannot be used to thicken oil carriers.** In the field, Vistik can increase viscosity of herbicidal sprays to an optimum for any specific ground or aerial application. The spray emerges in relatively large drops with a minimum number of fine droplets. The viscous droplets cling to leaves instead of running off, washing **off**, or blowing away.

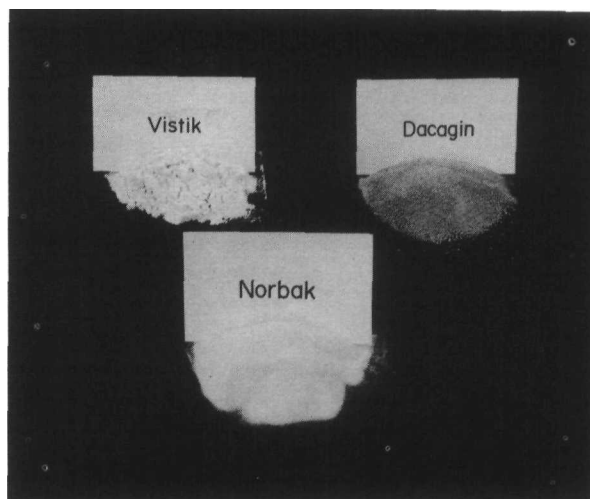


Figure 4.—Appearance of commercial form of Vistik, Dacagin, and Norbak.

The amount of Vistik required varies **with** the type of application equipment. In general, the amount used is not affected by the type of herbicide, for Vistik thickens only the water phase of herbicidal solutions. Four to 6 pounds **of** Vistik are usually added to each 100 gallons of spray solution.

For helicopter application at altitudes of 75 to 100 feet above the vegetation, Vistik-thickened sprays should have a viscosity requiring 75 to 80 seconds to drain a filled Vistik viscosity cup (fig. 5). This viscosity is obtained with about 4 to 6 pounds of Vistik per 100 gallons of spray mixture. When herbicides are sprayed from altitudes near 150 feet above vegetation, 6.5 pounds per 100 gallons of spray is suggested. Either D-8 or D-10 hollow cone tips without whirl plates on standard diaphragm tee-jet nozzles are recommended for optimum control with Vistik sprays. When spraying at low elevations of about 20 feet above vegetation, No. 8 flat fan

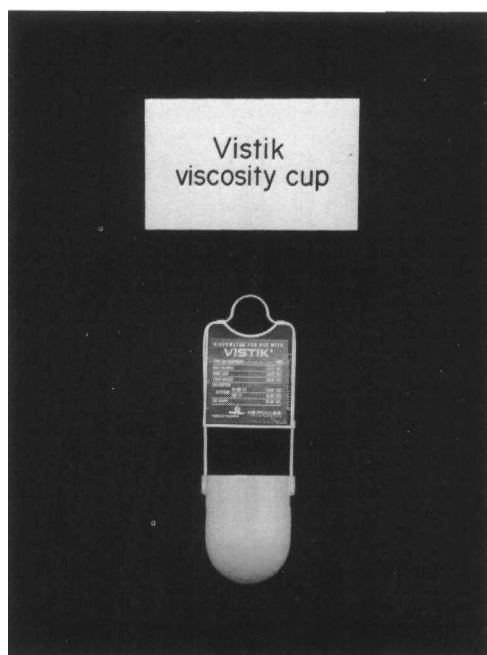


Figure 5.—Vistik cup for measuring viscosity of Vistik-thickened sprays.

nozzles have given good results (Fox 1967). Recommended pump pressures are 25 to 35 p. s. i.

With ground spray equipment, 4.5 pounds of Vistik are added per 100 gallons of spray mixture. No. 8 or 10 disk type spray tips are most satisfactory with hand guns operated at 75 to 100 p. s. i. With spray booms or fixed nozzles using fan tips, No. 60 or 80 tips with pump pressures of 50 p. s. i. are recommended.

In the field, Vistik solutions can be mixed in most herbicidal nurse tanks, but a tank with good mechanical agitation is especially recommended. Mixing instructions are specific and should be carefully followed. The recommended procedure is:

1. Fill the tank with the total volume of water desired for the spray mixture (DO NOT ADD THE HERBICIDE).

2. Turn on agitator.
3. Disperse the recommended amount of Vistik in the agitating water (fig. 6).
4. After 1 minute, add one-fourth pound of soda ash (sodium carbonate) per 100 gallons of water.
5. Continue agitation for 5 minutes or as long as necessary to set up the thickened Vistik-water solution.
6. Add the herbicide while continuously agitating the thickened mixture. When oil-in-water emulsions are to be used, first premix the desired amount of oil and herbicide, then add this oil-herbicide mixture to the thickened water in the tank.
7. Continue agitation until the herbicide is completely dispersed throughout the mixing tank.

After use of Vistik-thickened sprays, flush all tanks, lines, screens, and nozzles



Figure 6.—A funnel for adding and dispersing Vistik in the nurse tank by feeding the powder into a 2-inch bypass.

with water. Vistik solutions should not be allowed to dry in tanks or lines. When spraying is completed, thoroughly clean all spray equipment with water and detergent solutions, flush with water, and then spray all rinse solutions **on** one of the treated areas.

Water temperature has a pronounced effect on both mixing time and final viscosity of Vistik-thickened sprays. Vistik dissolves more slowly in cold water. Use of cold water in the spray tank will, therefore, increase mixing time (step 5) required to thicken Vistik-water solutions. In addition, cold water increases viscosity of Vistik solutions. Where water is taken from a cold mountain stream, the recommended rates of Vistik may produce solutions that are too thick. Warm water increases Vistik solubility, decreases mixing time, and reduces final viscosity of Vistik-water solutions.

Even in well planned spraying operations, batches of thickened spray must often be left temporarily in spray tanks because of adverse weather conditions, equipment breakdowns, or the end of a working period. If the spray solutions have cooled before spraying is resumed, viscosity may have increased and the spray solution may need to be thinned before application. In warm water or when nurse tanks have been left standing in the sun, solutions may be too thin. Therefore, it is always advisable to measure and correct the viscosity just before application. Viscosity can be increased by adding Vistik or decreased by adding water to the spray solution with continuous agitation. When water temperature is above 75° F., an increase of one-half pound of Vistik per 100 gallons of spray solution is recommended.

High viscosity Vistik spray mixtures for aerial application exhibit a

marked decrease in viscosity within 24 to 48 hours as a result of enzymes present in water. The enzymes attack and degrade the cellulose thickener (Suggitt 1965). This decrease can be detected by a viscosity check before aerial operations are resumed.

When Vistik is used with certain water-soluble herbicide formulations that contain surfactants, bubbles may form during agitation and be stabilized in the viscous solution. Such bubbles can usually be eliminated by adding about 1 percent by volume of kerosene or diesel oil or small amounts (one-tenth percent by volume of total spray) of a defoamer such as Hercules Defoamer 357. The defoamer is very effective.

Water available in the field can vary considerably in hardness. Suggitt (1965) indicates that hard water has little effect **on** low-viscosity spray mixtures but may slightly increase thickness of high-viscosity aerial spray mixtures.

Suggitt also learned that mildly acid water (pH 5) retarded the rate at which hydroxyethylcellulose dissolved but gave satisfactory initial viscosities. However, viscosity decreased significantly with time, because of acid hydrolysis of the cellulose. With alkaline water (pH 8), thickening rate was reasonably rapid and viscosity of the mixture remained relatively stable. Sodium carbonate (added in step 4 of the mixing procedure) increases alkalinity of the water, speeds the solution rate of Vistik, and increases stability of the final mixture.

It seems possible that the increased pH of Vistik mixtures could reduce penetration and translocation of herbicidal esters. Kirch (1961) stated that maximum penetration and translocation of 2,4-D and 2,4,5-T apparently occur at pH levels

below 5 (Crafts 1953, Hamner et al. 1948). The presence of free acid in an emulsifiable form in an ester formulation increases acidity of the formulation. Although the pH of an ester containing no free acid would be approximately 7, one containing 5 to 10 percent free acid is in the range of pH 3 to pH 5. Penetration and translocation from an acid ester formulation are believed to be better than from a neutral ester without free acid in an emulsifiable form. Measured pH of four commercial formulations of low volatile esters of 2,4-D and 2,4,5-T were in the range of pH 3 to pH 4. Such formulations could conceivably lower the pH of water and oil-in-water carriers for aerial sprays in forestry, where spray volumes of only 5 to 10 gallons of spray containing 2 to 4 pounds acid equivalent of phenoxy herbicides are applied per acre. However, field measurement showed a pH of 8 in a 1,000-gallon batch of Vistik-thickened aerial spray on the Siuslaw National Forest. The spray mixture contained 3 pounds acid equivalent of low volatile esters of 2,4,5-T per 10 gallons of water.

In addition to reducing spray drift, Suggitt (1965) listed several other advantages of hydroxyethylcellulose as a spray thickener. He found it: (1) readily available, (2) required in only small amounts in each batch of spray, (3) light and easily transported, (4) easily handled and mixed in the field, and (5) formed viscosities of the wide range needed for both ground and aerial spraying. Vistik is compatible with almost all herbicides in water carriers or water-based sprays. Such sprays may be in the form of solutions, emulsions, or suspensions of wettable powders. It has been used successfully with amitrole-T, phenoxy esters and amines, picloram, silvex, diquat, and maleic hydrazide (Fox 1967).

DACAGIN

NOTE: *This adjuvant, manufactured by Diamond Shamrock Chemical Company, may not be available in the near future.*

Dacagin is described as a pseudo-plastic spray gel agent. It is a chemically inert polysaccharide-gum in granular form (fig. 4). It is composed primarily of naturally occurring carbohydrates, and a small amount of protein and organic acids, a trace of fats, and ash (Ekins et al. 1970). When mixed with water, Dacagin becomes a thin flowable gel that serves as a carrier for various herbicidal formulations including water soluble materials, emulsifiable concentrates, and wettable powders. Examples are water soluble amine salts, ester formulations of 2,4-D and 2,4,5-T, and atrazine. As with Vistik, **Dacagin cannot be used to thicken oil carriers.**

Dacagin gels are both pseudo-plastic and thixotropic. The practical aspect of pseudo-plasticity is that initial viscosity of the gel is dependent upon the rate of agitation when Dacagin is first mixed with water. The slower it is mixed, the greater the initial viscosity of the gel. Once attained, this increased viscosity is irreversible. The gels do not become more fluid on standing.

Because they are also thixotropic, however, Dacagin gels decrease in viscosity when agitated or pumped. They regain their initial viscosity after agitation or pumping is stopped. Practically, this means that Dacagin gels are low in viscosity while being agitated and pumped but regain their high viscosity after they leave the spray nozzle. As a result, Dacagin gels can be applied with conventional spray equipment.

The amount of Dacagin to be added per 100 gallons of spray solution depends on application equipment, formulation, and conditions of use. With ester formulations, 4-1/2 to 5-1/2 pounds of Dacagin are added per 100 gallons of spray solution. With water soluble amines, 5-1/2 to 6-1/2 pounds of Dacagin are added per 100 gallons of spray solution.

Mixing instructions are quite simple. The recommended procedure is:

1. Place the required amount of water in a clean mixing tank.
2. Start agitation of water. Agitation should be vigorous enough to maintain a uniform distribution of Dacagin throughout the water in the tank.
3. Slowly sprinkle in the required amount of Dacagin while continuing agitation.
4. Add herbicides.

A centrifugal or positive displacement pump should be used to pump Dacagin gels from the mixing tank to spray tanks. The pump should be equipped with 1-1/2- to 2-inch hose fittings on both intake and discharge ends of the pump.

Although Dacagin can be applied with conventional spray equipment, the modified **R-511** spray system should be especially good for applying Dacagin gels. All screens in nozzles and spray lines must be 50-mesh or larger. Recommended pump pressures for application of Dacagin gels are 25 to 35 p. s. i., depending upon thickness of the gel.

It is important that enough Dacagin be added to attain the desired viscosity when Dacagin gels are first mixed. If the gel is too viscous, it can be thinned by adding more water with vigorous agitation. Thickening is much more difficult. If necessary, more Dacagin may

be added by first slurring the granules in water and then adding the slurry to the tank. This procedure, however, is difficult and not recommended.

Spray equipment should be kept clean. The gel should not be allowed to dry in spray tanks. When spraying operations cease, the spray tank and other equipment should be flushed with water to remove any gel that might dry to form a film and foul screens and nozzles. Before storage, more thorough cleaning is recommended. It is suggested that the spray equipment be cleaned with a detergent solution and then rinsed with clean water before storage.

LO-DRIFT

A new product is Lo-Drift manufactured by Amchem Products, Inc.

Lo-Drift is a water soluble polyvinyl polymer that increases viscosity of herbicidal sprays to reduce drift. It may be used with water carriers or oil-in-water emulsions. **Lo-Drift is not designed for use with oil carriers**, but a special oil-soluble form may be available in the near future. Lo-Drift differs from Vistik and Dacagin in that it: (1) is a liquid formulation, (2) requires a wetting agent to activate the polymer, and (3) can be applied through conventional spray equipment.

For aerial application, 4 to 8 ounces of Lo-Drift are added per 100 gallons of spray solution. The thickened mixture has a viscosity similar to that of mineral oil and is easily pumped at the recommended pressure of 30 p. s. i. Maximum drift control is obtained **with** either D-4, D-6, or D-8 nozzles without whirl plates; the nozzles directed back along the airstream at an angle not greater than **30** degrees from horizontal. All screens

in the spray system should be 50-mesh or larger.

The recommended mixing procedure is:

1. Add herbicide to water in nurse tank.
2. Agitate thoroughly.
3. With continued agitation, add 8 ounces of surfactant, such as X-77, per 100 gallons of spray solution.
4. Shake Lo-Drift container for at least 1 minute, then add required amount of Lo-Drift while continuing agitation of the spray mixture.
5. Continue agitation of the spray mixture for several minutes until the spray mixture becomes viscous. After the spray thickens, reduce agitation rate to provide a continual gentle mixing that will maintain viscosity with a minimum of shear degradation.

Some herbicidal formulations do not require additional surfactant, and step 3 (above) may be omitted. Amchem Products, Inc. provides a list of their formulations that do not require additional surfactant as well as of those that do.

When herbicides formulated by other manufacturers are used, mix a small test batch following directions for spray mixtures requiring additional surfactant. Although the added surfactant may not be needed, it will not affect the spray mixture and may improve wetting of foliage. If desired, a small test batch may also be prepared without additional surfactant to determine whether the additive is needed.

When spraying is completed, all tanks, lines, screens, and nozzles should be flushed **with** a water and detergent solution as soon as possible. Spray all rinse solutions on one of the treated areas. Measuring equipment should be cleaned

with petroleum solvents or hot water.
Do not add water to Lo-Drift containers.

Particulating Agents

In this publication, a distinction is made between thickening agents and particulating agents. Vistik and Dacagin are spray thickeners that are soluble in water and increase the viscosity of water carriers or the water phase of herbicidal sprays. In contrast, particulating agents are classified as granular polymers in which each granule imbibes the spray solution and swells to a limited size. Norbak (manufactured by The Dow Chemical Co.) is a particulating agent originally developed for use with Tordon 101 Mixture (amines of picloram and 2,4-D). Norbak also increases viscosity of spray solutions, but flow is in the form of imbibed granular particles. Thickened sprays, on the other hand, flow as viscous solutions or gels.

NORBAK

Norbak is a water swellable plastic polymer for herbicidal sprays (fig. 4). In an aqueous solution, each particle **ab-**sorbs liquid and swells to a limited size. If sufficient Norbak is added to a spray mixture, almost all **of** the liquid phase may be taken up and immobilized in the swollen particles. When properly mixed, Norbak produces a thick mixture with a granular appearance. Each swollen polymer particle is essentially separate when sprayed. Such formulations are referred to as "particulate sprays" (Ekins et al. 1970).

Norbak is designed for use **with** water solutions of pesticides. **It does not give satisfactory drift control when used with oil or oil-in-water emulsion carriers.** It is especially useful with herbicides formulated as metallic salts and water soluble amine salts, but it can

also be used with ester formulations of phenoxy herbicides and wettable powders. With wettable powders, Norbak will im-
bibe only the water phase of the spray mixture.

Although mixing procedures are relatively simple, mixing tanks, pumps, and spray application equipment have certain requirements. Good agitation in the mixing tank is essential. All tanks must be provided with mechanical agitation, and openings in baffle plates of large tanks should be big enough to permit rapid passage of particulated spray between the tank sections. Agitation must be sufficiently vigorous to induce movement and blending of the mixture from all parts of the tank. The mixing tank should be equipped **with** a positive displacement vane, gear, roller, or piston pump. The tank should have a bottom outlet, and the pump should be mounted at or below the level of the tank bottom. Hoses and supply lines should be 1-1/2 inches or larger in inside diameter and as short as possible.

The recommended procedure for mixing Norbak sprays is:

1. Cleanse nurse tank of all oil and other herbicides.
2. Place one quarter of the required amount of water in the tank.
3. Start agitation and then slowly add the required amount of herbicide with continuous agitation. Mix thoroughly.
4. With continuous agitation, slowly add 6 to 12 pounds of Norbak for each 100 gallons of the final spray volume. Continue agitation for 3 to 5 minutes.
5. With continuous agitation, add the remaining three quarters of the water. Continue agitation for 3 to 5 minutes after all water is added.

6. Wait at least **10** minutes for proper swelling to occur before spraying.
7. Determine consistency of the spray mixture with a Dow consistency test funnel (fig. 7). Spray mixtures for helicopter application should take from **45** to **85** seconds to drain from the funnel. If the mixture is too thick, it may be thinned by adding more water. If an appreciable amount of water must be added, spray volume applied per acre should be proportionately increased.

Norbak sprays should be applied with either Dow's **R-511** spray system or the modified **R-511** system with short boom. The **R-511** with its clustered nozzles should be used only on utility rights-of-way. The modified **R-511** should be used in forest spraying and can also be used on rights-of-way. Spray nozzles should be standard diaphragm shut-off

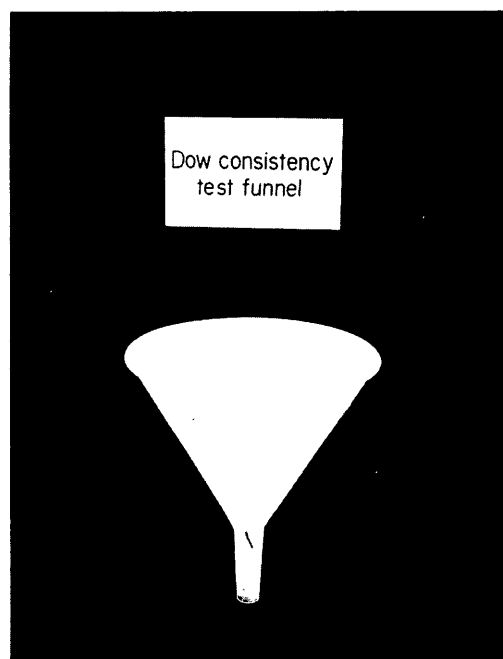


Figure 7.—Dow test funnel for determining consistency of Norbak-thickened sprays.

nozzles with flat-fan orifice tips or cone nozzles without inserts. Orifice diameter must be 0.04 inch or larger. Nozzle screens may be necessary with the smaller orifices. All screens should be 50-mesh or larger. Inside diameter of spray booms must be at least 1.20 inches, and pressure gauges should be mounted on the ends of the boom. Recommended spray pressure at the end of the boom is 20 p. s. i.

Foam Sprays

Foam-producing additives are the newest materials designed to increase viscosity and wetting properties of herbicidal sprays. Foam sprays are easier to transport, mix, and apply than invert emulsions or spray thickeners discussed earlier. Basic components of this system are: (1) a water soluble liquid surfactant containing the foaming agent, stabilizers, and wetting agents and (2) specially designed spray nozzles that mix air into the spray solution to create

a foam (fig. 8). Minimal shearing of foam into fine droplets and good coverage can be achieved by orienting the aerial spray nozzles back along the airstream at a 30° angle from the horizontal.

Foaming agents are produced by several companies. Among these are Accutrol (marketed by Velsicol Chemical Corp.), Foamspray (LTV Aerospace Corp.), and Fomex (Colloidal Products Corp.). Each company sells suitable foam-generating nozzles or makes them available to applicators for a small handling fee. Special foam-producing nozzles have also been developed by Delavan Manufacturing Corporation and by Spraying Systems Company. Delavan nozzles are used with Fomex by Colloidal Products. Spraying Systems' FoamJet tips are interchangeable with their TeeJet tips. Boom pressures of 40 p. s. i. or greater are generally recommended for application of foam sprays.

Foaming agents produced by different

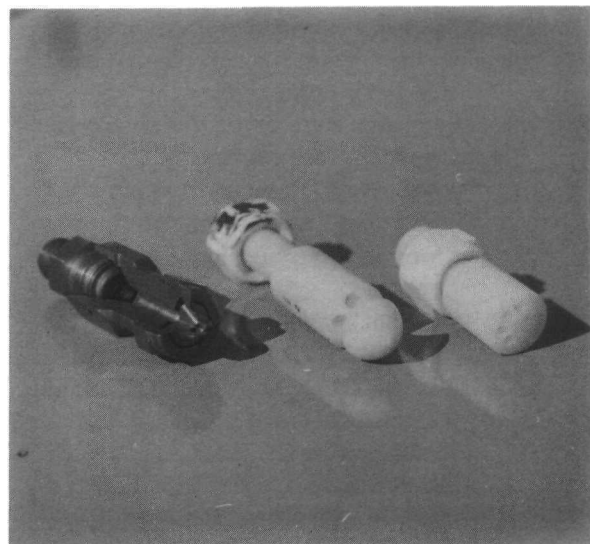
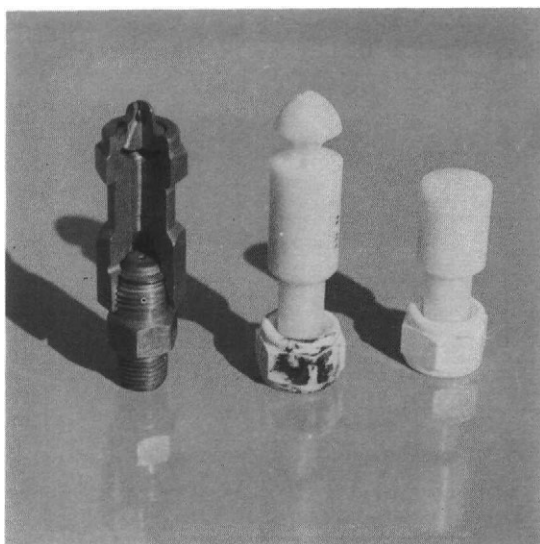


Figure 8.—Accutrol foam nozzles. The two white plastic nozzles are designed for aerial spraying: cone-topped nozzle produces finer droplets than the flat-topped nozzle.

companies vary in their chemical composition. Therefore, unless future research proves it unnecessary, foresters should **use only nozzles recommended by the manufacturer of the foaming agent** (i.e., Accutrol with Accutrol nozzles, Fomex with Delavan nozzles, etc.). The nozzles are designed to match the expansion ratio of the foaming agent.

Foaming agents may be used with water soluble herbicides, with oil-in-water emulsions, and with wettable powders. They act only upon the water phase of the spray mixture. **They cannot be used with pure oil carriers.** Foam sprays can be applied with conventional aerial spray equipment modified only by adding the special foam-producing nozzles.

Only small amounts of foaming agent are needed in herbicidal sprays. Recommended rates are 1/2 to 1 gallon per 100 gallons of spray. The lower rate is suitable for water carriers; 3 quarts to 1 gallon per 100 gallons of spray may be needed for oil-in-water emulsions containing 1/2 to 1 gallon of oil per 10 gallons of spray—a normal spray volume per acre in aerial application of herbicides on forest lands.

Foam sprays discharged from the nozzle are a frothy mixture containing widely varied sizes of air bubbles rather than a thick, heavy foam of uniform consistency. The expansion ratio of foam to water is in the range of 3:1 to 5:1. Each gallon of liquid spray forms 3 to 5 gallons of foam. The bubbles cling together to form large globules that fall in a sheetlike pattern beneath the helicopter (fig. 9). Stabilizing agents keep the foam from breaking down while falling from the nozzles to vegetation; wetting agents then allow the spray droplets to **run** together and spread over leaf surfaces.



Figure 9.—Aerial application of an oil-in-water emulsion of 2,4,5-T as a foam spray during critical weather conditions: wind velocity about 5 m.p.h. and relative humidity near 50 percent. Note absence of whorls evident in figure 1.

Advantages **claimed** for foam sprays are that they:

1. Reduce drift,
2. Reduce evaporation in the air, and thus increase amounts of herbicide that reach vegetation in the treated area,
3. Increase adhesion of herbicides on foliage,
4. Reduce evaporation of herbicides from leaf surfaces,
5. **Allow** spraying at higher temperatures and lower relative humidity,
6. Are visible to pilots on return passes and thus reduce skips in application,
7. Hold fine solids uniformly suspended, and
8. Stabilize emulsions.

Mixing instructions vary. Velsicol recommends adding the foaming agent to the water phase of oil-in-water emulsions before adding the oil and herbicide; Colloidal Products Corp. recommends adding the foamer after all other ingredients are thoroughly mixed. Both methods are probably equally effective, but adding the foaming agent last is probably easier

in the field. In either case, after adding the foaming agent, the spray mixture should be agitated to thoroughly mix and dissolve it in the water phase of the carrier.

As with spray thickeners, mechanical agitation will provide the best mixing in nurse tanks. If bypass hydraulic agitation is used, it is important that the inlet to the nurse tank be kept below the liquid surface to minimize foaming. A bypass that splashes in from above **will** add air and cause foaming in the nurse tank. After adding the foaming agent, use only enough agitation to maintain dispersion of emulsions and prevent settling of wettable powders.

After spraying, equipment may be cleaned with water and detergent and then flushed with water. Apply this material and rinse water from herbicide containers on one of the treated areas to minimize environmental contamination.

Foaming agents are biodegradable and some manufacturers claim that they do not cause dermatitis. However, long exposure is not recommended, because **some foaming agents have a drying action on the skin.** Wet areas should be rinsed with water as soon as possible.

HERBICIDAL EFFECTIVENESS OF THICKENED SPRAYS

The possibility that herbicidal activity might be decreased in viscous sprays deserves consideration. Unfortunately, few studies have been carried out to determine the relative biological effectiveness of herbicides in thickened sprays vs. conventional carriers.

McKinlay et al. (1972) studied the effect of droplet size on phytotoxicity of oil-soluble 2,4-D amines. Their

results indicate that phytotoxicity is directly related to coverage--number of droplets per unit of plant surface area. Herbicidal effect increased as droplet size decreased. When compared with droplets 100 microns in diameter, equal spray volumes of 200 micron and 400 micron droplets required approximately three times and six times as much herbicide to obtain the same herbicidal effect. However, for a given droplet size, herbicidal activity could be increased equally well either by increasing the concentration or by increasing the number of droplets per unit area. Field application of these results would indicate that invert emulsions and thickened sprays producing larger droplet sizes would require either an increased amount of herbicide per acre or an increased volume of carrier to insure herbicidal effects equal to those obtained with conventional carriers that produce many more small droplets.

INVERT EMULSIONS

The consensus of research results is that invert emulsions of 2,4-D and 2,4,5-T esters are usually less effective in killing woody plants than equal amounts of herbicide applied in normal oil-in-water emulsions or oil carriers (Kirch et al. 1960, Darrow and Silker 1959, Phillips 1963, Brady et al. 1969). This agrees with observations of foresters in the Pacific Northwest. However, invert emulsions have proved a useful tool for insuring accurate placement of aerial sprays on utility rights-of-way.

VISTIK

The possibility that viscous Vistik-thickened sprays might be less effective than conventional sprays was considered by Suggitt (1965) and others. Although viscous sprays improve adhesion to

foliage, the higher viscosity also reduces spread and coverage on leaf surfaces. After observing the effects of thickened and conventional sprays of 2,4,5-T and 2,4,5-T/TCA herbicides on woody plants, Suggitt concluded that herbicidal properties of the viscous sprays were equivalent to those of conventional sprays. He stated that higher volumes are probably not required in foliage and stem spraying. Ekins et al. (1970) determined that Vistik did not reduce the herbicidal effect of paraquat, nor did it prevent amitrole-T from being washed from leaves of treated plants.

In field tests on the Siuslaw National Forest, Vistik-thickened sprays were less effective and more variable than unthickened sprays in defoliation of salmonberry (table 1). Neither treatment produced an acceptable degree of topkill. However, the sprays were applied in water carriers during late August, much too late for good results on this species. Neither spray caused any appreciable damage on young Douglas-firs averaging 2 to 3 feet in height.

DACAGIN

Dacagin was also compared to Vistik and Norbak as drift reduction adjuvants on field crops in Oregon (Ekins et al. 1970). None of the three adjuvants alone injured wheat, barley, or red clover. Like Vistik, Dacagin did not reduce the herbicidal effectiveness of paraquat nor prevent amitrole-T from being washed from leaf surfaces. It did, however, reduce vapor loss of a high volatile ester of 2,4-D from plant surfaces.

No studies are known where herbicidal effects of Dacagin-thickened sprays were compared with normal carriers on woody plants. However, Dacagin-thickened sprays have been applied on shrubs and weed trees in National Forests in northern California. After observation, foresters were pleased with drift reduction achieved with Dacagin and were of the opinion that Dacagin-thickened sprays were as effective as similar treatments in oil-in-water emulsions or water carriers.^{1/}

^{1/} Personal communication from M. Knight, Region 5, Forest Service, U.S. Department of Agriculture.

Table 1.--*Comparison of Vistik-thickened vs. unthickened sprays of amitrole-T in water carriers on salmonberry and young Douglas-firs*^{1/}

Area	Salmonberry				Douglas-fir			
	Unthickened		With Vistik		Unthickened		With Vistik	
	Defoliation	Topkill	Defoliation	Topkill	Defoliation	Topkill	Defoliation	Topkill
1	87	20	27	11	6	2	4	0
2	90	11	66	14	4	0	4	0
3	99	10	42	16	5	0	12	2
Means	92	14	45	14	5	1	7	1

^{1/} Based on examination of 40 plants of each species per area, 12 months after treatment.

LO-DRIFT

Since Lo-Drift is a new product, only limited data are available concerning its effect on herbicidal activity. Information provided by Amchem Products, Inc. indicates that Lo-Drift did not change the effectiveness of six different herbicidal formulations on sorghum, soybeans, alfalfa, or cucumbers. No such information is yet available for woody plants.

NORBAK

Byrd and Reimer (1966) found no reduction in effect of picloram solutions particulated with Norbak. However, Ekins et al. (1970) state that Norbak did reduce the effect of paraquat on field crops. They suggest that this reduction may have resulted from insufficient coverage of plant surfaces by the spray solution. Norbak markedly reduced the number of droplets in the spray swath, and fewer droplets contacted plant surfaces.

The reduction in number of droplets detected by Ekins may have resulted from clumping or aggregation of Norbak particles during application. Furthermore, it seems possible that herbicides absorbed within Norbak particles may not be readily available for absorption from the particles on leaf surfaces. Both effects could seriously reduce the activity of herbicides in low volume aerial sprays on forest-land brush species and weed trees.

Norbak-thickened sprays were compared with invert emulsions in an early June aerial application of picloram plus 2,4-D on the Siuslaw National Forest.² Norbak was used with triisopropanolamine salts of both herbicides

² Special formulations were provided by L. E. Warren of The Dow Chemical Company. This cooperation is appreciated.

in a water carrier; the invert emulsion contained a potassium salt of picloram and a low volatile ester of 2,4-D. The herbicides were tested as preburn desiccants. Evaluation before the areas were burned 3 months later indicated that both formulations were equally effective on salmonberry, thimbleberry, vine maple, and swordfern. The Norbak-vs.-invert comparison, however, must be considered with reservation, since each contained different forms of the two herbicides. Increasing spray volume of the invert carrier from 10 to 15 gallons did not increase either defoliation or topkill during the 3-month period after treatment. Unfortunately, no comparison was possible with similar forms of the two herbicides in conventional carriers.

FOAM SPRAYS

Foam sprays are a relatively recent innovation as carriers for herbicides. Experimental data concerning the influence of foam carriers on effectiveness of herbicides are as yet extremely limited and inconclusive. However, observation of both ground and aerial applications on crop and weed species indicates: (1) liquid spray volumes for foam application must be about the same as volumes used with conventional carriers, and (2) herbicidal effects are similar to those obtained with equal rates of chemical in conventional carriers, although phytotoxicity of some herbicides may be increased on sensitive plants.

Foam carriers were used in early August 1972 foliar sprays on red alder, salmonberry, and thimbleberry in the Siuslaw National Forest. Coarse Accutrol nozzles were used for this application. In the opinion of foresters, based upon observation 2-1/2 months after application, foam carriers were producing results at least equal to those obtainable

with similar rates of herbicide in oil-in-water emulsions. The foam carrier was used with an emulsion containing one-half gallon of No. 2 fuel oil per acre. Liquid spray volume was 10 gallons per acre as usual.

Observations of early July foliar applications on the same species in the Elliott State Forest near Reedsport,

Oregon, also indicate that effects of herbicides in foam carriers were equal to those obtained with normal carriers. Foam sprays were used with emulsion carriers along buffer strips near streams and other ecologically sensitive areas. Main portions of the cuttings were treated with identical sprays, equipment, and nozzles; but the foaming agent was not used.

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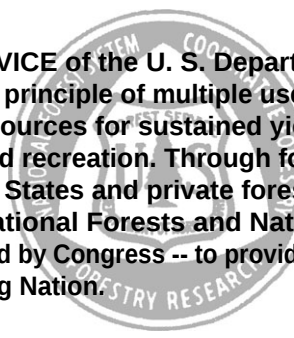
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