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Adjuvants for enhancing herbicide performance[2]

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Overview

An adjuvant is any substance in a herbicide formulation or added to the spray tank to improve herbicidal activity or application characteristics.

Spray adjuvants are generally grouped into two broad categories–activator adjuvants and special purpose adjuvants.

Special purpose adjuvants:

- widen the range of conditions under which a given herbicide formulation is useful.
- may alter the physical characteristics of the spray solution.
- include compatibility agents, buffering agents, antifoam agents, and drift control agents.

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Activator adjuvants:

- commonly are used to enhance postemergence herbicide performance.
- can increase herbicide activity, herbicide absorption into plant tissue, and rainfastness; can also decrease photodegradation of the herbicide.
- can alter the physical characteristics of the spray solution.
- include surfactants, crop oil concentrates, nitrogen fertilizers, spreader-stickers, wetting agents, and penetrants.

Surfactant:

- primarily reduces the surface tension between the spray droplet and the leaf surface.
- includes nonionic, anionic, cationic, and organosilicones.
- is required with many post-herbicides.
- is applied at 1/2 to 2 pt/acre or 0.25% volume/volume.

Crop oil concentrate:

- contains petroleum-based oils plus some nonionic surfactant.
- increases herbicide penetration and reduces surface tension.
- commonly is used with post-grass herbicides and atrazine.
- is applied at 1 to 3 pt/acre or 1% volume/volume.

Vegetable oil concentrates serve the same function as crop oil concentrates but are derived from vegetable-based oil.

Nitrogen fertilizer:

- can increase herbicide activity on certain weed species such as velvetleaf and certain grasses.
- improves the effectiveness of weak acid-type herbicides (e.g., Accent, Classic, Pursuit, Basagran, etc.).
- ammonium sulfate can reduce problems with hard water.
- generally is used in combination with surfactants or crop oil concentrates.
- application rate varies depending on product.

Adjuvant selection:

- should be primarily based on herbicide label.
- should consider percent active ingredient as well as cost.

Adjuvants are commonly used in agriculture to improve the performance of pesticides. Broadly defined, “an adjuvant is an ingredient that aids or modifies the action of the principal active ingredient.” The use of adjuvants with agricultural chemicals generally falls into two categories: (1) formulation adjuvants are present in the container when purchased by the dealer or grower; and (2) spray adjuvants are added along with the formulated product to a carrier such as water. The liquid that is sprayed over the top of a crop, weeds, or insect pest often will contain both formulation and spray adjuvants.

Formulation adjuvants are added to the active ingredient for a number of reasons including better mixing and handling, increased effectiveness and safety, better distribution, and drift reduction. These traits are accomplished by altering the solubility, volatility, specific gravity, corrosiveness, shelf-life, compatibility, or spreading and penetration characteristics. With the large number of formulation options available (solutions, emulsions, wettable powders, flowables, granules, and encapsulated materials), adjuvants become even more important in assuring consistent performance.

Spray adjuvants are added to the tank to improve pesticide performance. Literally hundreds of chemical additives are now available that fall into this category. Spray additives can be grouped into two broad categories: *activator adjuvants* include surfactants, wetting agents, stickers-spreaders, and penetrants; *special purpose* or utility modifiers such as emulsifiers, dispersants, stabilizing agents, coupling agents, co-solvents, compatibility agents, buffering agents, antifoam agents, drift control agents, and nutritionals. Descriptions of the more common types of special purpose adjuvants follow. Table 1 lists some common products sold for these purposes.

Table 1. Selected trade names and manufacturers of special purpose adjuvants.

Trade name	Manufacturer
Compatibility agents	
Blendex VHC	Helena
Combine	Riverside/Terra
Complete	Cenex/Land O'Lakes
Latron AG-44M	Rohm and Haas
Drift inhibitors	
Intac Plus	Loveland Industries
Spray-Start	Kalo, Inc.
Sta-Put	Nalco Chemical Company
Strike Zone DC	Helena
Target NL	Agway
Windbreak	Riverside/Terra
Windcheck	Riverside/Terra
Anti-foaming agents	
DeFoamer	Riverside/Terra
Foam Buster	Helena
Buffers	
Ballast	Cenex/Land O'Lakes
Buffer P.S.	Helena
BS-500	Drexel
Combine	Riverside/Terra
Latron AG-44M	Rohm and Haas
Penetrator Plus	Helena

Special purpose adjuvants

Compatibility agents allow simultaneous application of two or more ingredients. They are most often used when herbicides are applied in liquid fertilizer solutions. Unless the pesticide label states that it can be mixed with liquid fertilizers, a compatibility agent should be included.

Buffering agents usually contain a phosphate salt or more recently citric acid, which maintains a slightly acid pH when added to alkaline waters. These are added to higher pH solutions to prevent alkaline hydrolysis (a chemical reaction) of some organicophosphate (OP) and carbamate insecticides. Some acidifying agents are also sold to enhance herbicide uptake and performance. However, there is little evidence to support the need for these acidifying agents for this purpose with most herbicides. Some buffering agents are also "water softening" agents that are used to reduce problems with hard water. In particular calcium and magnesium salts may interfere with the performance of certain pesticides. Ammonium sulfate (AMS) is sometimes added to reduce hard water problems. Examine the specific pesticide and water source to determine the need for a buffering agent.

Antifoam agents usually are added to suppress surface foam and minimize air entrapment that can cause pump and spray problems. Defoamers often contain silicone.

Drift control agents (thickeners) modify spray characteristics to reduce spray drift, usually by minimizing small droplet formation. Drift inhibitors are generally polyacrylamide or polyvinyl polymers to increase droplet size.

Activator adjuvants

Activator adjuvants are by far the most common type of additives used to enhance herbicide performance. Although some products are sold to alter pesticide-soil interactions, the emphasis of this discussion will be on foliar-applied materials. The primary use of activator adjuvants is with postemergence herbicide applications.

Before any foliar-applied herbicide can perform the desired biological function, it must be transferred from the leaf surface into the plant tissue. The above-ground portions of plants are covered by a continuous noncellular, nonliving membrane called cuticle (Figure 1). Cuticle is the first barrier that any herbicide must overcome to be effective. The plant cuticle is composed of water-repellent waxes and less water-repellent cutin and pectins which can provide pathways for more water-soluble pesticides. The structure of plant cuticle can be likened to a sponge where the matrix of the sponge corresponds to the cutin and the holes correspond to the embedded wax. The surface of the sponge is also covered with wax (epicuticular wax). Cuticle is extremely diverse and varies greatly between different species of plants.

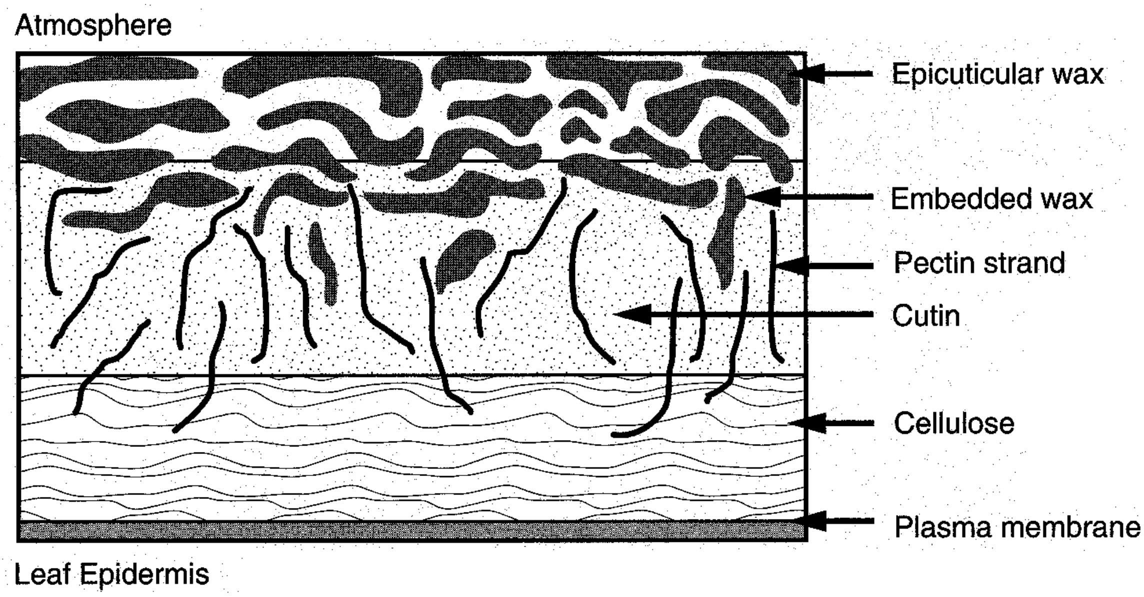

Figure 1. Simplified plant cuticle (taken from F. D. Hess, Sandoz Crop Protection)

Waxes are the principal barrier restricting herbicide movement into plant foliage. The chemical or physical properties of the wax appear to be more important than thickness in restricting penetration. Surface wax high in hydrocarbons and other repellent molecules is less permeable to water and most herbicide sprays than cuticle membranes with lower amounts of water-restrictive waxes. For example, lambsquarters cuticle wax is known to be a strong barrier to the penetration of many herbicides. Lambsquarters cuticle is high in chemical substances called aldehydes, which may help prevent the passage of more water-soluble herbicides. Not only does cuticle composition vary between species, but also the age of the plant has been associated with differences in leaf wax chemistry over time.

The most common types of activator adjuvants employed are surfactants, oils, and salts. Activator adjuvants influence the physical and chemical properties of the spray solution, including surface tension, density, volatility, and solubility. These properties will in turn modify the spreading, wetting, retention, and penetration of the spray solution. It is important that the appropriate adjuvant is selected for a particular pesticide product. The type of adjuvant added to the spray tank can enhance or reduce the performance of the pesticide. The relative effectiveness of several adjuvants on herbicide performance is shown in Table 2. In both these trials, nonionic surfactant was less effective than other types of adjuvants, however, nonionic surfactant might be the more appropriate choice with other weeds or herbicides. The first step in choosing the correct additive for a specific product is to read the pesticide label. The wrong adjuvant may increase the risk of poor performance and/or crop injury.

Table 2. Effectiveness of adjuvants in selected weed trials at Penn State

Treatment [a]	(% Control) Wirestem Muhly [b]	Giant Foxtail [c]
Accent + NIS	67	—
Accent + COC	73	—
Accent + MVOC	78	—
Pursuit + NIS	—	78
Pursuit + COC	—	95
Pursuit + DASH	—	94
Pursuit + DASH + UAN	—	99

[a] NIS = nonionic surfactant; COC = crop oil concentrate; MVOC + methylated vegetable oil concentrate; DASH = surfactant from BASF; UAN = 28 percent urea ammonium nitrate.
[b] Accent applied at 2/3 oz/A and averaged over two locations.
[c] Pursuit applied at 4 oz/A.

Surfactants

The primary purpose of a surfactant or “surface active agent” is to reduce the surface tension of the spray solution to allow more intimate contact between the spray droplet and the plant surface. Any substance that brings a pesticide into closer contact with the leaf surface has the potential to aid absorption. Surface tension is a measure of the surface energy in terms of force measured in dynes/cm. Water has a surface tension of 73 dynes/cm. Surfactants lower the surface tension of water to that of an oil, or solvent which spreads more readily than water on plant surfaces. Surfactants typically lower the surface tension of a solution to between 30 and 50 dynes/cm.

The interaction between surfactant, herbicide, and plant surface is far more complex than simply lowering the surface tension of the pesticide solution. Surfactant molecules may also alter the permeability of the cuticle. Surfactants form a bridge between unlike chemicals such as oil and water or water and the wax on a leaf surface. Although there are many different types of surfactants, in general, they are constructed of a long chain hydrocarbon group on one end that is considered lipophilic (fat loving) and a more hydrophilic (water loving) group of atoms on the other end. The structure of surfactants is often represented by a tadpole or polliwog type of arrangement such as seen in Figure 2. The zigzag tail represents the long chain hydrocarbon group that gives the molecule its lipophilic characteristics. The head of the polliwog contains more water-soluble (polar) groups that give the molecule its hydrophilic characteristics.

The influence of the surfactant on herbicide performance can be species specific because leaf wax composition varies. For some herbicides, surfactant preference is also herbicide dependent. For example, Roundup (glyphosate) is a more water-soluble herbicide that requires a more polar type of surfactant (such as the ethoxylated fatty amines) to improve activity. Highly lipophilic surfactants can actually decrease the performance of Roundup in comparison to no surfactant at all.

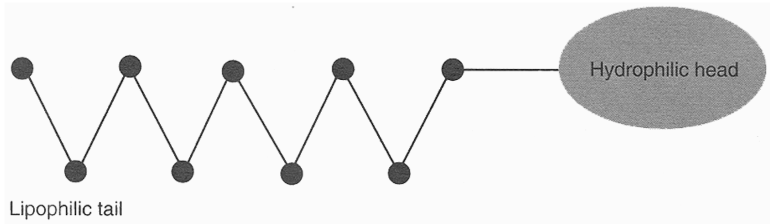

Figure 2. Polliwog representation of a surfactant molecule

Surfactant molecules can be synthesized to achieve specific solubility characteristics often referred to as the hydrophilic-lipophilic balance (HLB). The capability of a surfactant to modify herbicide penetration is partially attributable to the HLB, with each herbicide-species interaction having an optimum HLB requirement for the surfactant employed. HLB numbers for surfactants are often given on technical information sheets for specific products. They range from 0 to 40 with most of them between 1 and 20. Low HLBs are very oil soluble, while higher HLBs prefer water.

Although there are hundreds of different surfactants, only a few are used in the pesticide adjuvant business. More than half the products used as stickers or wetter-spreaders use the same general surfactant type, alkyl-aryl-poly-oxy-ethylenate, or AAPOE. Examples of AAPOE surfactants commonly used with herbicides are X-77 and Triton AG-98. The next most common type (about 25 percent) is very similar to AAPOE and is an alcohol ethoxylate or alcohol-poly-oxy-ethylene (APOE). Examples of this type include Wex and Surfactant WK. Some surfactants may also contain free fatty acids or fatty acid esters or linear alkyl sulfonates (anionic) in the formulation that also contribute to the principal functioning agent. All surfactants contain inert ingredients that are considered nonfunctioning agents or formulation aids and can include isopropyl alcohol (IPA), propylene glycol (PG), and a poly siloxane foam retardant (Si). Although surfactants can vary considerably within these groups depending on molecular structure (e.g., number of carbon and hydrogen groups) and within a group whose principal function is the same, such as wetters-spreaders, it is not likely that differences between the same type of surfactant are great.

Surfactants are classified as *nonionic*, *anionic*, or *cationic*. Nonionic surfactants have no electrical charge and are generally compatible with most pesticides. Nonionic surfactants are most commonly used because of their universal fit. An anionic surfactant possesses a negatively charged functional group and is most often used with acids or salts. Anionic surfactants are more specialized and sometimes used as dispersants or compatibility agents. Cationic surfactants are used less frequently, but one group (ethoxylated fatty amines) has been frequently used with the herbicide Roundup.

The *organosilicone*-based materials are another group of surfactants more recently introduced. These surfactants are used in place of or in addition to more traditional nonionic surfactants. Proponents of these surfactants stress low surface tension, greater rain fastness, and possible stomatal penetration characteristics. Several silicone-based products are currently available for use with postemergence herbicides (Tables 3 and 4). Surfactants and other adjuvants are either added to the spray tank on a per acre basis or a percent volume per volume (%v/v) concentration. For example, surfactants are usually applied at ½ to 2 pints per acre or at 0.25% v/v (i.e., 2 pt/100 gal) unless otherwise directed.

Table 3. Selected trade names and manufacturers of nonionic surfactants

Trade name	Manufacturer
Activate Plus	Riverside/Terra
Activator 90	Loveland Industries
Adspray 80	Helena
Dash (surfactant + fatty acids)	BASF
Induce	Helena
Kinetic (organosilicone)	Helena
Latron AG-98	Rohm and Haas
Silkin (organosilicone)	Riverside/Terra
Silwet L-77 (organosilicone)	Loveland Industries
Spray Booster-S	Cenex/Land O'Lakes
Spret	Helena
Surf-Aid	Riverside/Terra
Surf-Ac 820	Drexel Chemical
Surf-Ac 910	Drexel Chemical
Triton AG-98	Rohm and Haas
X-77	Loveland Industries

Oils

Adjuvants that are primarily oil based are very popular with pesticide applicators. Crop oils are probably the oldest group within this category.

Crop oil is a misnomer because the material actually is from petroleum (paraffin or naphtha base, not vegetable derivative), a phytobland (nonphytotoxic), nonaromatic oil of 70 to 110 second viscosity (water = 1 and 30 w motor oil = 300). Crop oils are 95 to 98 percent oil with 1 to 2 percent surfactant/emulsifier. Crop oils are believed to promote the penetration of pesticide spray through waxy cuticle or the tough chitinous shell of insects. Traditional crop oils are more commonly used in insect and disease control than with herbicides. Crop oils are typically used at 1 to 2 gallons per acre.

Crop oil concentrate contains 80 to 85 percent phytobland emulsifiable crop oil (petroleum based) plus 15 to 20 percent nonionic surfactant. The purpose of the surfactant in this mixture is to emulsify the oil in the spray solution and lower the surface tension of the overall spray solution. Crop oil concentrates attempt to provide the penetration characteristics of the oil, while capturing the surface tension reduction qualities of a surfactant. Crop oil concentrates are also important in helping solubilize less water-soluble herbicides such as Assure, Poast, Fusilade, Select, and atrazine on the leaf surface. Crop oil concentrates are used at 1 to 3 pints per acre at 1%v/v (1 gal/100 gal) unless otherwise directed.

Vegetable oil concentrates have performed less consistently than their petroleum-based counterparts. However, manufacturers are attempting to improve plant or vegetable-based oils by increasing their nonpolar or lipophilic characteristics. The most common method has been through esterification of common seed oils such as methylated sunflower, soybean, cotton, and linseed oils. The methylated forms of these seed oil concentrates are comparable in performance to traditional (petroleum) crop oil concentrates so their importance has increased. In taking it one step further, organosilicone-based methylated vegetable oil concentrates are also available. These adjuvants boast the surface tension-reducing properties of silicone but have the advantages of a methylated vegetable oil concentrate. The more widely available oil-based additives are given in Table 4.

Table 4. Selected trade names and manufacturers of oil-based additives.

Trade name	Manufacturer
Crop oils	
Cenex Spray Oil	Cenex/Land O'Lakes
Dormant Oil	Riverside/Terra
Knock-Down Crop Oil	Cenex/Land O'Lakes
Crop oil concentrates	
Activate Oil Adjuvant	Drexel Chemical
Agri-Dex	Helena
CLASS 17% Concentrate	Cenex/Land O'Lakes
Crop Oil Concentrate	various
Herbimax	Loveland Industries
Peptoil	Drexel Chemical
Prime Oil	Riverside/Terra
Vegetable oil concentrates	
CLASS Destiny (methyl soybean)	Cenex/Land O'Lakes
Dyne-Amic (silicone methyl vegetable)	Helena
Meth Oil (methyl soybean)	Riverside/Terra
MSO	Loveland Industries
Prime Oil II (vegetable)	Riverside/Terra
Sun-It II/Scoil (methyl vegetable)	Agsco
Vegetable Oil Concentrate (vegetable)	Helena
Vegetoil	Drexel Chemical

Nitrogen fertilizer

Within the last 15 years, nitrogen fertilizers have been more frequently added to the spray solution as an adjuvant to increase herbicide activity. Ammonium salts (NH_4^+) appear to be the active component of these fertilizer solutions and have improved the performance consistency on some weeds. It is still unclear how ammonium salts improve herbicide performance. Herbicides that appear to benefit from the addition of ammonium are the relatively polar, weak acid herbicides such as Basagran, the sulfonylureas (Accent, Beacon, Classic, and Pinnacle, etc.), and the imidazolinones (Pursuit and Raptor). Nitrogen fertilizers may replace surfactant or crop oil concentrate with some of the contact-type herbicides, but are usually added in addition to surfactant or crop oil concentrate with systemic products.

Velvetleaf and some grassy annual weeds in particular have been responsive to the addition of nitrogen fertilizer in the spray mix. In general, velvetleaf control has improved by as much as 10 to 25 percent by the addition of an ammonium-based fluid fertilizer (28, 30, or 32 percent UAN, 10-34-0, or 21-0-0), compared to crop oil concentrate or surfactant. Common rates are 2 to 4 quart/acre of 28, 30, or 32 percent UAN, I quart/acre of 10-34-0, or 17 pounds/100 gallons dry ammonium sulfate. Some broadleaves and grasses show little or no response with the inclusion of ammonium fertilizer solutions.

Ammonium-based fertilizers and, in particular, ammonium sulfate (AMS) are also being promoted to reduce potential antagonism with hard water or antagonism with other pesticides. Both hard water antagonism and pesticide antagonism can occur with some herbicides. Roundup (glyphosate) is one product that specifically recommends on its label the addition of ammonium sulfate (or a higher rate of Roundup) for hard water, cool air temperatures, or drought conditions. Examine the specific pesticide label, water source, and environmental conditions to determine the need for AMS or other adjuvants.

Adjuvant selection

Adjuvant selection should be based on several factors including what the pesticide calls for, what the adjuvant claims to be, cost of the adjuvant, and what is available in your area. The primary source in deciding whether an adjuvant is necessary and the type of adjuvant used should come from the pesticide label. The following are some general guidelines to consider when given a choice of adjuvants.

- If both oil concentrate (crop or vegetable oil) and nonionic surfactant are listed, then use nonionic surfactant under normal weather conditions when weeds are small and well within label guidelines. Use oil concentrate if weeds are stressed due to dry weather or with more mature weeds.
- If labeled, include oil concentrate for control of grasses.
- Include nitrogen fertilizer only if it is recommended on the herbicide label.
- If the potential for crop injury is great, then use nonionic surfactant instead of oil concentrate.
- To improve crop safety, do not include oil concentrates with plant growth regulator-type herbicides (i.e., dicamba, 2,4-D, etc.)

Manufacturers of most products and particularly the newer materials have invested time and money in adjuvant research. Some labels are very specific in their recommendation of adjuvants. For example, the Pursuit label for postemergence use in soybean states "use a nonionic surfactant containing at least 80% active ingredients and apply at 1 qt/100 gal *or* a petroleum or vegetable seed-based oil concentrate at 1.5 to 2 pt/acre *and* a nitrogen-based fertilizer such as 28% N, 32% N, or 10-34-0 at 1 to 2 qt/A." Other product labels such as Buctril on corn are not as specific and simply state that "Buctril can be applied in combination with sprayable liquid fertilizer or spray additives such as surfactants or crop oil concentrate." When pesticide labels are not specific enough, other important sources include university crop management guides (i.e., *Penn State Field Crop Weed Control Guide* or *The Agronomy Guide)* and industry-based publications.

Next select an appropriate product within the required group or type of adjuvants recommended. This can be confusing since some products contain several different types of adjuvants. The claims made for an adjuvant product on the label and in the active ingredient statement can be helpful in selecting the best adjuvant for your needs. In particular, pay close attention to the percent active vs. inert ingredients. For example, Activate Plus from Riverside/Terra Corp. is a nonionic spreader/activator that is typical of nonionic surfactants recommended for use with postemergence herbicides. The active ingredient portion of Activate Plus includes AAPOE, free fatty acids, and isopropyl alcohol.

These three ingredients make up 90 percent of the product with the remaining 10 percent being inert ingredients. Agri-Dex from Helena claims to be a nonionic spray adjuvant or more specifically a crop oil concentrate that is recommended for use with pesticides requiring an oil concentrate adjuvant. The active ingredients make up 99 percent of the formulation and include paraffin-based petroleum (crop oil), fatty acid esters, and AAPOE or APOE, which all contribute to the active portion of the adjuvant. Loveland Industries manufactures Chem-Trol that is identified as a spray additive for deposition and drift retardation. The active ingredient in Chem-Trol is a polyvinyl polymer at 1 percent with 99 percent inert ingredients. This product is not recommended to enhance pesticide activity, but rather to reduce pesticide drift. Be sure to thoroughly read the label.

The active ingredient portion of the label can also be helpful in comparing costs. If two products have the same or similar active ingredients yet slightly different concentrations, you can calculate the cost of each product on an active ingredient (ai) basis. For example, two adjuvant products both cost $11.00 per gallon. Product A has 90 percent active ingredient, while Product B contains 80 percent. Both products serve the same principal function. Product A's actual cost is $12.22 per gallon of active ingredient (11.00/0.90), while Product B's is $13.75 (11.00/0.80). Which would you choose? This may become even more important as new higher-cost adjuvants enter the marketplace.

Summary

The type of adjuvant added to the spray tank can enhance or reduce the performance of the pesticide. Both herbicide and species influence the appropriateness of the adjuvant. Although a number of different kinds of activator adjuvants are on the market, their primary purpose is to reduce the surface tension, improve the wetting action, and increase the penetration of the pesticide. To choose the correct additive for a specific product, first read the pesticide label. An appropriate adjuvant assures maximum performance and crop safety. The wrong adjuvant increases the risk of poor performance and crop injury.

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