OPTIMIZING HERBICIDE PERFORMANCE THROUGH ADJUVANTS: RESOLVING MISCONCEPTIONS AND CONFUSION

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Spray Adjuvants

POST herbicide effectiveness depends on spray droplet retention, deposition, and herbicide absorption by weed foliage. Adjuvants and spray water quality influence POST herbicide efficacy. Adjuvants are not needed with PRE herbicides unless weeds have emerged and labels include POST application.

Spray adjuvants generally consist of surfactants, oils and fertilizers. The most effective adjuvant will vary with each herbicide, and the need for an adjuvant will vary with environment, weeds, and herbicide used. Adjuvant use should follow label directions and be used with caution as they may influence crop safety and weed control. An adjuvant may increase weed control from one herbicide but not from another. To compare adjuvants and determine adjuvant enhancement herbicide rates should be used at marginal weed control levels. Effective adjuvants will enhance herbicides at reduced rates and provide consistent results under adverse conditions. However, use of below-labeled rates exempts herbicide manufacturers from liability for nonperformance.

Surfactants are used at 0.125 to 0.5% v/v (1 to 4 pt/100 gal of spray solution). Surfactant rate depends on the amount of active ingredient in the formulation, plant species and herbicides used. The main function of a surfactant is to increase spray retention, but surfactants also function in herbicide absorption. When a range of surfactant rates is given, the high rate is for use with low rates of the herbicide, drought stress and tolerant weeds, or when the surfactant contains less than 90% active ingredient. Surfactants vary widely in chemical composition and in their effect on spray retention, deposition, and herbicide absorption.

Silicone surfactants reduce spray droplet surface tension, which allow the liquid to run into stomata on leaves ("stomatal flooding"). This entry route into plants is different than adjuvants that aid in absorption through the leaf cuticle. Rapid entry of spray solution into leaf stomata from use of silicone surfactants often does not result in improved weed control. Silicone surfactants are weed and herbicide specific just like other adjuvants.

Oils generally are used at 1% v/v (1 gal/100 gal of spray solution) or at 1 to 2 pt/A depending on herbicide and oil. Oil additives increase herbicide absorption and spray retention. Oil adjuvants are petroleum or methylated vegetable or seed oils (MSO) plus an emulsifier for dispersion in water. The emulsifier, the oil class (petroleum, vegetable, etc.), and the specific type of oil in a class all influence effectiveness of an oil adjuvant. MSOs have been especially effective with most all herbicides but generally are equal to or better than petroleum oils with most herbicides, except glyphosate, Ignite, and Cobra. Results vary when comparing specific adjuvants, even within a class of adjuvants.

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Fertilizers containing ammonium nitrogen increase effectiveness of most herbicides formulated as a salt. Fertilizers should be used with herbicides only as indicated on the label or where experience has proven acceptability. AMS is recommended at 8.5 to 17 lb/100 gal spray volume (1 to 2%) on most glyphosate labels. Enhancement of glyphosate, and many other herbicides, from AMS is most pronounced when spray water contains relatively large quantities of certain ions, such as calcium, sodium, and magnesium. AMS may contain contaminants that may not dissolve and then plug nozzles. Use spray grade AMS to prevent nozzle plugging. Commercial liquid solutions of AMS are available and contain approximately 3.4 lb of AMS/gallon. For 8.5 lb of AMS/100 gallons of water add 2.5 gallons of liquid AMS solution. AMS at 4 lb/100 gal (0.5%) is adequate to overcome most salt antagonism. AMS at 0.5% has adequately overcome antagonism of glyphosate from 300 ppm calcium. Use at least 1 lb/A of AMS when spray volume is less than 12 gpa. Ammonium ions also are involved in herbicide absorption and have enhanced phytotoxicity of many herbicides in absence of antagonistic salts in the spray carrier. Herbicide enhancement by nitrogen compounds appears most pronounced in most species like velvetleaf or sunflower. AMS enhances phytotoxicity and overcomes salt antagonism for most salt formulated herbicides, including dicamba, glyphosate, Poast, and 2,4-D amine. Liquid 28% UAN fertilizer is effective in enhancing weed control from many POST herbicides and overcoming sodium but not calcium antagonism of glyphosate. Sodium bicarbonate antagonism of Poast is overcome by 28% UAN, ammonium nitrate, and AMS. AMS or 28% UAN does not preclude the need for an oil adjuvant. Adjuvants vary in enhancement of herbicide action. The precise salt concentration in water that causes a visible loss in weed control is difficult to establish because weed control is influenced by other factors.

Some water pH modifiers are used to lower (acidify) spray solution pH because many insecticides and some fungicides degrade under high water pH. Most solutions are not high or low enough in pH for important herbicide breakdown in the spray tank. pH-reducing adjuvants (example: LI-700) are sometimes recommended for use with herbicides because of greater absorption of weak-acid-type herbicides when the spray solution is acidic. However, low pH is not essential to optimize herbicide absorption. Many herbicides are formulated as various salts, which are absorbed as readily as the acid. Salts in the spray water may antagonize formulated salt herbicides. In theory, acid conditions would convert the herbicide to an acid and overcome salt antagonism. However, herbicides in the acid form are less water soluble than in salt form. An acid herbicide with pH modifiers may precipitate and plug nozzles when solubility is exceeded, such as with high herbicide rates in low water volumes. Antagonism of herbicide efficacy by spray solution salts can be overcome without lowering pH by adding AMS or, for some herbicides, 28% UAN.

Basic pH blend adjuvants are non-oil based and increase spray solution pH. They contain nitrogen fertilizer to overcome antagonistic salts; a surfactant to aid in spray retention, spray deposition, and herbicide absorption; and a buffer to increase water pH. Basic pH blend adjuvants increase water pH, which increases water solubility of most ALS and HPPD inhibitor herbicides. For example, Accent solubility at water pH 5 is 360 ppm, at pH 7 is 12,200 ppm, and pH 8 is 39,200 ppm. Basic pH blend adjuvants reduce precipitation problems with Betamix*/ Betanex*/ Betamix Progress plus UpBeet at low rates by increasing water pH. Research has shown that basic pH blend adjuvants enhance weed control similar to MSO type adjuvants. They may be used in those situations where oil adjuvants are restricted. For example, some dicamba labels restrict oil adjuvants when used alone or in tank-mix with Accent on corn. Basic pH blend adjuvants are less expensive at field use rates than MSO type adjuvants.

Antagonism of glyphosate by calcium in a spray solution was overcome by sulfuric but not nitric acid, indicating that the sulfate ion was important, but not the acid hydrogen ion. The importance of the sulfate ion explains the effectiveness of ammonium sulfate, and not 28% UAN, in overcoming calcium antagonism of glyphosate. Other herbicides that become acid at a higher pH than glyphosate may realistically benefit from a reduced pH as has been shown for Poast. However, Poast does not require a low pH for efficacy. Spray solution pH of 4 has overcome sodium antagonism of Poast, but nitrogen fertilizer or AMS also will overcome sodium antagonism of Poast without lowering the pH. The ammonium ion provided by these fertilizers is apparently the important ion.

In summary, adjuvants that are designed specifically to reduce pH generally are not required for herbicide efficacy. The type of acid or components of buffering agents and the specific herbicide all need to be considered before using pH-modifying agents.

Choosing Adjuvants with Herbicides

Several POST herbicides allow use of nonionic surfactant, petroleum oil additives, methylated seed oil additives, and nitrogen fertilizer. Questions about adjuvant selection are common. MSO additives have often given greater weed control than petroleum oil additives and nonionic surfactants (NIS) but cost two to three times more. The added cost of MSO and increased risk of crop injury when used at high temperatures have deterred people from using this class of adjuvants. Using reduced herbicide rates with MSO can enhance weed control while lowering risk of crop injury.

Some herbicide labels restrict use of oil adjuvants and recommend only use of NIS alone or combined with nitrogen based fertilizer solutions. Follow label directions for adjuvant selection. Where labels allow use of oil additives, petroleum oil based adjuvants (COC) or methylated seed oil (MSO) adjuvants may be used. The term crop oil concentrate is misleading because the oil type in COC is petroleum based oil and not a crop vegetable based oil.

NDSU research has shown wide difference in adjuvant enhancement of herbicides. However, in many studies, no or small differences occur depending on environmental conditions at application, growing conditions of weeds, rate of herbicide used, and size of weeds. For example, under warm, humid conditions with actively growing weeds, NIS + nitrogen fertilizer may enhance weed control the same as oil additives. The following are conditions where MSO type additives may give greater weed control than other adjuvant types:

1. Low humidity, hot weather, lack of rain, and drought-stressed weeds or weeds not actively growing due to some condition causing stress.
2. Weeds larger than recommended on the label.
3. Herbicides used at reduced rates.

4. Target weeds are somewhat tolerant to the herbicide. For example, control of wild buckwheat, biennial wormwood, lambsquarters or ragweed with Pursuit or Raptor, or control of yellow foxtail with Accent.
5. When university data support reduced herbicide rates. Most herbicides except glyphosate give greater weed control when used with MSO type adjuvants. Oil adjuvants should not be used with glyphosate only when research or experience shows no reduction in weed control.

Adjuvant Use in Low Gallonage Spray Volumes

In certain instances, spray adjuvant rates should be adjusted for low sprayer volumes. For example, oil adjuvants are applied with ALS, ACCase, and HPPD inhibitor herbicides and other POST herbicides at 1% v/v or 1 gal/100 gal water. At 15 to 20 GPA, 1% oil adjuvant would provide adequate adjuvant load. However, in aerial applications at 5 GPA, 1% v/v may not provide enough adjuvant for optimum herbicide enhancement.

Some herbicide labels contain information on adjuvant rates for different spray volumes. For example, Pursuit and Raptor labels require oil adjuvants to be added at 1.25% v/v or 1.25 gal/100 gal water for aerial application (5 GPA). To insure sufficient adjuvant concentration, add oil adjuvant on an area basis. Instead of using oil adjuvants at 1% v/v, apply at 1.25 to 2 pt/A at all spray volumes. Surfactant at 0.25% v/v or 1 qt/100 gal water is sufficient across all water volumes. Basic pH blend adjuvants are recommended at 1% v/v regardless of spray volume. Data indicate basic blend adjuvants at 1% v/v from 5 to 20 GPA will provide adequate adjuvant enhancement for similar weed control.

Spray Carrier Water Quality

Minerals, clay, and organic matter in spray carrier water can reduce the effectiveness of herbicides. Clay inactivates paraquat, diquat, and glyphosate. Organic matter inactivates many herbicides, and minerals can inactivate the activity of most salt formulated herbicides, including 2,4-D amine, MCPA amine, Achieve, dicamba, Ignite, glyphosate, and Poast.

Water in North Dakota, South Dakota, and Montant is often high in sodium bicarbonate, which does not normally occur in other areas of the U.S. Sodium bicarbinate reduces the effectiveness of most salt formulated herbicides, including amine phenoxys, ALS, ACCase, dicamba, Ignite, and glyphosate. Water with 1600 ppm sodium bicarbonate can occur, but antagonism of above herbicides occurred at or above 300 ppm. The antagonism is related to the salt concentration. At low salt levels, loss in weed control may not be noticeable under normal environmental conditions. However, antagonism from low salt levels will cause inadequate weed control when weed control is marginal because of drought or partially susceptible weeds.

High salt levels in spray water can reduce weed control in nearly all situations. Calcium and magnesium are antagonistic. Calcium antagonism may occur at 150 ppm. Sulfate ions in the solution have reduced the antagonism from calcium and magnesium, but the sulfate concentration must be three times the calcium concentration to overcome antagonism. Natural sulfate in water can be disregarded.

Water often contains a combination of sodium, calcium, and magnesium, and these cations generally are additive in the antagonism of herbicides. Many adjuvants are marketed to modify spray water pH, but low pH is not essential to the action of most herbicides. AMS, granular or liquid, and 28% UAN fertilizer help overcome antagonistic salts in spray carrier water. Generally, 4 gal of 28% UAN/100 gal of spray has been adequate. UAN overcomes mineral antagonism of most herbicides, but not glyphosate. AMS and 28% UAN enhance herbicide control of certain weeds even in water without salts. Nitrogen fertilizer/surfactant blends may enhance weed control of most herbicides formulated as a salt.

Understanding a Water Quality Analysis Report

Water quality is important to herbicide efficacy and spray problems. However, the issue is complex as each herbicide may respond differently to water quality.

1. Water pH

High and low pH can reduce efficacy of pesticides and cause nozzle plugging with some herbicides. Some insecticides are degraded rapidly in extreme pH. Most SU (sulfonylurea) herbicides are hydrolyzed by high and low pH. However, this is not normally a problem when sprayed within a normal time period but efficacy could be reduced when mixed in water with extreme pH for a day or more. Low pH forces salt formulated herbicides into the acid state that may not be soluble in the amount of water being sprayed and thus plug nozzles and reduce efficacy.

High and low pH can increase the efficacy of certain herbicides. Some adjuvants for glyphosate formulations lower pH, but glyphosate is soluble at low pH and maintains efficacy. In addition, the low pH overcomes antagonism from salts in the water (water salts will be discussed later). Herbicides need to be in solution for absorption into plant foliage. Sulfonylurea herbicides are more soluble at high pH so water with high pH may increase their efficacy. This is especially true for Accent, but certain minerals (sodium) in water may not allow the total benefit from the high pH.

2. Total Dissolved Solids and Electrical Conductivity

The major mineral constituents in northern plains water and their ionic chargers are:
Cations (+ charge) = calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and iron (Fe).
Anions (- charge) = sulfate ($SO_{4)}$, chloride (Cl), bicarbonate (HCO_3), and nitrate (NO_3).

The sum of all the minerals dissolved in a sample of water is normally referred to as the total dissolved solids (TDS). The higher the TDS, the more electric current water can conduct. Because of this characteristic, a measure of the electrical conductivity (EC) is often used to provide a quick, economical estimate of the TDS in water. If the EC is less than 500 umho/cm, water quality problems for herbicides are very unlikely. Water EC values in ND and western U.S. run between 1000 and 2,500. Usually hardness and cation concentration, not TDS, are used to evaluate water quality on herbicide performance.

3. Hardness

Water hardness is caused by potassium, calcium, magnesium, and iron. These minerals can react and antagonize water soluble formulations of many weak acid herbicides like glyphosate, 2,4-D amine, MCPA amine, dicamba, Basagran, Curtail, etc. The ester formulations of herbicides are oil soluble and do not react directly with the salts in the water. However, these oil type formulations need an emulsifier so that the formulation will mix with water and sometimes these emulsifiers may be ineffective when in water with salts and cause an oil-like scum or precipitate in the spray water reducing efficacy and plugging nozzles.

Sodium contributes to water hardness but functions to soften water similar to home water softener systems. Hardness levels are reported in mg/L (ppm) of calcium carbonate (CaCO3). Hardness values are calculated by adding meq/L of Ca and Mg then multiplying by 50. Hardness of individual cations can be confusing because they can be reported as milliequivalents/L (meq/L), milligrams per liter (mg/L), parts per million (ppm), or grains per U.S. gallon (gpg). The mg/L and ppm are considered equal, and 1 grain per gallon is equal to 17.1 mg/L or ppm.

To convert meq/L to ppm, multiply meq/L x atomic number of the atom: K meq/L x 39.102, Na x 22.991, Mg x 12.156, Ca x 20.04. Water hardness values in MT, ND, and MN run between 0 and 2,000 ppm. There are variations in water hardness classifications but the following scale can be used: Soft = <75 ppm; Moderately hard = 75 – 150 ppm,;Hard = 150 – 300 ppm; Very hard = >300 ppm.

The amount of AMS needed to overcome antagonistic ions can be determined as follows:

lbs AMS/100 gal = (0.002 X ppm K) + (0.005 X ppm Na) + (0.009 X ppm Ca) + (0.014 X ppm Mg) + (0.042 X ppm Fe).

This does not account for antagonistic minerals on the leaf surface on some species like lambsquarters, sunflower, and velvetleaf, which may require additional AMS.

4. Sodium Absorption Ratio

Water high in sodium, when added to clay soils, may have a detrimental effect. Excess sodium will attach to clay particles and displace other ions, namely chloride and sulfide. A high SAR may indicate a limited ability for plants to extract water from the soil. The adjusted SAR has reference to bicarbonates. Some water in the northern plains is very high in bicarbonates, which increases the SAR problem. Water quality standards for SAR are as follows:
Excellent = <3, Good = 3 – 5, Permissible = 5 – 10, Doubtful = 10 – 15, Unsuitable = >15.

5. Residual Sodium Carbonate

Values greater than 0 increase the sodium hazard.

6. Bicarbonates

Since bicarbonate is anionic (-) it is always associated with a cation (+) like sodium or calcium to make sodium or calcium bicarbonate in ground water. The corresponding cation (Ca, Na) may have a greater role in herbicide antagonism than the bicarbonate. High sodium and sodium bicarbonate antagonism of herbicides is usually overcome by ammonia type adjuvants. Small amounts of antagonistic salts do not appear to reduce herbicide efficacy with full use rates. This is because the use rate was established for efficacy using various waters. However in principle to optimize herbicide efficacy, any amount of antagonistic salts will have some effect and to optimize efficacy for all conditions one may wish to consider taking action to overcome even low amounts of antagonistic salt.

Water with high bicarbonate levels may have low levels of other anions like chloride and sulfate. Calcium chloride is also antagonistic and spray water pH should be below 7. Bicarbonate levels greater than 500 ppm may reduce herbicide efficacy of Achieve, Poast, Select, MCPA amine, and 2,4-D amine. When using water with more than 500 ppm bicarbonates the high rate of these herbicides should be used and applied at the most susceptible weed stage for efficacy. Bicarbonate also increases water pH and high bicarbonate levels may also be associated with high water pH (See #1 above). Water bicarbonate levels in mid-west, plains and northern plains range from 200 to 1,000 ppm.

Analysis of spray water sources can determine water quality effects on herbicide efficacy. Water samples can be tested at (analysis is approximately $25.00 to $29.00):

U.S.Postal Service: NDSU Dept 7680, Fargo, ND 58108-6050,
UPS and Physical Address: NDSU Soil and Water Laboratory, Waldron Hall 202,
1360 Bolley Dr. NDSU, Fargo, ND 58102. 701 231-7864.

The analysis may report salt levels in ppm or grains. To convert from grains to ppm, multiply by 17 (Example: 10 grains calcium X 17 = 170 ppm calcium). AMS at 2% (17 lb/100 gallons water) will overcome antagonism from the highest calcium and/or sodium concentrations in water. However, AMS at 4 lb/100 gal is adequate for most water sources in the U.S. Iron is also antagonistic to many herbicides but not abundant in water in the mid-west or northern plains.