APPENDIX J
HERBIDICE EFFICACY
ADJUVANTS, WATER QUALITY, NOZZLES, TEMPERATURE, & RAINFASTNESS

SPRAY ADJUVANTS & WATER QUALITY[1]

Postemergence herbicide effectiveness depends on spray droplet retention and herbicide absorption by weed foliage. Adjuvants and spray water quality influence postemergent herbicide efficacy.

Surfactants and Adjuvants

Adjuvants are spray solution additives, and are considered to be any product added to an herbicide solution to improve the performance of the spray mixture. Spray adjuvants 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 present, and herbicide used. Adjuvant use should follow label directions and be used with caution as they may increase injury to crops or reduce weed control. An adjuvant may increase weed control from one herbicide but not from another. Comparisons of adjuvants should be made at marginal control levels to determine the effectiveness of adjuvants for specific herbicides, sprays, water and weeds. Effective adjuvants will enhance herbicides at reduced rates and provide consistent results under adverse conditions. However, reduced rates exempt herbicide manufacturers from liability for nonperformance.

Examples of adjuvants include compatibility agents (used to aid mixing two or more herbicides in a common spray solution), drift retardants (used to decrease the potential for herbicide drift), suspension aids (used to aid mixing and suspending herbicide formulations in solution), spray buffers (used to change the spray solution acidity), and surfactants.

Surfactants (surface active agents) are a type of adjuvant designed to improve the dispersing/emulsifying, absorbing, spreading, sticking and/or pest-penetrating properties of the spray mixture. Pure water will stand as a droplet, with a small area of contact with the waxy leaf surface. Water droplets containing a surfactant will spread in a thin layer over a waxy leaf surface.

Because postemergence herbicide effectiveness is greatly influenced by plant factors such as age, size and the growing conditions encountered before application, herbicide performance can vary. A way to minimize the variations in postemergence herbicide performance is to use an adjuvant or surfactant in the spray solution. Adjuvants, specifically surfactants, generally improve the effectiveness of postemergence herbicides. Typically, surfactants are not added to herbicides that are soil applied (pre-emergence).

The surfactants listed below are categorized into groups or classes based on their chemical composition and how they work. Generally, five surfactant classes are recognized. Table K-1 lists their general usage.

TABLE K-1: SURFACTANT CLASS AND GENERAL USAGE

Surfactant Class	General Usage
non-ionic surfactants (NIS)	all purpose
crop oil concentrates (COC)	used primarily with grass herbicides
nitrogen-surfactant blends	used primarily with broadleaf herbicides
esterified seed oils	all purpose
organo-silicones	all purpose

Non-ionic surfactants are comprised of linear or nonyl-phenol alcohols and/or fatty acids. This class of surfactant reduces surface tension and improves spreading, sticking and herbicide uptake.

Crop oil concentrates are composed of a blend of paraffinic-based petroleum oil and surfactants. This surfactant class reduces surface tension and improves herbicide uptake and leaf surface spreading.

Nitrogen-surfactant blends consist of premix combinations of various forms of nitrogen and surfactants. They generally are used with herbicides recommending the addition of ammonium sulfate or 28 percent nitrogen. These surfactants reduce surface tension and improve leaf surface spreading.

Fertilizers containing ammonium nitrogen have increased the effectiveness of herbicides like glyphosate, and 2, 4-D amine. Fertilizer applied with other herbicides may reduce weed control or cause crop injury. Some fertilizers enhance non-target plant growth to stimulate competition from weed species re-establishing. Fertilizers should be used with herbicides only as indicated on the label or where experience has proven acceptability. Ammonium sulfate is effective for tall larkspur control on its own, as outlined in chapter 3.

[1] Miller et. al., 1998 and NSDU 1999.

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Esterified seed oils are produced by reacting fatty acids from seed oils (corn, soybean, sunflower, canola) with an alcohol to form esters. The methyl or ethyl esters produced by this reaction are combined with surfactants/emulsifiers to form an esterified seed oil. These surfactants reduce surface tension and improve herbicide uptake by improving herbicide distribution on the leaf surface.

Oils generally are used at one gallon per 100 gallons of spray solution) or at 1 to 2 pints per acre depending on herbicide and oil. Oil adjuvants are petroleum, vegetable, or methylated vegetable or seed oils (MSOs) plus an emulsifier for dispersion in water.

Organo-silicones are usually silicone/surfactant blends of silicone to non-ionic or other surfactants; a few within this classification are composed entirely of silicone. These surfactants provide a tremendous reduction in surface tension and spread more than conventional surfactants. In addition, this class of surfactant provides improved effectiveness through maximum rainfastness.

TABLE K-2. SURFACTANT TYPE BY HERBICIDE

Herbicide (Examples of common brands)	**Recommended[2] adjuvant *types,* for the herbicides listed in this analysis**
2,4-D (many brands)	Most brands recommend adding a nonionic surfactant; may be mixed with a nitrogen fertilizer or crop oil concentrate
Aminopyralid	Nonionic surfactant
Clopyralid (Transline®, Stinger®)	Nonionic surfactant
Diuron	Nonionic surfactant
Glyphosate (RoundUp Original®)	Adjuvants already added; nonionic surfactant or ammonium sulfate may also be added
Glyphosate (RoundUp Ultra®)	Adjuvants already added; ammonium sulfate may also be added
Glyphosate (Rodeo®, Aquamaster®, Glypro®)	*Nonionic surfactant*
Hexazinone (Velpar L®)	No recommendations on label
Imazapic (Plateau®)	Methylated seed oil or crop oil concentrate; nonionic surfactant; silicone-based surfactant; fertilizer-surfactant blends
Imazapyr (Arsenal®)	Methylated seed oil or crop oil concentrate; nonionic surfactant; silicone-based surfactant; fertilizer-surfactant blends
Picloram (Tordon 22K®)	Nonionic surfactant
Triclopyr (Garlon 3A®, Garlon 4®)	Nonionic surfactant

TABLE K-3. SURFACTANT CLASS, PRODUCT, AND PRODUCT MANUFACTURER.

Surfactant Class	**Product Name[3]**	**Manufacturer**
non-ionic surfactant (NIS) – (See Table K-4 for more available NIS products.)	Activator 90 Penetrate II Triton Ag 98 X-77	United Ag Products Wilfarm Rhône-Poulenc United Ag Products
crop oil concentrates (COC)	Agri-Dex (99:1) Crop Oil Plus (83:17) Prime Oil (83:15)	Helena Wilfarm Terra
nitrogen-surfactant blends	Cayuse Plus (surfactant + AMS) Chaser (surfactant + 28% N) Dispatch (surfactant + 28% N) Patrol (surfactant + 28% N)	Wilfarm Terra United Ag Products Helena
esterified seed oils	Hasten Meth-Oil MSO Sun-it II	Wilfarm Terra United Ag Products Cyanamid
organo-silicates	Sylgard 309 (straight silicone) Silwet L-77 (straight silicone) Kinetic (silicone/surfactant blend) Herbex (silicone/surfactant blend)	Wilfarm United Ag Products Helena American Colloid

[2] Recommended from herbicide labels. Be sure to always follow the label instructions for specifics on choosing and mixing herbicides and adjuvants.
[3] Including but not limited to these surfactants. No endorsement is intended, nor is any criticism implied of similar products not mentioned.

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TABLE K-4. NONIONIC SURFACTANTS[4]
Suggested use rate of 2 pints/100 gallons unless noted[5]

Product	Supplier
Activate Plus	Riverside
Activator 90	Loveland Industries
Active 80	Walker Distributing
Ad-Here XL	Simplot
Ad-Wet 90	Simplot
Adspray 80	Helena
Advance 90	Countrymark Cooperatives, Inc.
Alliance 90	Countrymark Cooperatives, Inc.
American Spreader	VPG
APSA 80	Amway
Aquagene 90	Universal Cooperatives
Baron	Estes, Inc.
Bio-88	Kalo, Inc.
Bio Surf	Loveland Industries
Boost	Precision Labs
Century	Precision Labs
ChemSurf	United Suppliers
ChemSurf 80	Chemorse
ChemSurf 90	Chemorse
ChemSurf 90	United Suppliers
Chemwett Plus	Coastal Chemical Corp.
CLASS Preference	Cenex/Land O'Lakes Agronomy
CLASS Spraybooster S	Cenex/Land O'Lakes Agronomy
Cohort DC[6]	Helena
Co-op Spreader-Sticker	Farmland
Escort 100	Walker Distributing
Freeway	Loveland Industries
Galactic	Custom Chemicides
Herbraid Plus	Walker Distributing
Impact	Chemrose
Induce	Helena
Inspray 90	Brandt Colsolidated
Kenetic[7]	Helena
Kinetic HV	Helena
Latron Ag-98	Rohm and Haas
Low Foam Surfactant	Cleveland Chemical Co.
M-90	The McGregor Company
Maxi-Surf	T-Tech
Maxisurf 90	T-Tech
Motion	Loveland Industries
Neptune	Loveland Industries
Pen-A-TrateII	Precision Labs
Penetrate II	Farmland
Penetrex	Midsouth Chemical Co.
PHT Spray-Ad 90	Simplot
Premier 90	VanDiest Supply Co.
Premium 80	Big Rivers
Purity 100	Rosen's Inc.
R-11	Wilbur-Ellis/Wilfarm
RP 80/20 Surfactant	Red Panther
S-80/20	T-Tech
Saturall 60	Conklin
Saturall 85	Conklin
Satruate	Walker Distribution
Silkin	Riverside
Silwet L-77	Loveland Industries
Spray Activator 85	VanDiest Supply Co.
Spray Fuse 90	Combelt Chemical Co.
Spreader 80	Loveland Industries
Spreder-Sticker	Lesco
Spret	Helena
Super Surf 90	Cleveland Chemical Co.
Surf-Ac 820	Drexel
Surf-Aid	Riverside
Surf-King Plus	Estes, Inc.
Surfactant 80	Estes, Inc.
Sylgard 309	Wilbur-Ellis/Wilfarm
Tradition 93	Rosen's Inc.
Tronic-98	Kalo
Unifilm 707	Custom Chemicides
Widespread	Loveland Industries
X-77	Loveland Industries
X-90	Cornbelt Chemical Co.
80-20 Surfactant	Universal Cooperatives
80-20 Surfactant	Johnston-Locke Co.
80-20 Surfactant	Cannon

Non-ionic Surfacant Approved for use in Water

Only Aquamaster, Glypro, Rodeo, and some 4 lb ae/gal formulations of glyphosate can be applied on water because they do not include adjuvants that are toxic to fish and aquatic life. For any herbicide used in and around water, add only approved surfactants for effective weed control. Some surfactants labeled for use in and around water are: Activate Plus, Agridex, Class Act NG, Induce, Liberate, LI-700, Preference, R-11, Widespread, and X-77.

Some water pH modifiers are used to lower (acidify) spray solution pH because many insecticides and some fungicides breakdown under basic conditions (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 these 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. Formation of herbicide acid with pH modifiers may precipitate and plug nozzles when solubility is exceeded, such as with high 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% liquid nitrogen fertilizer.

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.

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[4] Source: Bussan, et al, 2001-2002
[5] Always follow the herbicide label for surfactant use.
[6] Use at 28 oz./100 gal.
[7] Use at 1 pt./100 gal.

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Choosing adjuvants with herbicides: Several herbicides allow use of nonionic surfactant, petroleum oil additives, methylated seed oil (MSO) additives, and nitrogen fertilizer. Questions about adjuvant selection are common. MSO type additives have often given greater weed control than petroleum oil additives and nonionic surfactants (NIS) but cost up to 2 to 3 times more. The added cost of MSO's and increased risk of crop injury when used at high temperatures have deterred people from using this class of adjuvants.

Some herbicide labels restrict use of oil adjuvants and recommend only the use of NIS alone or combined with nitrogen based fertilizer solutions. Follow label directions for adjuvant selection. Where labels allow use of oil additives, a petroleum oil based adjuvant referred to as crop oil concentrates (COC) or methylated seed oil (MSO) adjuvants may be used. The following are conditions where MSO type additives may give greater weed control than other adjuvant types:

Conditions that favor use of MSO type adjuvants

- Low humidity, hot weather, lack of rain, and drought stressed weeds or weeds not actively growing due to some condition causing stress.
- Herbicides used at reduced rates.
- When university data supports use. Only some herbicides give greater weed control when used with MSO type adjuvants. Glyphosate should never be used with an oil adjuvant because glyphosate is very water soluble (water + oil do not mix) and the added cost of an MSO is not necessary.

Adjuvant use in low gallonage spray volumes

Many herbicides may be applied in low spray volumes by aircraft. In certain instances, spray adjuvant rates should be adjusted upward for low sprayer volumes.

Some herbicide labels contain information on adjuvant rates for different spray volumes. Additional recommendations to assure sufficient adjuvant load would be to determine the adjuvant rate on an area basis.

DYES

It is recommended that dyes be mixed with the herbicide so applicators can see which plants have been treated and if they have gotten any herbicide on themselves or their equipment. Some pre-mixed herbicides include a dye (e.g., Pathfinder II® includes the active ingredient triclopyr, a surfactant, and a dye). Ester based herbicides like Garlon 4® require oil-soluble dyes like colorfast purple®, colorfast red®, and basoil red® (for use in basal bark treatments), which are sold by agricultural chemical and forestry supply companies.

SPRAY CARRIER WATER QUALITY

Minerals, clay, and organic matter in spray carrier water can reduce the effectiveness of herbicides. Clay inactivates glyphosate. Organic matter inactivates many herbicides and minerals can inactivate 2, 4-D amine, dicamba, and glyphosate.

Water in many parts of the United States is high in sodium bicarbonate which reduces the effectiveness of 2, 4-D amines (not esters), glyphosate, and dicamba. 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, to a lesser degree, magnesium are antagonistic to 2, 4-D amine, dicamba, and glyphosate.

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 does not appear essential to the action of most herbicides.

SPRAY AND VAPOR DRIFT

Drift-Reducing Nozzles: Several sprayer nozzles designed to reduce spray drift are available. These nozzles increase spray droplet size and reduce the number of small droplets. These drift-reducing nozzles are flat-fan types and are adapted for conventional spray equipment. The two primary types of drift-reducing nozzles are pre-orifice and veturi designs.

Pre-orifice nozzles: The two most common are the Drift Guard and Turbo TeeJet nozzles from Spraying Systems Co. Pre-orifice nozzles regulate the liquid flow rate prior to the exit orifice and cause a pressure drop within the nozzle so fewer fine spray droplets are produced. Drift Guard nozzles are available in 80 and 110 spray angles with a recommended pressure range of 30 to 60 psi. The Turbo TeeJet combines the pre-orifice technology with a turbulence chamber to produce a wide-angle flat-fan spray pattern that greatly reduces the amount of spray in fine droplets. Turbo TeeJet nozzles are available in 11001 to 11008 sizes with a spray pressure range of 15 to 90 psi although pressures below 30 psi are recommended to maximize average droplet size and drift reduction.

Venturi (Air induction) nozzles. These include the AI TeeJet from Spraying Systems Co.; the TurboDrop and TurboDrop XL from Greenleaf Technologies Inc.; the Lurmark Ultra-Lo-Drift from Precision Fluid Control Products; the Spraymaster Ultra from Delavan Spray Technologies, and the Lechler ID from Hardi. Although each nozzle has a distinct design, the technology is basically the same. Each includes a pre-orifice to regulate the flow rate so a large exit orifice can be used to produce the spray pattern. Additionally, venturi nozzles include an air-induction assembly that incorporate air into the liquid stream thereby forming air-filled spray droplets. The design allows air-filled droplets to shatter upon impact thus improving spray coverage and retention of the large droplets. A spray pressure of 40 psi will maintain a good spray pattern but pressures greater than 60 psi result in the most consistent performance of herbicides. The air-induction system operates more efficiently at higher spray pressures and in contrast to standard flat-fan nozzles, the droplet size spectrum of venturi nozzles is not greatly influenced by this pressure change.

Drift reduction. Research at NDSU has shown the greatest reduction in spray drift with venturi type nozzles or Turbo TeeJet nozzles operated at low pressure (20 psi). Drift Guard nozzles significantly reduce drift compared to a standard flat-fan nozzle but produce a quantity of fine droplets that result in greater spray drift than venturi or Turbo TeeJet nozzles. The following table compares droplet size data for various sprayer nozzles.

TABLE K - 5. NOZZLE DROPLET SIZE COMPARISON

Nozzle	Pressure	% spray vol.	VMD*
	(psi)	(<191 microns)	(microns
Extended Range 8002	40	65	154
Drift Guard 8002	40	32	292
Turbo TeeJet 11002	40	32	271
Turbo TeeJet 11002	15	19	393
TurboDrop 11002	60	10	520

*VMD = volume median diameter = diameter in which 50% of the spray volume is in droplets smaller than, not an average droplet size.

Percentage of small spray droplets (<191 microns) is the best indicator relating to spray drift. Venturi nozzles (TurboDrop) produced the largest spray droplets and the fewest number of fine spray droplets compared to other nozzles. The data in the table also illustrates the importance of using low spray pressures to maximize the drift-reducing potential of Turbo TeeJet nozzles.

Sufficient spray coverage to maintain effective weed control is a common concern of using nozzles that produce large spray droplets. In most situations, coverage is adequate. Total spray coverage will decrease as droplet size increases, but the number of drops delivered to the target weed will generally still is sufficient for excellent weed control with drift-reducing nozzles.

TABLE K - 6. SPRAY VOLUME PER DROPLET DIAMETER

	Spray Volume		
Spray Droplet Diameter	**5 gpa**	**10 gpa**	**20 gpa**
(microns)	**— drops per square inch ----**		
200	720	1440	2880
300	214	428	856
400	90	180	360
500	46	92	184

Even at 5 gpa spray volume, nozzles that produce large spray drops up to 500 microns in diameter will theoretically produce 46 drops/sq. inch, which should be adequate to cover even small target weeds. Research at NDSU supports this premise as herbicides applied at 2.5 gpa spray volume with drift-reducing nozzles provided weed control similar to herbicides applied with standard flat-fan nozzles.

Large spray droplets may bounce off leaves upon impact resulting in poor droplet retention. The concern is legitimate if applying herbicides without adjuvants. Spray adjuvants applied with herbicides improve droplet retention and deposition. NDSU research has found that spray retention is similar for drift-reducing nozzles and standard nozzles when herbicides were applied with NIS or MSO type adjuvants.

For maximum drift control without affecting herbicide performance, use venturi type nozzles at more than 60 psi or Turbo TeeJet nozzles at less than 30 psi. Contact herbicides, hard-to-wet weed species, and small target weeds are examples where drift-reducing nozzles may reduce herbicide performance. Weed control with drift reducing nozzles may be better than with conventional nozzles when environmental conditions favor lateral droplet movement. Always read the label as some herbicide labels place restrictions on the spray application equipment or spray volume/acre that can be used.

HERBICIDE EFFICACY - TEMPERATURE AND RAINFASTNESS

SPRAYING TEMPERATURES

Foliar treatments are most effective when the herbicide is applied to actively growing foliage. Weeds growing during prolonged cool weather or under droughty conditions do not actively translocate herbicides and thus require a higher rate of application than do weeds that are actively growing. Ideal temperatures for applying most post-emergence herbicides are between 60 and 85 degrees F. Speed of kill may be slow when temperatures remain below 60 F. Some herbicides may injure non-target species if applied above 85 F or below 40 F. At temperatures above 85 degrees F, the risk of vapor drift from certain herbicides such as 2, 4-D esters, dicamba, or triclopyr is much greater.

Avoid applying volatile herbicides such as 2,4-D ester and dicamba during hot weather, especially near susceptible broadleaf crops, shelterbelts, or farmsteads. Glyphosate is not susceptible to UV light but research has shown reduced weed control if glyphosate is applied after 4:00 pm or before 10:00 am. 2, 4-D, dicamba, Stinger, and glyphosate (resistant crops) have adequate non-target species safety and provide similar weed control across a wide range of temperatures, but weed death is slowed when cold temperatures follow application.

Temperatures following herbicide application influence non-target species safety. Cold temperatures may affect non-target species safety and weed control from herbicides. Plants metabolize herbicides, but metabolism slows during cool or cold conditions, which extends the amount of time required to degrade herbicides in plants. Rapid degradation under warm conditions allows non-target species to escape herbicide injury. Herbicides may be sprayed following cold night-time temperatures if day-time temperatures warm to at least 60 degrees (NDSU 2005).

HERBICIDE STORAGE TEMPERATURES[8]

Herbicides may be exposed to freezing temperatures in storage. The following information gives the minimum storage temperature of some herbicides to avoid risk of reduced herbicide activity.

TABLE K – 7. STORAGE RESTRICTIONS

Restriction	Herbicide
No storage temperature restriction	Wettable powders and granules, as a rule, are not affected by low temperatures. These formulations should be stored in a dry place as moisture may promote caking or lead to certain chemical changes that reduce their effectiveness.
Do not store below 32 F	Redeem, Stinger, Tordon 22K, Velpar.
Do not store below 20 F	Plateau, Weedar 64
Do not store below 10 F	Arsenal, glyphosate, Rodeo, Roundup

Minimum storage temperature refers to the temperature required to keep the pesticide in solution. Below that temperature, the pesticide will form crystals and freeze. The freezing point of many pesticides is lower than 32 degrees due to the hydrocarbon solvents or inert ingredients. Pesticides that cannot be frozen must be placed in a heated or adequately insulated area to avoid sub-zero temperatures.

Before storing pesticides for the winter, read the label. While care was taken to assure the accuracy of the above table, labels continue to be amended. Therefore, they should always be consulted.

RAINFASTNESS. The term "Rainfastness" refers to the time needed between application and rainfall/snow event to avoid significant reduction in efficacy. Rainfall shortly after application of most post-emergent herbicides may reduce weed control. Effect will vary with product, the interval between spraying and rainfall and the intensity and duration of the rainfall. The guidelines outlined in the following tables are based on label information. Refer to the specific product

[8] NDSU 2005 and MSU Extension Service, 1995.

labels for rainfastness information. Use the longest time interval on the component products when considering tank mixes.

Rainfall shortly after post-emergent herbicide application reduces weed control because herbicide is washed off the leaves before absorption is complete. See rainfast interval tables below. Dew at application may reduce weed control if spray, in combination with dew, runs off the leaf surface. If no spray run-off occurs after application, weed control may be equal or greater than if no dew was present at application.

TABLE K – 8. EFFECT OF RAINFALL ON HERBICIDE EFFICACY[9]

Required Interval	Product
1 hour	Plateau. Roundup UltraMax/ Roundup WeatherMax
2 hours	Milestone
4 hours	Accent, Ally + 2,4-D Amine, 2,4-D Amine, Cimmarron, Clarity4, Escort
6 hours	Curtail M, Tordon 22K, Rodeo, Redeem, Roundup/glyphosate

[9] NDSU 1999

- End of Appendix J -