GENERAL INFORMATION

A1. PPI AND PRE HERBICIDES

Incorporation of herbicides

Good weed control with PPI and PRE herbicides depends on many factors, including rainfall after application, soil moisture, soil temperature, soil type and weed species. For these reasons, PRE herbicides applied to the soil surface sometimes fail to control weeds. Herbicides that are incorporated into the soil surface usually require less rainfall after application for effective weed control than unincorporated herbicides. Small weeds just emerging through a PRE herbicide may be controlled by a rotary hoe or harrow, which may also help activate the herbicide under dry conditions.

Many factors influence the activity and performance of soil-applied herbicides. Factors that should be considered are: rate too low for soil type, high weed pressure, weeds not listed on label, poor control in wheel tracks, cloddy soil, wet soil, amount of previous crop residue, dry weather, poor incorporation, improper setting of incorporation implement, herbicide resistant weeds, incorporation too shallow or deep, incorporation speed too slow, worn sweeps on cultivator, single pass instead of two pass incorporation, and second incorporation deeper than first. Consider these possibilities before poor weed control is attributed only to the herbicide.

Buckle, Eptam, Far-Go, Ro-Neet, Sonalan, and Treflan* require incorporation. Eptam, Far-Go, and Ro-Neet must be incorporated immediately (within minutes) after application. Treflan incorporation may be delayed up to 24 hours if applied to a cool, dry soil and if wind velocity is less than 10 mph. Sonalan incorporation may be delayed up to 48 hours. Prowl* is labeled only PPI in soybean, dry beans, and pulse crops and labeled PRE, not PPI, on corn. Dual*, Harness/Surpass*, Intrro*, and Outlook* may be used PRE but shallow PPI improves weed control, particularly on fine textured soils. Incorporation of Dual*, Intrro*, and Nortron* may be delayed several days. Incorporation of Eradicane and Eptam can be delayed up to 4 hours when applied with liquid fertilizer and the same day when impregnated on dry bulk fertilizer. Ro-Neet can be incorporated up to 4 hours after application and up to 8 hours when impregnated on dry fertilizer.

Perform a second tillage at right angles to the initial incorporation is needed if a disk or field cultivator is used. The second incorporation will incorporate any herbicide remaining on the soil surface and provide more uniform distribution in the soil, thereby improving weed control and reducing crop injury.

A2. SOIL ORGANIC MATTER TEST

Soil-applied herbicides are adsorbed and inactivated by the clay component in soil but more by organic matter. Adjust herbicide rates for soil type and organic matter content. Most soil-applied herbicides require higher rates to be effective in high organic matter soils, but crop safety may be marginal on low organic matter soils. Some herbicides (linuron) give good weed control only when organic matter levels are low.

Far-Go, Treflan* and most POST herbicides are affected only slightly by organic matter levels. Organic matter levels should be determined on each field where organic-matter-sensitive herbicides are to be used. Organic matter levels change very slowly, and testing once every 5 years should be adequate.

*Or generic equivalent.

A3. POST APPLIED HERBICIDES

Weed control from POST herbicides is influenced by rate, weed species, weed size, and climatic conditions. Low labeled rates will be effective under favorable conditions and when weeds are small and actively growing. Use the highest labeled rates under adverse conditions and for well established weeds.

Sunlight inactivates some herbicides by the ultraviolet (UV) spectrum of light. Treflan* and Eptam degradation is minimal when incorporation is soon after application. “Dim” herbicides (Achieve, Select*, and Poast) are highly susceptible to UV light and will degrade rapidly if left in nonmetal spray tanks for an extended period of time or if applied during mid-day. To avoid UV breakdown, apply soon after mixing and add an effective oil adjuvant which speeds absorption.

Ideal temperatures for applying most POST herbicides are between 65 and 85 F. Speed of kill may be slow when temperatures remain below 60 F. Some herbicides may injure crops if applied above 85 F or below 40 F. Avoid applying volatile herbicides under conditions where vapors and particle drift may injure susceptible crops, shelterbelt trees, or farmsteads.

Temperatures following herbicide application influence crop safety and weed control. Crops metabolize herbicides but metabolism slows during cool or cold conditions, which extends the amount of time required for plants to degrade herbicides. Rapid degradation under warm conditions allow plants to escape herbicide injury. Herbicides may be sprayed following cold night-time temperatures if day-time temperatures warm to at least 60 degrees.

Some “Fop” ACCase herbicides are more effective during cold/cool temperatures and are much less effective when grass weeds are drought stressed. Other ACCase herbicides, such as Assure II*, Poast, and Select* control grasses best in warm weather when grasses are actively growing. ALS grass herbicides in wheat generally provide more consistent and greater grass control in warm, dry conditions compared with cool, wet conditions. Cool or cold conditions at or following application of ACCase herbicides and significant rainfall shortly after Achieve application may increase injury to wheat. Wild oat is a cool season grass but green and yellow foxtail are warm season grasses which may stop growing under cold conditions, resulting in poor control. Weeds are controlled most effectively when plants are actively growing.

Cold temperatures and freezing conditions following application of ALS herbicides, Buctril*, and Sencor* may increase crop injury with little effect on weed control. Delay applying fenoxaprop, ALS herbicides, and Sencor* until daytime temperatures exceed 60F and after active plant growth resumes.

Basagran*, Cobra, Flexstar, Ignite, paraquat*, Reflex, and Ultra Blazer are less likely to cause crop injury when cold temperatures follow application but less weed control may result.

2,4-D, MCPA, Banvel*, Starane*, Stinger*, and Roundup* (resistant crops) have adequate crop safety and provide similar weed control across a wide range of temperatures, but weed death is slowed when cold temperatures follow application.

Dew may increase absorption and weed control by hydrating leaf cuticle but may reduce weed control if spray run-off occurs. Rainfall shortly after POST herbicide application reduces weed control because herbicide is washed off the leaves before absorption is complete (See the rainfast interval chart on the next page).

*Or generic equivalent.

Minimum Interval Between Application and Rain for Maximum POST Weed Control.

Herbicide	Time Intrvl.	Herbicide	Time Intrvl.
Accent*	4-6 hr	**Orion**	4 hr
Achieve	1 hr	**Paramount**	6hr
Aim	6-8 hr	paraquat*	0.5
Ally*/Escort*	4 hr	**Peak**	4hr
Amber	4 hr	**Permit**	4 hr
Assert	3 hr	**Plateau**	1 hr
Assure II / Targa	1 hr	**Poast**	1 hr
atrazine*	4 hr	**PowerFlex**	4 hr
Avenge	6 hr	**Prequel**	- hr
Axial XL	0.5 hr	Progress*	6 hr
Axial TBC	4 hr	**Pulsar**	4 hr
Banvel* / Clarity*	6-8 hr	**Puma**	1 hr
Basagran*	4-8 hr	**Pursuit**	1 hr
Betamix*/Betanex*	6 hr	**Rage D-Tech**	6-8 hr
Bronate*	1 hr	**Raptor**	1hr
Buctril*	1 hr	**Rave**	4 hr
Cadet	1 hr	**Raze**	1 hr
Callisto	1 hr	**Realm Q**	- hr
Cimarron X-tra*	4 hr	**Redeem**	2 hr
ClearMax	1 hr	**Reflex**	1 hr
Cobra	0.5 hr	**Reglone**	0.5 hr
Curtail* / M*	6-8 hr	**Remedy**	6-8 hr
diquat*	0.5 hr	**Require Q**	4 hr
Discover NG	0.5 hr	Resolve*/**Q**	4 hr
Express*	4 hr	**Resource**	1 hr
Everest 2.0	1 hr	**Rezult**	4 hr
Extreme	1 hr	**Rimfire Max**	4 hr
FirstRate	2 hr	Roundup*(Full adjuvant)	6-12 hr
FirstStep	6-12 hr	Roundup* (Partial adj.)	6-12 hr
Flexstar	1 hr	Roundup* (No adjuvant)	6-12 hr
Fusilade DX	1 hr	Select*	1 hr
Fusion	1 hr	**Select Max**	1 hr
Glean*	4 hr	**Sharpen**	1 hr
Goal	1 hr	**Spartan Charge**	6-8 hr
GoldSky	4hr	Starane NXT*	1 hr
Halex GT	4 hr	**Status**	4 hr
Harmony*	4 hr	**Steadfast**	4 hr
Hornet	2 hr	Starane*/ Flex	4 hr
Huskie	1 hr	Stinger*	6-8 hr
Ignite 280	4 hr	**Supremacy**	2 hr
Impact	1 hr	**Tordon 22K**	6-8 hr
Laudis	1 hr	**Ultra Blazer**	4 hr
Lumax	4 hr	**UpBeet**	6 hr
Maverick	4 hr	Weedmaster*	6-8 hr
MCPA amine	4-6 hr	WideMatch*	6hr
MCPA ester*	1 hr	**Wolverine**	1 hr
Milestone	4 hr	2,4-D amine	4-8 hr
Olympus	4 hr	2,4-D ester	1 hr
Option	2 hr		

*Or generic equivalent

A4. ROUNDUP / GLYPHOSATE
The information below, when used, will increase the effectiveness Roundup*/generic glyphosate.

1. Use the correct rate.
- 0.188 to 0.75 lb ae/A controls annual grass species
- 1 lb ae/A controls fall planted rye or wheat in spring
- 0.75 to 2.25 lb ae/A controls perennial grass species
- 0.56 to 2.25 lb ae/A controls annual broadleaf species
- 0.75 to 3 lb ae/A controls perennial broadleaf species

Roundup* contains from 3 to 5 lbs acid equivalent (4 to 6.1 lb active ingredient) per gallon. Refer to table on next page for rate based on formulation used. Do not reduce Roundup* rates. Reducing Roundup* rates will encourage the development of resistant weed biotypes. See "Herbicide Resistant Weeds", Paragraph X1 for more information.

2. Apply to small, actively growing annual plants. This early timing will not coincide with the preferred timing of early bud to early flower for most perennial weeds. Larger and older annual plants are more difficult to control.

3. Delay tillage at least 1 day after treating annual weeds and 3 days after treating perennial weeds. Glyphosate absorption into plant tissue is slow and usually less than 30-40% in most weed species. Delay in tillage will allow time for additional glyphosate absorption.

4. Roundup* can be applied in the spring before emergence of most crops. Adding residual herbicides, including 2,4-D or Banvel* with Roundup* will require delay in planting of some crops. A rain event after application and before crop emergence increases risk of 2,4-D or Banvel* injury to the emerging crop seedlings. Follow planting interval restrictions on pages 6 and 108-109.

5. Use the lowest water volume (gpa) allowed on the label.
Low spray water volumes produce spray droplets of high glyphosate concentration which results in greater absorption. Low spray volume also reduces the amount of antagonistic salts in water to interact with glyphosate. Low gpa produces small drops which may increase risk of damaging drift.

6. Roundup* is very water soluble.
High water solubility causes slow absorption through plant cuticles (cuticular wax repels water). Roundup* activity greatly increases in humid conditions when air moisture hydrates plant cuticles. Roundup activity also increases when plants are growing under good soil moisture. Inversely, weed control is reduced under low humidity and when weeds are drought stressed.

7. Always add NIS to Roundup* unless prohibited by the label. Add NIS at 0.25% v/v to full adjuvant load formulations, 0.25 to 0.5% v/v to partial adjuvant formulations, and 0.5 to 1% v/v to glyphosate formulations with no adjuvant. NIS adjuvants are preferred as oil adjuvants antagonize glyphosate. Addition of NIS will improve control of hard-to-wet species such as lambsquarters. Use reputable adjuvants from major suppliers.

8. Oil adjuvants antagonize Roundup*. (See #6).
To control volunteer Roundup Ready crops, to delay weed resistance to Roundup*, and to control weeds that have developed tolerance or resistance to Roundup* requires herbicides of different modes of action to be added with Roundup*. Many of these herbicides are oil soluble (POST grass herbicides, HPPD inhibitor herbicides) and are greatly enhanced by oil adjuvants (petroleum and MSO). Oil adjuvants antagonize Roundup*. AMS has been shown to partially overcome oil adjuvant antagonism of Roundup* from MSO.

*Or generic equivalent

A4 - GLYPHOSATE

Some adjuvants known as “High Surfactant Oil Concentrates” (HSOC) (See page 130) enhance oil soluble herbicides without decreasing Roundup* activity. Most petroleum (PO) based HSOC adjuvants do not perform different than PO adjuvants. However, MSO type HSOC adjuvants enhance oil soluble herbicides without antagonizing glyphosate. Do not reduce HSOC label rates. Using high rates of Roundup* + NIS + AMS may give adequate control of many but not all weeds.

9. Always add AMS to Roundup*.
AMS enhances Roundup* absorption and translocation and deactivates antagonistic hard water salts. In the spray droplet on the leaf surface, as the droplet dries ammonium binds with glyphosate resulting in greater absorption. Sulfate binds with antagonistic salts in spray water preventing binding with glyphosate resulting in herbicide antagonism. Addition of AMS increases weed control under good and adverse growing conditions even in the absence of antagonistic salts in water (See Section A6). Allow sufficient time for AMS to dissolve before application.

10. Roundup* labels suggest AMS at 8.5 to 17 lb/100 gallons of water. However, analysis of water across the U.S. show 4 to 6 lbs/100 gal of AMS are adequate to overcome most hard water in the U.S. Add AMS at a minimum of 1 lb/A if using greater than 12 gpa spray volume or 4 to 6 lb/100 gallons of water. 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 minerals on leaf surfaces. Refer to A6.
Water in Montana and western ND and SD can have hardness levels of 1600 to 2500 ppm hardness and require AMS at 8.5 to 17 lb/100 gal water. Growers should know their water quality to determine AMS rate. If using adjuvants called “Water Conditioning”, or “AMS Replacement” adjuvants, use only those containing at least 4 lbs of AMS/100 gallons of water at their recommended rates. Data show generally less control from these AMS deficient adjuvants as compared to AMS at 8.5 lb/100 gal + NIS at 0.25% v/v.

11. Applying Roundup* with contact herbicides may result in antagonism and reduced weed control. Rapid wilting and desiccation occur when contact herbicides are applied with Roundup* but the contact herbicides may desiccate leaf tissue before the systemic glyphosate is absorbed reducing absorption and translocation within the plant. Roundup* plus a contact herbicide may quickly kill small and susceptible plants but antagonism on large weeds may be noticeable only a few days after application when weed regrowth begins. Some contact herbicides that may antagonize Roundup* are Aim, Cadet, Cobra, diquat, Fierce, Flexstar, Ignite, paraquat*, Phoenix, Reflex, Resource, Sharpen, Spartan, and Valor. When tank-mixing glyphosate with contact herbicides and large or troublesome weeds are present, use high water volumes as recommended on labels and increase the Roundup* rate.

12. When tank-mixing with Roundup*, use the recommended rate of Roundup*, the most effective rate and the most effective adjuvant of the tank-mix partner. Use the least antagonistic adjuvant to Roundup* whenever possible.

13. Cold weather is a stress to plants. Weed control from Roundup* applied during or after cold weather may be the same as when applied in warm weather but the end result (weed control) may take longer. Ideal temperatures for applying POST herbicides are between 65 and 85 F. Speed of kill will be slower during cold weather. Use higher rates to overcome reduced control from cold temperatures before or after application. Roundup* applied during cold weather, to large weeds, and weeds with low level resistance will result in less weed control. AMS enhances weed control and can partially overcome reduced control of stressed plants.

Research data show wide temperature fluctuations (>15 F) 1 to 2 days before and after application are more likely to reduce weed control than consistently cool or cold temperatures. More research is needed but wide temperature fluctuations can likely explain many situations where weed control is poor due to cold weather.

14. Excessive dew on plant foliage at application may reduce weed control by diluting the glyphosate concentration in spray droplets and negate the effect of low spray volume at application. Allow a 6 to 12 hour rainfast period for all Roundup* formulations regardless of label rainfast recommendation. Research has consistently shown increased glyphosate activity in humid conditions when leaf cuticles are hydrated. Dew on leaves will hydrate leaf cuticles and facilitate absorption.

15. Roundup* is not deactivated by sunlight.
Time of day application studies show that activity of Roundup* is greatest when applied after 8:00 am and before 8:00 pm.

16. Use drift management techniques. Roundup* is a non-selective, non-residual, translocated, foliar herbicide. Roundup* can cause severe injury or death of plants intercepting even a small amount of active ingredient in down-wind spray droplet drift. Several drift reducing nozzles (example, Turbo Tee-Jet) can reduce drift without reducing phytotoxicity. Some drift reducing adjuvants can negatively alter spray pattern and reduce phytotoxicity.

17. Roundup* is not volatile. Roundup* does not produce fumes or vapor after application. Off-target movement of Roundup* from wind or during temperature inversions is in the form of droplets or particle drift, not volatility.

18. Tolerant plants escape phytotoxicity by metabolizing herbicides. Except for Optimum GAT technology in crops, plants can not metabolize glyphosate (including Roundup Ready). Plant metabolism slows during cool or cold conditions, which extends the amount of time required to degrade herbicides in plants. Therefore, absorbed glyphosate will remain in the plant until warm temperatures cause plants to resume translocation of glyphosate to growing points via the phloem.

19. Roundup* can be applied in the fall after several frosts and will result in excellent control of annual, biennial, and perennial weeds. However, plant tissue must be green or purple and leaves firmly attached to the stem to absorb and translocate the herbicide. Low freezing temperatures may desiccate plant tissue. Weed control will decrease when Roundup* is applied to desiccated plant tissue. Application to new plant growth is required for optimum herbicide activity.

*Or generic equivalent.

20. Dust inactivates Roundup*.
Roundup* absorption in plants is slow which partially explains the 6 to 12 hour rainfast period. Slow absorption allows Roundup* on the plant leaf surface to be inactivated by dust present either on the leaf surface or transported by wind. This applies also to using slough or river water for spraying. Organic matter and clay particles in water will inactivate Roundup*. The addition of NIS or AMS will not overcome inactivation. Roundup* is strongly and irreversibly absorbed to clay particles and organic matter. Placing nozzles before or after wheels may reduce inactivation from dust. Applying glyphosate perpendicular to the previous application or shifting the sprayer to one side of the previous path may also reduce inactivation by dust.

21. Do not apply Roundup* brands formulated with surfactant (partial or full adjuvant formulations) to bodies of water because they include surfactant components that are toxic to fish and aquatic life. Only some non-adjuvant loaded formulations, such as Aquamaster, Rodeo, and some 4 lb ae/gal formulations of glyphosate can be applied to water. An approved NIS surfactant at 0.5 to 1% v/v must be added to non-loaded generic glyphosate formulations for adequate weed control. Refer to the Adjuvant Section, on page 130 for a list of NIS adjuvants registered for use in water.

22. Roundup* may inhibit manganese (Mn) uptake in plants and soil. Roundup* is a strong nutrient chelator and immobilizes Mn and other micronutrients through enzyme inhibition. This reduces the efficiency of micronutrients. The glyphosate-resistant gene may also reduce Mn efficiency even without the presence of glyphosate. Micronutrient deficiencies can be managed by applying micronutrients as warranted by soil test analysis and fertilizer recommendation.

23. To optimize glyphosate phytotoxicity from sequential applications, delay the second application until new growth appears (>10 days).

24. Reduced glyphosate rates may increase resistant weed biotypes with low-level resistance. Biotypes of weeds like lambsquarters, waterhemp, ragweed, and kochia that require a standard use rate or greater for adequate control will only show temporary phytotoxicity from reduced glyphosate rates. These biotypes may recover, resume growth, and produce seed allowing more plants to survive glyphosate at reduced rates. A higher rate may be required to give the same level of control from previous history. Survivors will likely contribute to populations with enhanced low-level resistance where weed control with standard or greater rates is marginal. Refer to section on Herbicide Resistant Weeds on page 102.

*Or generic equivalent.

Partial List of Registered Glyphosate Products:

Trade Name	Manufacturer	Glyphosate salt	lb ae/gal	lb ai/gal	Adjuvant Load*
Abundit	Dupont	ipa	3	4	Full
Accord	Dow	ipa	4	5.4	None
Aquamaster	Monsanto	ipa	4	5.4	None
Buccaneer	Tenkoz	ipa	3	4	Partial
Buccaneer Plus	Tenkoz	ipa	3	4	Full
Buccaneer 5	Tenkoz	ipa	3.7	5	Partial
Cornerstn 5 Plus	Winfield Sol.	ipa	4	5.4	Full
Credit / 41	NuFarm	ipa	3	4	Partial
Credit / 41 Extra	NuFarm	ipa	3	4	Full
Nfrm Credit/Extra	NuFarm	NH_4 & K	1.65+1.35	1.8 + 1.6	Full
Credit Xtreme	NuFarm	ipa & K	2.5 + 2	6	Full
Duramax	Dow	dma	4	5.4	Full
Durango DMA	Dow	dma	4	5.4	Full
Extra Credit 5	NuFarm	ipa	3.7	5	Partial
Gly + N-Go adj.	MEY	acid	97%	-	Full
Glyfos	Cheminova	ipa	3	4	Partial
Glyfos X-tra	Cheminova	ipa	3	4	Full
Glyphogan	MANA	ipa	3	4	Partial
Glysort	Glysortia	ipa	3	4	Partial
Glysort Plus	Glysortia	ipa	3	4	Full
Gly Star 5	Albaugh	ipa	4	5.4	None
Gly Star 5 Extra	Albaugh	ipa	4	5.4	Partial
Gly Star Gold	Albaugh	ipa	3	4	Partial
Gly " Gold Extra	Albaugh	ipa	3	4	Full
Gly Star Original	Albaugh	ipa	3	4	Partial
Gly Star Plus	Albaugh	ipa	3	4	Full
Helosate Plus	Helm Agro	ipa	3	4	Full
Helosate 70	Helm Agro	ipa	4.72	6.3	Full
Kull 41S	Ritter Chem.	ipa	3	4	Partial
Mad Dog	UAP	ipa	3	4	Partial
Mad Dog Plus	UAP	ipa	3	4	Full
Makaze	UAP	ipa	3	4	Full
Lajj Plus	Northmoose	ipa	3	4	Partial
Rattler / Plus	Helena	ipa	3	4	Part/Full
Rodeo	Dow	ipa	4	5.4	None
RT 3	Monsanto	K	4.5	5.5	Full
RU PowerMax	Monsanto	K	4.5	5.5	Full
RU/Private labels	Various	ipa	3	4	Partial
RU WeatherMax	Monsanto	K	4.5	5.5	Full
Strikeout	-	ipa	3	4	Partial
Touchdown CT	Syngenta	K	4.17	5.1	Full
Touchdn HiTech	Syngenta	K	5	6.1	None
Touchdown iQ	Syngenta	$(2(NH_3)$	3	4	Full
Touchdown Total	Syngenta	K	4.17	5.1	Full
Traxion	Syngenta	K	4.17	5.1	Partial
-	Helm Agro	ipa	68SG	75.7SG	Full

*Unless prohibited: Full = add NIS at 0.25% v/v.
Partial = add NIS at 0.25 to 0.5% v/v.
None = add NIS at 0.5 to 1% v/v.

Glyphosate product rates based on acid equivalent (ae) and active ingredient (ai). (Refer to page 4 for explanation of ai and ae).

lb ae		lb ai		0.38 ae	0.57 ae	0.75 ae	1.125 ae	1.5 ae
				fl oz/A				
3	=	4	=	16	24	32	48	64
3.75	=	5	=	13	20	26	38	52
4	=	5.4	=	12	18	24	36	48
4.17	=	5.1	=	12	18	24	36	48
4.5	=	5.5	=	11	16	22	32	44
4.72	=	6.3	=	10	15	20	30	40
5	=	6.1	=	10	15	19	29	38

A5. SPRAY ADJUVANTS

Questions about adjuvant selection are common. Adjuvants are not regulated by the EPA or any other regulatory agency allowing an unlimited number of adjuvants. Adjuvants are composed of a wide range of ingredients which may or may not contribute to herbicide phytotoxicity. Results vary when comparing specific adjuvants, even within a class of adjuvants. POST herbicide effectiveness depends on spray droplet retention, deposition, and herbicide absorption by weed foliage. Adjuvants and spray water quality (Paragraph A6) 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 (nonionic surfactants = NIS) are used at 0.25 to 0.5% v/v (1 to 4 pt/100 gal of spray solution) regardless of spray volume. NIS rate depends on the amount of active ingredient in the formulation, plant species and herbicides used. The main function of a NIS is to increase spray retention, but may, to a lesser degree, function in herbicide absorption. When a range of surfactant rates is given, the high rate is for use with low herbicide rates, 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 leaf stomata (“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 2 pt/A depending on herbicide and oil. Oil additives increase herbicide absorption and spray retention. Oil adjuvants are petroleum (PO) 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. Oil adjuvants enhance POST herbicides more than NIS and are effective with all POST herbicides, except Ignite and Cobra, and will antagonize Roundup*. The term crop oil concentrate (COC) is used to designate a petroleum oil concentrate but is misleading because the oil type in COC is petroleum and not a crop vegetable oil.

MSO adjuvants greatly enhance POST herbicides much more than NIS and PO adjuvants. MSO adjuvants are more aggressive in dissolving leaf wax and cuticle resulting in faster and greater herbicide absorption. The greater herbicide enhancement from MSO adjuvants may occur more in low humidity/low rainfall environments where weeds develop a thicker cuticle. MSO adjuvants cost 2 to 3 times more than NIS and PO adjuvants. 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 adjuvants can enhance weed control while lowering risk of crop injury.

Some herbicide labels restrict use of oil adjuvants and recommend only NIS alone or combined with nitrogen based fertilizer solutions. Follow label directions for adjuvant selection. Where labels allow use of oil additives, PO or MSO adjuvants may be used.

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 to the same level as oil adjuvants. 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 stress condition.
2. Weeds larger than recommended on the label.
3. Herbicides used at reduced rates.
4. Target weeds that are somewhat tolerant to the herbicide. (buckwheat, lambsquarters, ragweed to Pursuit or Raptor, or yellow foxtail to Accent).
5. When university data supports reduced herbicide rates. Most herbicides, except Roundup*, give greater weed control when used with MSO type adjuvants.

Oil adjuvant applied on a volume or area basis

Labels of many POST herbicides recommend oil adjuvants at 1% v/v. At water volume 15 or 20 GPA, 1% oil adjuvant will provide the minimum adjuvant concentration (1% v/v PO in 17 gpa = 1.4 pt/A). Optimum rate of a PO is 2 pt/A. ND surveys show common spray volumes used are at or below 10 gpa. PO at 1% v/v in 8.5 gpa = 0.68 pt/A and does not provide an adequate amount of oil adjuvant. Further, in aerial applications at 5 GPA, PO at 1% v/v will not provide sufficient adjuvant. 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 at 5 GPA.

Some herbicide labels contain information on adjuvant rates for different spray volumes. To insure sufficient adjuvant concentration add the oil adjuvant at 1% v/v but no less than 1.25 pt/A at all spray volumes. Surfactant at 0.25 to 0.5% v/v water is sufficient across all water volumes.

High surfactant oil concentrates (HSOC) were developed to enhance lipophilic herbicides without antagonizing glyphosate. HSOC adjuvants contain at least 50% w/w oil plus 25 to 50% w/w surfactant, are PO or MSO based, and are usually applied at ½ the oil adjuvant rate (area basis). Glyphosate must be applied with other herbicides to control glyphosate tolerant weeds and delay resistant weeds. Glyphosate is highly hydrophilic, is enhanced by NIS and nitrogen fertilizer surfactant type adjuvants, and is antagonized by oil adjuvants. Postemergence herbicides preferred by growers to mix with glyphosate to increase weed control are lipophilic (Select*, Banvel*, Laudis, others) and require oil adjuvants for optimum herbicide enhancement. Surfactants are less effective in enhancing lipophilic herbicides. Oil adjuvants, including PO and MSO adjuvants, may antagonize glyphosate. NDSU research has shown wide variability among PO based HSOC adjuvants with many performing no different than common PO adjuvants. However, MSO based HSOC adjuvants enhance both glyphosate and the lipophilic herbicide. MSO based HSOC adjuvants can enhance lipophilic herbicides more than PO based HSOC, MSO and PO adjuvants.

Fertilizers - See Section A6 - Spray Carrier Water Quality.

*Or generic equivalent.

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 blends of nonionic surfactant, fertilizer, and basic pH enhancer and are used 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.

Basic pH blend adjuvants are surfactant based, increase spray solution pH, and 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 blends adjuvants increase water pH which increases water solubility of many herbicides. The water solubility increase as pH increases from 5 to 9 resulting in enhanced phytotoxicity from basic blend adjuvants. Within the sulfonylurea chemistry the magnitude of solubility from high spray solution pH can increase from 40 fold (Harmony GT*) to 3,670 fold (UpBeet). The solubility of herbicides in other chemical families increase with high pH: Florasulam (a triazolopyrimidine sulfonamide in PowerFlex), Everest (sulfonylamino carbonyltriazolinone), Achieve (cyclohexandione), Sharpen (pyrimidinedione), Callisto and Laudis (triketone), Pyrasulfatole (a pyrazolone in Huskie and Wolverine), Impact (also a pyrozolone), and diflufenzopyr (in Status). Some herbicides degrade rapidly in high pH spray solution. Cobra (diphenylether), Resource and Valor (N-phenylphthalimide), and Sharpen (pH 9) degrade within a few minutes in high pH water but are stable for several days at low pH. Optimum use of pH adjusting adjuvants requires some knowledge of herbicide chemistry or experience.

Research has shown that basic pH blend adjuvants may enhance weed control similar to MSO adjuvants. They may be used in situations where oil adjuvants are restricted. Basic pH blend adjuvants reduce precipitation problems with Betamix*/ Betanex*/ Betamix Progress plus UpBeet at low rates by increasing water pH.

Commercial adjuvants differ in effectiveness with herbicides. Data from the table below are from experiments conducted at 6 NDSU R&E Centers in ND from 1992 through 1995 and repeated in 2005 and 2006 comparing commercial adjuvants with Roundup. In 1993-95, Roundup was applied at 1 to 1.5 oz ae/A to 16 grass and broadleaf weed species. In 2005-06 Roundup was applied at 1 to 4 oz ae/A to 26 grass and broadleaf weed species (272 averages). Higher rates were used in western ND because of low activity in low humidity.

Commercial adjuvant effect on glyphosate phytotoxicity[a,b].

	Rate	Grass		Broadleaf	
Adjuvants	% v/v	93-95	05-06	93-95	05-06
		% control			
Surfactants					
None	0.5	49	68	31	42
R-11	0.5	74	90	51	66
APSA 80	0.5	74	87	50	62
Wet-Sol 99	0.5	--	86	--	61
Premier 90	0.5	--	81	--	58
Purity 100	0.5	--	82	--	56
Preference	0.5	67	79	38	58
Liberate	0.5	--	76	--	51
X-77	0.5	66	70	40	52
Spray Booster S	0.5	64	--	41	--
Activator 90	0.5	64	69	41	50
LI-700	0.5	58	66	42	41
Silwet L-77	0.25	56	--	40	--
AMS	8.5 lb/100 gal	--	86	--	68
Surfactant + AMS Fertilizer					
Class Act	2/2.5	90	94	75	76
R-11 + AMS	0.5+8.5 lb/100	--	93	--	76
R-11 + Bronc Max	0.5 + 0.5	--	92	--	73
Surfate	1	89	93	75	74
Dispatch	2	85	--	69	--
R-11+Cayuse	0.5 + 0.5	82	--	66	--
AMS Replacement / Water Conditioning Agent					
N-Tense	0.5	--	90	--	67
Alliance + Prfrnc	1.25 + 0.5	--	89	--	68
Citron + Prefernce	2.2 lb/A + 0.5	--	84	--	66
Quest + Prefernce	0.5 + 0.5	--	83	--	62
Choice + Liberate	0.5 + 0.5	--	81	--	60
Herbolyte		--	79	--	55

Conclusions from the study:
1. Not all adjuvants are created equal.
2. Small numerical differences in data is significant as data was averaged across 68 means making outlying values have less affect to change the mean.
3. Most adjuvants enhanced Roundup* but some did not enhance Roundup* more than no adjuvant added.
4. The better adjuvants in 93-95 are the same as 05-06.
5. Data is arranged in numerically descending order showing similar enhancement in both 93-95 data and 05-06 data.
6. Adjuvants are non-regulated. Changes in individual adjuvant formulations have probably occurred since 1995. However, this data shows relatively little change in herbicides enhancement of Roundup* over time.
7. The 05-06 data is approximately 15 to 20 points higher probably due to higher Roundup* rates used in 05-06.
8. Surfactant + AMS fertilizer adjuvants as a group were more effective than the surfactants or AMS Replacment / Water Conditioning Agent adjuvants.
9. The results are averaged over various locations and may not represent adjuvant effectiveness for all situations.
10. Adjuvants differ in effectiveness and users should compare several products for their specific conditions or select an effective adjuvant from the list.

A6. 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 herbicides. Hard water cations or micronutrients such calcium, magnesium, manganese, sodium, and iron reduce efficacy of all weak-acid herbicides. Cations antagonize glyphosate efficacy by complexing with glyphosate to form salts (e.g. Glyphosate-Ca) that are not readily absorbed by plants. Antagonistic minerals can inactivate the activity of most POST herbicides, including glyphosate, growth regulators (not esters), ACCase inhibitors, ALS inhibitors, HPPD inhibitors, and Ignite. The antagonism is related to the salt concentration. At low salt levels, loss in weed control may not be noticeable under normal environmental conditions but will occur when weed control is marginal because of drought or partially susceptible weeds. 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.

ND water often contains a combination of sodium, calcium, magnesium, and iron and these cations generally are additive in the antagonism of herbicides. Water in ND, SD, and MT is often high in sodium bicarbonate which does not normally occur in other areas of the U.S. Calcium levels above 150 ppm and sodium bicarbonate levels above 300 ppm in spray water can reduce weed control in all situations. Water with 1600 ppm sodium bicarbonate occur in ND, but total hardness levels can exceed 2,500 ppm.

Ammonium nitrogen increases effectiveness of most weak-acid herbicides formulated as a salt. Fertilizers should always be used with herbicides unless prohibited by label. Ammonium ions greatly enhance herbicide absorption and phytotoxicity even in the absence of antagonistic salts in the spray carrier. However, enhancement of Roundup* and most other POST herbicides from ammonium is most pronounced when spray water contains large quantities of antagonistic cations. Herbicide enhancement by nitrogen compounds appears in most weed species but is most pronounced in species like volunteer corn and species that accumulate antagonistic salts on or in leaf tissue (lambsquarters, velvetleaf, and sunflower).

AMS enhances phytotoxicity and overcomes salt antagonism for weak-acid herbicides formulated as a salt including glyphosate, growth regulators (not esters), ACCase inhibitors, ALS inhibitors, HPPD inhibitors, and Ignite. The antagonism may be overcome by increasing the glyphosate concentration relative to the cation content or by adding AMS and some water conditioners to the spray solution. Effective water conditioners include EDTA, citric acid, AMS, and some acidic AMS replacements. Of these, AMS has been the most widely adopted. In spray solution, ammonium (NH_4^+) ions complex with glyphosate molecule to reduce glyphosate interaction with the hard-water cations. The sulfate (SO_4^{2-}) ions complex with hard-water cations (e.g. calcium sulfate), causing the salt to precipitate from solution. This combined effect increases absorption and efficacy. Natural sulfate in water can be disregarded but can reduce antagonism if the sulfate concentration is at least three times the calcium concentration.

Antagonism of Roundup* 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 Roundup* may realistically benefit from a reduced pH as has been shown for Poast. However, Poast does not require a low pH for efficacy. 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.

AMS is recommended at 8.5 to 17 lb/100 gal spray volume (1 to 2%) on most Roundup* labels. However, AMS at 4 lb/100 gal (0.5%) is adequate to overcome most salt antagonism but more than 4 lb/100 gal may be required to fully optimize herbicides. 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 more than 12 gpa. 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 or in the leaf tissue in species like lambsquarters, sunflower, and velvetleaf which may require additional AMS.

AMS may contain contaminants that may not dissolve resulting in plugged nozzles. Use spray grade AMS to prevent nozzle plugging. Commercial liquid solutions of AMS are available and contain approximately 3.4 lbs of AMS/gallon. For 8.5 lbs of AMS/100 gallons of water add 2.5 gallons of liquid AMS solution.

28% UAN fertilizer is effective in enhancing weed control and overcoming mineral antagonism of most POST herbicides, but not calcium antagonism of Roundup*. Sodium bicarbonate antagonism of Poast is overcome by 28% UAN and AMS. AMS or 28% UAN does not preclude the need for a oil adjuvant with lipophilic herbicides. Generally, 4 gal of 28% UAN/100 gal of spray has been adequate. AMS and 28% UAN enhance herbicide control of most weeds even in water without antagonistic salts. Nitrogen fertilizer/surfactant blends may enhance weed control of most herbicides formulated as a salt.

Analysis of spray water sources can determine water quality effects on herbicide efficacy. Water samples can be tested at the NDSU Soil and Water Laboratory:
USPS: NDSU Dept 7680, Fargo, ND 58108-6050,
UPS and Physical Address: Waldron Hall 202, 1360 Bolley Dr. NDSU, Fargo, ND 58102. 701 231-7864.
Analysis is approximately $25.00 to $29.00.
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 North Dakota water. However, AMS at 4 lb/100 gal is adequate for most North Dakota water. Iron is also antagonistic to many herbicides but not abundant in ND water.

Water conditioner adjuvants are liquid for user preference, applied at low use rates, may contain no or very little AMS, may lower spray solution, and are advertised to replace AMS, and thus are also called AMS replacement adjuvants. Pesticide applicators prefer the convenience of low use rate water conditioners, but performance has been inconsistent. Glyphosate plus commercial water conditioner products that included AMS at the equivalent rate of 1% w/w can give similar control to 1% w/w (8.5 lbs/100 gal) AMS. Commercial water conditioners that do not provide an equivalent amount of AMS give less control than glyphosate with 1% or 2% w/w AMS and are often no better than glyphosate alone.

Acidic AMS replacement (AAR) adjuvants have been developed for use with glyphosate and other weak acid herbicides. Claims are made to enhance activity, negate affects of antagonistic salts in spray water and the antagonism from micronutrient solutions added for crop health. Most adjuvants in this class contain monocarbamide dihydrogen sulfate or AMADS (urea plus sulfuric acid) which lowers spray solution pH to 1.4 to 3. The low pH is below the pKa of postemergence herbicides causing most herbicide molecules to be in the acid state which results in fewer molecules binding to positively charged salts.

*Or generic equivalent.

Some water conditioner adjuvants and acidic AMS replacement adjuvants (AAR) are marketed to modify spray water pH, but low pH is 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. Several commercial AAR adjuvants applied with glyphosate in distilled water were tested and ranked as follows: surfactant + AMS > AMS > NIS = AAR. A commercial AAR adjuvant composed primarily of sulfuric acid was much less phytotoxic than most AAR adjuvants which support the concept and use of ammonia to enhance weak acid herbicides. Generally, AAR adjuvants applied with glyphosate in 1000 ppm hard water (Ca and Mg) gave similar weed control as when applied in distilled water supporting the theory of non-binding herbicide molecules when pH is below the pKa of the herbicide. Clearly, commercial adjuvants vary greatly in function, use, and chemical and biological effect.

Low spray volumes (5 to 10 gpa) have been equally or more effective than higher spray volumes for many herbicides. Low spray volume originally was considered important to glyphosate efficacy because it would reduce the ratio of glyphosate and antagonistic cations in the spray solution. However, low spray volumes have enhanced glyphosate efficacy because of higher glyphosate concentration in the spray deposit. Greater efficacy from higher concentrated droplets has been shown with many other herbicides but is logical that the highly concentrated droplets with low volume would be positive for translocated herbicides (NDSU Pile Theory). Contact herbicides (Cobra, Cadet, Ignite, Flexstar/Reflex, paraquat, Sharpen) require higher spray volume for adequate and thorough coverage to enhance control.

Low spray volumes usually imply use of low-volume nozzles that produce small droplets which can increase off-target movement. However, drift-reducing nozzles have been developed that produce large droplets at low volume. In low spray volumes, larger droplets produced by drift-reducing nozzles have been equally effective as small droplets with several translocating herbicides. However, coarse or larger droplets may be less phytotoxic than fine and medium size droplets for sethoxydim, imazethapyr, tembotrione, and 2,4-D. Limited research is available about efficacy based on droplet size although will become important as regulation requires larger droplet size to mitigate drift from small droplets.

*Or generic equivalent.

A7. SPRAY AND VAPOR DRIFT

Refer to NDSU Extension Circular A-657, "Herbicide Spray Drift" for additional information. Risk of off-target herbicide movement and injury to non-target plants depends on the susceptibility of the plant to the herbicide applied. In general, POST herbicides that are highly phytotoxic at low rates (2,4-D, MCPA, Banvel*, Tordon, Roundup*, and all ALS herbicides have the greatest potential for damaging non-target plants.

Wind velocity and direction: Apply when wind direction is away from susceptible plants, during low wind speed, and in the absence of temperature inversions. Vertically stable air (temperature inversion) occurs when air near the soil surface is cooler or similar in temperature to air above the crop. Normally, air near the soil surface is warmer than air above the crop. Warm air rises and cold air sinks, which causes vertical mixing of air and dissipation of spray droplets. Small spray droplets can be suspended in stable air, move laterally in a light wind, and affect plants more than two miles downwind. Inversions can be identified by fog or dust from a gravel road.

Boom height: Adjust boom as close to the target as possible while maintaining uniform spray coverage. Choose nozzles with a wide angle as opposed to narrow angle nozzles.

Herbicide formulation: Dimethyl amine (dma) formulations of dicamba and ester formulations of 2,4-D and MCPA may volatilize at 70 to 90 F and cause plant injury from vapors. Amine formulations of 2,4-D and MCPA are non-volatile at high temperatures. Soil surface temperature is much warmer than the air. Herbicide vapor can drift farther and over a longer time than spray droplets. Volatile herbicides should not be used near susceptible plants.

Spray shields: Cones around nozzles reduce drift by 25 to 50% and spray shields that enclose the entire boom reduce drift by 50 to 85%. Spray shields should not be used as a substitute for other drift control techniques but as a supplement to drift reduction.

Drift control: Increase droplet size to reduce drift by by increased by reducing spray pressure, increasing nozzle orifice size, using special drift reduction nozzles, including additives that increase spray viscosity, and orienting nozzles rearward on aircraft.

Drift-reducing nozzles: Sprayer nozzles designed to reduce spray drift increase spray droplet size and reduce the number of small droplets. The two primary types of flat-fan drift-reducing nozzles are pre-orifice and air-induction (venturi) designs.

Pre-orifice nozzles: Pre-orifice nozzles (Drift Guard and Turbo TeeJet) regulate the liquid flow rate prior to the exit orifice causing a pressure drop in the nozzle resulting in fewer fine spray droplets. Use Drift Guard nozzles at a pressure range of 30 to 60 psi. The Turbo TeeJet design combines pre-orifice technology with a turbulence chamber to produce a flat-fan spray pattern that greatly reduces the amount of spray in fine droplets. Use Turbo TeeJet nozzles at a pressure range of 15 to 90 psi (30 psi to maximize average droplet size).

Air-induction (venturi) nozzles include AI TeeJet, TurboDrop, Lurmark, Spraymaster Ultra, and Lechler. Each nozzle has a distinct design but use a pre-orifice to regulate the flow rate and a large exit orifice. Venturi nozzles include an air-induction assembly that incorporates air into the stream, thereby forming air-filled droplets that shatter upon impact improving spray coverage and retention of large droplets. The air-induction system operates more efficiently at higher spray pressures (60 psi) 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. The greatest reduction in spray drift occurred with air induction or Turbo TeeJet nozzles operated at low pressure (20 psi). Drift Guard nozzles reduced drift but produced fine droplets that result in greater spray drift than air induction or Turbo TeeJet nozzles. The following table compares droplet size data for various sprayer nozzles (Univ. of Tennessee Agric. Experiment Station, Bull. 695).

Nozzle	Pressure	Droplets <191 um	VMD*
	(psi)	(%)	(µm)
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.

% of small spray droplets (<191 µm) is the best indicator relating to spray drift. Air induction nozzles (TurboDrop) produced the largest spray droplets and the fewest number of fine spray droplets compared with 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.

Herbicide performance. Weed control from most POST herbicides, including contact herbicides of Aim and paraquat*, were similar when applied through drift-reducing nozzles or standard flat-fan nozzles. Weed control from Reflex applied with drift-reducing nozzles was slightly less.

In most cases, drift reducing nozzles will produce sufficient spray coverage to maintain effective weed control. Total spray coverage will decrease as droplet size increases, but the number of drops delivered to the target weed will generally still be sufficient for excellent weed control with drift-reducing nozzles.

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

A spray volume of 5 gpa from drift reducing nozzles will produce large droplets (500 µm) to theoretically produce 46 drops/sq. inch, which should be adequate to cover even small target weeds. Research at NDSU supports the premise that herbicides applied at 2.5 gpa spray volume with drift-reducing nozzles provide 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. Spray adjuvants applied with POST 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 air induction 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. Go to http://www.ageng.ndsu.nodak.edu/spraynozzles to compare spray nozzles.

A8. USING HERBICIDES AT REDUCED RATES

Ideally, control of target weeds at the lowest herbicide rate provides the greatest return over herbicide and application costs. This "best" herbicide rate will be different for every herbicide-weed-environment-adjuvant combination. Sometimes, the "best" rate will be lower than the lowest rate on the herbicide label. Below are factors considered by companies when they write a label.

Weed Size and Crop Size. Companies make an assumption of weed and crop size at herbicide application. Small weeds are more susceptible to herbicides than large weeds, but small crop plants may also be more susceptible. Reduced herbicide rates may control weeds smaller than listed on label but the crop may also be smaller so knowledge of crop safety also is needed.

Environment. Companies write labels that cover most environments in which herbicides are used. Environment has a large influence on efficacy of herbicides. Herbicide rates may be reduced under ideal environmental but special knowledge and experience is needed on the environment-herbicide interaction.

Adjuvants. Most POST herbicides require addition of adjuvants such as surfactants, crop oils, methylated seed oils, or fertilizer. See section on spray adjuvants (A5) for more information. Adjuvant information is fairly general on pesticide labels to address adequate weed control under most situations. Herbicide rates sometimes can be reduced by using adjuvants that are highly effective with a specific herbicide but additional knowledge is needed. The herbicide-adjuvant combination must be safe on the crop as well as provide good weed control.

Weed Species. Labels sometimes list weed species separately on the label with different rates for different weeds. Herbicide rates may be reduced when small or highly susceptible weed species are present.

Performance Complaints. Using reduced rates may result in poor weed control. User assumes all risk and liability of unacceptable weed control when less than labeled rates are used.

Are Low Rates Legal? Herbicide can legally be applied at rates lower than listed on the herbicide label unless the label specifically prohibits low rates. However, the company has no obligation to support herbicide efficacy when the application rate was less than labeled rates. Herbicide users should not expect a company representative to provide any comfort or assistance if weed control is less than expected from a rate of herbicide that is less than the labeled rate.

*Or generic equivalent.

A9. SPRAYER CLEANOUT
The risk crop injury from a contaminated sprayer is greatest when spraying highly susceptible crops, when the previous herbicide is very active in small amounts, or when the entire plumbing system of the sprayer is not cleaned after application. Rinsing with just water may not remove the residue and the herbicide may remain tightly adsorbed in sprayers through water rinsing and even through several tank-loads of other herbicides. Then, an added tank-load of mixture including an oil adjuvant, nitrogen solution, or basic pH blend adjuvant may cause the herbicide to desorb, disperse into the spray solution, and damage susceptible crops. Highly active herbicide residues that persist in sprayers and cause crop injury include dicamba and ALS herbicides.

Herbicides attached to all tank and sprayer components must be desorbed and the residue removed in a cleaning process. Sprayer cleanout procedures are given on herbicide labels and should be followed. The following procedure illustrating a thorough sprayer cleanup procedure is effective for most herbicides:

Step 1. Drain tank and thoroughly rinse interior surfaces of tank with clean water. Spray rinse water through the spray boom for at least 5 minutes.
Step 2. Fill the sprayer tank with clean water and add a cleaning solution (many labels provide recommended cleaning solutions). Fill the boom, hoses, and nozzles and allow the agitator to operate for 15 minutes.
Step 3. Allow 8 hours for the cleaning solution to fully desorb the residues inside the sprayer.
Step 4. Spray the cleaning solution through the booms.
Step 5. Clean nozzles, screens, and filters. Rinse sprayer to remove cleaning solution and spray rinsate through the booms.

Common types of cleaning solutions are chlorine bleach, ammonia, and commercially formulated tank cleaners. Chlorine lowers the pH of the solution which speeds the degradation of some herbicides. Ammonia increases the pH of the solution which increases the solubility of some herbicides. Commercially formulated tank cleaners generally raise pH and act as detergents to remove herbicides. Read herbicide label for recommended tank cleaning solutions and procedures.

WARNING: Never mix chlorine bleach and ammonia as a dangerous and irritating gas will be released.

Sprayers should be cleaned soon after use to prevent deposit of dried spray residues. A sprayer should not remain empty overnight without cleaning; fill the tank with water to prevent dried spray deposits from forming. A clean sprayer is essential to prevent damage to susceptible crops from herbicide contamination.

SPRAYER CLEANING SOLUTIONS FOR HERBICIDES:
Water: Command, Extreme, Roundup*, Lightning, Raptor.

Ammonia or commercial tank cleaner + water:
2,4-D, Accent, Affinity*, Ally*, Amber, Amplify, Assure II, Banvel*, Basagran*, Beacon, Buctril + Atra*, Buctril*, Cadet, Callisto, Cimarron Xtra*, Classic, Cobra, Dual*, Extreme, FirstRate, Fusilade DX, Fusion, Glean*, Gramoxone*, Harmony*, Harness/Surpass*, Hornet, Lasso*, Lightning, Northstar, Option, paraquat*, Peak, Permit, Prowl*, Pursuit, Pursuit Plus, Python, Raptor, Reflex, Resolve*, Resource, Select*, Stinger*, Steadfast*, Surpass*, Targa*, Treflan*, and Ultra Blazer.

Detergent or commercial tank cleaner + water:
Aim, atrazine*, Clarity*, Flexstar, Ignite, Sencor*, Liberty, Poast, Poast Plus, Shotgun, Status, Ultra Blazer, and Yukon.
*Or generic equivalent.

A10. FIELD INVESTIGATION OF CROP INJURY:
Keep an open mind and investigate all possible causes and sources of the problem when assessing crop injury. Question all statements from involved persons about the cause and the source of the problem. The truth often is not obvious. Crop injury can have many causes other than herbicides and symptomology does not always provide definitive answers.

NDSU Extension staff can assist in determining the cause of crop injury but are not responsible for conducting an extensive investigation to determine the cause or extend of economic loss. Extension staff will not act as a mediator in disputes. Independent consultants can be hired for investigations. Samples can sent to the Plant Diagnostic Lab (PDL) at NDSU.

Contact the ND Dept. of Agriculture for the proper procedure before filing a civil action seeking reimbursement for property damage allegedly stemming from the application of a pesticide. Individuals can contact the ND DOA at 600 E. Blvd, Bismarck, ND 58505-0020. (800) 242-7535 or (701) 328-2231.

The PDL at NDSU will analyze samples and evaluate injury symptoms to provide opinions and possible explanations on causes of the problem. The PDL does not test soil or plant material for herbicide residues. Refer to page 111 for list of testing labs.

Analysis of plant tissues or soil by a testing laboratory may not show the cause of the problem. Each active ingredient must be tested individually, which increases expense. A positive detection can be useful but the detected herbicide may not cause the symptoms. A negative test does not prove that the herbicide did not cause the problem because the herbicide may cause injury at concentrations less than the detection limit or the herbicide may have degraded before the samples were taken.

The pattern of crop injury in a field can identify the injury source. A sprayer skip is valuable in diagnosing a herbicide problem. Herbicide field history for the past 3 years should be considered. Uniform damage over the field would suggest herbicide carryover or injury from a direct application rather than drift.

Drift is usually worse near the source with damage diminishing as the distance increases. Differences between affected and non-affected plants should become more visible with time since recovery by damaged plants will be more rapid. Crop injury that is associated with one or two sprayer tank loads would suggest sprayer contamination or a mistake in mixing. An aerial photograph is useful in identifying patterns of crop injury.

Injury symptoms can identify the herbicide family. Look in the affected field, surrounding fields, and between fields. The size of plants when affected by a growth regulator herbicide can be determined by the height of the stem where malformed leaves first occur. A soil-applied herbicide will affect plants as they emerge. rather than drift. Dates that injury occurred can coincide to dates of herbicide application on and around the field.

The direction of herbicide drift can sometimes be determined by finding “drift shadows” by trees, buildings or elevated roads. Anything that intercepts or deflects spray droplets can cause an area of undamaged plants on the downwind side of the object.

Vapors from growth regulator herbicides are volatile and a wind shift after application may cause vapor drift in a different direction than the drift of spray droplets. Spray droplets only move in the direction that the wind is moving.Sources of unintended herbicide exposure are difficult to identify. For example, the residue of long residual herbicides from drift or an accidental spraying, or soil movement due to wind or water erosion can damage a susceptible crops planted in successive years.

Damage from drift may not be as severe as the initial appearance and a decision to keep or till should not be made until sufficient time for regrowth to occur. Rapid conclusions can lead to unwarranted decisions with spray drift.

Degree of yield loss caused by the herbicide damage is difficult. Accurate visual estimation of yield loss from a non-lethal exposure to herbicide is not possible. Collecting representative yield comparisons can be used to estimate of yield loss. Yield from injured and uninjured portions of the field can be compared. Usually, splitting the field into several strips is better than comparing one half of the field to the other. Comparisons to nearby fields can be done but variability among fields is great. Average yields of several nearby fields also could be considered.

A11. HERBICIDE + INSECTICIDE COMBINATIONS have increased crop injury compared to either pesticide applied alone. Efficacy data on herbicide-insecticide mixtures are limited because of the number of potential combinations. Non-registered tank-mixtures should be used with caution until experience or research has shown that the combination is effective and safe. The following information is based on label restrictions and/or research indicating crop injury or decreased control.

<u>2,4-D:</u> Wheat injury but not lower wheat yield with 2,4-D amine combined with Lorsban. 2,4-D, Banvel*, Bronate*, or Curtail* mixed with Asana, Cygon, Di-Syston, Warrior, or Lorsban caused no wheat injury in U. of Wyoming studies.

<u>Dicamba:</u> Oil-based insecticides increase risk of wheat injury.

<u>POST Grass Herbicide:</u>
<u>Assure II*, Fusilade DX, Fusion, Poast, and Select*:</u>
Reduced grass control may result from tank-mixes of Fusilade DX with Lorsban, malathion, Sevin XLR, or Pydrin, or Poast mixed with Sevin XLR Plus or Pydrin. No decrease in grass control resulted from Poast tank-mixed with Lorsban or malathion.

<u>Sulfonylurea Herbicides (SU):</u> Severe crop injury may result from tank-mixing SU herbicides with organophosphate insecticides. Most SU labels do not allow addition of Lorsban or malathion. SU herbicides and insecticides should be tank-mixed only when experience or research indicated crop safety.

A12. HERBICIDE + FUNGICIDE COMBINATIONS may cause crop injury. Refer to the following table for additional information.

<u>Herbicide/Fungicide Combinations For Small Grains</u>.

Herbicide	Mancozeb	Adjuvant with Mancozeb	Tilt
Affinity*, Aim, Ally*, Ally Extra*, Amber, Assert, Avenge, Axial XL/TBC, Banvel*, Curtail*/M*, Discover NG, Everest, Express*, Finesse*, Glean*, MCPA, Orion, Peak, Pulsar, Puma, Starane*=			
	Not Prohibited	Yes, if required	Not Prohibited
Achieve	PROHIBITED	PROHIBITED	PROHIBITED
Bromoxynil + MCPA	See Product Bulletin 2ee	Not needed	Not Prohibited
Bromoxynil	See Product	Not needed	Not Prohibited
Rimfire	PROHIBITED		
2,4-D	Not Prohibited	Not Prohibited	Yes, if required

NDSU studies show Puma or Discover plus Bronate Advanced applied with the strobilurin fungicides of Quadris, Quilt, Headline, and Gem cause severe leaf burn on wheat; new tissue that emerged was unaffected. Bronate, or generic formulations, plus strobiluron fungicides may also cause similar injury.

*Or generic equivalent.

A13. HERBICIDE + LIQUID-FERTILIZER COMBINATIONS require thorough mixing and continuous agitation to obtain even application. Some herbicide + fertilizer combinations will not form a uniform mixture even with agitation. To test, combine small quantities of components to be mixed in the same proportions used in the sprayer tank. One tsp of liquid herbicide in 1.5 pt of fertilizer is equivalent to 1 qt of herbicide in 35 gal of fertilizer. One tsp of DG granules in 1.5 pt of fertilizer is equivalent to 1 lb of DG in 16 gal of fertilizer. One tsp of WP in 1.5 pt of fertilizer is equivalent to 1 lb of WP powder in 32 gal of fertilizer. WP and DG formulations should be mixed with water to form a slurry before adding to fertilizer. Shake after mixing.

Watch the mixture for 30 minutes. If the mixture does not separate, the combination is compatible. If the mixture separates or gets very thick or syrupy, do not use. Mixing ability may be improved by adding a compatibility agent. Batches of fertilizer may differ in mixing properties and should be tested separately.

HERBICIDE + DRY-FERTILIZER COMBINATIONS created by impregnation on dry bulk fertilizer are used. Read the label for use directions. Ammonium sulfate, ammonium phosphate-sulfate, diammonium phosphate, potassium chloride, superphosphate, treble superphosphate, and urea are approved fertilizer materials for impregnation. Impregnated fertilizer should be applied and incorporated according to label instructions. Consult the herbicide label for minimum amount of fertilizer/A and maximum amounts of herbicide per given weight of fertilizer. Apply at least 200 to 400 lb/A of dry bulk fertilizer to maintain uniform herbicide application.

A14. MIXING INSTRUCTIONS:
A.P.P.L.E.S.
<u>A</u>gitate
<u>P</u>owders soluble
<u>P</u>owders dry
<u>L</u>iquid flowables and suspensions
<u>E</u>mulsifiable concentrates
<u>S</u>olutions.

Some herbicide labels list a specific mixing sequence. In absense of specific directions, the recommended sequence for adding pesticide formulations to a tank partially filled with water follows the **<u>A.P.P.L.E.S.</u>** method.

Each ingredient must be uniformly mixed before adding the next component, e.g., a soluble powder must be completely dissolved before adding the next component. Adjuvants are added in the same sequence as pesticides, e.g., ammonium sulfate is a soluble powder, oil adjuvants are emulsifiable concentrates; and most surfactants are solutions. Within each group, usually add the pesticide before the adjuvant, e.g., a soluble-powder pesticide before ammonium sulfate.

A15. Herbicide Storage Temperatures:
Herbicides may be exposed to freezing temperatures in storage. The following information gives the minimum storage temperature to avoid risk of reduced herbicide activity.

No storage temperature restriction
Most dry formulated herbicides in DF or WDG formulations and Harness/Surpass*, Aim, Authority MTZ, Axial XL, Balance Pro, Select*, Banvel*, Discover NG, Eptam, Extreme, Roundup*, Impact, Dual*, Laudis, Outlook*, Rage D-Tech, Status, and Valor.

May store below freezing but warm before using
2,4-D amine, 2,4-D ester*, atrazine 4L*, Betamix*, Betanex*, Dual Magnum*, MCPA amine and ester*, Tordon*, and Weedmaster*.

Do not store below 40 F
Assert, Authority First, Curtail*, Extreme, Flexstar, LI-700, Prowl*, Pursuit Plus, Sonalan, Spartan 4F, Treflan*.

Do not store below 32 F
Assure II*, Basagran*, Beyond, Bronate*, ClearMax, Far-Go, Flexstar, Fusilade DX, Fusion, Goal, Grazone P+D, Hyvar, Ignite 280, Liberty, Lorox DF, Nortron SC, paraquat*, Poast, Pramitol, Progress*, Prowl H2O, Puma, Pursuit, Quest, Raptor, Redeem, Reflex, Reglone*, Remedy, Resource, Select Max, Stinger*, Thistrol, Ultra Blazer, Wolverine.

Do not store below 20 F
Fusilade DX, Milestone, Plateau, Ro-Neet, Starane NXT*, Weedar 64.

Do not store below 10 F
Amitrole T, Arsenal, Curtail M*, Crossbow, Fusion, Roundup (ipa salt)*, Rodeo, Starane*, and WideMatch*.

Do not store below 3 F
Buctril*, Discover, Huskie, Shotgun.

Do not store below -10 F
Callisto, Halex GT, Lumax, Spartan Advance

*Or generic equivalent.

A16. BACKPACK SPRAYER CALIBRATION
No-Math Version:
Step 1. Mark a calibration plot 18.5 foot wide X 18.5 feet long.
Step 2. Spray the plot uniformly with water while recording the number of seconds required to spray the plot.
Step 3. Spray into a bucket for the same number of seconds.
Step 4. Measure the collected volume of water in ounces.
Step 5. The number of ounces collected equals the number of gallons per acre the sprayer is delivering.

Hand-held Sprayers:
Hand-held sprayers are used for spot treating weeds or small areas. Spray coverage should be uniform and the foliage of target plants should be wet but the amount of spray solution applied should be limited so that run-off does not occur.

Hand-held sprayers should be calibrated by:
1) spraying a known area using water following a standard, reproducible procedure
2) measuring the amount of water applied
3) calculating gallons per acre (gpa).

For example, 0.75 gallon on 500 sq ft is the same as 65 gallons per acre: 43,560 sq ft per acre / 500 sq ft x 0.75 gallon = 65 gpa.
The desired rate in lb/A or pt/A can be used to calculate the amount of herbicide to add to the spray solution.
If 3 pt/A is desired: 3 pt/A / 65 gpa = 0.046 pt or 0.73 fl oz or 1.5 tbsp/gal of spray solution (16 fl oz = 1 pt, 2 Tbsp = 1 fl oz).

When calibration of a hand-held sprayer is not possible and the herbicide being used is safe to the environment and non-target plants, a volume of 50 to 70 gpa can be assumed. However, the actual volume applied can vary considerably with the type of sprayer, spray pressure, and technique of the applicator, so calibration is strongly encouraged.

Some herbicide labels specify a percent solution for use in hand-held sprayers. The following chart provides mixing instructions to obtain solutions of varying percent concentrations on a volume/volume basis:

	% concentration of herbicide				
Desired solution volume	0.5	1.0	1.5	2.0	5.0
gallons	Amount of herbicide to add, fl oz				
1	0.6	1.3	1.9	2.6	6.4
2	1.3	2.6	3.8	5.2	12.8
5	3.2	6.4	9.6	12.8	32.0
10	6.4	12.8	19.2	25.6	64.0
100	64.0	128.0	192.0	256.0	640.0

1 pt = 16 fl oz	16 Tbls = 1 cup
1 Tbls = 3 tsp	1 fl oz = 30 mls
1 Tbls = 15 ml	1 fl oz = 2 Tbls