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, <u>not PPI</u>, on corn. Lasso*, Harness/Surpass*, Outlook*, and Dual* may be used PRE but shallow PPI improves weed control, particularly on fine textured soils. Incorporation of Lasso*, Nortron*, and Dual* 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.

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

*Or generic equivalent

The information below, when used, will increase the effectiveness of weed control from 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 by formulation used. Do not use reduced 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 perennial weeds. Larger and older vegetative plants are more difficult to control.

3. Tillage should not occur until at least 1 day after treating annual weeds and 3 days after treating perennial weeds.

4. Roundup* can be applied in the spring before emergence of most crops. Potential for crop injury exists when 2,4-D* or Banvel* mixtures with Roundup* are applied immediately before or after planting due to the PRE soil activity of 2,4-D* and Banvel*. A rain event after application and before crop emergence increases risk of 2,4-D* or Banvel* injury to the emerging crop seedlings.

5. Roundup* is very water soluble.
High water solubility is why Roundup* absorption through plant cuticles is slow (cuticular wax repels water), activity is greater in humid conditions (moisture in the air hydrates the cuticle), NIS adjuvants are preferred, and why oil adjuvants are not recommended as they antagonize phytotoxicity. Always add NIS at 0.25 to 0.5% to Roundup* unless the label prohibits use.

6. Roundup* activity greatly increases under humid conditions and good soil moisture. Inversely, weed control is reduced under low humidity and when weeds are drought stressed.

7. 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.

8. 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 increase risk of damaging drift.

9. Dew on plant foliage at application may reduce weed control.
Dew on leaves dilutes herbicide concentration in spray droplets and negates 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.

10. 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.

*Or generic equivalent.

A4 - GLYPHOSATE

11. Roundup* is not volatile. Roundup* does not produce fumes or vapor after application. Off-target movement of Roundup* is from droplet or particle drift, not volatility.

12. 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, ammonium binds with glyphosate resulting in greater absorption. 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.

13. Roundup* labels suggest AMS at 8.5 to 17 lb/100 gallons water. However, analysis of water across the U.S. show that 4 to 6 lbs/100 gal of AMS are adequate. 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 quality in Montana and western ND and SD can have hard water 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.

14. Add NIS of high quality if the Roundup* labels allows use. Research has shown greater weed control even when NIS was added to full-load Roundup* formulations. Use reputable adjuvants from major adjuvant manufacturers.

15. Oil adjuvants antagonize Roundup*. (See #2).
To control volunteer Roundup Ready crops, to delay weed resistance to Roundup*, and to control weeds that have developed tolerance or resistance to Roundup* require 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. Adjuvants known as “High Surfactant Oil Concentrates” (See page 130) also enhance oil soluble herbicides without decreasing Roundup* activity. Using higher rates of Roundup* may partially overcome oil adjuvant antagonism but control of some weeds species may not be adequate.

16. Weed control from Roundup* applied during or after cold weather may be the same as from application in warm weather but the end result (weed control) will take longer. Ideal temperatures for applying POST herbicides are between 65 and 85 F. Speed of kill will be slower during cold weather also. Use higher rates to overcome reduced control from cold temperatures before or after application. Cold weather is a stress to plants. Weeds with low level resistance may not be controlled whether in good or adverse conditions. Proper timing of Roundup* application is critical for adequate weed control. Roundup* applied during cold weather and to large weeds will result in less weed control. AMS enhances weed control and can partially overcome reduced control of stressed plants.

*Or generic equivalent.

17. Weed control is reduced when Roundup* is applied to desiccated plant tissue affected by frost. Below freezing temperature may desiccate plant tissue. Plant material injured by freezing temperatures may not translocate herbicides. Application to new plant growth is required for optimum herbicide activity.

18. Tolerant plants escape phytotoxicity by metabolizing herbicides. Except for Optimum GAT technology, plants do 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. To optimize glyphosate phytotoxicity from sequential applications, delay the second application until new growth appears (>10 days).

19. 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 in windy conditions. This applies also to using slough water for spraying. Organic matter and soil in slough water will inactivate Roundup* and 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.

20. Do not apply Roundup* brands formulated with surfactant (partial or full adjuvant formulations) to bodies of water because they include adjuvants 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 on water. An approved NIS surfactant at 0.5 to 1% v/v must be added to non-loaded generic glyphosate formulations for weed control. Refer to the Adjuvant Section, on page 130 for a list of NIS adjuvants registered for use in water.

21. Applying Roundup* with contact herbicides may result in antagonism and reduced weed control. Quicker wilting and desiccation occurs when contact herbicides are applied with Roundup* but the contact herbicides 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 the antagonism on large broadleaf 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, Flexstar, Ignite, paraquat*, Phoenix, Reflex, Resource, Spartan, and Valor. When tank-mixing with contact herbicides and large or troublesome weeds are present, use high water volumes as recommended on labels and increase the Roundup* rate.

22. 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.

23. 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.

*Or generic equivalent.

Partial List of Registered Glyphosate Products:

Trade Name	Manu-facturer	Active ingredients	lb ae/gal	lb ai/gal	Adjuvant Load*
Accord	Dow	glyphosate-ipa	4	5.4	None
Aquamaster	Monsanto	glyphosate-ipa	4	5.4	None
Buccaneer	Tenkoz	glyphosate-ipa	3	4	Partial
Buccaneer Plus	Tenkoz	glyphosate-ipa	3	4	Full
Buccaneer 5	Tenkoz	glyphosate-ipa	3.7	5	Partial
Cornerstone	Agriliance	glyphosate-ipa	3	4	Partial
Cornerstn 5 Plus	Agriliance	glyphosate-ipa	4	5.4	Full
Cornerstone Plus	Agriliance	glyphosate-ipa	3	4	Full
Credit Duo	NuFarm	glyt-ipa & glyt-NH_4	3	4	Partial
Credit Duo Extra	NuFarm	glyt-ipa & glyt-NH_4	3	4	Full
Credit Extra	NuFarm	glyphosatet-ipa	3	4	Partial
Nfrm Credit/Extra	NuFarm	glyt-NH_4 & glyt-K	3	3.4	Full
Credit Xtreme	NuFarm	glyt-ipa & glyt-K	3	4.5	Full
Duramax	Dow	glyphosate-dma	4	5.4	Full
Durango DMA	Dow	glyphosate-dma	4	5.4	Full
Extra Credit 5	NuFarm	glyphosate-ipa	3.7	5	Partial
Glyfos	Cheminova	glyphosate-ipa	3	4	Partial
Glyfos X-tra	Cheminova	glyphosate-ipa	3	4	Full
Glyphogan	MANA	glyphosate-ipa	3	4	Partial
Gly Star Plus	Albaugh	glyphosate-ipa	3	4	Full
Gly Star 5	Albaugh	glyphosate-ipa	4	5.4	None
Gly Star 5 Extra	Albaugh	glyphosate-ipa	4	5.4	Partial
Gly Star Gold	Albaugh	glyphosate-ipa	3	4	Partial
Gly " Gold Extra	Albaugh	glyphosate-ipa	3	4	Full
Gly Star Original	Albaugh	glyphosate-ipa	3	4	Partial
Gly Star Plus	Albaugh	glyphosate-ipa	3	4	Partial
Helosate Plus	Helm Agro	glyphosate-ipa	3	4	Full
Helosate 70	Helm Agro	glyphosate-ipa	5	6.5	Full
Kull 41S	Ritter Chem.	glyphosate-ipa	3	4	Partial
Mad Dog	UAP	glyphosate-ipa	3	4	Partial
Mad Dog Plus	UAP	glyphosate-ipa	3	4	Full
Makaze	UAP	glyphosate-ipa	3	4	Full
Lajj Plus	Northmoose	glyphosate-ipa	3	4	Partial
Rattler / Plus	Helena	glyphosate-ipa	3	4	Part/Full
Rodeo	Dow	glyphosate-ipa	4	5.4	None
RT 3	Monsanto	glyphosate-K	4.5	5.5	Full
RU PowerMax	Monsanto	glyphosate-K	4.5	5.5	Full
RU/Private labels	Various	glyphosate-ipa	3	4	Partial
RU WeatherMax	Monsanto	glyphosate-K	4.5	5.5	Full
Strikeout	-	glyphosate-ipa	3	4	Full
Touchdown CT	Syngenta	glyphosate-K	4.17	5.1	Full
Touchdn HiTech	Syngenta	glyphosate-K	5	6.1	None
Touchdown iQ	Syngenta	glyt -(2(NH_3)	3	4	Full
Touchdown Total	Syngenta	glyphosate-K	4.17	5.1	Full
Traxion	Syngenta	glyphosate-K	4.17	5.1	Partial

*Full = No additional NIS needed.
Partial = Additional NIS needed.
None = Additional NIS at full rate required.

Glyphosate product rates based on formulation, acid equivalent (ae) and active ingredient (ai).

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
5	=	6.1	=	10	15	20	30	40

Pounds ae/gal or ai/gal are found on glyphosate product labels.

Refer to page 4 for an explanation of active ingredient (ai) and acid equivalent (ae).

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

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

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

Fertilizers containing ammonium nitrogen increase effectiveness of most herbicides formulated as a salt (See pages 124-130). Fertilizers should be used with herbicides only as indicated on the label or where experience has proven acceptability.

AMS is recommended at 8.5 to 17 lb/100 gal spray volume (1 to 2%) on most Roundup* labels. Enhancement of Roundup*, and many other herbicides, from AMS is most pronounced when spray water contains relatively large quantities of certain ions, such as calcium, sodium, and magnesium. AMS may contain contaminants that may not dissolve and then plug nozzles. Use spray grade AMS to prevent nozzle plugging. Commercial liquid solutions of AMS are available and contain approximately 3.4 lbs of AMS/gallon. For 8.5 lbs of AMS/100 gallons of water add 2.5 gallons of liquid AMS solution.

*Or generic equivalent.

A5 - SPRAY ADJUVANTS

AMS at 4 lb/100 gal (0.5%) is adequate to overcome most salt antagonism. AMS at 0.5% has adequately overcome antagonism of glyphosate from 300 ppm calcium. Use at least 1 lb/A of AMS when spray volume is less than 12 gpa. Ammonium ions also are involved in herbicide absorption and have enhanced phytotoxicity of many herbicides in absence of antagonistic salts in the spray carrier. Herbicide enhancement by nitrogen compounds appears most pronounced in most species like velvetleaf or sunflower.

AMS enhances phytotoxicity and overcomes salt antagonism for most salt formulated herbicides, including Banvel*, Roundup*, Poast, and 2,4-D amine*. Liquid 28% UAN fertilizer is effective in enhancing weed control from many POST herbicides and overcoming sodium but not calcium antagonism of glyphosate. Sodium bicarbonate antagonism of Poast is overcome by 28% UAN, ammonium nitrate, and AMS. AMS or 28% UAN does not preclude the need for a oil adjuvant. Adjuvants vary in enhancement of herbicide action. The precise salt concentration in water that causes a visible loss in weed control is difficult to establish because weed control is influenced by other factors.

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

Basic pH blend adjuvants are non-oil based and increase spray solution pH. They contain nitrogen fertilizer to overcome antagonistic salts; a surfactant to aid in spray retention, spray deposition, and herbicide absorption; and a buffer to increase water pH. Basic pH blends adjuvants increase water pH, which increases water solubility of most ALS and HPPD inhibitor herbicides. For example, Accent solubility at water pH 5 is 360 ppm, at pH 7 is 12,200 ppm, and pH 8 is 39,200 ppm. Basic pH blend adjuvants reduce precipitation problems with Betamix*/ Betanex*/ Betamix Progress plus UpBeet at low rates by increasing water pH.

Research has shown that basic pH blend adjuvants enhance weed control similar to MSO type adjuvants. They may be used in those situations where oil adjuvants are restricted. For example, Banvel* labels restrict oil adjuvants when used alone or in tank-mix with Accent on corn. Basic pH blend adjuvants are less expensive at field use rates than MSO type adjuvants.

Antagonism of 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.
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.

Commercial adjuvants differ in effectiveness with herbicides. Data from the table below are from experiments conducted in ND from 1992 through 1995 and repeated in 2005 and 2006 comparing commercial adjuvants with Roundup*. Data are included only when a differential in control occurred among adjuvant treatments. In some experiments, all treatments gave similar control, probably because of a more humid and favorable environment for glyphosate uptake and translocation.

The following are application parameters for the studies:

		93-95	05-06
Glyphosate:		Roundup	RU Original Max
Rate:		1 to 1.5 oz ae/A	1.125 to 4 oz ae/A
No of species:	Grass	5	7
	Brdlf	11	19
No of means	Grass	13	30
	Brdlf	12	68 (total 272 ratings)

Roundup* was applied at low rates to avoid complete weed control. Higher rates were used in western ND because of low activity from low humidity.

The following are some observations and conclusions.
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.

*Or generic equivalent.

Commercial adjuvant effect on glyphosate phytotoxicity to selected grass and broadleaf plants[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 + Pref.	1.25 + 0.5	--	89	--	68
Citron + Pref.	2.2 lb/A + 0.5	--	84	--	66
Quest + Pref.	0.5 + 0.5	--	83	--	62
Choice + Liberate	0.5 + 0.5	--	81	--	60
Herbolyte		--	79	--	55

Pref = Preference.

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

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

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

1. Low humidity, hot weather, lack of rain, and drought-stressed weeds or weeds not actively growing due to some condition causing stress.
2. Weeds larger than recommended on the label.
3. Herbicides used at reduced rates.
4. Target weeds are somewhat tolerant to the herbicide. For example, control of wild buckwheat, biennial wormwood, lambsquarters or ragweed with Pursuit or Raptor, or control of yellow foxtail with Accent.
5. When university data supports reduced herbicide rates. Most herbicides except Roundup* give greater weed control when used with MSO type adjuvants. Oil adjuvants should be used with Roundup* only when research or experience shows no reduction in weed control.

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

Some herbicide labels contain information on adjuvant rates for different spray volumes. For example, Pursuit and Raptor labels require oil adjuvants to be added at 1.25% v/v or 1.25 gal/100 gal water for aerial application (5 GPA). To insure sufficient adjuvant concentration add the oil adjuvant on an area basis. Instead of using oil adjuvants at 1% v/v, apply at 1.25 to 2 pt/A at all spray volumes. Surfactant at 0.25% v/v or 1 qt/100 gal water is sufficient across all water volumes.

Basic pH blend adjuvants are recommended at 1% v/v regardless of spray volume. Data indicate basic blend adjuvants at 1% v/v from 5 to 20 GPA will provide adequate adjuvant enhancement for similar weed control.

*Or generic equivalent.

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 many herbicides, and minerals can inactivate the activity of most salt formulated herbicides, including 2,4-D amine*, MCPA amine*, Achieve, Banvel*, Ignite, Roundup*, and Poast.

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

High salt levels in spray water can reduce weed control in nearly all situations. Calcium and magnesium are antagonistic. Calcium antagonism may occur at 150 ppm. Sulfate ions in the solution have reduced the antagonism from calcium and magnesium, but the sulfate concentration must be three times the calcium concentration to overcome antagonism. Natural sulfate in water can be disregarded. The amount of AMS needed to overcome antagonistic ions can be determined as follows:
Lbs AMS/100 gal = (0.002 X ppm K) + (0.005 X ppm Na) + (0.009 X ppm Ca) + (0.014 X ppm Mg) + (0.042 X ppm Fe).
This does not account for antagonistic minerals on the leaf surface on some species like lambsquarters, sunflower, and velvetleaf which may require additional AMS.

Analysis of spray water sources can determine water quality effects on herbicide efficacy. Water samples can be tested at:
USPS: NDSU Dept 7680, Fargo, ND 58108-6050,
UPS and Physical Address: NDSU Soil and Water Laboratory, Waldron Hall 202, 1360 Bolley Dr. NDSU, Fargo, ND 58102.
701 231-7864. 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 often contains a combination of sodium, calcium, and magnesium, and these cations generally are additive in the antagonism of herbicides. Many adjuvants are marketed to modify spray water pH, but low pH is not essential to the action of most herbicides. AMS, granular or liquid, and 28% UAN fertilizer help overcome antagonistic salts in spray carrier water. Generally, 4 gal of 28% UAN/100 gal of spray has been adequate. UAN overcomes mineral antagonism of most herbicides, but not Roundup*. AMS and 28% UAN enhance herbicide control of certain weeds even in water without salts. Nitrogen fertilizer/surfactant blends may enhance weed control of most herbicides formulated as a salt.

*Or generic equivalent.

A7. 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 be used if herbicides are applied to weeds smaller than listed on label. The crop will probably 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 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.

A8. SPRAYER CLEANOUT

Crop injury may occur from a contaminated sprayer. The risk of damage is greatest when spraying crops highly susceptible to the previous herbicide, when the previous herbicide is very active in small amounts, or when tanks and the entire plumbing system of the sprayer are not cleaned after herbicide application. Rinsing with water is not adequate to remove all herbicides. Some herbicides have remained tightly adsorbed in sprayers through water rinsing and even through several tank-loads of other herbicides. Then, when a tank-load of mixture including an oil adjuvant, nitrogen solution, or basic pH blend adjuvant was put in the sprayer, the herbicide was desorbed, dispersed into the spray solution, and damaged susceptible crops. Highly active herbicides that have been difficult to wash from sprayers and have caused crop injury include dicamba and ALS herbicides.

Herbicides difficult to remove from sprayers are thought to attach to abrasions on tank liners or formulation carrier residues remaining from spray mixtures that deposit in a sprayer, including tank, boom, hoses, and nozzle bodies. The herbicide must be desorbed from the residue or the residue removed in a cleaning process so the herbicide can be removed from the sprayer. Sprayer cleanout procedures are given on most herbicide labels and the procedure on the label should be followed for specific herbicides. 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. Sufficient rinse water should be used for 5 minutes or more of spraying through the boom.

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 the sprayer to sit for 8 hours while full of cleaning solution so the herbicide can be fully desorbed from the residues inside the sprayer.

Step 4. Spray the cleaning solution through the booms.

Step 5. Clean nozzles, screens, and filters. Rinse the 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 as soon as possible after use to prevent the 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*, Distinct, Flexstar, Ignite 280, Marksman, Sencor*, Liberty, Poast, Poast Plus, Shotgun, Status, Ultra Blazer, and Yukon.

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*Or generic equivalent.

A9. SPRAY AND VAPOR DRIFT
Refer to NDSU Extension Circular A-657, "Herbicide Spray Drift" and Circular WC-751 "Documentation for Suspected Herbicide Drift Damage" for additional information. Off-target herbicide movement from fields into areas containing crops or other susceptible plant species should be avoided. The risk of injury to non-target plants varies greatly among herbicides. In general, POST herbicides that are highly phytotoxic at low rates (2,4-D*, MCPA*, Banvel*, Ignite, paraquat*, Roundup*, Tordon, and all ALS herbicides have the greatest potential for damaging non-target plants. Spray drift and injury to plants are affected by several factors.

Wind velocity and direction: Apply when wind direction is away from susceptible plants, when velocity is 10 mph or less, 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.

Distance between nozzle and target (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: Some herbicides volatilize under warm or hot temperature and cause plant injury from vapors or fume drift. Low volatile esters of 2,4-D* or MCPA* may produce damaging vapors between 70 to 90 F. Amine formulations are essentially non-volatile even at high temperatures. Temperature on the soil surface often is several degrees warmer than air temperature. Herbicide vapor can drift farther and over a longer time than spray droplets. Wind blowing away from susceptible plants during application will prevent damage from droplet drift but a later wind shift toward the susceptible plants could move damaging vapors to the plants. To minimize the risk of drift injury, Banvel* and ester formulations of 2,4-D* and MCPA* should not be used near susceptible plants.

Spray shields: Small plastic cones that fit around individual nozzles reduce drift by approximately 25 to 50% and spray shields that enclose the entire boom reduce drift by approximately 50 to 85%. Spray shields provide greater drift reduction when winds are low and droplets are relatively large. Therefore, spray shields should not be used as a substitute for other drift control techniques but as a supplement to all other applicable methods of drift reduction.

Drift control: Spray drift can be reduced by increasing droplet size. Droplet size can be 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: Several sprayer nozzles are designed to reduce spray drift. 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 sprayer equipment. The two primary types of drift-reducing nozzles are pre-orifice and air-induction (venturi) designs.

*Or generic equivalent.

Pre-orifice nozzles: Two common designs are Drift Guard and Turbo TeeJet nozzles from Spraying Systems Co. Pre-orifice nozzles regulate the liquid flow rate prior to the exit orifice causing a pressure drop in the nozzle resulting in fewer fine spray droplets. Drift Guard nozzles are available in 80° and 110° spray angles with 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. 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.

Air-induction (venturi) nozzles include AI TeeJet from Spraying Sys., the TurboDrop and TurboDrop XL from Greenleaf Tech., the Lurmark Ultra-Lo-Drift from Precision Fluid Control Products, the Spraymaster Ultra from Delavan Spray Tech., and the Lechler ID from Hardi. Each nozzle has a distinct design, but the similar technology of 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 incorporates 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 large droplets. Spray pressures of 40 to 60 psi adequate but pressures greater than 60 psi result in the most consistent performance of POST 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 air induction or Turbo TeeJet nozzles operated at low pressure (20 psi). Drift Guard nozzles significantly reduce drift compared with a standard flat-fan nozzle but produce a quantity of 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. NDSU research has demonstrated weed control from Assure II/Targa, Banvel*, Poast, Pursuit, Raptor, Roundup*, and Poast to be similar when applied through drift-reducing nozzles or standard flat-fan nozzles. The same results were observed with fast-acting contact herbicides of Aim and paraquat*. Reflex applied with drift-reducing nozzles was the only herbicide examined in which weed control was slightly less as compared with a standard nozzle. All other herbicides gave similar control regardless of nozzle type.

*Or generic equivalent.

Sufficient spray coverage to maintain effective weed control is a common question 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 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

Even at 5 gpa spray volume, nozzles that produce large spray drops up to 500 µm 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 when herbicides are appled without adjuvants. 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 (>60 psi) or Turbo TeeJet nozzles (< 30 psi). Contact herbicides, hard-to-wet weed species, and small 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. Follow label directions for spray application equipment or spray volume/acre. Go to http://www.ageng.ndsu.nodak.edu/spraynozzles to compare spray nozzles.

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 Plant Diagnostic Lab 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, especially if when skip occurred can be remembered. Herbicide field history for the past 2 to 5 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 of the drift with damage becoming less as the distance becomes greater. Differences between affected and non-affected plants should become more visible with time since recovery by damaged plants will be more rapid and complete as distance from the drift source increases. 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.

The family of the herbicide that caused the injury often can be identified by the injury symptoms and the species that are not injured. Look in the affected field, in surrounding fields and between fields. The approximate date of injury can sometimes be determined by observing or learning the date that the injury first became evident. The size of plants when affected by a growth regulator herbicide can sometimes be determined by the height of the stem where malformed leaves first occur. Plants that are affected as soon as they emerge usually are being damaged by a herbicide in the soil rather than drift. Dates that injury occurred can coincide to dates of herbicide application on and around the field.

The direction of the source 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. The shape and direction of the “drift shadow” often will identify the direction of the drift source and will usually show a distinct line between damaged and undamaged plants at the edge.

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.

2,4-D*: 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.

Dicamba: Oil-based insecticides increase risk of wheat injury.

POST Grass Herbicide:
Assure II*, Fusilade DX, Fusion, Poast, and Select*:
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.

Sulfonylurea Herbicides (SU): 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 result in crop injury. The following table gives information on many possible combinations.

Herbicide/Fungicide Combinations For Small Grains.

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		
Silverado	PROHIBITED	PROHIBITED	Not 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 caused 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.
Agitate
Powders soluble
Powders dry
Liquid flowables and suspensions
Emulsifiable concentrates
Solutions.

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 **A.P.P.L.E.S.** 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.
Step3. 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