# Increasing efficiency with adjuvants and herbicide mixtures

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## Summary

**Growers commonly mix herbicides with other herbicides and adjuvants to improve performance. Herbicide mixtures use complementary weed spectrums and additive action to improve control and reduce rates. Adjuvants increase post-emergence efficacy as much as 10-fold depending on type and concentration. Avoiding unwanted interactions and using sequential applications are additional ways to improve mixture performance. This paper illustrates a more quantitative approach to mixtures than is now practiced. Such an approach increases complexity for growers and would require an expert system to prescribe the lowest rates of the most economical and environmentally safe herbicides for each application.**

## Introduction

The judicious use of herbicide mixtures is important for successful crop production. Mixture use has evolved rapidly from high rates of single herbicides to low rates of complex mixtures. The use of mixtures in U.S. corn has increased from 39% in 1980 to 70% today with an additional 40% receiving sequential herbicide treatments (3,4). Similar use patterns occur in other crops and countries (2).

Post-emergence herbicides require adjuvants to be tank-mixed or built into the formulation to enhance performance (5,11). Often a good adjuvant can reduce the herbicide rate 10-fold. Today, growers commonly use two adjuvants which they adjust to weed spectrum and environmental conditions.

Every herbicide label warns against unwanted interactions that reduce performance. Antagonism is common and reduces weed control (6). Synergism is rare and increases crop injury.

Adequate technical information exists, but current product labelling is not adequate to communicate how to use mixtures most efficiently. Labels serve primarily to provide directions for use and precautions in handling the herbicide. Ideally, mixture use should start with identification of the weed spectrum and potential herbicides, evaluation of dose-response curves and additive action, selection of adjuvant(s), and then determination of the lowest rates of the most economical and environmentally safe products.

## How adjuvants affect the dose required

Post-emergence herbicides require adjuvants to be tank-mixed or built into the formulation. These adjuvants include surfactants, paraffin oils, vegetable oils, methylated fatty acids and fertilizers. Adjuvants are often mixtures, e.g., crop oil concentrates are oils and surfactants. Additionally, labels often recommend two adjuvant types, e.g., ammonium fertilizers and surfactant to enhance control of *Abutilon theophrasti*. Adjuvant use often varies according to weed spectrum and environmental conditions.

Figure 1 shows how adjuvant concentration affects the performance of nicosulfuron on *Setaria faberi* and *Echinochloa crus-galli*. This adjuvant, a non-ionic surfactant, (trimethyl nonyl polyethylene glycol ether), increased nicosulfuron activity more than 4-fold on *Setaria* and 10-fold on *Echinochloa*. The surfactant effect increased sharply up to 0.1% w/v (weight per volume).

In addition to concentration, the adjuvant type is important. For example, with nicosulfuron non-ionic surfactants are usually more effective than ionic surfactants. The type of non-ionic surfactant also affects nicosulfuron activity (8). The most important surfactant property is its hydrophilic-lipophilic balance or HLB (10). Figure 2 shows the effect of HLB on nicosulfuron activity on *Setaria* *faberi*. The optimum HLB is from 13 to 17. Unfortunately, most adjuvant products do not define their ingredients or provide much technical information.

## How mixtures affect the dose

### Dose Response

Identifying weed spectrum and using dose response information increases herbicide efficiency. Commercially available expert computer systems already use dose response information for single herbicides to advise growers (1).

Using dose response to select mixture rates is more complex (7). Conceptually, mixtures should first consider the herbicides alone. Table 1 compares nicosulfuron, DPX-E9636, and thifensulfuron[1] on several important corn weeds. All three herbicides control *Amaranthus retroflexus* below recommended rates[1], but require higher rates on other weeds. Because these herbicides do not control all weeds, they are often mixed. To properly mix, requires quantitative understanding of their dose-response relationships on each weed.

In addition to their single responses, predictive models must also include a quantitative measure of their mixture response. Appropriate tests can readily quantify additive action (9). These models then use biological, economic, and environmental criteria to determine the best mixture.

[1] Accent®, Titus®, and Pinnacle® Product Label, Du Pont Company, Wilmington, Delaware 19898, U.S.A.

Figure 3 illustrates the mixture response of nicosulfuron and thifensulfuron on *Abutilon theophrasti*. Nicosulfuron does not control *Abutilon theophrasti* at 75 g $ha^{-1}$; but 5 g $ha^{-1}$ thifensulfuron does. However with additive action, the partial activity of nicosulfuron at 30 g $ha^{-1}$ can reduce the thifensulfuron rate about one-third in a mixture. At this rate, thifensulfuron does not control monocotyledons nor allow a reduced nicosulfuron rate.

Increasing mixture efficiency is more complex when there are more weeds. Figure 4 shows the 85% control isoboles for nicosulfuron and DPX-E9636 on three species. Because both herbicides control *Echinochloa* and *Setaria* and act additively, the question is, what is the most efficient mixture? Since *Echinochloa* is more sensitive to both, the answer only depends on *Setaria*.

*Digitaria* adds complexity, because only DPX-E9636 controls it. Thus, *Digitaria* requires DPX-E9636 in the mixture. Such two-way mixtures are easy to model and explain, however the response of three- and four-way mixtures are difficult to present.

### Sequential applications.

Herbicides also interact with chemicals applied sequentially. Sequential applications often allow growers to avoid unwanted interactions and improve application timing. Timing can be as important as the rate or mixture partner.

***Table 1*** *Comparison of nicosulfuron, DPX-E9636, and thifensulfuron rates to control weeds 85%. (Observations were made 2 to 10 weeks after application. The associated 90% confidence intervals and number of observations are in parentheses. All weed stages were combined for analysis).*

| **Weeds** | **85% Control Rates (g ha⁻¹)** | | |
|---|---|---|---|
| **Dicotyledons** | **Nicosulfuron** | **DPX-E9636** | **Thifensulfuron** |
| *Abutilon theophrasti* | >75 ( – , 1003) | 44(37 – 53, 294) | 5 (4 – 6, 360) |
| *Amaranthus retroflexus* | 9 ( 7 – 11, 783) | 4( 3 – 5 , 385) | 3 (2 – 4, 227) |
| *Chenopodium album* | >75 ( – , 1013) | >75(64 – , 810) | 5 (4 – 6, 368) |
| **Monocotyledons** | | | |
| *Elytrygia repens* | 37 (31 – 45, 168) | 20(16 – 25, 110) | >75 |
| *Digitaria sanguinalis* | 68 (59 – 78, 364) | 11(10 – 13, 366) | >75 |
| *Echinochloa crus-galli* | 19 (17 – 23, 325) | 7( 6 – 8 , 617) | >75 |
| *Setaria faberi* | 37 (33 – 42, 1129) | 29(26 – 33, 251) | >75 |
| *Sorghum halepense* | 41 (38 – 45, 1070) | 29(24 – 38, 155) | >75 |

Table 2 shows the advantage of proper timing and mutiple applications of DPX-E9636 on a mixed weed population. Applying the same total rate of DPX-E9636 in multiple applications improves control and spectrum more than a single application. For example, a single application of 7.5 g $ha^{-1}$ DPX-E9636 controlled *Setaria faberi* 67 to 77%, depending on growth stage. Applying three 2.5 g $ha^{-1}$ applications increased control to 93%. Early application controlled the first flush of *Amaranthus retroflexus* and *Abutilon theophrasti*, but control of later flushes required later or multiple applications.

***Table 2*** *Effect of application time and multiple application of DPX-E9636*
*Results are means of three replicates. All treatments were safe to corn.*

| DPX-E9636 | Post-emergence Timing(s) | *Setaria faberi* | *Amaranthus retroflexus* | *Abutilon theophrasti* |
|---|---|---|---|---|
| | | | % Control | |
| 5 g $ha^{-1}$ | Early | 70 | 77 | 92 |
| 7.5 g $ha^{-1}$ | Middle | 67 | 94 | 37 |
| 7.5 g $ha^{-1}$ | Late | 70 | 48 | 33 |
| 2.5 g $ha^{-1}$ | Early, Middle, and Late | 93 | 96 | 99 |
| LSD | | 11 | 6 | 6 |

## Synergistic mixtures

Excluding adjuvants, few mixtures rely on synergism to control weeds. Such mixtures are highly sought, but rare. Although synergism has positive connotations, it usually increases crop injury. Much work is done during the development of a new herbicide to determine factors that might cause synergism.

***Table 3*** *Corn injury with 35 to 70 g $ha^{-1}$ nicosulfuron applied post-emergence with various soil insecticides applied in-furrow at their recommended rates.*
*(Results are the means of three observations during the first two weeks from 13 field tests).*

| Insecticide | % Injury | % > 15% |
|---|---|---|
| None | 1.5 | 2 |
| Carbofuran | 1.4 | 0 |
| DPX-43898 | 6.1 | 0 |
| Chlorpyrifos | 4.6 | 6 |
| Fonofos | 8.5 | 19 |
| Phorate | 17.5 | 67 |
| Terbufos | 27.8 | 81 |

For example, organophosphate insecticides synergize many different herbicides (12). About 25% of corn receives such insecticides to control *Diabrotica* spp. larvae (corn rootworm). To develop a new herbicide for this market requires extensive field testing for synergism that could increase corn injury.

Table 3 shows the results of 13 field tests from 1988 to 1990 for synergism between nicosulfuron and six corn rootworm insecticides[2]. These tests showed that nicofulfuron is safe to corn when applied alone or with carbofuran, a carbamate insecticide. The other five insecticides are organophosphates and their responses varied from DPX-43898 never causing more than 15% injury, to terbufos that caused more than 15% injury 81% of the time. Such tests are necessary to label herbicides properly.

## Antagonistic mixtures.

Antagonism is a common mixture problem. Table 4 shows the results of a test to evaluate whether five potential broadleaf tank-mixture partners antagonize nicosulfuron[3]. No treatment injured corn and all mixtures controlled the broadleaved weeds. Unfortunately, the cyanazine mixture reduced nicosulfuron control of *Echinochloa* from 93% to 25%. No other herbicide had any significant effect.

***Table 4*** *Mixture response of nicosulfuron with various broadleaf herbicides on **Echinochloa crus-galli**.*
*(Results are means of 3 replicates. LSD at the 0.05 level was 10%).*

| Herbicide | Rate g $ha^{-1}$ | No Nicosulfuron | 17.5 g $ha^{-1}$ Nicosulfuron |
|---|---|---|---|
| | | % Control | |
| None | 0 | 0 | 93 |
| Atrazine | 1120 | 23 | 92 |
| Cyanazine | 1120 | 17 | 25 |
| Dicamba | 560 | 0 | 100 |
| Bromoxynil | 560 | 3 | 95 |
| 2,4-D | 560 | 0 | 93 |

[2] M.D. Dobrotka. 1990. Unpublished, Du Pont Company, Wilmington, Delaware 19898, U.S.A.

[3] G. L. Leek and H. Kuratle. 1988. Unpublished, Du Pont Company, Stine-Haskell Research Center, Newark, Delaware 19714, U.S.A.

## Conclusion

We must improve herbicide efficiency to meet increasing societal concerns about environmental degradation, worker safety, and public health. Additionally, we must consider many other issues that relate to short-term profit and long-term sustainability. Mixtures can help achieve these goals by reducing herbicide rates through the full use of complementary weed spectrums and additive action. Herbicide labels that recommend narrow rate ranges and only classify weeds as controlled or suppressed are inadequate and obsolete. Deciding how to use mixtures most efficiently is complex and requires expert analysis and understanding.

## References

1. Baandrup, M. and Ballegaard, T. (1989). Three years of field experience with an advisory computer system applying factor-adjusted doses. Brighton Crop Protection Conference, Weeds, p. 555.
2. Bodeker, W., Altenburger, R., Faust, M. and Grimme, L.H. (1990). Methods for the assessment of mixtures of plant protection substances (pesticides). *Nachrichtenbl. Deut. Pflanzenschutzd* 42, 70.
3. Delvo, H.W. (1984). Inputs Situation and Outlook Report. U.S.D.A. Econ. Res. Serv. Rep. I05-6, Nov.
4. Delvo, H.W. (1990). Inputs Situation and Outlook Report. U.S.D.A. Econ. Res. Serv. Rep. AR-17, Feb.
5. Foy, C.L. (1989). Adjuvants for agrochemicals: introduction, historical overview, and future outlook, *In* 'Adjuvants and Agrichemicals, Vol. 2', ed P.N.P. Chow, CRC Press, Boca Raton, Florida.
6. Green, J.M. (1989). Herbicide antagonism at the whole plant level. *Weed Technology* 3, 217.
7. Green, J. M. (1991). Maximizing herbicide efficiency with mixtures and expert systems. *Weed Technology* (in press).
8. Green, J.M. and Brown, P.A. (1990). Influence of surfactant properties on nicosulfuron, DPX-E9636, and thifensulfuron performance in corn. Seventh IUPAC Vol. 2, 16.
9. Green, J.M. and Streibig, J.C. (1992). Herbicide mixtures. *In* 'Herbicide Bioassays', ed J.C. Streibig and P. Kudsk, CRC Press, Boca Raton, Florida, (in press).
10. Griffin, W.C. (1954). Calculation of HLB of non-ionic surfactants. *Journal of the Society of Cosmetic Chemists* 5, 249
11. Hodgson, R.H. (1982). Ed., 'Adjuvants for Herbicides', Monogr. 1, Weed Science Society of America, Champaign, Ill..
12. Hatzios, K.K. and Penner, D. (1985). Interactions of herbicides with other agrochemicals in higher plants. *Review of Weed Science* 1, 1.

*Figure 1 Effect of surfactant concentration on nicosulfuron control of **Setaria faberi** and **Echinochloa crus-galli***

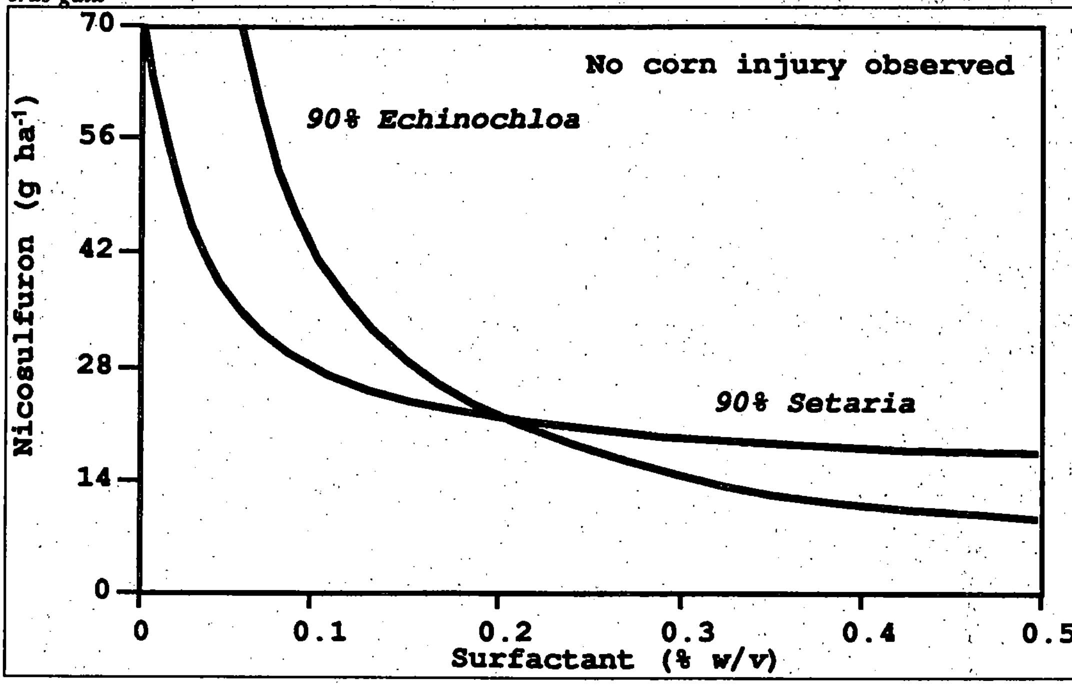


*Figure 2 Effect of surfactant HLB on nicosulfuron control of **Setaria faberi***

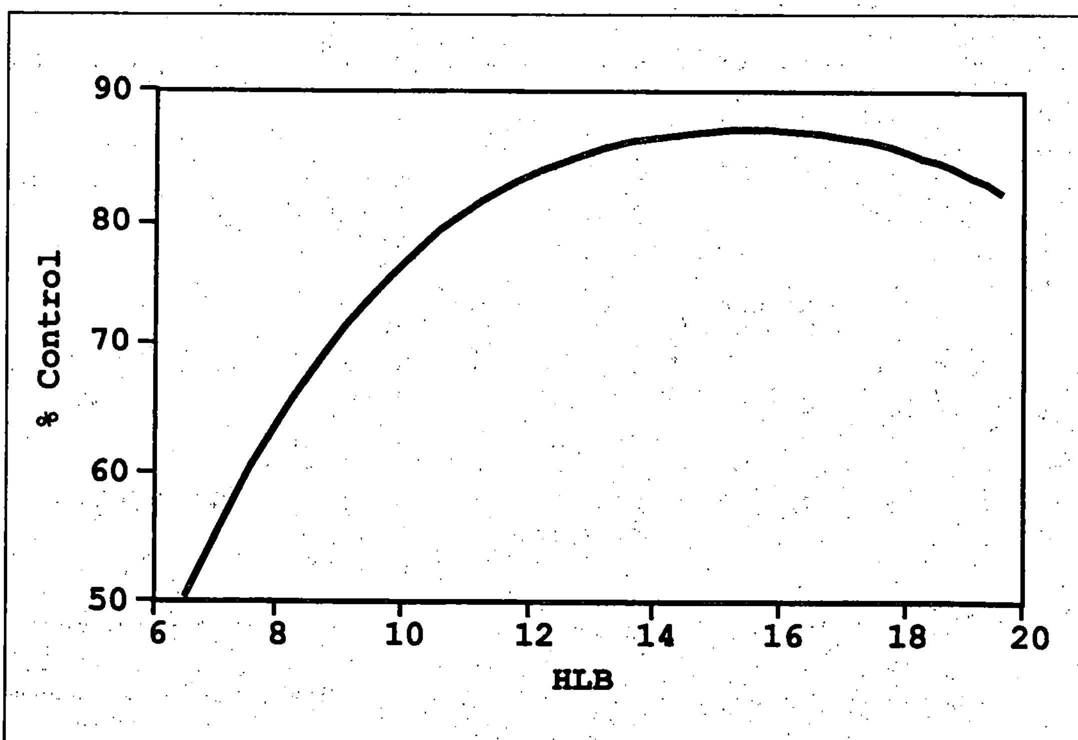

*Figure 3* *The 85% control of* ***Abutilon theophrasti*** *with nicosulfuron and thifensulfuron mixtures*

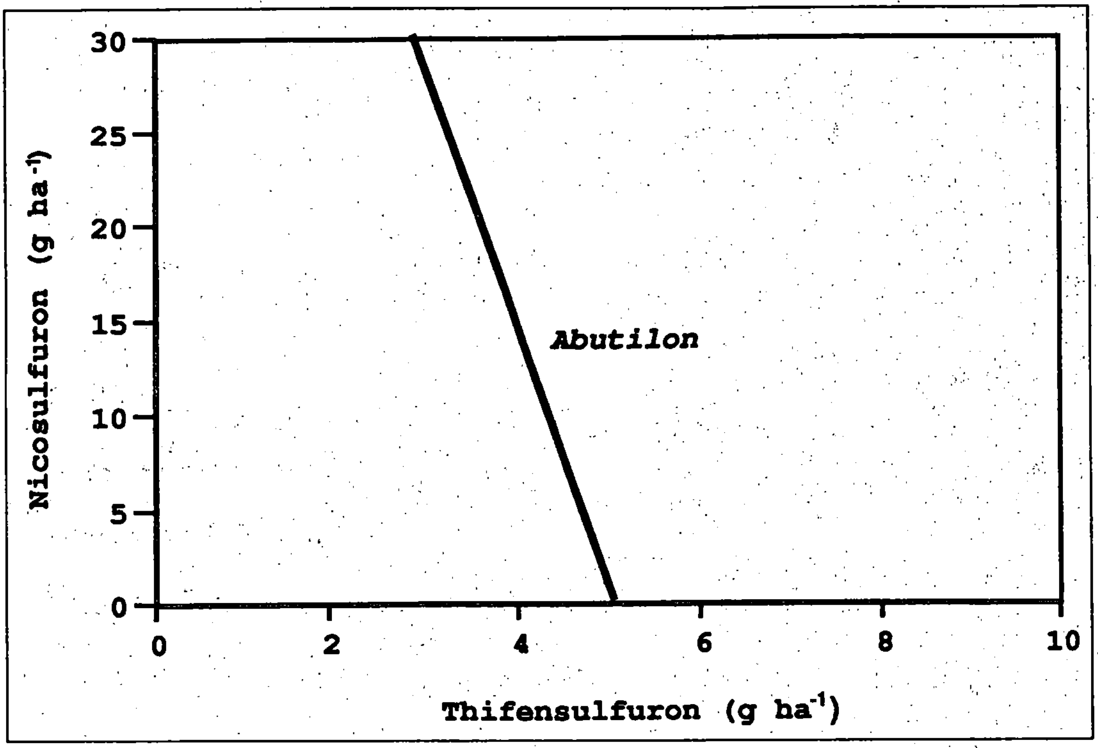


*Figure 4* *The 85% control isoboles of* ***Echinochloa crus-galli, Digitaria sanguinalis****, and* ***Setaria faberi*** *with nicosulfuron and thifensulfuron mixtures*