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The Development and Biology of Glyphosate- and Multiple-Resistance

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Extension Agronomist – Sugarbeet Weed Science
NDSU and U of MN
# Glyphosate Formulation Rates

<table>
<thead>
<tr>
<th>Glyphosate formulation (lb ae/gal)</th>
<th>Product rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.75 lb ae/A</td>
</tr>
<tr>
<td>3.0 lb ae/gal</td>
<td>32</td>
</tr>
<tr>
<td>4.0 lb ae/gal</td>
<td>24</td>
</tr>
<tr>
<td>4.17 lb ae/gal</td>
<td>23 (24)</td>
</tr>
<tr>
<td>4.5 lb ae/gal</td>
<td>21.3 (22)</td>
</tr>
<tr>
<td>5.0 lb ae/gal</td>
<td>19.2 (20)</td>
</tr>
</tbody>
</table>
Why is Glyphosate Resistance Different From Other Types of Herbicide Resistance?

1. Resistance to the BEST herbicide EVER discovered!
   • Reduces the number of effective herbicides to control weeds.

2. Fields driven to high frequencies of resistance to herbicides with other modes of action are at GREATEST RISK for selecting multiple resistance containing glyphosate!
   • Further reduces the number of effective herbicides to control weeds.

3. NO NEW herbicide modes of action are known to be released anytime soon!
   • Last mode of action discovered was greater than 20 years ago!
     • HPPD-inhibiting herbicides

4. Confirmation of glyphosate resistance is difficult!
   • Due to low-level resistance
   • Potentially multiple genes controlling resistance
1. Retail / Wholesale Manager
2. Retail / Wholesale Agronomist
3. Retail Spray Rig Driver
4. Consultant
5. Chemical Manufacturer Representative
6. Seed Company Representative
7. Equipment Manufacturer
8. Farmer / Grower
9. University Employee
10. Other
How Many Acres Do You Manage or Develop Recommendations?

1. 0 to 1000 A
2. 1000 to 3000 A
3. 3000 to 6000 A
4. 6000 to 10,000 A
5. 10,000 to 15,000 A
6. 15,000 to 20,000 A
7. 20,000 to 30,000 A
8. 30,000 to 40,000 A
9. > 40,000 A
Which Choice Best Defines Resistance?

1. The successful survival of a species to the initial application of the labeled rate of an herbicide and responds the same in future generations.

2. Individual weeds that survive greater than 10 times the normal rate.

3. The evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal rate.

4. All of the Above

5. None of the Above

6. Other
Types of Herbicide Resistance

- **High-Level Resistance** = Survival at rates > 10 times the labeled rate
  - Application parameters (coverage, environment, etc.) *unlikely* to affect control of species!!
  - Usually *minimal* injury
  - The correct *rate usually does not* matter when *initially* selecting
  - Second applications *usually do not* reduce seed production!
  - Examples = triazine, ALS, and ACCase
Types of Herbicide Resistance

• **Low-Level Resistance** = Survival at rates $< 10$ times the labeled rate

  – Many different application parameters (coverage, environment, etc.) **likely** to affect control of species!!

  – **Significant** injury **always** occurs initially & **CAN** kill small plants

  – The correct **rate** **DOES** matter when **initially** selecting!!!

  – Second applications **USUALLY REDUCE** numbers of plants & seed production!

  – Examples = **glyphosate**, PPO, synthetic auxins, paraquat
Of the Acres You Work With, Are Glyphosate-Resistant Weeds Present on Any of Those Acres?

1. Yes
2. No

35% Yes  65% No
What Percentage of The Acres You Work With Have At Least A Few Plants in a Field That are Resistant to Glyphosate?

1. 0%
2. < 5%
3. 5 to 10%
4. 10 to 20%
5. 20 to 30%
6. 30 to 40%
7. 40 to 60%
8. > 60%
What Percentage of The Acres You Work With Have Large Dense Patches of Glyphosate-Resistant Weeds or in Which Glyphosate is Nearly Ineffective on a Particular Species?

1. 0%
2. < 5%
3. 5 to 10%
4. 10 to 20%
5. 20 to 30%
6. 30 to 40%
7. 40 to 60%
8. > 60%

0% 62% 27% 9% 0% 0% 0% 0% 0%
Which Weed Species are Glyphosate-Resistant on the Most Acres You Work With?

1. None
2. Common Ragweed
3. Giant Ragweed
4. Waterhemp
5. Lambsquarters
6. Pigweed species
7. Kochia
8. Other

- None: 22%
- Common Ragweed: 4%
- Giant Ragweed: 18%
- Waterhemp: 16%
- Lambsquarters: 2%
- Pigweed species: 4%
- Kochia: 4%
- Other: 2%
Which Weed Species are Glyphosate-Resistant on the Most Acres You Work With?

1. None
2. Common Ragweed
3. Giant Ragweed
4. Waterhemp
5. Lambsquarters
6. Pigweed species
7. Kochia
8. Other
Which Weed Species are Glyphosate-Resistant on the Most Acres You Work With?

1. None 47%
2. Common Ragweed 5%
3. Giant Ragweed 7%
4. Waterhemp 5%
5. Lambsquarters 2%
6. Pigweed species 7%
7. Kochia 23%
8. Other 5%
Species Glyphosate-Resistant in MN and ND

- Common ragweed (MN & ND)
- Waterhemp (MN)
- Giant ragweed (MN)
- Lambsquarters (MN & ND)
  - Lowest level of resistance
  - Multiple applications usually kill most or all plants
Study Initiated by:
Carlyle & Doug Holen
Supported by:
MN Soybean Council

Map by: Phillip Glogoza
Traill Co., ND
Glyphosate 1.125 fb 0.75 fb 0.75 lb ae/A (2.625)
Starting at ≤ 1” common ragweed
Traill Co., ND
Glyphosate 1.125 fb 0.75 fb 0.75 fb 0.75 lb ae/A (3.375)
Starting at \( \leq 1" \) common ragweed
40-75% acreage with g. ragweed
25-60% acreage with waterhemp
Western McLoed Co., MN
Glyphosate 32 oz/A followed by Flexstar? (1.0 pt/A)
Western McLoed Co., MN
Touchdown (32 oz/A) plus FirstRate (0.3 oz/A)

99% of flagged plants survived!
40-75% acreage with g. ragweed
25-60% acreage with waterhemp

15-40% acreage with c. ragweed
5-30% acreage with waterhemp
Western Stearns Co., MN
Glyphosate applied twice followed by Flexstar
Glyphosate-Resistant Species in Other States

• Horseweed (16 states!)
• Waterhemp (IL, KS, MO)
• Giant ragweed (AR, IN, KS, MO, OH)
• Common ragweed (AR, KS, MO, NC, OH)
• Lambsquarters (OH, IN, VA, WI)
  – Lowest level
  – Usually controlled with multiple applications
• Kochia (KS)
• Palmer amaranth (AR, GA, NC, TN)
• Johnsongrass
• Ryegrass (Italian & rigid)
Materials and Methods

• Treatments (12 total - single application)
  – Glyphosate rate
    • 0.75 lb ae/A (recommended rate)
    • 1.125 lb ae/A (max. single appl. in sugar beet & corn)
    • 1.5 lb ae/A (max. single appl. in soybean)
    • 3.0 lb ae/Aa
  – Application timing (common ragweed size)
    • T1 = ≤ 1” (ave. = 0.75”) [June 4, 2008]
    • T2 = ≤ 2” (ave. = 1.25”) [June 16th]
    • T3 = ≤ 6” (ave. = 3”) [June 26th]

• 15 plants flagged prior to application
# Single Glyphosate Application

<table>
<thead>
<tr>
<th>Glyphosate (lb ae/A)</th>
<th>16 or 17 DAT</th>
<th>Harvest</th>
<th>LSD (0.05)</th>
<th>LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>70</td>
<td>33</td>
<td>58</td>
<td>13</td>
</tr>
<tr>
<td>1.125</td>
<td>89</td>
<td>48</td>
<td>65</td>
<td>13</td>
</tr>
<tr>
<td>1.5</td>
<td>88</td>
<td>53</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>100</td>
<td>77</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Single Glyphosate Application

### Mortality (flagged plants)

<table>
<thead>
<tr>
<th>Glyphosate (lb ae/A)</th>
<th>16 or 17 DAT</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>0.75</td>
<td>62</td>
<td>9</td>
</tr>
<tr>
<td>1.125</td>
<td>93</td>
<td>16</td>
</tr>
<tr>
<td>1.5</td>
<td>84</td>
<td>22</td>
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<tr>
<td>3.0</td>
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<td>33</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
## Application Temperatures

<table>
<thead>
<tr>
<th>Application</th>
<th>Temperature (F)</th>
<th>High Temperature (F)</th>
<th>Temp. (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At Time of App.</td>
<td>2 Days Before</td>
<td>Day Before</td>
</tr>
<tr>
<td>T1</td>
<td>65</td>
<td>72</td>
<td>57</td>
</tr>
<tr>
<td>T2</td>
<td>61</td>
<td>58</td>
<td>71</td>
</tr>
<tr>
<td>T3</td>
<td>76</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>Treatment</td>
<td>Control - Harvest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(glyphosate – lb ae/A)</td>
<td>T1</td>
<td>T2</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 0.75</td>
<td>22</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 1.1</td>
<td>30</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>1.1 fb 0.75</td>
<td>27</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 0.75 fb 0.75</td>
<td>35</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 1.1 fb 0.75</td>
<td>40</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>1.1 fb 0.75 fb 0.75</td>
<td>33</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 0.75 fb 0.75 fb 0.75</td>
<td>70</td>
<td>55</td>
<td></td>
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<tr>
<td>0.75 fb 1.1 fb 0.75 fb 0.75</td>
<td>70</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>1.1 fb 0.75 fb 0.75 fb 0.75</td>
<td>78</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Multiple Glyphosate Applications for T1

<table>
<thead>
<tr>
<th>Treatment (glyphosate – lb ae/A)</th>
<th>Mortality (flagged plants)</th>
<th>16/17DAT Initial App.</th>
<th>16/17DATL last App.</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75 fb 0.75</td>
<td></td>
<td>69</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td>0.75 fb 1.1</td>
<td></td>
<td>60</td>
<td>64</td>
<td>69</td>
</tr>
<tr>
<td>1.1 fb 0.75</td>
<td><strong>76</strong></td>
<td>78</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>0.75 fb 0.75 fb 0.75</td>
<td></td>
<td>67</td>
<td>67</td>
<td>73</td>
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<tr>
<td>0.75 fb 1.1 fb 0.75</td>
<td></td>
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<td>71</td>
</tr>
<tr>
<td>1.1 fb 0.75 fb 0.75</td>
<td><strong>84</strong></td>
<td>88</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>0.75 fb 0.75 fb 0.75 fb 0.75</td>
<td></td>
<td>80</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>0.75 fb 1.1 fb 0.75 fb 0.75</td>
<td></td>
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<tr>
<td>1.1 fb 0.75 fb 0.75 fb 0.75</td>
<td><strong>76</strong></td>
<td>80</td>
<td>80</td>
<td>93</td>
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<tr>
<td>LSD (0.05)</td>
<td></td>
<td>19</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
Untreated

Glyphosate

0.75 lb/A  3.0 lb/A

Traill Co., ND

OH Resistant

Susceptible
Untreated

Stearns Co., MN

Traill Co., ND

OH Resistant

Susceptible

Glyphosate

0.75 lb/A

3.0 lb/A
Recommendations to Improve Glyphosate Activity

- Glyphosate should be
  - Applied early (≤ 1” common ragweed) at a minimum rate of 0.75 lb/A
  - Applied multiple times (3-4)
    - Only sugar beet benefited
  - Applied just prior to flowering of common ragweed at the last application
    - Sugar beet most benefited (vegetative crop)
  - Applied at 14-21 day intervals
  - Applied at the highest maximum rate at the second application
    - Soybean most benefited (1.5 lb/A maximum rate)
  - Applied during good weather conditions
Scouting for Resistance – 3 WAT (glyphosate+FirstRate)

Dead

Injured

Healthy main meristem
Scouting for Resistance – at Harvest (glyphosate)

Main meristem dead, but healthy branches

Dead

Healthy main meristem & shortened internodes
CRITICAL Best Management Practices

• Know when resistance is occurring AND react quickly!
  – Plants per field, NOT per acre!
Reaction Time

12 plants/field

12 plants/ft²

12 plants/A
CRITICAL Best Management Practices

• Diversify weed management strategies
  – Cultural, mechanical, diversify herbicide modes of action

• Maximize glyphosate activity!
  – Small weeds, correct rate, low stress, AMS, others

• Utilize PRE herbicides whenever possible
  – May reduce resistance risk

• Maximize POST tank-mix or sequential partner!
  – Correct rate!, small weeds, correct adjuvant, increase glyphosate rate, others
Was This Presentation Helpful to Your Job?

1. Yes
2. No
• Thank You

• Are There Any Questions?