Glyphosate.

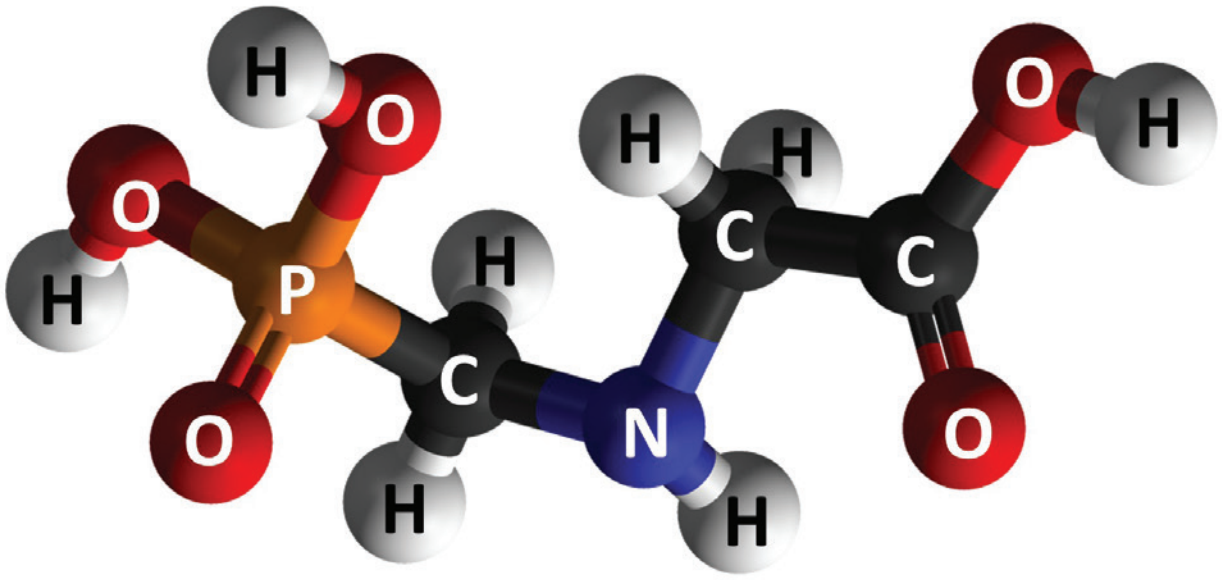

Figure 1. *Glyphosate molecule (Photo: Adapted from Wikipedia author Benja-bmm27)*

Love it? Hate it? Learn more.

ERIN HILL
WEED SCIENCE DIAGNOSTICIAN, MSU PLANT & PEST DIAGNOSTICS
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To understand how glyphosate became the most widely used herbicide in the United States we need to look back in time. Glyphosate (Figure 1) was originally discovered by a Swiss chemist named Henri Martin in 1950, while seeking pharmaceutical compounds. It was not until 20 years later that the herbicidal properties of glyphosate were realized by Monsanto chemist, John Franz. Glyphosate was found to kill plants by preventing the synthesis of certain amino acids (the building block of proteins in cells). This happens in the shikimic acid pathway, which is unique to plants and some microorganisms.

Figure 2. *Glyphosate drift injury on conventional soybeans showing chlorosis and stunting seven days after treatment; untreated (left), 1/10x field rate of 32 fl oz/A Roundup Powermax (center), 1/2x field rate (right) (Photo: Erin Hill)*

As the plants are starved for these amino acids, symptoms initially manifest at the growing points as tissues turn yellow or white in herbaceous species (Figure 2) and progress over a couple weeks, severely injuring or killing the plant. In woody species, symptoms of glyphosate exposure are not always seen right away, in fact, they may not show up until the following growing season and can progress over time with subsequent exposures. While woody species exposed to glyphosate can be chlorotic, they can also display irregular growth (Figure 3), sometimes referred to as a "witches' broom".

Monsanto first introduced Roundup® (a.i. glyphosate) in 1974 as a postemergence, non-selective herbicide for use in fallow areas, burndown applications, and other special situations (e.g. orchards). At the time of glyphosate's introduction, paraquat, the most acutely toxic herbicide available, was used in these situations but regrowth was possible. Other leading herbicides at the time were atrazine, 2,4-D, and trifluralin. What made, and still makes, glyphosate special is that it translocates (moves) well within plants resulting in a more complete kill and less need for retreatment. Glyphosate is less likely to move and persist in the environment than these other herbicides and acute toxicity is very low. From its introduction until 1995, the total annual use of glyphosate (agricultural) rose steadily to nearly 30 million pounds in the U.S. In 1996, Roundup Ready® soybeans were released and along with the other glyphosate-resistant crops released later, resulted in increased utility of glyphosate. Now, glyphosate could be applied over resistant crops to kill any type of weed without crop injury and adoption of these technologies skyrocketed. By 2000, Monsanto's patent on glyphosate expired and generic products containing glyphosate became available. All of these factors resulted in a reduction to weed management costs in these crops and reduced reliance on tillage. By 2012 there was a 10-fold increase in glyphosate use. While this seems alarming it is important to note that total herbicide use per year (in pounds of active ingredients) had not changed, but the composition of what was being applied shifted and glyphosate was and continues to be the most applied pesticide active ingredient in cropping systems in the U.S.

As with all pesticides, Roundup® was registered with the Environmental Protection Agency (EPA) and it has been re-register and reviewed several times since (as well as other glyphosate products). The EPA examines application utility, research study data, and proposed labels before granting registration. Examples of the types of research study data required include the following:

- Product chemistry
- Product performance
- Toxicology data
- Humans
- Wildlife & aquatic organisms
- Drift evaluation
- Environmental fate
- Degradation
- Metabolism
- Mobility
- Dissipation
- Accumulation

You can view more detailed information on the required tests on the EPA's website (epa.gov/pesticide-registration).

Questions about glyphosate use. Following are a few issues that get asked about glyphosate use and brief responses. In some cases, there is no definitive answer at this time.

- **Does external exposure to glyphosate cause cancer in humans?** This issue came to the forefront following a couple key events.

  1. The World Health Organization (WHO) International Agency for Research on Cancer (IARC) declared glyphosate a probable human carcinogen in 2015. It did not conclude what types of exposure are most risky or the dosage or frequency with which exposure would need to take place for cancer to likely develop. In 2016, an EPA review stated that glyphosate was not a likely human carcinogen when used as directed. They evaluated both public and private data used for registrations and their determination implied that the likelihood of exposure at rates high enough to cause cancer is extremely low. Several other entities have agreed with the EPA (e.g., National Institute of Health, European Food Safety Authority, Health Canada, etc.)
  2. A California jury ruled in favor of Dewayne Johnson v. Monsanto in a lawsuit claiming that Roundup® caused his non-Hodgkin's lymphoma in 2018. While considering this case and the media surrounding it, it is important to realize that a jury verdict is not necessarily reflective of scientific evidence and one should do their own fact-checking.

  While currently the overall conjecture in the scientific community is that the risks are low, the glyphosate studies and interpretations continue as it is challenging to perfectly extrapolate results on test animals to humans and in human studies it is difficult to rule out other possible causes of cancer. Bayer (which purchased Monsanto) has self-reported ~138,000 legal cases brought forward regarding Roundup®, the majority of which are from residential users, including some class action lawsuits. As part of their five-point plan to mitigate future Roundup® lawsuits, Bayer intends to replace glyphosate in the residential lawn and garden market in 2023 with alternative products. Agricultural and professional products will not be affected. When working with the public, I find that risk assessment in this arena is a personal choice, which I respect.

Figures 3. *(Above and below)Glyphosate injury on white pine showing 'witches' broom' (i.e. excessive bud break) symptoms (Photo: Erin Hill)*

- **Does glyphosate cause resistance to develop in weeds?** Herbicide resistance in weeds can develop over time. If we apply an herbicide to thousands (or millions) of weeds, there is likely to be a small fraction of plants that, based on genetic diversity and sheer number, are resistant. As these survivors reproduce the proportion of resistant weeds increases over time. Therefore, repeated exposure to an herbicide (or multiple herbicides that act in the same way) results in the appearance of resistance; the herbicide does not cause a mutation within the plants. The evidence for resistance in weeds developing following repeated use is

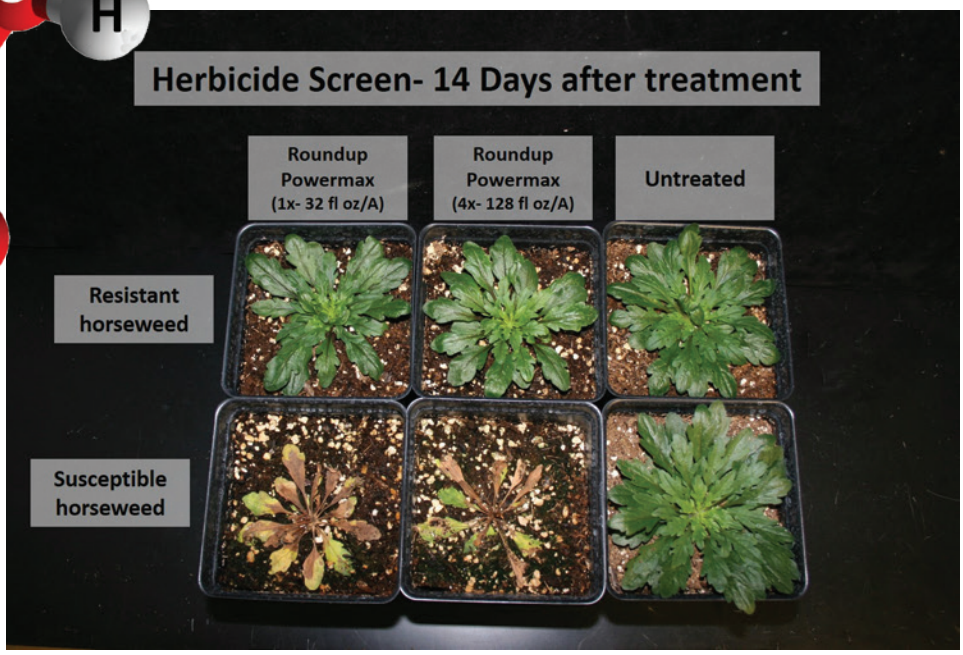

Figure 4. *Glyphosate resistant horseweed (top row) compared to a known susceptible population (bottom row) after exposure to 1x and 4x field rates of Roundup Powermax (a.i. glyphosate, 1x rate= 32 fl oz/A) 14 days after treatment (Photo: Erin Hill)*

clear, particularly when weed control strategies are not diversified. Thus far in the Midwest, the weed most likely to be glyphosate-resistant in Christmas tree production systems is the annual, horseweed (aka marestail, *Erigeron Canadensis;* Figure 4). Horseweed can develop resistance due to selection pressure as described above, but given that the minute seed is dispersed by wind, it can also 'show up' at your farm already resistant from neighboring areas.

- **Does glyphosate increase plant susceptibility to diseases?** The short answer is possibly. As previously mentioned, glyphosate acts on the Shikimate acid pathway in plants. This pathway is also involved in plant defenses against pathogen infection. Remember though, in order for any disease to occur the pathogen must be present, the host must be susceptible, and the environmental conditions must be favorable for disease development, this is referred to as the disease triangle. What this all means is that Christmas trees exposed to sublethal doses of glyphosate could show increased disease susceptibility if pathogens and conditions favorable for disease development are present.
- **Does glyphosate interfere with microbes?** We know that the shikimic acid pathway is present in some microorganisms (e.g. some fungi and bacteria), and some are sensitive to glyphosate. This can result in changes in the composition of microbes present in the soil matrix and possibly the guts of organisms if they consume glyphosate. What is not understood and is currently being studied is if there is any impact of microbial shifts in these environments.
- **Are Christmas tree consumers concerned with glyphosate use?** I posted a question to the attendees of the 2022 Got Weeds? Weed Management Webinar Series put on by Michigan State University Extension; "How often do your Christmas tree customers inquire about your pesticide practices?" The results were mixed with 6% saying customers inquired 'often', 51% 'occasionally', and 43% 'not thus far' (127 surveyed). These results may be different if Christmas trees were eaten, but it does demonstrate some interest in this type of information. It will be important to think about what information you wish to communicate ahead of time. Customers are interested in the facts as well as your perspective and experiences as a grower.

Glyphosate alternatives. As of late, it is often asked, what herbicide can replace glyphosate? As previously mentioned, glyphosate is unique in its utility as a postemergence herbicide with non-selective, systemic activity and lack of persistence in the soil. While there are no other herbicides exactly like glyphosate for use in Christmas trees (or other crops), the following are some examples of products that share some attributes (bold text shows differences). Note, as with all pesticides it is critical to read and follow all labeled instructions to maximize effectiveness and minimize crop injury and personal and environmental exposure.

- Non-selective, **Contact activity** (postemergence), Not persistent- these products are best on small, annual broadleaf species, control of perennial broadleaves and some grasses is limited
  - Finale (a.i. glufosinate, Group #10)
  - Scythe (a.i. pelargonic acid, Group #26)
  - Axxe (a.i. ammonium nonanoate)- some products are approved by the Organic Materials Review Institute (OMRI)
- Non-selective, **Contact activity (pre- or post-emergence activity), Persistent –** these products are best on small, annual broadleaf weeds and some grasses
  - SureGuard (a.i. flumiozaxin, Group #14)
  - Goaltender (a.i. oxyflurofen, Group #14)
- **Selective-grass control,** Systemic activity (postemergence), Not persistent- these products have no

activity on broadleaf species when used as directed

- o Envoy Plus (a.i. clethodim, Group #1)
- o Segment (a.i. sethoxydim, Group #1)

- **Selective- broadleaf control,** Systemic activity (postemergence), Somewhat persistant-
  - o Stinger (a.i. clopyralid, Group #4)
  - o Garlon (a.i. triclopyr, Group #4)
- **Selective- broadleaf and grass control,** Systemic activity (pre and post-emergence activity), **Somewhat persistent –** Actual selectivity depends on timing, weed species, and size. Consult label for specifics.
  - o Mission (a.i. flazasulfuron, Group #2)

There is a lot of press about glyphosate, but at the end of the day, just like any other controversial subject, it is important to do some investigating into what is known and consider the sources of information before deciding where you lie on the spectrum. Whether or not you find glyphosate acceptable, consider the alternative choices and their impacts and know that everyone agrees that only using glyphosate is not a sustainable path forward.

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