Union of Concerned Scientists

POLICY BRIEF

The Rise of Superweeds—and What to Do About It

Solutions based on the science of agroecology can avert a looming crisis for farmers and the environment.

In what may sound like science fiction but is all too real, "superweeds" are overrunning America's farm landscape, immune to the herbicides that used to keep crop-choking weeds largely in check. This plague has spread across much of the country—some 60 million acres of U.S. cropland are infested—and it is wreaking environmental havoc, driving up farmers' costs and prompting them to resort to more toxic weed-killers.

How did this happen? It turns out that big agribusiness, including the Monsanto Company, has spent much of the last two decades selling farmers products that would ultimately produce herbicide-resistant weeds. And now that thousands of farmers are afflicted with this problem, those same companies are promising new "solutions" that will just make things worse.

Herbicide-resistant weeds are also symptomatic of a bigger problem: an outdated system of farming that relies on planting huge acreages of the same crop year after year. This system, called monoculture, has provided especially good habitat for weeds and pests and accelerated the development of resistance. In

A University of California extension agent stands behind a patch of herbicide-resistant marestail (also known as horseweed) and talks about its effect on farmers. This aggressive weed, which can grow to be six feet tall, has emerged in many parts of the country but is particularly problematic in the Midwest and eastern United States.

response, Monsanto and its competitors are now proposing to throw more herbicides at resistant weeds, an approach that ignores the underlying biology of agricultural systems and will inevitably lead to more resistance and a further spiraling up of herbicide use.

What is needed instead is support for approaches—which already work and are available now—that target the problem at its source. Scientists and farmers alike have developed, tested, and refined methods of growing crops that reduce the likelihood of resistance in the first place, while providing many other benefits for consumers, the environment, and farmers themselves.

[*Almost 50 percent of surveyed farms are infested with glyphosate-resistant weeds, and the rate of these weeds' spread is increasing.*]

Unfulfilled Promises

Monsanto first introduced its line of "Roundup Ready" seeds in the mid-1990s. These crops—which now include corn, soybeans, cotton, canola, alfalfa, and sugar beets—are genetically engineered to be immune to the company's Roundup herbicide (glyphosate). This convenient system enabled farmers to plant these seeds and later spray fields with Roundup to kill any weeds that might compete with the crops. The seeds were expensive, but in the early days farmers enthusiastically adopted them because they saved time and made weed control easier.

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Palmer amaranth, also known as pigweed, infests a soybean field.

This system was heralded as an environmental breakthrough. Using it was supposed to make farming safer: because Roundup was widely thought to be more effective than other common herbicides and not as toxic, less total herbicide would be needed. Advocates claimed that Roundup would reduce soil loss through erosion, given that farmers would not need to plow (till) their fields as much to control weeds.

For several years, Monsanto's system did seem to work as intended. But after a temporary reduction, herbicide use on U.S. farms has increased dramatically because of growing weed resistance to Roundup; given that other chemical agents also have to be employed, overall pesticide use is an estimated 404 million pounds greater than if Roundup Ready crops had not been planted (Benbrook 2012). Farmers' costs are rising, moreover, and the short-term benefit of reduced soil erosion is being reversed because farmers facing resistant weeds often find they need to till again (Price et al. 2011).

What Went Wrong?

At present, more than 15 years after farmers began growing Roundup Ready crops, the most widely grown U.S. commodity crops are glyphosate-resistant, and farmers douse at least 150 million acres with the herbicide every year (USDA 2013; USDA ERS 2013). As a result of this heavy use, weeds showing resistance to glyphosate began appearing in fields more than a decade ago (VanGessel 2001)—first as occasional interlopers but eventually as large infestations. (See the box, "How Resistance Occurs.") A recent survey revealed that almost 50 percent of surveyed farms were infested with glyphosate-resistant weeds (Fraser 2013), and the rate of these weeds' spread has been increasing. Twenty-four species of weed are now glyphosate-resistant (International Survey of Herbicide Resistant Weeds 2013).

The worst cases are in the southeastern United States, where a reported 92 percent of cotton and soybean fields are infested as a result of Roundup Ready crops (Fraser 2013). The now-resistant Palmer amaranth (*Amaranthus palmeri*), for example, is a fast-growing weed that can reach eight feet in height, outcompeting soybeans or cotton; it develops a tough stem that can damage farm machinery and must sometimes be removed by hand—an expensive proposition. Resistant ragweeds (*Artemisia* species), marestail (*Conyza canadensis*), and water hemp (*Amaranthus tuberculatus*) are also aggressive weeds, spreading through the Midwest and the Corn Belt. Meanwhile, farmers in the Great Plains are confronting resistant populations of kochia (*Kochia scoparia*), a weed adapted to drier climates.

The situation, alarming as it is, could get a lot worse. Survey data (Fraser 2013) show that in the absence of enlightened intervention, *most* U.S. farms from the Great Plains to

How Resistance Occurs

Glyphosate-resistant weeds have arisen largely because the overuse of this single herbicide, designed to make weed control easy in fields of crops genetically engineered to resist it, also permits those rare weeds with naturally occurring resistance genes to generate offspring. Thus while glyphosate kills the weeds that do not contain the resistance genes, it allows the resistant weeds to flourish and spread.

Pesticide resistance is not new. But the rapid spread of glyphosate-resistant superweeds today is the result of a "perfect storm" of three practices that have accelerated resistance problems (Mortensen et al. 2012).

1. Monoculture. Most pests, including many weeds, prefer some crops over others. By growing large swaths of the same crop in the same place year after year—a practice known as monoculture—farmers allow the weeds best adapted to compete with that crop to flourish and multiply over time. These extended populations of weeds increase the likelihood, when a particular herbicide is used, of the existence and selection of rare individual weeds resistant to that herbicide.

2. Overreliance on a single herbicide. Resistance has also been accelerated by heavy reliance on glyphosate alone. This herbicide is popular with farmers because it is relatively inexpensive, kills a broad spectrum of weeds, often controls larger weeds better than many other herbicides, and is easy to apply. Glyphosate-resistant crops give farmers the convenient option of spraying directly onto the crop, rather than having to apply herbicide to the soil (before the crop has germinated) or carefully spray it between crop rows. As a result, many farmers have come to rely exclusively on glyphosate. And whereas weed populations treated with a variety of herbicides are less likely to develop resistance—because different herbicides act by different molecular mechanisms and very few individual plants carry genes that can defeat more than one chemical—weeds treated only with glyphosate have quickly become resistant. (It is important to note, however, that weeds eventually develop resistance even to multiple herbicides when they are the predominant means of weed control.)

3. Neglect of other weed control measures. Many farmers have all but abandoned nonchemical weed control methods, even though sophisticated agricultural techniques—such as crop rotation—can control weeds without excessive dependence on herbicides and reduce the likelihood that resistance will develop. Other nonchemical methods include the use of cover crops, conservation tillage that does not facilitate erosion, and ways of planting crops that enhance their competitiveness with weeds (Liebman, Baustiaan, and Baumann 2003). Some crops or crop varieties may also produce substances that suppress weeds, a phenomenon known as allelopathy (Worthington and Reberg-Horton 2013).

But the temporary convenience of herbicide-resistant crops has led farmers to neglect the use of these other methods. Moreover, federal farm and biofuels policies that favor just a few crops have entrenched monocultures and essentially encouraged chemical-based approaches to weed control.

the East Coast will become infested with resistant superweeds. Can industry help reverse the damage it has wrought?

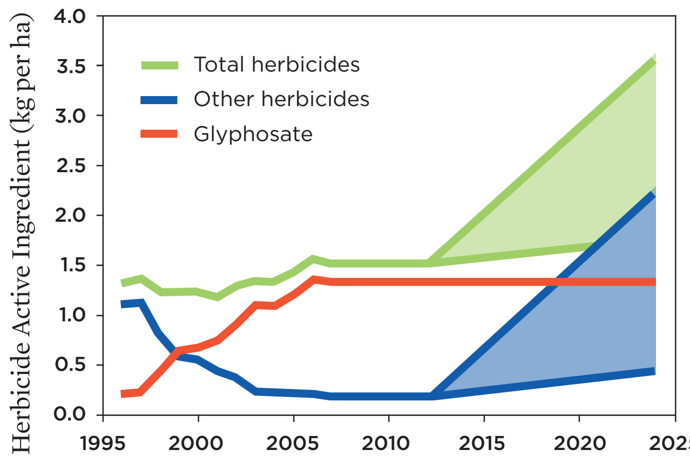
Industry's "Solutions" Won't Solve the Problem—and Will Create New Ones

Farmers desperately need sustainable solutions to the escalating weed resistance problem, but the pesticide and seed industry's answer is a new generation of herbicide-resistant crops, mostly corn and soybeans, that does not address the inherent drawbacks of monoculture and current biotech crops. And this next generation is engineered to withstand not just glyphosate but also older and more toxic herbicides—such as dicamba and 2,4-D. Thirteen of 20 crops awaiting clearance by the U.S. Department of Agriculture (USDA) for commercial cultivation and sale are engineered to tolerate herbicides other than or in addition to glyphosate (USDA BRS 2013). If these crops are approved and widely used, they will only exacerbate the current problem.

> ***The use of multiple herbicides would speed up the evolution of weeds that have multiple resistances—a nightmare scenario for farmers who rely primarily on herbicides.***

The herbicides slated for use together with the next generation of resistant crops raise both environmental and human health concerns. Dicamba and 2,4-D are members of a chemical class known as phenoxy herbicides, which studies have associated with increased rates of certain diseases, including non-Hogkins lymphoma, among farmers and farm workers (Blair and Zahm 1995). These herbicides, especially 2,4-D, are also highly prone to drifting on the wind and to volatilizing—dispersing into the air after application—so that they may settle far from where they are sprayed. And they are highly toxic to broadleaf plants—which include many of the most common fruit and vegetable crops.*

Total Herbicide Active Ingredient Applied to Soybean in the United States



This figure depicts estimates of actual herbicide use on U.S. soybeans through 2007, as well as future rates forecast by weed scientists. The lower shaded area represents 2,4-D and dicamba herbicide increases bounded by low and high recommended use rates, after expected approval of new herbicide-resistant crops. The upper shaded area represents the difference between low and high 2,4-D and dicamba plus all other herbicides after approval of the new crops. Those new varieties had been expected to be approved by the USDA and reach the market in 2013; that appears to have been delayed until at least 2014. The graph assumes that glyphosate use will remain constant at 2007 levels. (Adapted by permission from Mortensen et al. 2012.)

Although 2,4-D and dicamba are already in use, the new herbicide-resistant crops would encourage farmers to apply greater quantities of them (as the history of glyphosate use suggests) and to deploy them differently and more dangerously. As illustrated in the figure, some weed scientists have projected a doubling of herbicide use over the next decade if these crops were widely grown (Mortensen et al. 2012). And because the new crops could withstand herbicides being sprayed directly on them during the growing season, farmers would apply them then rather than only in the spring or fall, as is the dominant practice today. While the pesticide industry has developed new formulations of these herbicides that reportedly reduce volatilization, it is unclear how effective they would be and whether reduced volatilization would be offset by greatly increased use. Thus other crops growing nearby could be susceptible to damage, and as a result the local production of high-value crops such as fruits and vegetables may be discouraged in areas where resistant corn and soybeans are prevalent.

* *For a more extensive analysis of possible environmental and human health impacts of the proposed next-generation corn and soybean crops, see Freese and Crouch (2012).*

Some farmers may plant 2,4-D- or dicamba-resistant soybeans or cotton (both broadleaf crops) as a defensive measure, after neighbors adopt 2,4-D- and dicamba-resistant crops, in order to prevent damage from herbicide drift or volatilization. Cotton is especially sensitive to phenoxy herbicide damage. This defensive measure would further intensify the use of herbicide-resistant crops and the herbicides they require, thereby increasing the likelihood of resistant weeds.

In addition to harming neighboring crops, drift and volatilization may harm vegetation in uncultivated areas near farms, such as fencerows and woodlots. These habitats are critical to harboring beneficial organisms—pollinators and pest insects' natural enemies, for example—that greatly increase crop productivity (Meehan et al. 2011; Tscharntke et al. 2005).

The companies developing the next generation of herbicide-tolerant crops—including Monsanto and Dow Agrosciences—contend that the use of multiple herbicides will stave off further evolution of resistance and check the advance of currently resistant weeds, because most resistance genes confer immunity to only one type of herbicide. In order to develop resistance to multiple herbicides, the companies argue, a weed typically would have to possess genes for resistance to each individual herbicide—a very rare occurrence.

But there are several problems with this argument. Farmers growing new crops that have resistance to glyphosate and one other herbicide—such as 2,4-D—would deploy only that one effective herbicide when glyphosate-resistant weeds were present. Because glyphosate-resistant weeds are now so prevalent, this scenario may often be the case. In such a situation, the weeds would have to develop resistance to only the one additional herbicide to escape control. Moreover, weeds *can* develop resistance to multiple herbicides through single genes that detoxify multiple types of chemicals (Mortensen et al. 2012; Powles and Yu 2010).

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Many farmers are concerned about damage to their crops from increased use of drifting herbicides such as 2,4-D, in the event that new herbicide-tolerant crops are approved and planted widely. Damage from 2,4-D drift can occur in a variety of common crops, from the cotton pictured here (above) to vegetables and fruits such as grapes (right).

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Researchers at Mississippi State University collect samples of wild-type and herbicide-resistant pigweed for DNA analysis. The USDA and public universities should also devote more research funding to ecologically based farming practices and systems that can reduce the development of herbicide resistance.

So it is not surprising that several weed species that include populations of glyphosate-resistant weeds are already showing resistance to at least one other herbicide (International Survey of Herbicide Resistant Weeds 2013), including several of the herbicides slated to be used with the next generation of engineered crops. And if weeds that possess resistance to different herbicides happen to mate, the resulting progeny will be multiple-herbicide-resistant weeds—resistant to all of the herbicides that the parent plants could survive. Regarding waterhemp, for example—a prolific weed of corn and soybean fields in the Corn Belt—there is concern that multiple-herbicide resistance may limit farmers' options to less-effective herbicides (Tranel et al. 2011).

Rather than delaying resistance, the use of multiple herbicides would lead to the quicker evolution of weeds that have multiple resistances. Such weeds could be a nightmare scenario for farmers who rely primarily on herbicides, given that no fundamentally new types are in development that might be ready in the foreseeable future.

The Real Solution: The Science of Agroecology

Recent studies have shown that herbicide use could be reduced by more than 90 percent—while maintaining or increasing yields and net farmer profits—through practices based on the principles of ecological science that reduce weed numbers and growth (Davis et al. 2012; Coulter et al. 2011). These practices include crop rotation (alternating crops from year to year), the use of cover crops and mulches, judicious tillage, and taking advantage of the weed-suppressive chemicals produced by some crops and crop varieties. Even the use of composted livestock manure and crop residues rather than synthetic fertilizers can help to control some weeds, as these methods generally release nutrients more slowly, which can favor the growth of larger-seeded crops over small-seeded weeds (Liebman, Baustiaan, and Baumann 2003).

These agroecological methods have other important benefits, such as increased soil fertility and water-holding capacity, reduced emissions of water pollutants and global warming gases, and enhancement of habitat for pollinators and other beneficial organisms (Union of Concerned Scientists 2013). And when small amounts of herbicides are used in the context of biodiverse agroecology-based systems, weeds are much less likely to develop resistance because selective pressure is greatly decreased.

A series of farm-scale experiments in Iowa (Davis et al. 2012) demonstrated that the application of agroecological principles provides effective control of major weeds present in the Corn Belt, including waterhemp. Although glyphosate-resistant weeds per se were not present at the research site, the effective methods developed by this and other research projects should control resistant weeds equally well. This is because glyphosate-resistant weeds are not inherently more aggressive or competitive than their nonresistant counterparts. They are simply harder to control chemically.

Few studies to date have tested agroecological methods directly for controlling glyphosate-resistant weeds, but research in the southeastern United States has shown that thick stands of rye cover crops, when killed and flattened to serve as mulch, greatly reduce the growth of glyphosate-resistant Palmer amaranth (Aulakh et al. 2012; Reberg-Horton et al. 2011). While this research does not demonstrate that herbicides could be completely eliminated, it suggests that agroecology-based practices could greatly reduce their use while maintaining high crop yields and revenues.

Conclusions and Recommendations

Although agroecology-based practices show great promise for helping farmers control weeds without negative consequences, they have been discouraged by (1) federal farm policies that favor production of the same crops year after year, (2) a research agenda that favors monoculture and is greatly skewed toward herbicide use as the primary weed control measure, and (3) the lack of adequate information and technical support to help farmers change their methods.

To encourage the adoption of agroecology-based weed control practices, the Union of Concerned Scientists recommends the following actions:

- Congress should fund, and the USDA should implement, the Conservation Stewardship Program, which provides sustained national support for farmers using sustainable weed control methods; such support should include a bonus payment for resource-conserving crop rotations.
- The USDA should institute new regional programs that encourage farmers to address weed problems through sustainable techniques.

[*Herbicide use could be reduced by more than 90 percent—while maintaining or increasing farmers' yields and profits—through practices based on the principles of ecological science.*]

- Congress and the USDA should support organic farmers, and those who want to transition to organic, with research, certification, cost-sharing, and marketing programs. Organic agriculture, which controls weeds by means of approaches such as crop rotation, cover crops, and biodiversity, serves as a "test kitchen" for integrated weed management practices that can be broadly applied in conventional systems.
- The USDA should support multidisciplinary research on integrated weed management strategies and should educate farmers in their use.
- The USDA should bring together scientists, industry, farmers, and public interest groups to formulate plans for preventing or containing the development of herbicide-resistant weeds, and the agency should make the approval of new herbicide-tolerant crop varieties conditional on the implementation of such plans.
- The USDA should fund and carry out long-term research to breed crop varieties and cover crops that compete with and control weeds more effectively.

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