Like Americans, Australians are a “proud, patriotic people” who enjoy being number one, says Michael Walsh, an associate professor at the University of Western Australia. Still, Australians aren’t particularly proud of the title they’ve held lately: world leader in herbicide-resistant weeds.

The trouble began about 40 years ago when sheep pastures in southern Australia were converted to cropland—a change that also transformed a critical forage species, *Lolium* or Italian ryegrass, into a persistent weed. At the same time, Australians became the world’s fastest adopters of no-till farming, and they devoted 70 to 80% of their agricultural lands to a single crop: wheat. As a result,

Choosing the path of least resistance

The drumbeat for diversified, or integrated, weed management is sounding, partly due to the growing magnitude of herbicide resistance. But there is mounting recognition that diversified approaches aren’t something to embrace only when there’s no other choice. Instead, advocates say, they’re the only way forward if we ever hope to prevent future herbicide resistance and the loss of vital agrichemicals.

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farmers relied almost exclusively on herbicides for weed control, and *Lolium*, predictably, responded.

Today, the majority of *Lolium* populations across the Australian wheat belt are resistant to at least one herbicide mode of action and, in most cases, several, Walsh says. “So, we’ve been forced into other forms of weed control.” These include crop rotations, tillage, and manipulations of seeding rates and row spacing to make wheat more competitive—in a word, a *diversity* of techniques.

“As we learned the hard way in Australia,” Walsh says, “you cannot continually exploit or utilize herbicides in exclusion of other weed control practices.”

Australia may be a world away from North America, but the drumbeat for diversified, or integrated, weed management is sounding here as well. Partly this is due to the growing *magnitude* of herbicide resistance. For example, glyphosate-resistant Palmer pigweed in the U.S. Southeast now rivals *Lolium* as one of the planet’s worst weed management nightmares.

But just as important is the mounting recognition that diversified approaches aren’t something to embrace only when there’s no other choice. Instead, advocates say, they’re the only way forward if we ever hope to prevent herbicide resistance in the future and the loss of vital agrichemicals—especially one-in-a-million herbicides, like glyphosate, or Roundup.

For this reason, the Weed Science Society of America and the USDA Animal and Plant Health Inspection Service, or APHIS, published a comprehensive set of best management practices for managing herbicide resistance last year. But even the authors admit the practices are a tough sell. Over the past two decades, North American farmers have grown used to the simplicity and flexibility of broad-spectrum, post-emergence herbicides for weed control—mostly recently the Roundup Ready and LibertyLink systems. And now corn, soybean, and cotton that tolerate other broad-spectrum weed killers—2,4-D, and dicamba—are ready to launch, making it hugely tempting to stay on this path.

As many are now pointing out, however, these challenges also bring opportunities for CCAs and extension personnel to help farmers understand how integrated practices reduce herbicide resistance, overcome ob-
Mixing herbicides and using residuals

After helping identify the first specimens of Roundup-resistant Palmer pigweed in Georgia in 2004, University of Georgia extension agronomist Stanley Culpepper watched the plant spread to 71 counties, and approximately 98% of his farmers are now battling it. One solution is simply to replace Roundup with Liberty, or glufosinate, which cotton has now been engineered to tolerate. But Culpepper isn’t banking on Liberty-tolerant cotton alone, or on crops that resist 2,4-D or dicamba. Instead, he’s been working with farmers to implement a traditional regimen of overlapping, soil residual herbicides that span at least five different herbicide modes of action.

The justification for the approach is twofold. Pigweed grows so quickly and competes so fiercely with cotton that trying to control it all post-emergence is futile. If the plant reaches just three inches in height “you’re often mowing your crop down,” Culpepper says. So, for one, applying a series of pre-plant and post-emergence residuals helps keep pigweed from emerging in the first place, giving it less chance to compete with and overwhelm the crop.

Secondly, by dropping the pigweed population, residuals decrease the number of weeds that post-emergence herbicides, such as Liberty, have to kill. This helps protect Liberty, Culpepper explains, because when fewer weeds are exposed repeatedly to the chemical, there’s less selection pressure on them to develop resistance.

And protecting Liberty is essential, Culpepper adds, not only for the sake of Liberty-tolerant cotton—which 50% of his growers have now adopted—but also the dicamba and 2,4-D systems on the way. Liberty by itself, he explains, does a relatively poor job of killing pigweed, as do dicamba and 2,4-D. But control is excellent when Liberty is mixed with either of the other two chemicals, making it an “important cog in the system,” Culpepper says. “So, I think these future technologies depend on Liberty still
working when they become available. But if we're just bombarding everything with Liberty, then we're going to have resistance.”

This leads to another point. A single chemical will never control all weeds completely, which means its use will leave behind surviving plants that can wind up even more resistant. “The first thing I've always told people is to beware of using a product to kill something that's not its strength to begin with,” says Dave Green, a CCA with Servi-Tech Inc. in Haxtun, CO. In his region, for example, the weeds kochia, Russian thistle, barnyardgrass, mare's tail, and prickly lettuce are all poorly controlled by Roundup, leading some to conclude they've become glyphosate-tolerant. But the reality, Green says, is that due to the timing of application relative to the plants’ growth stage and related uptake issues, Roundup didn't perform well most of the time anyway.

“So in the years we've been using glyphosate to help manage weeds, I've always tried to avoid using that product by itself or just because it because it was cheap,” he says. “It had to fit a weed control niche to get recommended.”

**Combining herbicides with mechanical and biological weed control**

Using alternative herbicides can be expensive, however. Georgia cotton growers, for example, spent $22 to $25 an acre for weed control prior to 2004, Culpepper says; today they're paying about $100 per acre for a combination of herbicides and hand-weeding. Moreover, roughly 60% of the region's cotton farmers were no-tilling in the past, but the percentage has since dropped below 40% as they're taken up deep, moldboard plowing again as another check on pigweed emergence. These farmers essentially have no other choice right now, Culpepper says. But he's hoping to see some of them adopt another practice that could cut agrichemical costs and conserve soil: cover crops.

In a series of four ongoing farm trials in Georgia, Culpepper has helped farmers sow rye at the end of the growing season, roll it down prior to planting the following spring, and then strip-till cotton into the rye mulch. And when they get the rye biomass right, Culpepper says, Palmer pigweed emergence drops by 70 to 90%. Chemicals are then used to control other pigweeds, but less herbicide is needed, cutting expenses. A cover crop also reduces the need for tillage because it accomplishes the same thing as moldboard plowing: It smothers pigweed seeds. And the practice again decreases the probability
that weeds will develop resistance because “we’re spraying fewer plants,” Culpepper adds.

Growers can spray fewer plants and use less chemical because in essence “you’re using the mulch like a pre-emergence herbicide. You’re hoping to get four, five, or six weeks of control,” says Bill Curran, a Penn State University extension agronomist who tests ways to reduce herbicide use in no-till corn and soybean in Pennsylvania. As in Georgia, he and his collaborators then kill weeds that grow up through the mulch with a post-emergence herbicide. But they’re able to use much less chemical overall, in some cases eliminating the need for soil residuals completely.

Curran’s group also experiments with replacing chemical control with shallow-tillage tools designed for high-residue systems, such as vertical coulters and rotary harrows. Their attempts to use tillage in place of a burn-down herbicide program have met with “marginal success,” he notes. “Shallow tillage just doesn’t have the power of glyphosate.” But when the researchers combined banded, residual herbicides with high-residue cultivation, they were able to cut residual applications by two-thirds without affecting corn yields. Curran cautions that these results don’t hold when weed populations go sky-high, however. Then, “you pretty much need to hit things with a hammer,” he says, meaning more herbicide or tillage.

Depleting the weed seed bank

In a more than decade-long experiment at Iowa State University’s (ISU) Marsden Farm, ISU agronomy professor Matt Liebman and his colleagues have seen outcomes similar to Curran’s. By banding post-emergence herbicides over the crop row and using an inter-row cultivator to remove weeds in between, they’ve slashed herbicide use in corn and soybean by 94 to 96%. But Liebman also agrees with Curran that results like this are likely to be unattainable when weed pressure is high. And that’s why another key piece of the Marsden experiment is to deplete the weed seed bank by rotating crops.

Weeds that infest corn and soybean typically set seed late in the season, so to fight them Liebman and his colleagues tagged additional crops onto the usual two-year, corn–soybean rotation: a third year of oats or another small grain, harvested mid-summer; and corn–soybean–oats followed by alfalfa, which is cut three or four times a season. The system works like this: During the third year of oats, harvesting them in July not only cuts the crop, but also weeds like velvet leaf and water hemp, checking their growth. Then, if the farmer mows the oat stubble five or six weeks later, the mower again chops the weeds, while a
cover crop of red clover can also be grown in the stubble to further suppress weed growth. The end result? Both the cutting and the competition from clover severally impair the weeds’ ability to set seed, Liebman says.

It’s similar with alfalfa. Every time weeds begin to germinate and grow, they’re cut, baled, and removed before they can produce seed. Thus, during the rotations to oats and alfalfa, the seed bank for weeds that normally infest annual crops like corn and soybean is depleted. And this means that fewer weeds sprout and less herbicide is needed when corn and soybean are sown once again.

Of course, an entirely different set of weeds may then emerge, such as quackgrass or other perennials that are adapted to forage crops, Liebman cautions. But the larger point is that beyond exhausting the seed bank, rotations add variety to the system, including differences in herbicide regimes, cultivation, mowing, crop competitiveness, and timing of crop operations. “All those things vary among diverse crops, and they diversify the selection pressures,” Liebman says, which helps keep any one weed from dominating.

Australian farmers, too, have been focusing lately on destroying the weed seed bank. A few years ago, Walsh explains, people realized that combines weren’t just harvesting wheat. The machines were also collecting *Lolium* seeds, spitting them back out onto the soil in the chaff, and “readying the soil seed bank to be a problem in subsequent crop production seasons,” Walsh says. Researchers and farmers have since been working together on various ways to remove *Lolium* seeds instead, including gathering them up in bundles of chaff and straw for disposal off-site or burning the materials in windrows onsite. Their latest innovation is the “Harrington seed destructor,” named for the western Australian grain grower, Ray Harrington, who invented it.

Rather than simply collecting *Lolium* seeds to be taken off-site or burned, Walsh says, the seed destructor actually grinds up the weed seed-containing chaff with a cage mill, and then spreads the processed material back on the soil. Borrowed from the mining industry, the mill does such a good job of crushing that 95% of *Lolium* seeds are destroyed by the process. The technique fits perfectly with Australia’s conservation crop production systems because all harvest residues are retained. And all this innovation has been driven by one factor: the widespread development of herbicide resistance.

“There’s no doubt that new tools are needed,” Walsh says, “and that new tools will be created.”

Mid-summer harvest of oat disrupts the life cycle of summer annual weeds that are better adapted to grow with corn and soybean. Photo by David N. Sundberg.
The future

And yet, many of these tools and approaches aren’t new at all; it’s just that farmers have gotten away from using them. Cover crops and crop rotations “were important to my grandpa’s generation,” Winkle says. “He raised corn, then wheat with clover planted in it, then hay as long as the stand would last, and then he’d go back to corn, usually by five years.” Winkle is now seeing the benefits of reviving these practices and not just in the realm of herbicide resistance. Cover crops, for example, are netting Ohio farmers eight more bushels of soybeans on average, with less infection from soybean cyst nematode, as well as 12 to 20 more bushels of corn because of “all the nutrient scavenging,” he says. “It’s like planting into biological fertilizer canisters.”

Pleased as he is to see these practices making a comeback, however, Winkle is also realistic about their reach. “They help the smaller farmer who is adaptable, but they’re more of a problem for the big-time operator who wants everything done the same way for efficiency,” he says.

That’s precisely the issue, agrees Liebman. The trend in recent years has been toward simplified, highly efficient farming operations where the goal is to maximize net returns per unit of labor and expand over as many acres as possible. Any practice that takes even slightly more labor and management becomes unattractive as a result, which is one giant reason why farmers continue to bet so heavily on simple solutions like Roundup Ready crops.

But shifts are also taking place that favor diversity. After the droughts of 2011 and 2012, Midwest farmers are looking for ways to improve soil quality and boost crop resilience to stress, including cover crops and crop rotations, Liebman says. The Iowa Soybean Association has invested research money in the Marsden experiment, he adds, because of the four-year rotation’s success at dropping the incidence and severity of soybean sudden death syndrome.

Integrated approaches can also reduce farmers’ reliance on synthetic fertilizer, making them less vulnerable to the rising volatility in fuel and fertilizer prices. And in Georgia, cover crops could help with something that isn’t even on the radar of most growers yet, Culpepper says: demonstrating to regulators that herbicides are staying put and out of ground and surface waters. “Nothing leaves the field once you have that rye residue out there,” he says.

In other words, although herbicide resistance has helped raise their profile, diversified practices have a wealth of advantages beyond solving that particular issue—and researchers, CCAs, and educators need to emphasize all the benefits as they work with farmers to implement best practices.

“Diversity is not a panacea,” Liebman says. “But it’s a very important strategy for addressing many, if not most, of the key questions we have in resolving the tensions between agricultural productivity and environmental quality.” &.

Soybean tilled into rye. Photo by Matt Ryan.
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