Looking beyond the jug:

Non-chemical weed seedbank management

Growing reports of new herbicide-resistant weeds call for a reassessment of weed management strategies in row crops. This article will explore several non-chemical weed management strategies including current practices for limiting the weed seedbank in row crops at harvest. Earn 1 CEU in Integrated Pest Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/608

By **Liam Selfors**, Team Member, **Peter Werts,** Specialty Crop IPM Project Manager, and **Thomas Green**, Ph.D., CCA, TSP and President, IPM Institute of North America

Fluctuations in yield can greatly impact profitability for growers. Weed interference in fields with no weed control was shown to cause average yield losses of 52% in corn (Soltani et al., 2016) and 49.5% in soybean (Soltani et al., 2017) based on data from 2007 to 2013. Since the first selective herbicide was introduced to the agricultural market in 1948 (Quastel, 1950), herbicides have become synonymous with effective and economically viable weed control. Herbicides will certainly continue to be part of the weed management tool box. However, according to Dr. Tom Barber, Extension Weed Scientist at the University of Arkansas Division of Agriculture, growers need to begin "looking beyond the jug," by including non-chemical practices and seedbank disruption in weed management programs.

According to the International Survey of Herbicide Resistant Weeds, there are currently 495 unique instances of herbicide resistance in 255 weed species globally. Weeds have evolved resistance to 163 different trade-name herbicides, spanning 23 of the 26 known sites of action (Heap, 2018). Herbicide modes of action target a specific biological process or enzyme to disrupt normal plant growth and development (Armstrong, 2009). "We've come to the realization in several crops that our long-term weed control sustainability is not going to come out of a chemical," Barber says.

doi:10.2134/cs2018.51.0504




Far right: Kochia weeds extruding through a lentil crop. **Inset:** Roller crimpers are large weighted cylinders with a blunt edge and chevron pattern for cover crop termination. Some growers include roller-crimping in a single pass during planting.


In response to increasing reports of herbicide resistance, growers have adopted best management practices to delay resistance such as maintaining diversity in herbicide selection and rotating herbicide modes of action between applications, but this approach alone is not sustainable. For about 20 years, there have been no major new modes of action introduced to the marketplace, and there is no clear timeline for the introduction of new modes of action (Duke, 2011). "We have Palmer amaranth (*Amaranthus Palmeri*) populations in Arkansas that are resistant to up to four different herbicide modes of action," Barber says. "We're quickly running out of options from an herbicide perspective."

Dr. Tim Seipel, Assistant Research Professor at Montana State University, suggests the key is "to limit the buildup of the weed seedbank, especially if there are multiple resistant weeds present." A field's seedbank is the reservoir of viable seeds in the soil (Christoffoleti and Caetano, 1998). The seedbank can vary widely in density and diversity and will ultimately drive annual weed persistence (Buhler et al., 1997). New introductions typically drift from external sources, and seed dispersal by established weeds can multiply that species' seed density in the seedbank. "Any time we can reduce that soil seedbank, we're winning the battle against weeds."

Diversifying weed selection pressures

Applying an herbicide can reduce the number of seeds entering the seedbank. "If you have multiple herbicide-resistant weeds in the seedbank, you're constantly selecting for those weeds because all the other weeds are being killed by the herbicide," Seipel says. "If you come at it with different tools, like cover crops or crop rotation, then you're introducing a new selection pressure." Each new unique selection pressure added not only combats weed persistence, but will equally target the herbicide-resistant weed strains. "If it doesn't have competition, a Palmer amaranth plant can produce upwards of a million seeds per plant," Barber says. "With the competition in an average soybean field, we might see 100,000 to 300,000 seeds per plant. Still, it doesn't take many plants producing seed numbers like that for populations to get out of control."

For small-scale farmers, weeding fields by mowing, hoeing, or hand-pulling may be plausible, but some growers reported spending up to $150 per acre in labor to remove multiple-herbicide-resistant Palmer amaranth or pigweed by hand. Tillage can markedly reduce weed population densities but may cause erosion, increase greenhouse gas emissions, and reduce soil moisture levels (Demjanova et al., 2009). Barber says many farmers have "gone from full tillage numerous times during the year to a reduced or even no-till situation." He adds that we are now "seeing tillage come back due to the resistance issue."

Mechanical weed control may become more economically viable in the future with the implementation of vision-based intelligent weed-removal robots for both organic and conventional agriculture systems. "The costs and efficiency of automated weed-removal systems are complex," says Frank Poulsen, Manager at F. Poulsen Engineering. "Vegetable farmers in Europe [using intelligent weed removal] for substituting manual labor have reported earning the cost of the machine in one to two years, but this information is not based on data from research." Poulsen is collaborating with a university and a research organization in Denmark to gather hard data on crop, time, method (thermal or mechanical), machine parameters, capacity, and price, according to Poulsen. He expects to publish the results in two years.

Knowledge of the differences in biology and phenology between crops, weeds, and the surrounding ecosystem can be incorporated into integrated weed management programs. With planting date and weed life cycles in mind, cover crops can outcompete weeds and limit seedbank entry. Crop rotations effectively manage weeds by changing conditions in the field, thereby altering selection pressure. This can come in the form of competition from other weed species, alternating planting and harvest timing and soil disturbance, light transmission through crop canopies, and habitat for natural weed enemies (Lamichhane et al., 2016). The goal is to "optimize a rotation that maximizes economic return and minimizes seed introduction to the seedbank," Seipel says.

Many farmers already fit cover crops into their rotations to prevent soil erosion, conserve soil moisture, increase organic matter, and enhance soil health, but careful planning can provide additional weed-management benefits. "You want to have a highly competitive cover crop that's competing at the same time as the weed," Seipel says. Lentils are a notoriously non-competitive cover crop option compared with peas or oats whose biomass and soil moisture needs apply greater competitive pressure on weeds. Cover crops can rapidly become uncontrollable weeds if they aren't terminated before planting. To reduce the use of burndown herbicides for cover crop termination, mechanical rolling or roller-crimping effectively limits regrowth in some cover crops, including barley, cereal rye, and hairy vetch. When the cover crop reaches pollen shed, roller crimpers can reduce the chances of plant return by snapping stems with a blunt edge without severing the stems. The thick mat of cover crop biomass from roller-crimping can effectively inhibit weed growth in no-till cropping systems (Davis, 2010).

Current research by Dr. Seipel explores forage cover crops and targeted grazing. Farmers can install electric fences and introduce livestock that will graze weeds alongside the cover crops. "There are no negative health effects on the animal, and the farmer gets weed control," Seipel says. Benefits of targeted grazing with a forage cover crop include competition pressure against weeds, production of forage, diversification of land use, livestock feeding, efficient manure distribution, and reduced herbicide costs and resistance risks. "Timing of the grazing and timing of the termination of the cover crop are going to be really important to make sure they're outcompeting weeds at the right time to reduce seed production," Seipel adds.

"There's great potential to use integrated weed management tools and cover crops, but I think we need to be very deliberate and careful to really maximize their benefit," Seipel says. Soil-moisture effects of cover crops and crop rotations can impact net yield potential (Lamichhane et al., 2016). The most effective control methods vary by region and are designed around problematic weed species and available resources. The most effective weed-management programs will utilize several non-chemical techniques to support and prolong safe herbicide use, according to Seipel. "In the long run, if you think about it evolutionarily, we really want to combine a few tactics together because that will give us longer use of our herbicides in the future."

Below: A barley–pea forage crop one week after grazing. Grazing removed most biomass and limited seed production of wild oat and kochia weeds. **Right:** Using sheep grazing to terminate forage cover crops and remove weed biomass.

Seedbank management options at harvest

Commercial combine harvesters increase contribution to the weed seedbank from weeds like Palmer amaranth, which has seeds that are retained through harvest (Lazaro et al., 2017). This peak in seedbank contribution also presents an opportunity to reduce weed-seed retention

A combine making wheat windrows in Newport, AR. Windrows can be left to rot or burned to destroy weed seeds in the chaff.

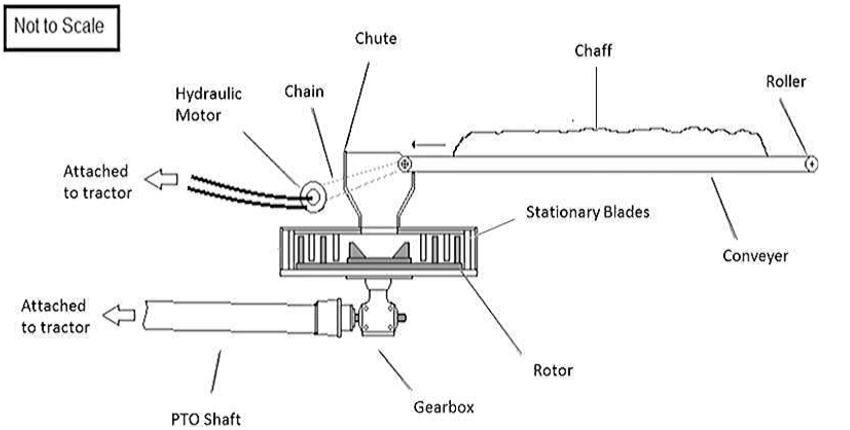
through a low-cost and highly effective combine adjustment, as an alternative to herbicides (Walsh et al., 2017).

Combines separate plant material, or chaff, from the crop during harvest. If weed seeds are retained at harvest, spreading chaff to reintroduce plant residue will also greatly increase distribution of weed seeds. A chute can be easily fitted to the combine to control chaff into narrow lines. The process, called chaff lining or chaff tramlining, creates a poor environment for weed seed establishment and persistence. Many weed seeds will rot or be outcompeted. Windrows can also be burned to destroy weed seeds and further limit seedbank buildup.

"There are a lot of areas where farmers are unable to burn that chaff because of proximity to towns and houses," Barber says. "Instead of burning the windrow, chaff can be gathered in a cart and hauled out of fields." Chaff carts are common in Australia as a collection and transfer mechanism for weed seeds. Some farmers utilize a bale-direct system that captures weed seed and straw material in bales that can be removed and fed to livestock. Research on annual ryegrass weeds in Australian dryland crops showed conventional chaff removal systems diverted up to 95% of seeds from the seedbank (Walsh and Powles, 2007). However, "If you can't get it burned before the dew hits or if you get a shower during the night, then chaff can be very difficult to burn," Barber warns.

Narrow-window burning, chaff carts, and direct balers are all effective weed seedbank management options, but aggressive residue removal can deprive soil of important nutrients like nitrogen and potassium, often leading to additional fertilizer inputs to overcome these deficiencies. An alternative approach is to mechanically destroy weed seeds and allow viable-seed-free residue to be safely left on the field.

The integrated Harrington Seed Destructor (iHSD), developed in Australia, uses a cage mill and chaff-transfer system to intercept seed-containing crop residue from the harvester and mechanically destroy the embedded weed seeds during harvest. The iHSD mill has proven to be highly effective at destroying seeds of common weeds in U.S. soybean and rice production systems (Schwartz-Lazaro et al., 2017); however, it is not yet commercially available in the U.S. Dr. Barber expects widespread adoption of the iHSD for weed control in the U.S. once the machine has begun



The integrated Harrington Seed Destructor (iHSD) utilizes the tractor's hydraulic system to feed chaff into a chute where rotating blades grind crop residue into a fine powder, erasing seed viability. Watch the iHSD in action here: https://youtu.be/MU-atcUQ_ZI.

to be manufactured for American harvesters. Although the upfront and maintenance costs of the iHSD are much higher than other harvest weed seed management tools, Barber believes its seedbank-limiting abilities will make the investment worthwhile.

Barnyardgrass, a weed very familiar to rice growers in the southern U.S., "releases its seeds before the rice crop is mature enough to harvest. In that type of situation, our harvest weed-control methods are not going to work in their current form," Barber says. A weed management program that diversifies selection pressures year-round is a higher priority for these growers who target weeds that release seeds before harvest.

Conclusion

Incorporating non-chemical weed-management tactics can provide good control at a vary low cost, enabling farmers to easily adopt alternative options and escape herbicide reliance. Farmers with target weeds that release seeds after harvest can proactively reduce herbicide reliance by reducing the size and interference of weed with harvest seedbank control tactics. Dr. Barber encourages farmers to adopt a zero-tolerance program for weed management. "If you see a Palmer amaranth, you don't let it go to seed," he says. Typically, "after three years of preventing seed from entering the seedbank, we have a much more manageable population."

With careful consideration, Dr. Seipel believes a non-chemical weed management program could be almost as good as herbicide-only systems for weed control. "As the need for tools other than herbicides continues to increase, integrated weed management will certainly be more economically viable in the future." &s

References

Armstrong, J. 2009. Herbicide how-to: Understanding herbicide mode of action. Oklahoma State University, Division of Agricultural Sciences and Natural Resources, Oklahoma Cooperative Extension Service.

Buhler, D.D., R.G. Hartzler, and F. Forcella. 1997. Implications of weed seedbank dynamics to weed management. Weed Science 45(3):329–336. https://www.jstor.org/stable/4046027?seq=1#page_scan_tab_contents

Christoffoleti, P. J. and R.X. Caetano. 1998. Soil seed banks. Scientia Agricola 55:74–78. http://dx.doi.org/10.1590/S0103-90161998000500013

Davis, A.S. 2010. Cover-crop roller–crimper contributes to weed management in no-till soybean. Weed Science 58:300–309. https://naldc.nal.usda.gov/download/45407/PDF

Demjanova, E., M. Macak, and I. Daloviicc. 2009. Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize. Agronomy Research 7:785–792.

Duke, S.O. 2011. Why have no new herbicide modes of action appeared in recent years? Pest Management Science 68(4):505–512. https://doi.org/10.1002/ps.2333

Heap, I. 2018. The International Survey of Herbicide Resistant Weeds. www.weedscience.org/default.aspx

Lamichhane, J.R., Y. Devos, H.J. Beckie, M.D. Owen, P. Tillie, A. Messean, and P. Kudsk. 2016. Integrated weed management systems with herbicide-tolerant crops in the European Union: Lessons learnt from home and abroad. Critical Reviews in Biotechnology 60(5). http://dx.doi.org/10.1080/07388551.2016.1180588

Lazaro, L. M., J.K. Green, and J.K. Norsworthy. 2017. Seed retention of Palmer amaranth (*Amaranthus palmeri*) and barnyardgrass (*Echinochloa crus-galli*) in soybean. Weed Technology 31(4):617–622. doi:10.1017/wet.2017.25

Quastel, J.H. 1950. 2,4-Dichlorophenoxyacetic Acid (2,4-D) as a selective herbicide. In Agricultural control chemicals. American Chemical Society, Montreal. doi:10.1021/ba-1950-0001. p. 244–249.

Schwartz-Lazaro, L.M., J.K. Norsworthy, M.J. Walsh, and M.V. Bagavathiannan. 2017. Efficacy of the Integrated Harrington Seed Destructor on weeds of soybean and rice production systems in the southern United States. Crop Science 57:2812–2818. doi:10.2135/cropsci2017.03.0210

Soltani, N., J.A. Dille, I.C. Burke, W.J. Everman, M.J. VanGessel, V.M. Davis, and P.H. Sikkema. 2016. Potential corn yield losses from weeds in North America. Weed Technology, 30(4):979–984. https://doi.org/10.1614/WT-D-16-00046.1

Soltani, N., J.A. Dille, I.C. Burke, W.J. Everman, M.J. VanGessel, V.M. Davis, and P.H. Sikkema. 2017. Perspectives on potential soybean yield losses from weeds in North America. Weed Technology 31(1):148–154. https://doi.org/10.1017/wet.2016.2

Walsh, M.J., J.C. Broster, L.M. Schwartz-Lazaro, J.K. Norsworthy, A.S Davis, B.D. Tidemann et al. 2017. Opportunities and challenges for harvest weed seed control in global cropping systems. Pest Management Science. https://doi.org/10.1002/ps.4802

Walsh, M.J., and S.B. Powles. 2007. Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology, 21(2):332–338. www.jstor.org/stable/4495856?seq=1#page_scan_tab_contents