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Societies**

From spreader to predator: Killing weed seeds with the combine

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Figure 1, Wheat of Australian farmer and harvest weed seed control pioneer, Ray Harrington, is ready for harvest but infested with rigid ryegrass. Note the weed seeds are retained above the combine's cutter bar at harvest, so the combine will take the seeds in and subject them to the Harrington Seed Destructor. Photo courtesy of Michael Flessner.

Faced with the daunting task of herbicide resistance management, Australian farmers developed various systems to target weed seeds during crop harvest. These systems are collectively called harvest weed seed control (HWSC). Despite being relatively unheard of in the U.S., currently more than 80% of Australian farmers practice HWSC. This article provides an overview of the six HWSC systems and the research conducted to date in U.S. cropping systems. This article also includes information for implementing HWSC, what weeds to target, potential costs, and where to find equipment.

Twenty years ago, Australian farmers were facing a problem many cannot imagine—herbicides were no longer working. Herbicide resistance had eliminated virtually all herbicide options. To keep farming and stay in business, something had to change.

Ray Harrington was one Aussie farmer who recognized what many others have—combines are excellent spreaders of weed seeds (Figure 1). But Ray took it a step further and decided to do something about it, addressing herbicide-resistant

weeds in the process. Ray, along with researchers and industry partners, eventually developed the Harrington Seed Destructor—a device that kills weed seeds as they exit the combine, turning the combine from a weed seed spreader into a weed seed predator.

Along with the Harrington Seed Destructor (now known as the iHSD), other systems of controlling weed seeds at harvest were developed and have been highly successful. Today, more than 80% of Western Australia farmers practice some form of harvest weed seed control (Walsh et al., 2017).

What Is Harvest Weed Seed Control?

Harvest weed seed control (HWSC) removes, concentrates, or kills weed seeds that are retained on weed plants at the time of crop harvest through various systems (Walsh et al., 2018). By targeting additions to the weed seedbank, future weed problems are reduced. By killing or removing seeds produced by weeds that escape herbicidal control earlier in the season, HWSC can also aid in herbicide resistance management. Since HWSC does not directly control weeds in crops, it must be used as part of an integrated weed management approach that also includes chemical, mechanical, and cultural tactics.

Making It Work

There are six HWSC systems currently in use on Australian farms. All systems are similarly effective (Walsh et al., 2017) but vary by combine modifications, expense, logistics, and other considerations. These systems include: seed impact mills, chaff lining, chaff tramlining, chaff carts, bale direct, and narrow windrow burning.

Firstly, the combine must be properly adjusted so that weed seeds exit the combine in the chaff fraction (not in the straw) for all systems except bale direct and narrow windrow burning. A properly adjusted combine will have more than 90% of seed exit in the chaff. A poorly adjusted combine can have up to 50% of weed seeds exit in the straw fraction, severely reducing the effectiveness of HWSC (Broster et al., 2016).

Generally, a combine that is properly set up to minimize grain loss will maximize weed seed in the chaff fraction. Regardless of the system you use, **a low harvest height is important to maximize weed seed capture.**

Seed Impact Mills

Seed impact mills process the chaff fraction of harvest residues, killing 93 to 99% of weed seeds contained therein (Schwartz-Lazaro et al., 2017). Chaff is then spread across the field as in conventional harvest operations in a one-pass operation. There are currently three seed impact mills commercially available: the Seed Terminator (www.seedterminator.com.au/), the iHSD (<https://ihsd.com/>), and the Redekop Seed Control Unit (<https://redekopmfg.com/products/harvest-weed-seed-control/>) (Figure 2). Seed impact mills generally require a late model Class 8 or larger combine, have a high up-front cost (typically \$60,000 to \$75,000), and require maintenance. But since seed impact mills are a one-pass system that effectively kills weed seeds, it is considered the ultimate in HWSC.

Chaff Lining



Figure 2, Redekop Seed Control Unit attached to a John Deere combine harvesting soybean infested with common ragweed. Photo courtesy of Michael Flessner.



Figure 3, The back of a combine modified for chaff lining. Photo courtesy of Michael Flessner.

Chaff lining is where only the chaff fraction, and weed seed therein, is funneled into a narrow row behind the combine (Figure 3). Chaff lining does not kill weed seeds but concentrates them in less than 10% of the field. Placing weed seeds into a chaff line exposes them to decay, may reduce germination due to a less suitable environment, and if weeds do germinate, they compete with each other (Condon, 2018).

Combine modifications are inexpensive and involve removing the chaff spreader and making a chute to direct the chaff. These modifications can be a do-it-yourself option (see WeedSmart's guide at <https://bit.ly/3mtFU3d> or GROW's video at <https://bit.ly/2XSVBGR>). Chaff lining kits are also commercially available, such as one from WestOz Boilermakers (<https://westozboilermakingservice.com.au/chaff-lining-kits>). Chaff lining, due to its low up-front cost, is usually considered a good entry-level HWSC option.

Chaff Tramlining (Chaff Decks)

Chaff tramlining (chaff decks) are similar to chaff lining but place the chaff in the combine's wheel tracks (Figure 4). In controlled traffic farming, placing the weed seeds into the tramlines subjects the seeds to being run over by the tractor or sprayer during the season. Combine modifications include adding a conveyor belt device, such as EMAR's Chaff Deck (<https://chaffdeck.com.au>), to transfer the chaff to the wheel tracks.

Chaff Carts

Chaff carts are towed behind the combine and collect the weed-seed-laden chaff, which can then be removed from the field or placed into piles. After harvest, the chaff dumps can be grazed by livestock and/or burnt to kill the weed seeds and planted through the following season. Chaff carts are often chosen for use on mixed cropping and livestock farms in Australia as the chaff is a valuable livestock feed.



Figure 4, *Chaff tramlines after wheat harvest in Western Australia. Photo courtesy of Claudio Rubione.*

It is critical to direct the weed-seed-laden chaff into the HWSC device and keep the chaff separate from the straw for the above systems to work. If the combine mixes the chaff and straw before spreading, then the addition of a baffle inside the combine is necessary, which is included with commercially available equipment. But do-it-yourselfers should heed the warning of one Aussie farmer: “Baffles can be baffling.” The HWSC systems mentioned below (bale direct and narrow windrow burning) collect all residues, so combine adjustments and baffles are not necessary.

Bale Direct

Bale direct collects all the crop residue directly from the combine and compacts it into large bales suitable for sale. The baler and the combine are directly connected in this system. There may be restrictions on selling the potentially weed-seed-laden material and/or low market demand.

Narrow Windrow Burning

Narrow windrow burning collects all of the crop residues (chaff and straw) and funnels them into narrow rows in the field. Combine modifications may not be necessary as many combines are capable of windrowing crop residues. But if necessary, modifications are minimal and can be a do-it-yourself option. After harvest, windrows are burnt to destroy the weed seed. This method is effective but removes all of the crop residue from the field, risks fire escapes, and may be prohibited by local regulations about burning.

All approaches are for crops harvested with a grain header, so no HWSC options are currently available for corn and cotton. Additional considerations for choosing a HWSC system include: planting through crop residues, nutrient implications from uneven crop residue distribution, and overall logistics of removing, burning, or condensing crop residues.

Research in the U.S.

Seed Retention

For HWSC to be effective, seeds must be retained on the weed plants at crop harvest. Seeds that fall off the weed plant prior to harvest are not collected by the combine and will not be controlled by HWSC. That is, HWSC does not affect weed seeds on or in the soil. Research across 14 U.S. states has found that many of our economic-decision-driver weed species are ideal candidates for HWSC at soybean harvest, including waterhemp, Palmer amaranth, and others (Schwartz-Lazaro et al., [2021a](#), [2001b](#)). However, species that have wind-dispersed seed, such as horseweed/marestail and perennial species are likely not good candidates for HWSC. Seed of some species, such as common lambsquarters and velvetleaf, can survive in the soil seedbank for many years (Burnside et al., [1996](#)), so HWSC may need to be practiced consistently for several years. Regardless of weed species, **a timely harvest**

is key. The longer harvest is delayed, the more likely weed seed will shed, and the less weed control is achieved.

Modeling

Weed scientists have modeled HWSC based on current data in the U.S. and Canada. Modeling in Canadian wheat (Tidemann et al., 2016) indicates HWSC reduces weed seedbanks, which corroborates field observations in Australian wheat (Walsh et al., 2013). Modeling in U.S. corn–soybean rotations (Shergill et al., 2020) also shows HWSC to be effective, greatly reducing the weed seed bank in four to five years.



Figure 1, *Italian ryegrass-infested wheat ready for harvest in Texas, an ideal situation for harvest weed seed control (HWSC). Harvest low and as soon as the crop is ready to maximize the effectiveness of HWSC. Photo courtesy of Claudio Rubione.*

On-Farm Proof of Concept

On-farm proof-of-concept work has also been conducted in the U.S., in addition to the large body of work in Australian systems. Italian ryegrass was reduced up to 69% in the following wheat crop in Virginia (Beam et al., 2019). A four-year experiment in Texas showed >90% reduction in Italian ryegrass densities when HWSC was integrated with herbicides (Maity et al., 2020; Figure 5).

Common ragweed density was reduced up to 26% and 43% from HWSC in two separate studies after a single soybean harvest in Virginia (Beam et al., 2019, 2021). As HWSC is successfully implemented over multiple seasons, greater weed control is expected as the weed seedbank is depleted. Reducing the weed seedbank is the key to the long-term sustainability of weed management practices (Liebman & Davis, 2009).

Seed Impact Mill Evaluation in the U.S.

University of Missouri testing of the Seed Terminator and Iowa State University testing of the Redekop Seed Control Unit (SCU) both resulted in approximately 90% kill of waterhemp seed that entered the mills during 2020 soybean harvest (Meadows et al., 2021; Winans et al., 2020). Regarding operating costs, preliminary data from the University of Missouri indicated that the Seed Terminator on a Case IH 8250 combine increased engine load 8 to 31% and fuel consumption 0.2 to 0.5 gal/ac while harvesting a waterhemp-infested soybean field (Winans et al., 2020). Virginia Tech testing of the Redekop SCU on a John Deere S680 combine harvesting soybean fields infested with common ragweed showed an approximate 20% increase in engine capacity used and about 3.5 gal/hour of additional fuel consumption (Flessner & Mirsky, 2021) when the SCU was on versus off. For both the Seed Terminator and Redekop's SCU, the combines had sufficient engine capacity to accommodate the seed impact mill and not slow soybean harvest.

Seed retention, modeling, and preliminary on-farm research indicate that HWSC holds tremendous potential for U.S. crop production.

Costs

As with any equipment on the farm, the cost per acre depends on how much acreage it is used across. Costs also differ among HWSC systems in terms of up-front costs for equipment and delayed costs from things like nutrient replacement from uneven crop residue distribution.

While costs vary somewhat between systems, Australian farmers say ***HWSC costs about the same as a cheap herbicide pass***. WeedSmart has developed a cost calculator, available on its website (weedsmart.org.au).

The Future of Harvest Weed Seed Control in the U.S.

Most weed scientists agree that given the current status of herbicide resistance and the pace of herbicide resistance development, integrating non-chemical options into weed management is sorely needed (Peterson et al., 2018). The GROW network has been actively researching HWSC in the U.S. since 2015. In 2020, the GROW team was funded by USDA-NRCS through an On-farm Conservation Innovation Grant to evaluate 16 seed impact mills across eight states. Further support from USDA-ARS will be adding more seed impact mills to the testing network as well as investigating chaff lining on-farm across multiple states. These projects will evaluate harvest weed seed control versus conventional harvest on commercial farms in collaboration with commercial farmers. The focus will be on corn-soybean rotations as well as wheat and will also include winter fallow versus cover crop comparisons. Updates will be posted to GROW's website (<https://growiwm.org/>) and social media accounts. Look out for HWSC coming to a field near you.

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