HARVEST WEED SEED CONTROL: APPLICATIONS FOR PNW WHEAT PRODUCTION SYSTEMS

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Harvest Weed Seed Control: Applications for PNW Wheat Production Systems

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Abstract

Herbicide resistance is of growing concern to wheat growers in the Pacific Northwest (PNW). Harvest weed seed control (HWSC) is an innovative, non-chemical approach developed in Australia that takes advantage of seed retention at maturity in many dominant annual weed species. Harvest weed seed control systems are focused on the management of chaff material in which most weed seed resides. Although HWSC has not been fully evaluated in the PNW, early work suggests that it can be an effective tool in an integrated weed management program. The choice of which particular HWSC system to use is dependent on the constraints of the cropping systems in which they are used and the specific needs of the grower. This publication discusses the various HWSC systems and their potential suitability for PNW wheat production systems across rainfall regions.

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Figure 1. Chaff cart system during wheat harvest in Australia.

Introduction

Herbicide resistance is of growing concern to wheat (*Triticum aestivum*) growers in the Pacific Northwest (PNW). Italian ryegrass (*Lolium perenne ssp. multiflorum*) populations are widely resistant to the ACCase and ALS inhibitors (common ACCase inhibitor herbicides include clethodim, quizalofop, and pinoxaden; and common ALS inhibitor herbicides include imazamox, metsulfuron, flucarbazone, and pyroxsulam), with some populations also resistant to VLCFA synthesis inhibitors and glyphosate. Numerous downy brome (*Bromus tectorum*) populations are resistant to the ALS inhibitors, and, recently, populations of downy brome were found to be resistant to glyphosate. Similarly, in Australia, the reliance on these same site-of-action herbicides led to widespread herbicide resistance in Australian wheat production systems. Consequently, Australian wheat growers have turned to non-chemical approaches to manage herbicide-resistant weed populations. Harvest weed seed control (HWSC) is an innovative, non-chemical approach developed in Australia that takes advantage of seed retention on the plant at maturity in many dominant annual weed species.

In Australian cropping systems, there is high weed seed retention at crop maturity by the dominant annual weeds: rigid ryegrass (*Lolium rigidum*), wild radish (*Raphanus raphanistrum*), ripgut brome (*Bromus diandrus*), and wild oat (*Avena fatua*). During crop harvest, these seeds are collected, threshed, separated from the grain, and expelled from the combine in the chaff fraction. The chaff material containing weed seed is then spread back across the harvest swath, a process that results in weed seeding. Consequently, a number of HWSC systems were developed to disrupt this process by targeting the chaff fraction during harvest to prevent the reseeding of weeds.

Harvest Weed Seed Control Systems

The chaff cart system, the initial HWSC system introduced in Australia in the 1980s, is a trailing cart attached to the rear of the combine that collects the chaff material (Figure 1), including the weed seed, during harvest (Walsh and Powles 2007). The collected chaff is placed in piles that, for ease of management, are normally lined up across the field for subsequent burning, grazing, or collection. However, there

Figure 2. Narrow windrows formed with chaff chute on rear of combine (left) are burned (right) in the fall under cooler and more humid conditions.

has been a move away from burning chaff piles in Australia due to the risks of fire escapes and air quality concerns from the smoke produced. Where chaff carts are used, growers have been leveling the chaff piles to allow planting while the resulting thick matt of chaff prevents most weed seedling emergence. Direct grazing or removal of these chaff piles is also now common with growers, realizing the value of this material as a livestock feed. As the majority (~90%) of rigid ryegrass and wild radish seed do not survive digestion by ruminants (e.g., sheep and cattle), chaff grazing does effectively remove viable weed seeds from the field (Stanton et al. 2002).

Narrow-windrow burning was introduced in the 1990s and because it is a cheap and simple HWSC option, it was subsequently widely adopted in Australia. This system requires a chute attached to the rear of the combine that concentrates the chaff and straw into a narrow (20- to 24-inch) windrow during harvest (Figure 2, left) (Walsh and Newman 2007). These windrows are subsequently burned the following fall prior to crop planting (Figure 2, right). To reduce the risk of fire escapes, burning is conducted during moderate air temperatures (70 to 85°F) and wind speeds (6 to 9 mph). When burned under these conditions, narrow windrows burn hotter and longer than standard field burning, resulting in higher seed mortalities. Research in Australia and eastern Washington has shown that 99% of rigid and Italian ryegrass seed in the windrow is destroyed by this method. The difficulty in containing burning windrows in cereal stubbles has resulted in Australian growers restricting the use of this practice to oilseed and pulse crop stubbles. In these stubbles, the risks of fire escapes from burning windrows are lower.

The bale direct system (BDS) consists of a large square baler attached directly to, and powered by, the combine that builds bales from the chaff and straw exiting the combine during harvest (Figure 3). This system was developed in Australia in the early 2000s to realize a commercial opportunity of using the baled harvest residues for livestock feed (Walsh and Powles 2007). This system is reliant on available markets for the baled material. There are concerns over the removal of crop residues and the negative impact that has on soil health. The transport of uncovered bales also raises concern about the risk of spreading weed seeds along roads and highways.

Integrated impact mills, such as the integrated Harrington Seed Destructor (iHSD, Figure 4), the Seed Terminator, and the Redekop Seed Control Unit are fit into the body of the combine itself and provide the opportunity to control weed seeds during the harvest operation without having to tow equipment behind the combine, as was the case with earlier versions of impact mills. Chaff material exiting the combine is processed by these impact mills sufficiently to destroy the contained weed seeds. The processed chaff is then spread back across the field. Impact mills are designed to match the maximum processing capacity (chaff production) of the combine. This HWSC system allows the retention of all residues in the field and is, therefore, the only HWSC system that is fully compatible with many soil conservation practices that promote full straw loads returning to the field.

Chaff lining and chaff tramlining are the two most recently developed HWSC systems that are rapidly gaining popularity in Australia, due primarily to their low cost. Attachments at the rear of the combine collect

Figure 3. With the bale direct system, straw and chaff (containing weed seed) are baled together directly behind the combine.

Figure 4. Integrated Harrington Seed Destructor mounted at the rear of the combine.

and place chaff into narrow 10- to 12-inch rows, either between stubble rows directly behind the combine (chaff lining) or in the wheel tracks (chaff tramlining) (Figure 5). Concentrating the chaff in narrow rows creates an unfavorable environment for weed seed germination and emergence. Those weeds that do emerge and grow are contained in narrow rows where they have little or no impact on overall crop yield. As the majority of Australian crop producers now use guidance and autosteer in controlled traffic farming systems, any weed seed produced from weeds growing in chaff lines and tramlines is returned to these same lines during harvest.

Efficacy and Adoption of HWSC Systems in Australia

The efficacy of HWSC systems on the dominant weed of Australian wheat cropping systems, rigid ryegrass, was evaluated in a series of commercial-scale field trials (Walsh et al. 2017a). Three systems, the Harrington Seed Destructor (HSD), the chaff cart, and narrow windrow burning were compared at 24 sites across the Australian wheat production region. At each site, these HWSC treatments were found to be similarly effective at reducing rigid ryegrass emergence. On average, population densities were reduced by 60%, but there was considerable variation in density between sites (37–90%) as influenced by seed production and the initial seedbank.

With equivalent efficacy, growers are able to choose an HWSC approach that best fits their production system. The results from this study highlighted the importance of combines and HWSC systems being setup to ensure the effective targeting of the weed seed contained in the chaff fraction during harvest. Ensuring that all or most weed seeds exit the harvester in the chaff fraction allows HWSC systems to target these weed seeds. As these studies also highlighted, the seedbank can dilute the impact of HWSC treatments. In situations where there is already a large weed seedbank, or for species with seed that survive in the soil for many years, it may take several years to see the impact of HWSC on weed emergence and population density.

Harvest weed seed control systems have been used in Australian crop production systems for almost 40 years, but grower adoption of these systems has been low (<20%) until recently. The introduction of narrow windrow burning, iHSD, chaff lining, and chaff tramlining systems stimulated substantial grower interest and adoption. A grower survey in 2014 established that 43% of Australian growers were routinely using HWSC systems to target weed seed production during grain harvest (Walsh et al. 2017b). At this time, narrow windrow burning (30%) was the most commonly used system with lower adoption of other currently available techniques chaff tramlining (7%), chaff carts (3%), bale direct system (3%), and the HSD (<1%). Subsequently, there has been a considerable increase in HWSC adoption as well as a shift in the preferred practices. It is likely that more than 50% of growers are now using a HWSC system and that there has been a large shift away from narrow windrow burning with chaff lining and chaff tramlining now the preferred options (P. Newman, personal communication). These very high levels of adoption signify that HWSC is now an established weed control practice for Australian

Figure 5. Chaff lining (left) and chaff tramlining (right) systems.

growers that may stop or slow the spread of herbicide resistant weed populations.

The Context and Opportunities for Harvest Weed Seed Control in the PNW

Harvest weed seed control systems are focused on the management of chaff material; therefore, it is important to examine the crop production environment when initially considering which of these systems is suitable for use. Influenced by rainfall variations and crop marketing opportunities, cropping systems differ across the region, and these differences will influence the suitability of HWSC practices for each region. In addition, weed species of importance vary across regions and may have an impact on the suitability of HWSC. When all costs are considered (e.g., capital investment, equipment maintenance, depreciation, labor, nutrient replacement), the costs of HWSC systems are similar and are estimated to be less than $10 per acre in an average Australian crop production program.

The PNW has a Mediterranean-like climate with 60 to 70% of the precipitation occurring from November through April. Average annual precipitation ranges from a low of about 6 inches in the west, where the Cascade Mountains impose a rain shadow effect, to a high of about 24 inches in the eastern portion of the region. The PNW is often divided into three rainfall regions based on average annual precipitation: Low (<12 inches), Intermediate (12 to 18 inches), and High (18 to 24 inches) (Schillinger et al. 2006).

Low rainfall. This is the most extensive of the three rainfall regions and is dominated by a tillage-based winter wheat-fallow system. Average long-term winter wheat grain yields in this region range from 20 to 50 bushels per acre. Wind erosion and soil water storage are major challenges in the region. Consequently, the retention of as much crop residue as possible on the soil surface is critical for the management of these challenges. With crop residue production as low as 2,000 pounds per acre (Table 1), HWSC practices that retain crop residues on the soil surface will be prioritized over systems that remove crop residues.

Intermediate rainfall. Cropping systems in this region transition from the tillage-based winter wheat-fallow system that dominates in the low rainfall region to a more intensive three-year rotation with less tillage. The dominant three-year crop rotation is winter wheat–spring wheat or barley (*Hordeum vulgare*)–fallow. Average winter wheat grain yields range from 45 to 90 bushels per acre (Table 1) with estimated crop residue biomass between 3,500 and 7,000 pounds per acre. Average spring wheat and barley grain yields range from 35 to 75 bushels per acre with crop residue biomass of between 2,400 and 4,800 pounds per acre for spring wheat and half of that amount for spring barley. Wind and water erosion are concerns in this region and crop residues, particularly following spring wheat or barley, must be retained on the soil surface to minimize the risk of erosion.

High rainfall. With sufficient precipitation, more

Table 1. Average grain yields, residue biomass, and chaff quantities across the low, intermediate, and high rainfall regions of the inland Pacific Northwest.

Rainfall region	Crop	Grain yield (bu/acre)	Residue biomass (lb/acre)	Chaff quantity (lb/acre)
Low	Winter wheat	20–50	2,000–5,000	500–1,250
Intermediate	Winter wheat	45–90	3,500–7,000	875–1,750
	Spring wheat	35–75	2,400–4,800	600–1,200
	Spring barley*	35–75	1,200–2,400	240–480
High	Winter wheat	95–105	7,100–9,800	1,775–2,450
	Spring wheat	50–75	3,200–4,800	800–1,200
	Spring barley	50–75	1,600–2,400	320–480

*One ton of barley = 42 bushels.

intensive crop rotations are used across this region. There are a wide variety of crop rotations and tillage systems used, but perhaps the most common rotation is winter wheat–spring wheat or barley–grain legume (chickpea [*Cicer arietinum*], dry pea [*Pisum sativum*], or lentil [*Lens culinaris*]). The steeply sloping Palouse area, which produces some of the highest winter wheat yields in the world, is located in the high rainfall region. Winter wheat yields average 95 to 105 bushels per acre and can exceed 135 bushels per acre. Average winter wheat residue biomass is between 7,100 and 9,800 pounds per acre (Table 1). Spring wheat yields average from 50 to 75 bushels per acre with residue biomass between 3,200 and 4,800 pounds per acre and half of that amount for spring barley. Grain legume yields average between 1,500 and 1,800 pounds per acre with a similar quantity of total crop residue that likely produces less than 300 pounds of chaff per acre.

Water erosion is a major concern in the high rainfall region, particularly in the steep, rolling hills of the Palouse. Although crop residue retention is valued for its role in reducing soil erosion, heavy winter wheat residue production (7,000 to 9,800 pounds per acre) can make subsequent seeding operations difficult, and the lower spring soil temperatures slow development of the following crop. Baling a portion of heavy crop residues can improve weed control by improving herbicide coverage. It also reduces the cost of later tillage or residue management and provides growers with a small additional revenue source from the sale of the straw. However, wheat straw contains nutrients that should be replaced when the straw is removed. The steep topography common in this region may limit HWSC practices that involve equipment that is towed behind the combine, for example, the chaff cart or BDS.

Chaff production across rainfall regions. Grain yields and the amount of crop residue produced vary across the rainfall regions of the PNW. An estimate of the amount of chaff produced across the rainfall regions can be useful in determining where the various HWSC systems may have their best fit. Chaff production estimates (Table 1) were made for the three rainfall regions of the PNW using average crop residue biomass reported by Schillinger et al. (2006) and chaff:straw ratios for a rotary combine reported by Stumborg et al. (1996). These ratios were 0.25:1 for wheat and 0.2:1 for barley.

HWSC Research in the PNW

Research on HWSC began in the PNW in 2013. Although still limited in scope, the research is starting to build interest in HWSC systems and is setting the stage for future research efforts. The following summary of HWSC research in the PNW may increase understanding of what has been done, and what still needs to be done, to promote the efficient deployment of HWSC in the region.

Narrow-windrow burning. In field studies conducted near Pullman, WA in 2013 and 2014, narrow-windrow burning of winter wheat stubble reduced the viability of Italian ryegrass seed on the soil surface to <1% (Figure 6) (Lyon et al. 2016). This result was similar to what Walsh and Newman (2007) reported for rigid ryegrass in Western Australia. The increased effectiveness of narrow-windrow burning compared to burning standing stubble (Italian ryegrass seed survival equals

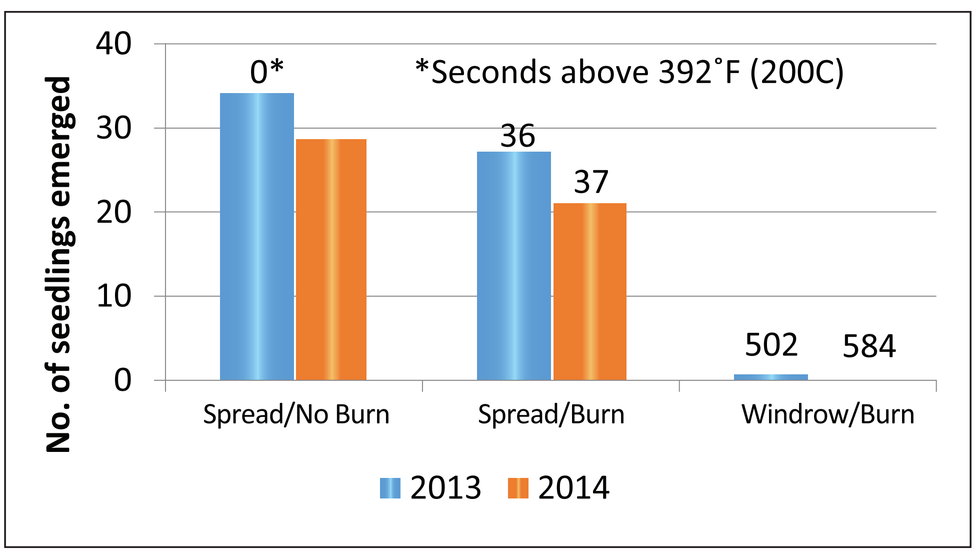

Figure 6. Italian ryegrass seedling emergence following burning treatments (no burn, straw spread and entire area burned, and narrow-windrow burned) near Pullman, WA. Trays, each with 50 Italian ryegrass seeds, were placed in each treatment prior to burning. After burning, trays were placed in the greenhouse and the number of seedlings emerging from each tray were recorded.

48%) is due to the extended duration and higher temperatures achieved by the concentration of crop residues in the narrow-windrow.

Chaff carts. In field studies conducted at the Columbia Basin Agricultural Research Center near Adams, OR in 2016 and 2017, the use of chaff carts resulted in an average weed infestation reduction of 18% in the following year. However, that percentage varied with weed species. Tumble mustard (*Sisymbrium altissimum*) had the greatest reduction (22%) and Menzies fiddleneck, also known as tarweed (*Amsinckia menziesii*), the lowest (0%). The average reduction for downy brome was 9%. These reductions may have been improved by harvesting earlier, that is, immediately after the crop was mature and before weed seed retention declined. It should also be noted that the quantity of weed seed in the soil seedbank will influence the reduction in weed infestation resulting from HWSC. Weed infestations will decline more rapidly with HWSC when weed seedbank numbers are low compared to when seedbank numbers are high.

Table 2. Seed retention at harvest for weeds of concern in wheat production systems of the inland Pacific Northwest.

Weed species	Seed retention (%)	Harvest weed seed control potential
Cereal rye	49–61	Intermediate
Downy brome	25–87	Low to high
Italian ryegrass	27–50	Low to intermediate
Jointed goatgrass*	>75	Intermediate
Rattail fescue	11–90	Low to high
Wild oat*	39	Low

*Data from the Great Plains (Walsh et al. 2018).

Bale direct systems. In studies similar to those conducted with chaff carts, the average weed infestation reduction with bale direct systems was 28% but varied among the weed species in the studies. Harvest timing influenced results. When harvested early, tumble mustard density was reduced 52%, but a grower field harvested 12 days later had just a 36% density reduction. Downy brome results were similar to the results obtained with the chaff cart. However, these are preliminary results because they come from only one harvest season. Future studies will provide results that are more robust.

Weed seed retention studies. The seed retention of several grass (Italian ryegrass, cereal rye [*Secale cereale*], downy brome, and rattail fescue [*Vulpia myuros*]) and broadleaf (Menzies fiddleneck, tumble mustard, and blue mustard, also known as purple mustard [*Chorispora tenella*]) species has been determined in PNW winter wheat crops (Table 2). Studies on seed retention of Italian ryegrass in winter wheat found that although site conditions, such as slope position, influenced the rate of seed shattering in Italian ryegrass, less than 50% of the seed remained in the head at wheat maturity. Consequently, HWSC has low to intermediate potential for the management of Italian ryegrass in winter wheat. However, recent research has shown that Italian ryegrass seed weight increased as seed matured, thus HWSC would target the heaviest, and likely the most robust, seed.

Menzies fiddleneck had seed retention rates that varied greatly between years, ranging from less than 10% in 2016 to greater than 90% in 2018. Tumble mustard retained between 39 and 62% of seed at harvest. Seed retention at harvest in blue mustard ranged from 23 to 48%. In general, seed retention was greater in wetter years than in drier years.

Vision for HWSC in PNW Wheat Production Systems

In the low rainfall region, maintenance of crop residues is critical for conserving soil health and soil water; therefore, HWSC systems that retain all or most crop residues in the field (for example, impact mills, chaff lining, and chaff tramlining) will have the best fit in this region. At the time of this writing, few growers in the PNW were using controlled traffic systems, which limits the benefits of chaff tramlining over chaff lining. The relatively low average winter wheat yields in this region result in low levels of chaff production, which, depending on the width of the combine header, will reduce the amount of chaff in these lines. With reduced chaff there will likely be increased weed seedling emergence and potentially the need to control weeds in the chaff lines. The efficacy of chaff lines will be reduced when tillage is used during summer fallow, which is still a common practice in the low rainfall region.

Winter annual grass weed species (cereal rye, downy brome, jointed goatgrass [*Aegilops cylindrica*], and rattail fescue) are widespread troublesome weeds in the low rainfall region, which is dominated by the winter wheat–fallow rotation. Weed seed retention data from the PNW and Great Plains (Table 2; Walsh et al. 2018) for these species suggests that HWSC systems could aid in the management of all four of these species.

The intermediate rainfall region is a region of transition, with cropping systems shifting from winter wheat–fallow in the west (drier side), to winter wheat–spring wheat or spring barley–fallow and in wetter years, to continuous annual cropping in the east (wetter side). Consequently, the utility of HWSC will change with the change in cropping systems across the intermediate rainfall region. With a somewhat reduced emphasis on residue retention with increasing rainfall, a wider range of HWSC systems can be used. The recommended HWSC options across this region change from chaff lining, chaff tramlining, and impact mills in the lower rainfall areas to potentially all HWSC systems in the higher rainfall areas. The burning of crop residues is regulated and limited in much of the PNW due to air quality and health concerns; therefore, narrow-windrow burning and burning chaff heaps produced by chaff carts will not be acceptable routine practices. The occasional removal of crop residues with chaff carts or bale direct systems is feasible in higher rainfall areas. The use of these systems will depend on the local demand for the baled material.

In the high rainfall region, even though the retention of crop residues is important to protect soil from water erosion, there is often sufficient winter wheat residue produced (Table 1) to allow for the occasional removal of residues. Impact mill systems that are integrated into the combine are well suited for the rolling landscapes of the region. Relatively consistent crop production in the region may also reduce the financial risk of purchasing integrated impact mill systems.

As mentioned for the low rainfall region, few growers in the PNW use controlled traffic systems, which currently limits the additional benefits of chaff tramlining. However, the large quantity of chaff produced in the high rainfall region (Table 1) could facilitate effective weed seed control with chaff lining.

In addition to downy brome and jointed goatgrass, other troublesome annual grass weeds in the high rainfall region include Italian ryegrass and wild oat. Unfortunately, seed retention at wheat harvest in these two species has been relatively low, suggesting that HWSC has less potential for assisting with their effective management.

In addition to winter wheat, other crops commonly grown in the high rainfall region include spring wheat, spring barley, chickpea, dry pea, and lentil. Although HWSC has not been evaluated extensively in these other crops, the following assumptions are likely:

- The relatively late harvest of chickpea will result in low weed seed retention at harvest, reducing the likely effectiveness of HWSC.
- All of these crops produce less residue than winter wheat, particularly chickpea, dry pea, and lentil, which should limit the use of HWSC systems that remove crop residues and potentially reduce the effectiveness of chaff lining or chaff tramlining.
- Dry pea and lentil are cut relatively close to the ground, which improves the weed seed collection potential and relative effectiveness of HWSC in these two crops.

Integrating HWSC into an integrated weed management system. In order to conserve the use of herbicides as a viable weed management option into the future, growers must integrate other non-chemical approaches to weed control into their cropping systems. Harvest weed seed control is used routinely in Australia, where growers have been dealing with some of the world's most difficult herbicide-resistant weed management issues. Its value in the PNW has not yet been fully evaluated, but early work suggests that it can be an effective tool in an integrated weed management program.

Integrating HWSC into PNW wheat-based cropping systems can help reduce weed populations and maintain them at lower densities. The choice of which particular HWSC system to use is dependent on the constraints of the cropping systems in which they are used and the specific needs of the grower. Although HWSC is not a standalone technology, when used as part of an integrated weed control program, it can help reduce weed seedbank levels for many problematic weed species in the region. Always consider the effect of residue removal on participation in various federal conservation programs.

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