HARVEST WEED SEED CONTROL (HWSC)

There is a new acronym in the herbicide-resistant [HR] weed management arena that we should become familiar with. It is HWSC, which stands for Harvest Weed Seed Control. HWSC systems, which include chaff carts, narrow windrow burning, chaff baling, and the Harrington Seed Destructor, are designed to destroy seeds of escaped weed plants that are present at harvest in order to minimize new weed seed inputs into the soil weed seedbank.

In the following narrative, results from research projects that were designed to evaluate HWSC methods are presented.

But first, some background for why this has become a much written-about and discussed topic. It is accepted dogma that relying totally on herbicides for weed control in the coming years will hasten the spread of HR weeds and will render the remaining efficacious herbicides ineffective. According to Univ. of Arkansas scientists in an article titled "Harvest Weed Seed Control–An Alternative Method for Measuring the Soil Seedbank", this dilemma needs to be addressed by developing and using alternative non-chemical weed control practices that can be used to aid in or supplement the control of HR weeds and/or HR weed escapes.

Australian researchers have summarized the new HWSC paradigm for weed control in an article titled "Targeting Weed Seeds In-Crop: A New Weed Control Paradigm for Global Agriculture". Major points of that article follow.

- The current system of weed control in crop systems is to apply PRE and POST herbicides to prevent weed seed germination or kill young weed seedlings in emerged crops. However, using this system alone for weed control will inevitably lead to weed escapes which survive to crop maturity and produce seeds which will be harvested with the crop and be evenly spread across the crop field by the harvesting machine. This then leads to replenishment of the soil weed seedbank each year.
- HWSC systems target the weed seed-bearing chaff or residue material that comes out the back of the harvester. The result should be a decline in weed seeds re-entering the soil, which when combined with in-season herbicide weed control, will result in low or lower weed populations and thus low weed seed replenishment in the soil.
- Current HSWC systems are described in "The Effectiveness of On-Farm Methods of Weed Seed Collection at Harvest Time" and the previously cited UA FSA2180.
- The authors state that using a combination of herbicides and HWSC systems reduced and maintained annual ryegrass populations at densities of <1.0 plant/m^2.

Of course, success of all of the HWSC tactics is dependent on escaped weeds retaining their seed until the crop is harvested. To investigate this, Australian researchers conducted studies to determine seed retention by several annual species. Their results that are reported in an article titled "High Seed Retention at maturity of Annual Weeds Infesting Crop Fields Highlights the Potential for Harvest Weed Seed Control" are summarized as follows.

- Beginning at the first opportunity for wheat harvest and on a weekly basis for the following 28 days, the proportion of weed seed retained by targeted weeds [annual ryegrass, wild radish, brome grass, and wild oat] in the study was determined.
- The four species tested in the study had seed retention rates >77% at crop maturity.
- Today's harvesters are efficient at separating crop grain from foreign material, including weed seed. Thus, the harvested weed seed will be 1) available to replenish the soil weed seedbank, and 2) subject to collection or dispensing into a designated pattern for later disposal or destruction.
- Weed seed shedding increased with increasing time between crop maturity and actual harvest date. Thus, HWSC measures will be most effective if crop harvest occurs as soon after crop maturity as possible.
- The effectiveness of HWSC measures will depend on the retention of significant portions of weed

seed at crop maturity.

Australian researchers Walsh and Newman investigated burning narrow windrows of harvest residue to destroy seeds of weeds that were present at crop harvest. Their results are reported in Field Crops Research 104:24-30, 2007, and are summarized below.

- A temperature of 400°C was required to kill annual ryegrass seed during a 10-second exposure to this temperature.
- Concentration of harvest residues into narrow and conventional windrows resulted in 6.7- and 4-fold increases in biomass per unit area compared to a standing stubble treatment.
- Burning residue that was concentrated into windrows resulted in higher burn temperatures that were longer-lasting than temperatures recorded during burning of standing stubble.
- Windrow burning resulted in greater destruction of ryegrass seeds [as measured by annual ryegrass seedling emergence at the start of the following growing season] than did burning of standing stubble. Thus, burn temperature and duration in the standing stubble were not sufficient to produce maximum kill of ryegrass seeds.
- A chute mounted at the rear of the harvester concentrated harvest residues, including weed seed, into narrow windrows that are preferred over conventional windrows because they 1) reduced the risk of soil erosion because of minimal soil exposure following burning, 2) increased the amount of fuel concentrated into a smaller area that resulted in a longer burn with prolonged higher temperatures, and 3) less likelihood of burning the whole field.

Click here to access guidelines for smoke management during the burning process.

Arkansas researchers conducted studies from fall 2010 through fall 2013, with the objective of elucidating how in-season herbicide programs and HWSC practices will impact Palmer amaranth population density and seed production over the 3-year period of the study. The results of this research are reported in an article titled "Integrating Herbicide Programs with Harvest Weed Seed Control and Other Fall Management Practices for the control of Glyphosate-Resistant Palmer Amaranth".

The experiments were conducted on a Sharkey clay at Keiser, Ark. The experimental site had been previously cropped with GR soybean in 2009 and 2010. They determined that this site contained a dense, uniform stand of GR Palmer amaranth at soybean maturity in the fall of 2010. The researchers evaluated 6 fall management strategies and 3 herbicide treatments as shown in the following table.

Fall Management Treatments
No-till, soybean residue spread and retained with no fall tillage
Raised beds reformed immediately following harvest with normal spread of soybean residues
Rye cover crop drill seeded at 80 lb./acre, glyphosate applied for burndown prior to soybean planting
Narrow windrowing of harvest residues, followed by burning
Narrow windrowing of harvest residues without burning
Harvest residue collected and removed from field
Herbicide Treatments/Program*
Glyphosate-only: Glyphosate applied at soybean stage V2 followed by (fb) glyphosate applied at stage V7
Glyphosate + residuals: Valor (flumioxazin) PRE fb glyphosate + Prefix (*S*-metolachlor + fomesafen) applied at V2 fb glyphosate applied at V7
Glufosinate + residuals: Valor PRE fb Liberty (glufosinate) + Prefix applied at V2 fb Liberty applied at V7
**Glyphosate applied 2-3 weeks prior to planting soybeans to control weeds and rye cover crop, and paraquat applied immediately after planting. Site was furrow irrigated as needed.*

Results from this study are as follows.

- Across the 3 years, residue collection and removal, rye cover crop, and windrowing with burning were the most effective fall treatments for reducing Palmer amaranth population density. The residue collection and removal treatment had the lowest weed density, followed by windrowing with burning and rye cover crop, which were equal in their reduction effect. Fall tillage [bedding] was erratic in its effect on weed density.
- The application of glyphosate in combination with PRE herbicides with sites of action different from that of glyphosate resulted in large reductions in Palmer amaranth population density and seed production in all fall management treatments compared to the glyphosate-only treatment, but the reductions were not as great as those following the application of PRE herbicides followed by [fb] glufosinate. The glufosinate herbicide program resulted in little to no Palmer amaranth plants or seed production across fall management treatments.
- Rye cover crop in the glyphosate-only herbicide treatment resulted in Palmer amaranth population densities and seed production that were significantly below those in the no-till treatment with glyphosate-only herbicide.
- The reduction in Palmer amaranth plants and seeds resulting from the rye cover crop was enhanced by PRE residual herbicides and POST glufosinate.
- These results point to 1) integrating fall management practices into an effective weed management program that uses PRE residual herbicides fb POST herbicides to reduce Palmer amaranth plant densities and seed production, 2) using a cereal rye cover crop to reduce weed densities, 3) combining herbicides with different sites of action, and 4) using a glufosinate-based weed control program to effectively control GR Palmer amaranth.

It is important to note that utilizing only 4) above will potentially lead to the development of glufosinate-resistant weeds. Thus, it is important that supplemental weed control practices such as the rye cover crop and HWSC used in this study be considered to supplement herbicide control so that weed seed production is minimized. In the authors' words "Farmers should broaden and diversify their weed control options by incorporating HWSC strategies that target Palmer amaranth escapes at crop harvest or integrate a fall-planted cover crop into current production systems....to ultimately reduce the soil weed seedbank".

ADDENDUM

WEED SEED DESTRUCTION IN SOYBEAN HARVEST RESIDUE

One of the technologies discussed in the above narrative is the destruction of harvested weed seed by the Harrington Seed Destructor or HSD [Walsh et al., Crop Sci., Vol. 52, May-June 2012]. The original HSD was towed behind the combine, whereas the integrated Harrington Weed Seed Destructor [iHSD] is an adaptation of this unit that is integrated into the harvester. The premise behind the iHSD is that weed seed mixed with the chaff that comes out the rear of the combine can be physically altered so that they are no longer viable. Thus, they will not be available to replenish the soil weed seedbank.

Research results reported in an article titled "Efficacy of the Integrated Harrington Seed Destructor on Weeds of Soybean and Rice Production Systems in the Southern United States" [Crop Sci., Vol. 57, Sept.-Oct. 2017] provide support for the potential use of this machine as a useful tool for HWSC in the Midsouth. Details about and results from this research follow.

- The following premises guided the direction of the research. 1) HR weeds are becoming increasingly problematic in Midsouth crop production. 2) Reduction in the soil weed seedbank is deemed an important component of long-term weed management. 3) The soil weed seedbank allows for long-term persistence of problematic weeds in crop fields. 4) Harvested weed seeds are mostly expelled from the rear of a harvester, and thus are dispersed across the field during harvesting. 5) The weeds that escape in-season control measures retain a large percentage of their seed at time of crop harvest, and these mature seed will replenish the soil weed seedbank via dispersal from the combine.
- The objective of the research was to determine the effectiveness of the iHSD in soybean and rice production systems for reducing the number of viable weed seeds that are returned to the field during crop harvesting.
- Three experiments were conducted using an iHSD mill and soybean harvest residues. 1) Efficacy of the iHSD was evaluated on seeds of 12 weed species (broadleaf and grass species varying in seed size, weight, and density) that are common in Midsouth soybean production systems by incorporating them into crop residue resulting from harvest. 2) Soybean harvest residue feeding rates were tested to determine their effect on the amount that could be processed without interfering with weed seed destruction [Palmer amaranth and morningglory species only]. 3) Soybean chaff moisture levels were varied to determine how high moisture content of chaff may affect iHSD performance and effectiveness.
- Number of emerged seedlings expressed as a percentage of germination of seeds that were not processed by the iHSD was used to estimate seed mortality caused by the iHSD.
- Weed seed destruction ranged from 99.8% to 100% [except for common cocklebur which was 97.5%] in soybean residue. There was no significant difference in mortality among the 12 weed species tested.
- Destruction of Palmer amaranth and morningglory seeds was not significantly affected by the residue feeding rates used in the study.
- Residue moisture levels used in the study [8, 12, 16, 20, and 24%] did not significantly affect destruction of Palmer amaranth and morningglory weed seeds by the iHSD. However, the results from these experiments indicate that efficacy in a commercial application likely would decline or the equipment would not operate properly as a result of clogging when residue moisture content is >16%.
- The authors concluded from the results of these studies that the iHSD has potential to improve weed management in Midsouth soybean production systems by destroying weed seeds at crop harvest, thereby reducing replenishment of the soil weed seedbank. However, they recognize that the iHSD should be further evaluated as a combine-fitted system that will be operated in commercial soybean production fields.

Click here for a video with Drs. Jason Norsworthy and Tom Barber discussing the iHSD attachment to a field-scale combine. This replaces the pull-behind HSD that is likely not practical in Midsouth cropping systems that include rice, soybeans, and corn. Research with this machine will be conducted to determine its effectiveness at reducing weed seed return to the soil weed seedbank in both research and producer fields. The premise is that this new cultural practice can be used in conjunction with current weed control practices to aid in the control of HR weeds.

Results from research reported in an article titled "Fate of Weed Seeds after Impact Mill Processing in Midwestern and Mid-Atlantic United States" [Weed Sci. Vol. 68, 2019] provide results from testing the effectiveness of a stationary HSD against weeds that are common in soybean production systems in those two regions of the U.S. Details about and results from this research follow.

- Objectives of the study were to 1) determine the efficacy of the HSD on seeds of common weeds in the two regions, and 2) determine the fate of treated but potentially viable weed seeds in the soil seedbank.
- Seeds of seven midwestern weed species (waterhemp, common lambsquarters, giant foxtail, velvetleaf, ivyleaf morningglory, giant ragweed, and common cocklebur) and five mid-Atlantic weed species (smooth pigweed, common ragweed, jimsonweed, common lambsquarters, and velvetleaf) were selected in 2015 and 2017.
- Chaff and weed seeds for testing were collected directly from a harvester in late summer/early fall from soybean fields in Urbana Illinois and Beltsville Maryland.
- Seeds from each treated lot were collected for use in winter burial studies.
- In tests of seed from both locations, weed seed destruction was greater than 96% except for the seed of smooth pigweed [92.4% destruction].
- Results indicated that the effect of weed seed size on weed seed destruction by the HSD was of little consequence–i.e., it effectively destroyed seed from both small- and large-seeded weed species.
- Fewer than 10% of the potentially viable seed [PVS] that were intact after HSD processing and that were buried overwinter for 90 days remained viable. Thus, the HSD significantly reduced seed viability and promoted seed mortality of PVS, likely by physical damage to the seed coat or seed.
- These results confirm findings from other studies that have shown that the HSD is effective in greatly promoting weed seed mortality at harvest, and thus reducing replenishment of the soil weed seedbank during the harvest operation. This is important for controlling seed replenishment from early-season weed escapes that may in fact be herbicide-resistant.

An article titled "Distribution of Common Cocklebur and Palmer amaranth Seed Exiting the Combine for Harvest Weed Seed Control in Soybean" presents results from Arkansas research that determined that the majority of weed seed, regardless of species, is likely to be in the chaff fraction of soybean residue that leaves the combine. This should provide guidance to producers about where to attach an iHSD to their combine to encounter the most weed seed for destruction.

In a recent publication titled "Seed destruction of weeds in southern US crops using heat and narrow-windrow burning" [Weed Tech. 34:589-596], Dr. Jason Norsworthy and colleagues present results from research that was conducted in Arkansas to determine the temperature and duration needed to kill the seed of Palmer amaranth, barnyardgrass, johnsongrass, pitted morningglory, hemp sesbania, prickly sida, sicklepod, velvetleaf, and Italian ryegrass [IRG]. These small- and large-seeded grass and broadleaf weeds frequently occur in southern U.S. soybean fields. Procedures used in and results from the research cited in the publication follow.

- The basis for conducting this research was 1) weeds that escape chemical control will continue to grow and produce seed, 2) seed that are retained by these weed escapes will enter the combine during harvest and will be redistributed in the field to replenish the soil weed seedbank, 3) the efficacy of narrow-windrow burning against weed seeds in soybean residue requires that seed of common problem weed species be evaluated for their response to the burning practice, and 4) the low cost of using this strategy makes it a viable HWSC option.
- Viability of seed of targeted weed species was determined prior to placing into a high-fire kiln where these seed were subjected to 20

combinations of temperature [200, 300, 400, 500, and 600 deg. C (to convert deg. C to deg. F, multiply deg. C by 1.8 and add 32 to the answer)] and duration [20, 40, 60, and 80 seconds] of each temperature. Number of viable seed was determined after each treatment.

- Heat index [HI] was calculated by summing the temperature above ambient [23.9 deg. C in these experiments] for each second duration of heat exposure. For example, a 400 deg. C temperature for 60 seconds would result in an HI of 22,566 [400 x 60 = 24,000 - (23.9 x 60 = 1,434) = 22,566]. Effective burn time [EBT] is defined as the number of seconds that a burn was above a specified temperature. For example, EBT 300 is the designation for the number of seconds that a burn was above 300 deg. C.
- A field experiment was conducted in a production field of irrigated soybean to assess the efficacy of burning on the viability of seed of Palmer amaranth, barnyardgrass, johnsongrass, and pitted morningglory. Viability of seed of these weed species was determined prior to their placement on the soil surface beneath the residue windrow.
- Results from these experiments follow. 1) An HI of 22,600 was needed to kill all seeds of Palmer amaranth, barnyardgrass, and IRG. 2) Lengthening the burn time–e.g. exposure time of weed seed to burning–reduced the temperature needed to achieve weed seed mortality. 3) Regardless of weed species and temperature duration, no seed kill was completely achieved at 200 deg. C. 4) Seed size had some impact on the mortality of seed–e.g. small-seeded species such as Palmer amaranth and barnyardgrass showed complete mortality at lower temperature and duration combinations than did seed of large-seeded species such as pitted morningglory and sicklepod. 5) As temperature increased for each species tested, viability decreased, thus showing that weed seed mortality can be achieved by heating. 6) The amount of soybean residue at the time of burning had an effect on results–i.e. the greater the amount of residue, the greater the weed seed kill. It is highly likely that residue resulting from an irrigated soybean crop will be greater than that resulting from a nonirrigated [NI] crop. Thus, the utility of burning residue to kill weed seed contained in residue from a harvested NI soybean crop is not known. 7) Wind speed had an effect on both HI and EBT–i.e. as wind speed increased, both HI and EBT decreased rapidly. 8) Regardless of the achieved HI and EBT, all seeds of Palmer amaranth, barnyardgrass, johnsongrass, and pitted morningglory were killed when the narrow windrows in the field experiment were burned. In fact, seeds of all but pitted morningglory were reduced to ash. Even though seeds of pitted morningglory remained intact after burning, they were not viable.
- These results showed that complete control of weed seeds expelled from the combine can be achieved by burning narrow windrows of soybean residue. The HI values that are needed for complete mortality of the nine weed species evaluated in the kiln study were easily achieved in the field burning experiments. Thus, weed seed that enter the combine during soybean harvest and that subsequently leave the combine with the soybean harvest residue are highly likely to be destroyed during narrow-windrow burning. This then will significantly reduce the amount of seed that will be available to replenish the soil weed seedbank. Of course, this process will be most effective against those weed species that retain a higher percentage of their seed at soybean harvest time so that they enter the combine and are expelled in the soybean residue that is burned in these narrow windrows.
- Further research is needed to determine 1) how this HWSC practice might affect the carbon and nutrient recycling benefits derived from soybean production, 2) how this burn removal of soybean residue from sloped fields might affect erosion potential of these sites, 3) the impact of this practice on soil microbial activity, and 4) how this practice might affect soil fertility management in fields with these burned strips..

Likely the most complete body of knowledge that addresses HWSC is Research Report No. 121 [Feb. 2020] titled "The War Against Weeds: Harvest Weed Seed Warriors" from WeedSmart. WeedSmart is the industry voice that delivers science-backed weed control solutions to growers and advisors for long-term profitability in Australian Agriculture. The concept of

HWSC originated in Australia, and was devised and refined to aid Australian producers battle HR weeds in their cropping systems. The above-linked report is the most up-to-date and detailed treatment of HWSC technology.

The contents of the above reports are summarized in a publication titled "Harvest Weed Seed Control" from GROW, a U.S.-based, publicly-led network of agricultural specialists that work to develop integrated weed management solutions that are practical and adoptable for U.S. producers. Their above-linked publication also contains links to videos that explain how the various HWSC concepts work and can be used.

It is doubtful that HWSC tools that may be deemed unconventional for weed management and/or control have been/are being used on a wide-scale basis in the Midsouth. However, with the increase in problematic HR weeds in soybean, the steadily decreasing chemical weed control options, and the continuing evolvement of HR weeds, it is reasonable to assume that alternative HSWC methods will necessarily become more commonplace to complement herbicide weed control where problem HR weeds are present. Using HSWC tools should result in a diminishing soil weed seedbank, and this, coupled with an effective herbicide weed management program, should help to improve weed control in soybeans over the long-term. Certainly, such alternative weed control measures should at least be implemented in soybean fields that have significant weed escapes that have produced/will produce seed at soybean harvest time.

Of course, in fields with no or few escaped weeds to produce seed, the above HWSC tactics will be of no benefit. However, if and when a crop production site becomes uniformly contaminated with HR weeds that persist through crop maturity and that produce seeds, then HWSC measures should be considered as an option on that field for the foreseeable future.

The following articles on this website provide additional information about HWSC.

- Harvest Weed Seed Control–blog
- Soil Weed Seedbank–One Source of Weed Problems–MSSOY White Paper
- Weed Seed Destruction in Soybean Harvest Residue–blog

MAR. 2023 UPDATE

HWSC PROMISING FOR ITALIAN RYEGRASS [IRG] CONTROL IN WHEAT

Italian ryegrass is a problem winter annual weed in Midsouth wheat and a following soybean crop. The weed emerges in the fall and grows quickly and rapidly in winter and early spring. If not controlled, it will compete with a fall-planted wheat crop through harvest. It will then likely be an uncontrollable weed when soybean is planted following wheat harvest, and will significantly reduce soybean yield.

IRG has developed resistance to multiple herbicide sites-of-action, thus making it very difficult to manage when it is not controlled in the fall with tillage [where allowed] or effective herbicides. In fact, it is recognized as one of the most successful weed species at developing resistance to herbicides. Neither tillage nor herbicides will effectively control this weed if it becomes large as a result of no control measure(s) being applied before or soon after its emergence in the fall.

In the Midsouth, wheat and soybean are often doublecropped [Click here to access a doublecropping White Paper on this website]. Thus, IRG will need to be controlled at wheat planting to prevent it from becoming problematic in both the fall-planted wheat crop and a following soybean crop.

In a Feb. 28, 2023 advertorial [sponsored by FMC Corporation] titled "Boost Weed Control and Increase Wheat Yields–Get Ahead of Italian Ryegrass" that appears in Progressive Farmer magazine, the problem of controlling this weed in a wheat crop is discussed. The FMC herbicide Anthem Flex [carfentrazone-ethyl (Group 14) plus pyroxasulfone (Group 15)] is highlighted in the article as a residual herbicide for control of IRG. The above-linked article and the Anthem Flex label provide guidance on the application timing of this PRE herbicide to wheat to control IRG since time of application is critical in relation to wheat seed germination.

In an article titled "Evaluation of Italian ryegrass seed dispersal prior to and at wheat harvest in Kentucky" by Herman and Legleiter [Crop, Forage, and Turfgrass Mgmt., 2023;9:e20200], results from a study that was conducted in Kentucky to evaluate the potential of the HWSC option as a control measure for IRG in a wheat crop are presented. Details of the research and its results follow.

- In the study, wheat fields with heavy infestations of IRG were selected. Overall, eight locations [3 producer fields and 1 experiment station field x 2 years–2020 and 2021] were used in the study.
- At time of wheat harvest, more seeds of IRG were retained on the seed head [89%] than was found on the soil surface [11%]. The authors state that this retention rate is likely based on the location and its environment. Also, it is likely dependent on the time of wheat harvest in relation to IRG maturity.
- The amount of IRG seeds that shattered at the combine header was significantly below that entering the combine. Thus, those seed that entered the combine would not have been deposited on the soil at harvest to replenish the soil weed seedbank.
- Unfortunately, this study's findings were that less than 50% of the IRG seeds that entered the combine with the wheat ended up in the chaff portion in both years. This means that a significant percentage of IRG seeds made their way to the grain tank along with the harvested wheat seed. While this would have contributed to less IRG seed deposition to the soil, it likely would result in significant dockage for foreign matter at the elevator. Also, the IRG seed in the grain tank would not be available for destruction by any HWSC method.

It is difficult for a combine to separate IRG seed from wheat seed during the threshing process. Thus, there needs to be work done to determine how to have most if not all of the IRG seed being contained in the chaff portion that leaves the combine so that all or most of the IRG seed entering the combine will be available for destruction by an HWSC method.

An effective strategy to control IRG early should be adopted so that IRG infestations at the time of wheat harvest and subsequent soybean planting are acceptably low. This will reduce the pressure on having to use HWSC methods to help manage IRG.

Click here for a Delta FarmPress article [Jan. 4, 2021] titled "Managing Italian Ryegrass in Mississippi Soybeans" that provides various control options for IRG, and here for an article [Sep. 2022] titled "Investigating Italian Ryegrass Management Options" from the Soybean Research and Information Network [funded by the soybean checkoff].

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