The Spread of Herbicide-Resistant Weeds: What Should Growers Know?

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The weed management decisions growers make will influence whether or not they are going to select for resistance in their fields. However, resistance can also be introduced in a previously resistance-free field through the movement of resistance from one field to another. While wise selection of in-field weed management programs is needed for fighting resistance evolution, it is also important for growers to realize that resistance can spread from one field to another and that the spread should be prevented. It is in fact likely that the spread of resistance has to be blamed for the widespread occurrence of resistant weeds in the Delta region. Therefore, preventing the spread of resistance should be an important element of herbicide resistance management, and such a tactic would require a good understanding of the routes of resistance movement. This fact sheet provides an insight into this rather neglected area.

Resistance can be carried (gene flow) from one field to another through three important routes: pollen, seed and vegetative structures (for example, nutsedge tubers). Resistance is most likely to be expressed in pollen (e.g., Burke et al. 2007) if it is nuclear encoded. If pollen from a resistant plant outcrosses with a susceptible plant, the resulting seed may carry resistance. If the resistant seed goes back to soil, emerges and then survives herbicide application, it is going to rapidly increase in the soil seedbank within a few years, provided the management remains the same. The level of such transfer and distance to which outcrossing can occur will depend on the weed species and environmental conditions. If the weed is a highly self-pollinating species (most grasses such as barnyardgrass), the level of resistance spread would be much lower compared to a highly outcrossing species such as pigweeds. For example, in research conducted in Fayetteville, Arkansas, approximately 3% outcrossing was observed in barnyardgrass plants present within a few feet and was very rare (<0.01%) at a distance of 150 feet (Bagavathiannan et al. 2012), whereas a study conducted in Georgia quantified as much as 20% to 40% outcrossing among Palmer pigweed plants that were up to about 1,000 feet apart from each other (Sosnoskie et al. 2012).

The distance to which outcrossing can occur is influenced by pollen grain size, pollen load (availability), the means of pollen movement (through wind, insects, etc.) and the period of pollen viability, which is affected by inherent pollen characteristics and environmental conditions (air temperature and humidity). For a wind-pollinated species, frequent high-velocity winds can move pollen to fairly long distances in the direction of the wind, whereas pollen-mediated transfer of herbicide resistance can occur even at farther distances in weed species that are pollinated by insects such as bees. Wind dispersal of pollen grains will also be greater in a weed that grows taller than crop canopy. The level of outcrossing can be spatially variable, but growers should realize that all that is needed for resistance buildup is a single resistant seed that can survive herbicide applications and reproduce. Therefore, pollen movement as a means of resistance spread should be taken very seriously.

Seed is another important avenue for the movement of herbicide resistance. Weeds typically produce numerous seeds that are dispersed through various means including natural forces, animals and birds, and human activities associated with agricultural production.

Natural forces such as rain and high-velocity wind can displace weed seeds and aid in seed dispersal. Weeds are important food sources for ants, rodents, birds and several grazing animals such as deer. The weed seeds collected by animals are typically dispersed as they are not all consumed nor will the consumed seeds lose viability. For most agricultural weed species, human activities associated with agricultural production serve as an important means for dispersal. Weed seeds can be dispersed through contaminated seed, irrigation water, tillage equipment, harvesters, transport of items such as crop produce, stover/hay material, livestock, manure and other agricultural by-products, and even through seed adherence to vehicles and trains. The distance of dispersal will depend on the nature of the dispersal agent, but some human activities may lead to the spread of herbicide resistance across regions and even across nations. For vegetatively propagated weed species, movement of stem portions, rhizomes, tubers and other regenerative parts can aid in the spread of resistance. However, the movement is often restricted to relatively shorter distances compared to weed seed movement, spreading typically within production fields as a result of tillage.

Non-Cropped Areas – An Important Avenue for Resistance Spread

When weed seeds disperse out of the production fields, they often end up in roadsides (field edges and ditchbanks), right-of-ways, railroads and other natural areas (Figure 1 a-d) where they are not usually controlled. The weeds present in non-cropped areas can acquire herbicide resistance through outcrossing (pollen movement) with nearby resistant weed populations or through seed movement from resistant fields. Sometimes these populations themselves are established by seed dispersal from resistant fields. It is going to be problematic if weeds occupying non-cropped areas are herbicide resistant because they can serve as sources for further spread of resistance to fields in other areas through movement of pollen and seed.

A large-scale survey was conducted in 2012 across the Delta region in eastern Arkansas to understand the prevalence of resistance-prone weeds on the roadsides. It was found that Palmer pigweed, johnsongrass and barnyardgrass were some of the important resistance-prone weeds commonly found along the roadsides. Screening of the roadside Palmer pigweed samples revealed that >90% of the collected populations contained individuals that were resistant to both Roundup® and Staple® (Bagavathiannan and Norsworthy 2013). This is alarming because such levels of herbicide-resistant pigweed on the roadsides can result in the movement of resistance to crop fields that have never had a Palmer pigweed problem in them. It is very important to recognize that effective

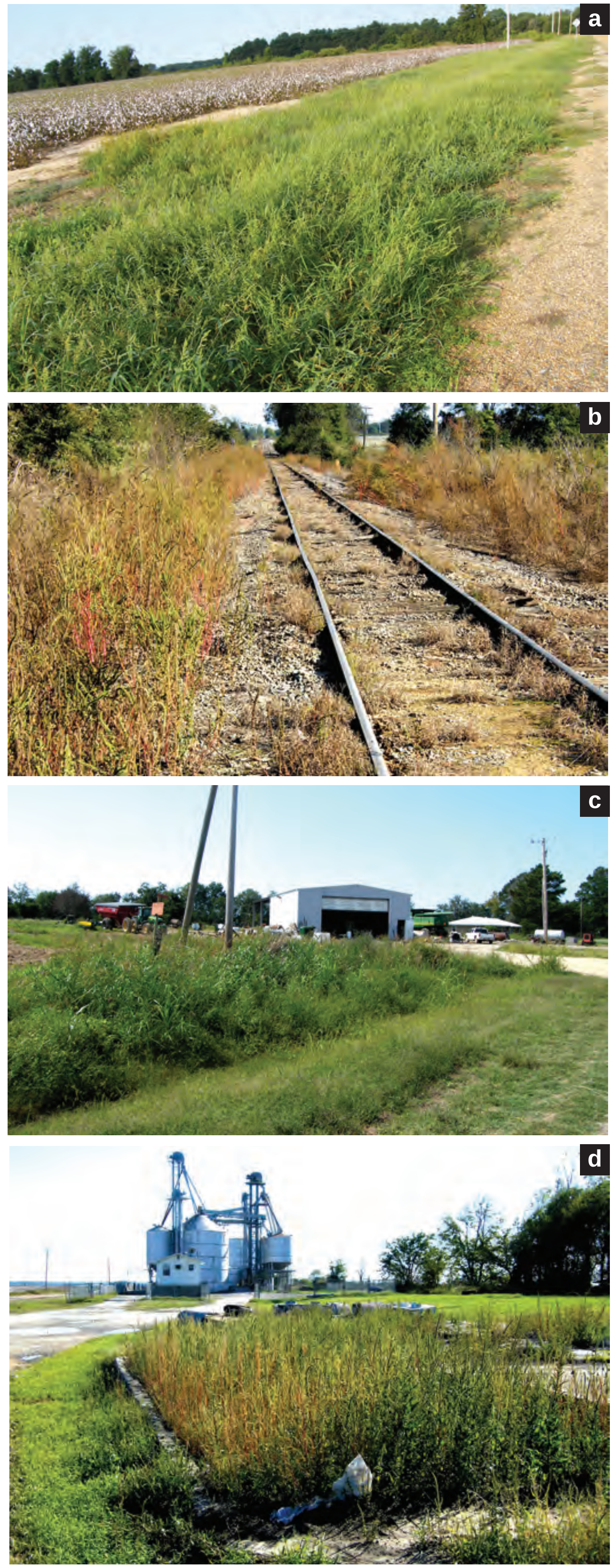


Figure 1 a-d. Occurrence of problematic weeds in (a) roadsides, (b) railroads and (c-d) other non-cultivated areas in the cropping region of eastern Arkansas.

resistance management requires a holistic approach that considers all weed escapes in the agricultural landscape.

Stewardship Practices for Preventing the Spread of Resistance

Growers can prevent the spread of herbicide resistance to a great extent by adopting stewardship practices that are based on a sound understanding of the routes of resistance spread across fields and regions. Below are some of the stewardship practices that would be helpful in achieving this goal:

A. Pollen-mediated transfer of herbicide resistance: Growers should be vigilant about the possibilities of the transfer of herbicide resistance from one field to another through pollen movement. If resistance is suspected in their field or in the vicinity, any escapes of a given weed species should be eliminated prior to flowering. Preventing flowering is particularly crucial for weeds that show a high tendency for outcrossing. Therefore, growers should develop an understanding of the levels of outcrossing for the important resistance-prone weeds that they are dealing with in their fields (see Table 1).

B. Seed-mediated transfer of herbicide resistance: For most weeds, seed movement is the main route for the spread of herbicide resistance for very long distances (Figure 2). The following tactics could minimize the transfer of resistance through seed:

1. ***Prevent the introduction of weeds through planting seeds:*** Planting seeds provides an important entry point for problematic weeds that were never present in the field before. Growers should always use clean seeds or certified seeds that are void of weed seeds.

2. ***Minimize field-to-field movement of weed seeds through irrigation/rainwater:*** Weed seeds that can easily float (such as pigweed, barnyardgrass, etc.) can be carried long distances through running water. As a result, resistance present in one part of a field can quickly spread to other areas within the field or to nearby fields depending on the drainage structure. Seed movement through drainage water can also contribute to the establishment of resistant weeds in ditchbanks and other areas outside of crop fields. The drainage structures should be altered such that the transport of weed seeds across fields is discouraged.

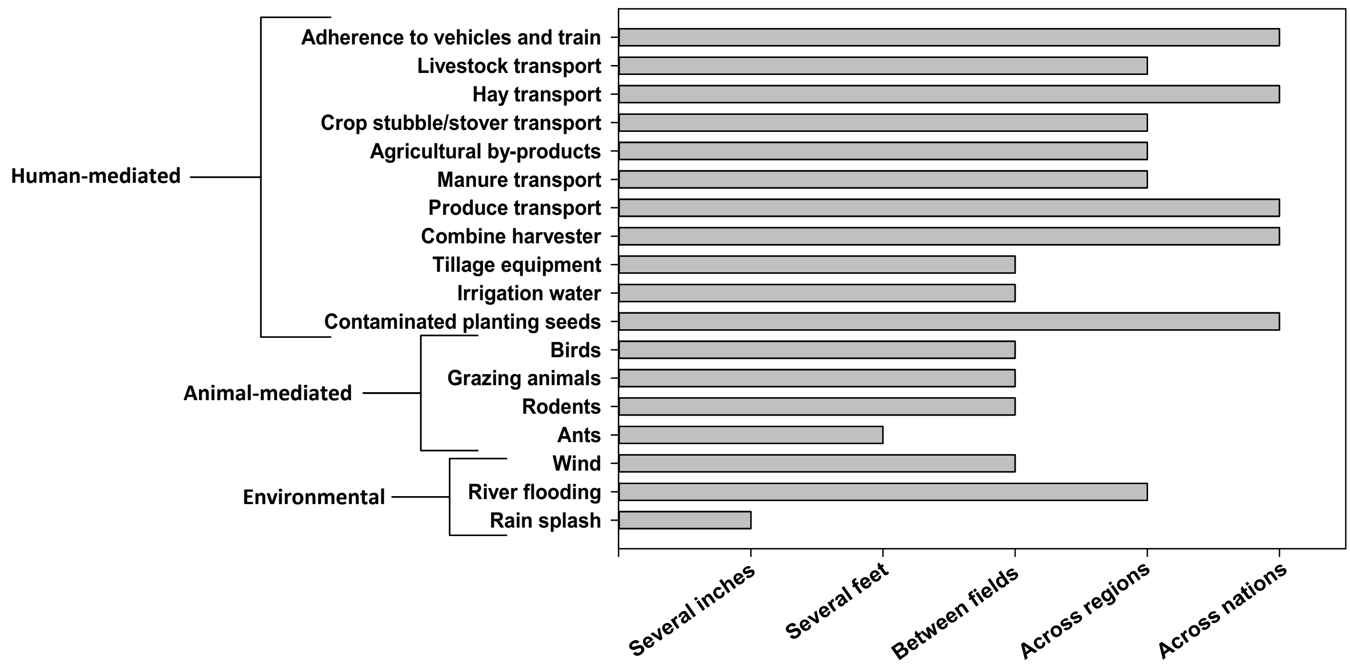
3. ***Prevent weed seed movement through equipment:*** Tillage and harvest equipment can greatly contribute to the movement of resistant weeds across fields and to non-cultivated areas such as roadsides (Figure 3). It is crucial to clean equipment before moving between fields, especially when it is used in a field infested with resistant weeds. Small seeds such as those of pigweed will stay in

Table 1. Distance of pollen movement and risk of pollen-mediated spread of herbicide resistance.*

Species	Primary Means	Distance	Risk	Other Particulars	Reference
Palmer pigweed	Wind	At least 1,000 ft	High	Separate male and female plants, obligate outcrosser	Sosnoskie et al. (2012)
Barnyardgrass	Wind	At least 200 ft	Low	High self-fertility	Bagavathiannan et al. (2012)
Johnsongrass	Wind	At least 700 ft	Medium	High self-fertility	Schmidt et al. (2013)
Horseweed	Wind	At least 250 ft	Low	High self-fertility	Based on Smisek (1995)
Italian ryegrass	Wind	>1 mile	Very high	High self-incompatibility	Busi et al. (2008)
Red rice	Wind	Up to 50 ft	Very low	High self-fertility	Burgos et al. (2003)
Giant ragweed	Wind	At least 500 ft	Low-medium	Facultative outcrosser	Based on Brabham et al. (2011)
Goosegrass	Wind	At least 500 ft	Low	High self-fertility	Expert opinion
Common waterhemp	Wind	At least 1,000 ft	High	Separate male and female plants	Costea et al. (2005)
Common ragweed	Wind	At least 300 ft	Low-medium	Separate male and female plants	Jonathan (2011)
Kochia	Wind	At least 100 ft	Low	Imperfect flowers – high outcrossing	Stallings et al. (1995)

*These are for indicative purposes only. Very low levels of outcrossing can occur even at distances farther than this, sufficient enough to spread resistance across a landscape. Likewise, the relatively low levels of outcrossing for some weeds (e.g., red rice) could still be sufficient, if it occurs near field edges, to spread resistance to bordering fields and to compatible plants in adjacent non-cropped areas.

Figure 2. Potential distances of seed-mediated spread of herbicide resistance.*



*The distances presented here are presumed based on expert opinions and field observations.

a combine or cotton picker and are harder to clean. It is worth every effort to thoroughly clean harvesting equipment to prevent the spread of problematic resistant weed seed. For this reason, growers should be cautious with any lease or purchase of used equipment from an area containing herbicide-resistant weeds. The spread of Palmer pigweed to the northern U.S. is possibly attributed to the movement of combines from the south. It has been speculated that the recent evidence of Palmer pigweed in Argentina is linked to the purchase of used combines from the southern U.S.

4. ***Prevent weed seed movement through commodity transport:*** Weed seeds can easily mix with harvested produce (Figure 4) and can travel for long distances through the transport of an agricultural commodity. Seed spill and escape can occur throughout the commodity supply chain and even lead to the movement of resistant weeds across regions and nations. Our observations suggest that seed spill along commodity transport routes is an important source for resistant weeds along roadsides and adjacent non-cultivated areas (Figure 5 a-b). Prevent-ing weed seed movement through commodity

Figure 3. Palmer pigweed and johnsongrass along the equipment transport route.

Figure 4. Weed seeds mixed with crop produce during harvest.

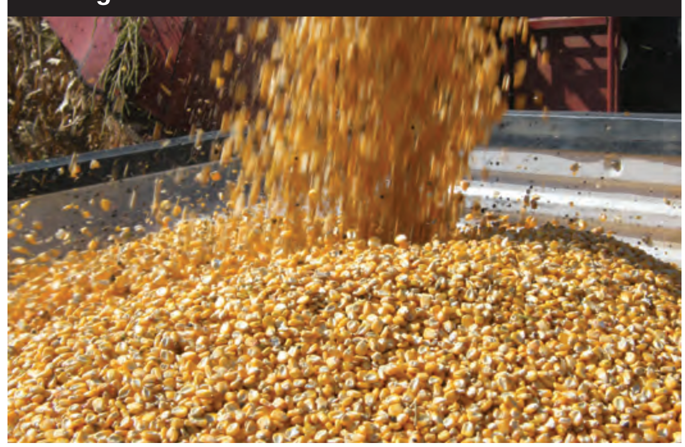


Figure 5 a-b. Spill of crop produce along roadsides and the establishment of problematic weeds.

transport starts with the prevention of weed seed contamination with harvested produce, but the use of spill-proof containers would be helpful in preventing seed dispersal during commodity transport.

5. ***Prevent weed seed movement through contaminated crop by-products and amendments:*** Sometimes growers bale straw/stover material for feeding animals (Figure 6), and it is not uncommon that the bales are sold to and transported across various regions and states. Some growers cut hay from roadsides that contain problematic weeds for feeding animals. It is important to keep in mind that animal manure can carry viable weed seeds, possibly leading to the spread of resistant weeds. Some weed seed contaminated crop by-products are directly used in fields without realizing the potential for acquiring resistant weeds. For example, cotton gin trash (Figure 7) and cotton seed hulls are usually recycled and used as soil amendments. A survey conducted on various cotton gin trash samples collected in Arkansas showed that gin trash contained several problematic weed seeds (Norsworthy et al. 2007). In some cases, top soil is bought as an amendment to improve poor soils. Such practices can introduce millions of weed seeds to the new field. It is therefore wise to avoid buying recycled plant material, manure or soil amendments from regions where resistance is widespread.

C. **Spread of herbicide resistance through vegetative structures:** While the evolution of resistance is rare in plants that reproduce primarily through vegetative structures, it is not impossible to happen. A nutsedge population with resistance to ALS-inhibiting herbicides was documented in Arkansas (Norsworthy et al. unpublished results). However, the spread of resistance in weeds regenerated primarily through vegetative structures such as rhizomes, tubers, stolons or stem portions would be less of a concern because the routes of dispersal are most likely

Figure 6. Baling rice straw: notice the johnsongrass escapes in the rice field (we confirmed that they were resistant to Fusilade®).

Figure 7. Weed seed contamination in cotton gin trash: notice Palmer pigweed plants in the areas adjacent to the gin trash heap.

limited to tillage equipment, compared to the many routes available for weeds that typically reproduce by seeds. Vegetative structures can easily end up in field edges and ditchbanks during tillage and persist in those places and may even result in the movement of resistance to nearby fields. In our roadside survey, nutsedges were commonly found in these areas. The movement of resistance through vegetative structures could be prevented by being cautious with tillage patterns and proper cleaning of tillage equipment before moving between fields.

Concluding Remarks

Preventing the spread of herbicide resistance cannot be accomplished without preventing the establishment of resistant weeds in non-cropped areas including roadsides (equipment yards, field edges, ditchbanks) and other areas. Growers should always keep in mind that resistant weeds present in non-cropped areas will allow the persistence and spread of herbicide resistance on regional scales, even if the resistant weeds are eliminated in production fields. As such, due diligence should be employed in eliminating resistant weeds in non-cultivated areas.

An important question is who should be delegated to control resistant weeds in these areas. The answer is that every stakeholder should be involved in fighting resistant weeds with a mutual interest. Because resistant weeds constitute a common-pool issue, regional-level cooperation among growers is fundamental to address this problem. A program was successfully executed in some counties (such as Crittenden County) where growers got together and determined to adopt zero-tolerance for pigweeds at a regional scale. Cooperative programs like this are crucial for eliminating resistant weeds in non-cropped areas. Collaborative programs should also be established among growers, county agents and highway weed managers to ensure that resistant weeds are prevented from entering new places and from establishing in the roadsides and other areas alike.

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Printed by University of Arkansas Cooperative Extension Service Printing Services.

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FSA2171-PD-6-13N