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Near Term Challenges for Global Agriculture - Herbicide Resistant Weeds

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Prior to the 1950s weeds were controlled by a wide variety of mechanical and cultural methods with limited use of inorganic chemicals at very high rates (100s kg ha^{-1}). With the advent of selective carbon-based herbicides in the 1950s, herbicide weed management became the norm throughout much of the world using grams to a few kg of active ingredient per ha. However, with the benefits, there are problems. A few resistant weeds were recognized in the 1970s, but today, in 2021, 521 unique cases of resistance have been documented throughout the world. It is imperative for farmers to rethink the herbicide paradigm and for researchers to explore and provide alternative weed management methods so that today's herbicides maintain efficacy and benefits into the future. Near-term management strategies include going back to more integrated approaches, employing mechanical mechanisms, and linking to new technologies to hit weeds with 'many little hammers' rather than the 'sledge hammer' of one or multiple herbicides.

INTRODUCTION TO THE CURRENT WEED RESISTANCE PROBLEM

There are many reasons why herbicides were widely and quickly adopted when introduced in the late 1940s and early 1950s. These include their cost/benefit ratio, convenience, labor saving, fast application methods and plant demise, high selectivity between crop and weed, and high efficacy. With multiple applications of the same herbicide annually, a few resistant weeds were documented [spreading dayflower (*Commelina diffusa*)

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(Hilton, 1957), wild carrot (*Daucus carota*) (Whitehead & Switzer, 1963) to auxin mimic herbicides, common groundsel (*Senecio vulgaris*) (Ryan, 1970) to triazine herbicides] through the first 20 years of intense herbicide use. Many of the resistant biotypes were considered anomalies, rather than substantial threats to crop production, as they were less robust (e.g. produced few seeds, grew slower etc.) than the susceptible biotype (Holt &Thill, 1994). In about 1982, acetolactate synthase (ALS) inhibitor herbicides and acetyl coenzyme A carboxylase (ACCase) inhibitor herbicides were introduced, and the types and extent of herbicide resistant weeds escalated (Powles and Holtum, 1994).

The numbers of unique cases of resistance (521 as of this writing) (Figure 1) and the number of herbicides sites of action that are compromised (23 out of 26) have been on a sharp incline since the early 1980's (Heap, 2021; Heap and Duke, 2018; Pieterse, 2010; Liu et al., 2019; Bo et al., 2019; Ruzmi et al., 2017; Heap, 2014; Baltazar, 2017; Owen et al., 2013). Across the globe, herbicide resistant weeds have been reported in 94 crops, including grains, vineyards and orchards, and vegetables, in 71 countries and includes 263 species (152 dicots and 111 monocots) (Heap, 2021). The ALS inhibitor mode-of action herbicides (e.g. sulfonylureas and imidiazlinones) have the largest number of cases (164 total; 100 dicotyledonous and 64 monocotyledonous species) with triazines having the second largest number of resistant cases (74). The number of weed species with multiple resistance (having resistance to two or more herbicide modes-of-action) is 110, with 74 resistant to two modes-of-action. Around the world, the most problematic weed species are crop-, country-, or region-specific (Pieterse, 2010; Owen et al., 2013; Heap, 2014, 2021; Green, 2014; Legleiter and Johnson, 2015; Ruzmi et al., 2017; Baltazar, 2017; Sarangi and Jhala, 2018; Liu et al., 2019).

Because weeds cross field, regional, and international boundaries, it is difficult to say if cases are *de novo* and unique or due to movement of weed seeds (annual and biennials) or perennating structures or seeds (in the case of perennials). For example, kochia (*Bassia scoparia* formerly *Kochia scoparia*) disperses seed by tumbling in the wind, if the biotype is herbicide resistant and is wind-blown throughout the area, multiple state/regions could report resistance to the same herbicide. In another example, Palmer amaranth (*Amaranthus palmeri*) was introduced from one area to another in hog (*Sus scrofa domesticus*) manure, resistance was not selected for in the new area where it was spread, but rather from the area of origin (Van de Stroet and Clay, 2019). Understanding the mechanism(s) of resistance (eg. specific changes in target enzyme that do not allow for herbicide binding, degradation or conjugation of the herbicide in the plant, sequestration into the vacuole so it cannot reach the target, etc.) (Vencill et al., 2012; Gaines et al., 2020) aids in understanding if resistance within a species in a new area is a new selection or perhaps related to other biotypes.

Depending on the density and emergence timing, weed infestations can result in complete loss of crops or loss of harvestability (Figure 2). Herbicide resistant problems further complicate weed management because the weeds are not controlled by the chosen method and continue future infestations due to weed seed dispersal into the soil seed bank. In addition, if present in no-till systems, these may need to be reverted to tillage for control (Shaw et al., 2012; Lee et al., 2014; Shaw et al., 2020). The economic impact of resistant weeds is in the billions of dollars (Hartzler, 2009, 2017; Kniss, 2015; Livingston et al., 2015; Kansas State University, 2016; Bo et al., 2019). Costs include increased competitive losses, increased herbicide use, paying for additional crop seed trait technology in order to use efficacious herbicides, harvest losses, and additional labor, time, and equipment, all of which reduce farm revenue. For example in 2011, it was estimated that resistant weeds in Tennessee soybean (*Glycine max*) increased herbicide costs by about \$40 ha^{-1} and yield loss by 17% which added up to about $104 million for that year and area alone (quoting Steckel, Brandon, H., Farm Press Blog, 2/25/2011).

Only a few techniques brought about resistance problems, i.e. little or no rotation of herbicide mode-of-action or cropping system, which selected resistant weed biotypes. Multiple management changes that link biodiversity and sustainability are needed to combat weed impacts (Colbach et al, 2020). Weed communities can be manipulated based on cropping system (Juarez-Escario et al., 2017), and these techniques can aid in alleviating the problem (Norsworthy et al., 2012; Westwood et al., 2018; Gage et al., 2019).

2 GROWER PERCEPTION OF WEED RESISTANCE

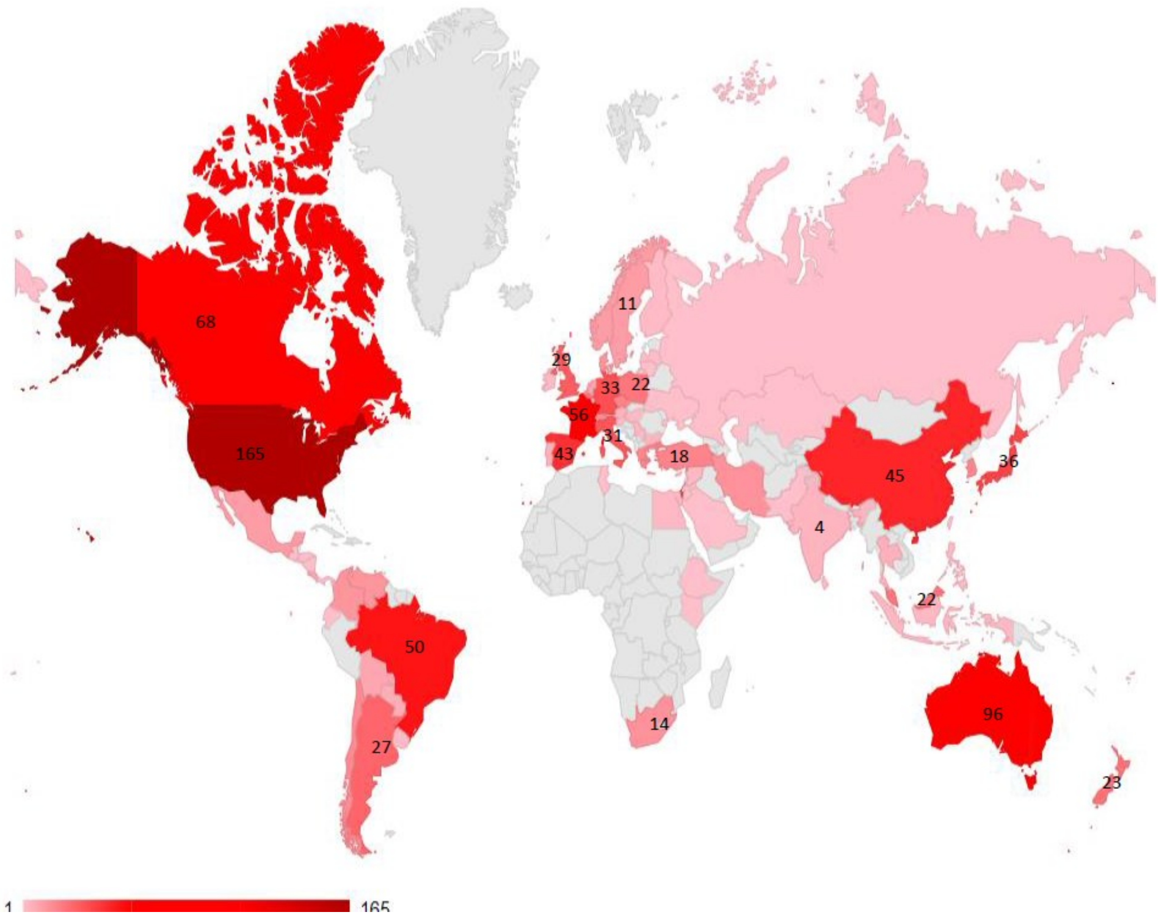

Figure 1. Reported numbers of herbicide resistant weeds by country as of the writing of the paper (Heap, 2021)

Figure 2. An example of the impact of resistant weeds in a crop. This is glyphosate resistant waterhemp (*Amaranthus tuberculatus*) in a soybean (*Glycine max*) crop (Crop treated twice with post-emergence applications of glyphosate prior to taking the picture).

While researchers have been quite concerned about weed resistance to herbicides, action ultimately must be taken by producers. Are producers concerned and aware about weed resistance? What are their thoughts about the problem? What do they see as future management issues and actions to address weed resistance? Is there critical information that needs to be provided or is missing? There have been studies that have investigated U.S. producer and crop advisor attitudes toward the awareness and response to weed resistance (Givens et al., 2011; Asmus et al., 2013; Prince et al., 2012a and 2012b; Ervin & Frisvold, 2016; Sarangi & Jhala, 2018). Most of these surveys have been specific for glyphosate-resistant weeds, so it is unclear if producers understand the threat of weed resistance to other herbicides. However, these studies highlight the complexity of the issue and difficulties that face establishment of more diverse management strategies.

Survey data indicate that US producers (88% in 2005 and 97% in 2010) are aware that resistance to at least one herbicide mode-of-action (glyphosate) occurs (Givens et al, 2011; Prince et al., 2012a and b). Despite this awareness, glyphosate-resistant crops are widely adopted and grown (about 90% of U.S. corn (*Zea mays*), cotton (*Gossypium hirsutum*), and soybean acreages use glyphosate resistant crops) (USDA-ERS, 2016). The seriousness of glyphosate weed resistance was rated as high by about 50% of producers and not serious by 30% (Prince et al., 2012a) but there was a regional difference. Only 18% of the eastern or western producers rated glyphosate-resistant weeds as 'very serious' whereas 45% of southern producers ranked these as serious.

In a 2010 survey of U.S. Certified Crop Consultants (CCA) (n=1700 respondents) formally reported by Asmus et al. (2013) [and repeated in 2016, n=350 (unpublished data)], about 45% of the respondents in each survey stated that the perceived level of weed resistance (not specific to glyphosate) was moderate. This response was similar across all regions. However, 28% of South/Southeastern CCA respondents stated that the level of resistance was high or epidemic, whereas no Northeastern and Western respondents felt there were epidemic levels of resistance, and only about 9% of all respondents felt the level of resistance was high. These data mirrored the producer data reported by Prince et al. (2012a). In a more recent Nebraska producer survey (Sarangi and Jhala, 2018), 60% of 425 respondents stated that they had glyphosate resistant weeds present on their farms.

When asked about what was the current grower response to resistant weeds (Asmus et al, 2013 and unpublished survey, 2016), about 50% of the CCA respondents in each survey stated that growers would only adopt best management practices (BMPs) for resistant weeds when the weed resistance was in their field. About 30% said that growers would be open to discussions about the BMPs, but typically, the added cost and effort stops them from implementing nonherbicidal practices. Clearly, herbicide applications and the herbicide paradigm remain the usual weed control treatment due to their low cost, ease of use, low labor requirements, crop safety, and their ability to still be efficacious to many weeds at many stages of weed growth. In fact, in these surveys, >50% of the CCA responses asking about '*what would be the most effective tools to reduce resistant weeds*' mentioned herbicide application for control of resistant weeds, whether it be rotating herbicides (16%), tank mixing herbicides or using herbicide formulations with multiple modes of action herbicides (26%), using preemergent residual chemicals (14%), or better herbicide application timing (3%). These practices were typical for the Nebraska producers (Sarangi and Jhala, 2018), where preemergent herbicides were used on an average of 65% of the farms and 80% were using postemergent herbicides. The CCAs also stated that other practices, which included rotating crops (16%), tillage (6%), and education (4%), were being used by producers. USDA-ERS (2016) reported that US corn and soybean farmers were scouting for weeds (almost 95%), rotating herbicides (about 50%), using tillage (about 70%), cultivating for weed control (10%) and mowing field edges (about 40%).

3 SUGGESTED SOLUTIONS

The unifying factor worldwide is that tactics to slow resistance are needed so that herbicides continue to be useful tools for agronomic production (Powles et al., 1996; Westwood et al., 2018; Shaw et al., 2020). There is no one management strategy that will take the place of herbicides, nor return weeds to a nonresistant condition (at least at this time). We would all like to imagine solutions that are similar in the positive aspects of herbicide application with the same cost/benefit ratio. Today and for the near future (10 yr) new herbicides with different sites of action to replace or improve herbicides that are used today may not be realistic (Duke and Dayan, 2015). What is anticipated is that if weed management practices remain status quo, resistant weeds will continue to spread and new resistant cases will be added to the (already) long list. Beckie (2020) states that "The ongoing challenge is development of user-friendly and cost-effective technologies or systems that can be easily integrated into existing farming enterprises". This is a great summation, but what are the suggested methods that can be implemented now, and in the near future, for integration to stop or slow the spread of resistance, or control the already resistant weeds? Beckie et al. (2019) and others (Shaw et al., 2020; Green, 2014; Asmus et al., 2013; CropLife International, 2012) have reviewed some of the trends and developments in managing resistance problems. Most consist of using multiple, diversified approaches (e.g. 'many little hammers') (Liebman and Gallandt, 1997; Fisher, 2012) with integrated weed management approaches (IWM) (Swanton and Weise, 1991; Buhler, 2002; Appleby, 2005; Harker and O'Donovan, 2013; Beckie and Harker, 2017) suggested to be used in strategic combinations rather than relying on a single method. Producers often are reluctant to adopt many IWM strategies due to increased costs, confusion about what will work, and lesser efficacy of the tactics (Moss, 2019). Specific recommendations and their implementation success will vary by producer, crop, region, and target weed(s) (Nakka et al., 2019; Al-Khatib et al., 2019).

Waiting for new, unique herbicides that will control the multitude of resistant weeds is a poor option. From 1950 to 1985, herbicides having 26 different modes of action had been commercialized, however, from 1985 to 2015 no new modes of action herbicides had been commercialized (Duke and Dayan, 2015). In addition, as mentioned above, each area of the globe has different resistant weed profiles in many diverse crops. Controlling grasses in grass crops or broadleaves in broadleaf crops is a difficult challenge. Because of the success and relatively inexpensive method of using herbicides such as glyphosate and glufosinate, the impetus of finding new chemistries has been low. Since weed resistance has become so wide-spread, there is renewed interest in finding new synthesized herbicides with different modes of action, as well as using natural products (e.g. citric acid, clove oil, gluten meal, pine oil, and others) (Abouzina, et al., 2009; Young, 2004). The efficacy, as well as crop, human, and environmental safety issues, and cost are factors that must be considered. At the same time, stewardship of any new chemical or herbicide resistant crop (such as auxin-tolerant soybean) is imperative so that new selections of resistance weeds are minimized.

Preventing resistant weeds from becoming established is best in the long term. However, there are many ways in which resistant species can become established, and often the threat is not recognized until it is widespread. Equipment sanitation, maintaining clean seed and clean feed are ways to prevent introduction of weed problems. For example, having clean equipment would limit weed movement. In the U.S. and Canada, custom combine crews start in the southern US and move north for grain harvest. Cleaning combines thoroughly to not move seeds, such as Palmer amaranth, can be time consuming but is a first line of defense against new infestations (Anderson et al., 2018). Movement of animals, spreading manure containing resistant weed seeds, or bringing in contaminated feed or bedding are other, sometimes unexpected, ways to introduce resistant weeds into areas (Modderman, 2020).

Early detection and rapid response with appropriate control measures need to be implemented to quickly stop problems from spreading (National Invasive Species Council, U.S. Dept. of the Interior, https://www.doi.gov/invasivespecies/early-detection-and-rapid-response). This implies that producers and land managers understand what species are typically present, which have become more problematic, and what new threats are present. In the 2010 survey (Prince et al., 2012a), about 69% of the surveyed group in the East and South were aware of glyphosate-resistance weeds in their state, but at the county level only about 38% were aware of the local threat. This means that there are opportunities to better educate producers about local threats to better detect and begin control in a timely manner.

Controlling escaped weeds is integral for both near- and long-term agronomic management and productivity. In the near-term, poor control leads to yield loss and weed seed addition to the seed bank. In the long-term, higher weed densities occur, and there can be even greater yield loss. Weeds not controlled by an herbicide application may have been skipped due to poor application, herbicide tolerant (not well controlled by the herbicide even before it was applied), or herbicide resistance. Escaped weeds can be challenging and their presence leads to more labor and time needed per field. When recognized, they are often large and may be beyond ideal application size. Controlling escaped weeds, however, is crucial to limit crop yield loss, and stop/hinder seed production, in order to prevent further spread and increase in seed banks (Scursoni et al., 2007) that may maintain resistant genotypes.

Another suggested tactic to combat herbicide resistance is to use more herbicide. Yes, this seems counterintuitive. However, applying preemergence residual herbicides for early season weed control followed by a postemergence application with different modes/sites of action rather than relying on a single application is becoming common practice (Sarangi and Jhala, 2018). These combinations are used to overlap control for the one or two weeds in a field that are the most important (because of high abundance or the ability of a low plant density to reduce yield) (i.e. 'driver' weeds) also is suggested (Legleiter and Johnson, 2015).

The development of new herbicide-resistant crops (e.g. glufosinate resistant crops; auxin resistant soybean; acetolactate synthase-tolerant sugar beets) (Lobmann et al., 2019) have both led to new applications of 'old' chemistries in different crops. The impacts of GMO crop advances on the environment have been positive (e.g. increased no-till acres, reduced greenhouse gas emissions) and negative (e.g. increased chemical use, herbicide resistant weed species) (Aslam and Gul, 2020; Brookes and Barfoot, 2011, 2017; Carpenter, 2011; Lee et al., 2014).

The application of auxin (particularly dicamba) in soybean has helped in control or resistant waterhemp (*Amaranthus tuberculatus*), although in some cases, led to new social problems due to drift issues (Lancaster et al. 2020).

Mechanical methods, such as mowing, flooding, tillage, flaming, grit application, and controlling weed seed at harvest can also be used to reduce weed populations. Just as with herbicide applications, timing and number of treatments needed for acceptable control are important considerations (Ulloa et al., 2010; Cordeau et al., 2017; Erazo-Barradas et al., 2018). Depending on the technology involved, the machines can be expensive (having machine vision, controllers, and computers for guidance and making on-the-go decisions) (Kennedy et al., 2020), and time consuming (due to slow travel speeds) (Ulloa et al., 2010; Erazo-Barradas et al., 2018; Kennedy et al., 2020). Mechanical innovations including drones, robotics devices (e.g. Robovator, Steketee, Teretill) and artificial intelligent (AI) technologies that recognize target weeds in the crop, will be integrated into future weed control strategies (Young et al., 2014; Westwood et al., 2018; Steward et al., 2019). These tools, while in limited use today, may be the norm in the future to assist in field scouting, or conduct site-specific management whether it be such as weed cutting, herbicide application, or precision tillage (Pitla et al., 2020). Training of future agronomists with the knowledge, skills, and abilities in AI and computer sciences, blended with agronomic understanding is needed from both the ag engineering and agronomic perspectives to make these new technologies seamless in day-to-day operations (Erickson et al., 2018).

To reduce additions to the weed seed bank, the Harrington Weed Seed Destructor has been developed. It is a machine with a hammer mill type device fitted to the combine that crushes or abrades the seed, reducing or eliminating viability (Walsh et al., 2012 and 2013; Schwartz-Larzaro et al., 2017). This method has been shown to be effective using weed seed incorporated into chaff and processing the chaff using varying amounts, system feeding rates, and moisture levels (Schwartz-Larzaro et al., 2017). This method assumes that seed shattering from the weed does not occur prior to crop harvest. Windrow burning, and bale and/or chaff removal also may be effective tactics to reduce seed numbers in infested fields (Walsh and Newman, 2007).

Use other non-chemical weed management options, of which there are many (Melander et al., 2017). This includes cultural control methods such as correct fertility, other pest management strategies, planting optimal densities, and choosing appropriate row widths to maximize crop growth and obtain early row closure to outcompete weeds. Crop-weed interference can be used to a producer's advantage. Planting weed suppressive varieties (Martin et al., 2007; Williams, 2015; Boydston and Williams, 2015; Watkins et al., 2018) or crops that are crowd-stress tolerant at optimum planting density and timing (Dhaliwal and Williams, 2020; Korres et al., 2020) can help maintain yields in the presence of weeds. Suppressive plants typically have a faster growth rate and a greater leaf area with ultimately greater resource capture earlier in the season, and early canopy and late canopy factors, such as greater plant height, and leaf area index. These factors can help in inhibiting, although not eliminating, weed growth and seed production (Martin et al., 2007; So et al., 2009). The downside to early canopy closure can be increased disease incidence, which is important to also consider (McDonald et al., 2013).

Plant smother crops, perennial crops that are cut for forage multiple times a year, or competitive cover crops can be used for control. Some weeds (like kochia) have short-lived seed and if the seed bank is depleted, some of the resistant weeds will be less problematic. The key is to have a competitive crop which minimizes weed growth and cut/remove before the weeds (or the crop) develop viable seed (Clay and Aguilar, 1998). Using cover crops, with or without allelochemicals (Haig, 2008), as a living crop or for residual mulches have been reported to reduce weeds in some studies (Mennan et al., 2020; Davis 2010; Lemessa and Wakjira, 2014; Teasdale et al., 2007). However, consistency across climate regimes and cropping systems, along with other factors [species used, allelopathic chemical content, establishment technique (e.g. drill vs broadcast) and timing (early, mid, or late season seeding), amount of cover crop biomass present, and termination timing] are still actively being researched (Kumar et al., 2020; Haramoto et al., 2020; Bich et al., 2014).

Hand weeding is a backache and is still used extensively in small land-holder farms in Africa (Gianessi, 2009; Grabowski and Jayne, 2016), Asia (Rice Knowledge Bank, n.d http://knowledgebank.irri.org/step-by-step-production/growth/weed-management/manual-and-mechanical-weeding) and in organic farming situations (Fennimore, 2014; Smith, 2017). The low number of herbicide resistant weeds throughout much of Africa (except South Africa, Pieterse, 2010) may be a combination of limited herbicide use and prevalent use of hand labor for weed control. The time needed, effort, and cost of manual labor is high (Fennimore, 2014) with one hectare of weeding taking hours, compared to minutes for different mechanical and spraying technology practices.

4 FUTURE OUTLOOK

As we better understand weed ecology and biology (Baucom & Holt, 2009) and as genetic sequencing and manipulation of the crop and weed genomes become routine, other possibilities for weed management are being developed (Westwood et al., 2018). For example, silencing resistant genes to restore herbicide efficacy through RNA interference (RNAi) has been proposed (Baduel, 2015). This concept has been discussed, and perhaps in the future it may be developed as a control alternative, but to date, it is still more conceptual than reality. Introduction of male sterility genes to reduce seed production (Gressel, 2012;

Wu et al., 2016), application of micropeptides to interfere with plant growth (Yeasmin et al., 2018; https://www.micro-pep.com/#, accessed 3/2021), and remodeling of specific regions of crop genes to make them unresponsive to weed presence (Horvath et al., 2015; Horvath et al., 2019), especially during the critical weed-free period, are other methods that, while looking futuristic today, are current projects that are in progress in the search of better crops and weed management.

For the near-term (10- to 15 yr), using integrated techniques from planting to after harvest will continue to be key to aid in maximizing yield and reducing the impact of weeds in general. As producers see greater problems with resistance in their production areas, more utilization of a diverse set of well documented techniques, as well as new innovations will evolve. Because weed resistance has already crossed field, county, regional, national, and international boundaries, community-based approaches to control, based on previously developed models for pest eradication (Caplat et al., 2012) or areawide invasive species management (Smith and Sheley, 2012) are being explored (Ervin and Frisvold, 2016). These methods require coordination and cooperation of all land managers in the area, using strong leadership, industry support (https://www.cropscience.bayer.us/learning-center/articles/zero-tolerance-weed-control-weed-control-a-million-to-1), producer buy-in, as well as, carrot (government help, subsidies, and resources) and stick (regulatory penalties) approaches (Ransom and Whitesides, 2012; Ervin and Frisvold, 2016). Some programs have been implemented, such as the Zero Tolerance program in Arkansas to deal with Palmer amaranth, where the problem has been severe. In areas with less acute issues, the participation in these types of approaches will most likely be limited until the weed is a direct threat to the producer (Asmus et al., 2013; Moss, 2019).

Weed science has come a long way from a control science with herbicides (Zimdahl, 2010) to a better understanding of weed/crop competition, weed biology, weed ecology, (Baucom &Holt, 2009) and genomics (Westwood et al., 2018). However, there are still challenges to overcome. Unfortunately, some type of unwanted plants will be present in crops in the future. When glyphosate-resistant soybean (followed by glyphosate-resistant corn) was introduced into South Dakota in the late 1990's, I was told my job as a weed scientist was no longer needed. Today, it appears that the knowledge, skills, and abilities of weed scientists, agronomists, plant physiologists, geneticists, crop production specialists, soil scientists, computer scientists, and others involved in agronomic production are still relevant and critical. The challenge is to continue to develop innovative, and sustainable weed management practices (Colbach et al., 2020) and through extension, advise land managers of these management options, in order to maintain crop production and biodiversity in the face of herbicide resistant weeds and other agronomic obstacles.

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REFERENCES

Abouziena, H.F.H., Omar, A.A.M., Sharma, S.D. & Singh, M. (2009). Efficacy comparison of some new natural-product herbicides for weed control at two growth stages. *Weed Technology*, **23,** 431-437.

Al-Khatib, K., Eckert, J.W., & Fischer, A. (2019). Integrated weed management. In: Agriculture: Rice Pest Management Guidelines online Integrated Weed Management / Rice /

Agriculture: Pest Management Guidelines / UC Statewide IPM Program (UC IPM) (ucanr.edu) (accessed 1/2021)

Anderson, M., Jarek, K., Johnson, A., Ohnesorg, W., & Hanna, M. (2018). Recommended procedures for a end-of-season combine cleanout. North Central Agriculture and Natural Resource Academy. Online at: https://agfaxweedsolutions.com/wp-content/uploads/2018/11/End_of_Season_Combine_Clean_out_Fact_Sheet_1_.pdf (accessed 1/2021)

Appleby, A.P. (2005). A history of weed control in the United States and Canada – A sequel. *Weed Science*, **53**, 762-768.

Aslam, S., & Gul, N. (2020). Impact of genetically modified crops on the environment. Pg. 237-248. In: Environmental Process and Management. Tools and Practices. Eds. Singh, R.M., Shukla, P., and Singh, P. Springer Nature Switzerland

Asmus, A., Clay, S.A., & Ren, C. (2013). Summary of certified crop advisors' response to a weed resistance survey. *Agronomy Journal*, **105**, 1160-1166.

Baduel, P. (2015). RNA interference technology could reduce weeds' resistance to herbicide but questions remain. Online. https://geneticliteracyproject.org/2015/09/30/rna-interference-technology-could-reduce-weeds-resistance-to-herbicide-but-questions-remain/ (accessed 1/2021)

Baltazar, A.M. (2017). Herbicide-resistant weeds in the Philippines: Status and resistance mechanisms. *Weed Biology and Management*, **17**, 57-67.

Baucom, R.S., & Holt, J.S. (2009) Weeds of agricultural importance: bridging the gap between evolutionary ecology and crop and weed science. *New Phytologist*, **184,** 741-743.

Beckie, H.J. (2020) Herbicide resistance in plants. *Plants*, **9**, 435 4 pages. Doi:10.3390/plants9040435.

Beckie, H.J., Ashworth, M.B., & Flower, K.C. (2019). Herbicide resistance management: Recent developments and trends. *Plants*, **8**, 161 doi:10.3390/plants8060161.

Beckie, H.J., & Harker, K. N. (2017). Our top 10 herbicide-resistant weed management practices. *Pest Management Science*, **73**, 1045-1052.

Bich, A.D., Reese, C.L., Kennedy, A.C., Clay, D.E., & Clay, S.A. (2014). Corn yield is not reduced by mid-season establishment of cover crops in northern Great Plains environments. *Crop Management*, **13**, 1-8.

Bo, A.B., Jeong, I.H., Won, O.J., Jia, W., Yun H., Khaitov, B., Le, T.H., Umurzokov, M., Ruziev, F., Lim, M.J., Cho, K.M., Park, K.W., & Lee, J.J. (2019). Current status and agronomic aspects of herbicide resistance in Korea. *Korean Journal of Agricultural Science*, **46**, 405-416.

Bo, A.B., Won, O.J., Sin, J.T., Lee, J.J., & Park, K.W. (2017). Mechanisms of herbicide resistance in weeds. *Korean Journal of Agricultural Science*, **44**, 1-15

Boydston, R.A. & Williams, M. (2015). Sweet corn hybrid tolerance to weed competition under three weed management levels. *Renewable Agriculture and Food Systems*, **31**, 281-287.

Brookes, G. & Barfoot, P. (2011). Global impact of biotech crops: Environmental effects 1996-2009. *GM Crops & Food*, **2**, 34-49 https://doi.org/10.4161/gmcr.2.1.15529

Brookes, G. & Barfoot, P. (2017). Environmental impacts of genetically modified (GM) crop use 1996–2015: Impacts on pesticide use and carbon emissions. *GM Crops & Food*, **8**, 117-147.

Buhler, D.D. (2002). Challenges and opportunities for integrated weed management. *Weed Science*, **50**, 273-280.

Caplat, P., Coutts, S., & Buckley, Y.M. (2012). Modeling population dynamics, landscape structure, and management decisions for controlling the spread of invasive plants. *Annuals New York Academy of Science*, **1249**, 72-83.

Carpenter, J.E. (2011). Impact of GM crops on biodiversity. *GM Crops & Food*, **2**, 7-23.

Clay, S.A., & Aguilar, I. (1998). Weed seedbanks and corn growth following continuous corn or alfalfa. *Agronomy Journal*, **90**, 813-818.

Colbach, N., Petit, S., Chauvel, B., Deytieux, V., Lechenet, M., Junier-Jolain, N., and Cordeau, S. (2020). The pitfalls of relating weeds, herbicide use and crop yield: Don't fall into the trap! A critical review. *Frontiers in Agronomy*, **2**, Article 615470. 14 pages.

Cordeau, S., Smith, R.G., Gallandt, E.R., Brown, B., Salon, P., DiTommaso, A., & Matthew, R.R. (2017). Timing of tillage as a driver of weed communities. *Weed Science*, **64**, 504-514.

CropLife International. (2012). Implementing integrated weed management for herbicide tolerant crops. 62 pg. online https://croplife.org/wp-content/uploads/2014/04/Implementing-Integrated-Weed-Management-for-Herbicide-Tolerant-Crops.pdf (accessed 1/2021)

Davis, A.S. (2010). Cover-crop roller–crimper contributes to weed management in no-till soybean. *Weed Science*, **58**, 300-309.

Dhaliwal, D., & Williams II, M.M. (2020). Understanding variability in optimum plant density and recommendation domains for crowding stress tolerant processing sweet corn. *PLoS One*, **15**(2):e0228809. https://doi.org/10.1371/journal.pone.0228809.

Duke, S.O., & Dayan, F.E. (2015). Discovery of new herbicide modes of action with natural phytotoxins. Pg 79-92. In: Discovery and Synthesis of Crop Protection Products. ACS Symposium Series Vol. 1204. https://pubs.acs.org/doi/10.1021/bk-2015-1204

Erickson, B., Fausti, S.W., Clay, D., and Clay, S. (2018). Knowledge, skills, and abilities in the precision agriculture workforce: An industry survey**.** *Natural Science Education*, **47**, pg 1-11.

Ervin, D.E., & Frisvold, G.B. (2016). Community-based approaches to herbicide-resistant weed management: Lessons from science and practice. *Weed Science*, **64 (Sp1),** 609-626.

Erazo-Barradas, M., Forcella, F., Humburg, D., & Clay, S.A. (2018). Propelled abrasive grit for weed control in organic silage corn. *Agronomy Journal*, **110**, 632-637.

Fennimore, S. (2014) The role of hand weeding in weed management. UC Weed Science. https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=14405 (accessed 1/ 2021)

Fisher, M. (2012). Many little hammers: Fighting weed resistance with diversified management. CSA news. Pg 4-10. https://www.agronomy.org/files/publications/csa-news/many-little-hammers.pdf (agronomy.org) (accessed 1/2021)

Gage, K.L., Krausz, R.F., & Walters, S.A. (2019). Emerging challenges for weed management in herbicide-resistant crops. *Agriculture*, **9**, 180 (11 pages)

Gaines, T.A., Duke, S.O., Morran, S., Rigon, C.A.G., Tranel., P.J., Kupper, A., & Dayan, F.E. (2020). Mechanisms of evolved herbicide resistance. *Journal of Biological Chemistry*, **295**, 10307-10330.

Gianessi, L. (2009). Solving Africa's weed problem: Increasing crop production and improving the lives of women. CropLife Foundation December 2009. 37 pages. https://croplifefoundation.files.wordpress.com/2012/05/solving-africas-weed-problem-report1.pdf

Givens, W.A., Shaw, D.R., & Newman, M.E. (2011). Benchmark study on glyphosate-resistance cropping systems in the USA. III. Grower awareness, information sources, experiences, and management practices regarding glyphosate-resistant weeds. *Pest Management Science*, **67**, 758-772.

Grabowski, P., & Jayne, T.S. (2016). Analyzing trends in herbicide use in sub-Saharan Africa. Feed the Future Innovation Lab for Food Security Policy Research Paper 16. East Lansing: Michigan State University. Analyzing Trends in Herbicide Use in sub-Saharan Africa - Feed the Future Innovation Lab for Food Security Policy (msu.edu) 25 pg. (Accessed 01/2021)

Green, J.M. (2014). Current state of herbicides in herbicide-resistant crops. *Pest Management Science,* **70**, 1351-1357.

Gressel, J. (2012). Containing and mitigating transgene flow from crops to weeds, to wild species, and to crops. Pg 509-523. In Plant Biotechnology and Agriculture. Prospects for the 21st Century. Altman, A. and Hasegawa, P.M. (eds). Science Direct, Elsevier Inc.

Haig, T. (2008) Allelochemicals in Plants. Pg 63-104. In: Zeng R.S., Mallik A.U., Luo S.M. (eds) Allelopathy in Sustainable Agriculture and Forestry. Springer, New York, NY. https://doi.org/10.1007/978-0-387-77337-7_4

Haramoto, E.R., Lowry, C.J., & Pearce, R. (2020). Cover crops are not affected by tobacco soil residual herbicides but also do not provide consistent weed management benefits. *Weed Technology*, **34,** 383-393

Harker, K.N. & O'Donovan, J.T. (2013). Recent weed control, weed management, and integrated weed management. *Weed Technology*, **27**, 1-11.

Hartzler, B. (2009) The cost of convenience: The impact of weeds on crop yields. Proceedings of the 21st Annual Integrated Crop Management Conference, 11, pg 71-74.

Hartzler, B. (2017). The cost of herbicide resistance. Integrated Crop Management. Iowa State University Extension and Outreach. (online https://crops.extension.iastate.edu/blog/bob-hartzler/cost-herbicide-resistance) (accessed Dec 2020)

Heap, I. (2014). Global perspective of herbicide-resistant weeds. *Pest Management Science*, **70**, 1306-1315.

Heap, I., (2021). International Herbicide Resistant Weed Database. Online. Tuesday, March 23, 2021 . Available www.weedscience.org.

Heap, I. & Duke, S.O. (2018). Overview of glyphosate-resistant weeds worldwide. *Pest Management Science,* **74**, 1040-1049.

Hilton, H.W. (1957). Herbicide tolerant strains of weeds. Honolulu, HI: Hawaiian Sugar Planters Association Annual Rep. pg. 69-72.

Holt, J.S., & Thill, D.C. (1994). Growth and productivity of resistant plants. Pg. 299-316. In: Powles, S.B. & Holtum, J.A.M. (eds) Herbicide Resistance in Plants: Biology and Biochemistry. CRC Press, Boca Raton, FL.

Horvath, D.P., Bruggeman, S.A., Moriles-Miller, J., Pierik, R., Yan, C., Clay, D.E., Scheffler, B., & Clay, S.A. (2015). RNAseq reveals weed-induced PIF3-like as a candidate target to manipulate weed stress response in soybean. *New Phytologist*, **207**, 196-210.

Horvath, D.P., Clay, S.A., Bruggeman, S.A., Anderson, J.V, Chao, W.S., & Yeater, K. (2019). Varying weed densities alter the corn transcriptome, highlighting a core set of weed-induced genes and processes with potential for manipulating weed tolerance. *The Plant Genome*, **12**, 1 of 9. doi: 10.3835/plantgenome2019.05.0035.

Juarez-Esacario, A., Conesa, J.A., & Sole-Senan, X.O. (2017). Management as a driver of functional patterns and alien species prominence in weed communities of irrigated orchards in Mediterranean areas. *Agriculture, Ecosystems, and Environment*, **249**, 247-255.

Kansas State University. "Left uncontrolled, weeds would cost billions in economic losses every year." ScienceDaily. ScienceDaily, 16 May 2016. <www.sciencedaily.com/releases/2016/05/160516130720.htm>. (accessed 1/2021)

Kennedy, H., Fennimore, S.A., Slaughter, D.C., Nguyen, T.T., Vuong, V.L., Raja, R., & Smith, R.F. (2020). Crop signal markers facilitate crop detection and weed removal from lettuce and tomato by an intelligent cultivator. *Weed Technology*, **34**, 342-350.

Kniss, A. (2015). The cost of preventing herbicide resistance. https://plantoutofplace.com/2015/11/the-cost-of-preventing-herbicide-resistance/ 4 pg. Accessed Dec. 2020.

Korres, N.E., Norsworthy, J., Mauromoustakos, A., Williams II, M.M. (2020). Soybean density and Palmer amaranth (*Amaranthus palmeri*) establishment time: effects on weed biology, crop yield and production cost. *Weed Science*, **68**, 467-475. https://doi.org/10.1017/wsc.2020.41.

Kumar, V., Obour, A., Jha, P., Liu, R., Manuchehri, M.R., Dille, J.A., Holman, J., & Stahlman, P.W. (2020). Integrating cover crops for weed management in the semiarid U.S. Great Plains: opportunities and challenges. *Weed Science*, **68**, (In press) DOI: 10.1017/wsc.2020.29

Lancaster, S., Griffin, T., Coffey, B., Wood, D., & Goeringer, P. (2020) Farmers' dilemma: Social aspects of weed management decisions. Kansas State University Extension Publication. AgManager.info 8 pgs. https://agmanager.info/production-economics/production-publications/farmers-dilemma-social-aspects-weed-managementm (accessed 3/2021)

Lee, S., Clay, D.E., & Clay, S.A. (2014). Impact of herbicide tolerant crops on soil health and sustainable agriculture crop production. Pg 211- 236 In: Convergence of Food Security, Energy Security, and Sustainable Agriculture, Songstad, D.E., Hatfield, J. and Tomes, D.T. (eds.) Biotechnology in Agriculture and Forestry 67, Springer-Verlag Berlin

Legleiter, T., & Johnson, B. (2015) Giant ragweed should be a driver weed for many Indiana farmers. Purdue Extension. Https://ag.purdue.edu/btny/weedscience (accessed Jan 2021)

Lemessa, F. & Wakjira, M. (2014). Mechanisms of ecological weed management by cover cropping: A review. *Journal of Biological Sciences*, **14**, 452-459.

Liebman, M., & Gallandt, E. (1997) Many little hammers: Ecological management of crop-weed interactions. In: Ecology and Agriculture Jackson, L.E. (ed.) Academic Press.

Liu, X., Xiang, S., Zong, T., Ma, G., Wu, L., Liu, K., Zhou, X., & Bai., L. (2019). Herbicide resistance in China: a quantitative review. *Weed Science*, **67**, 605-612.

Livingston, M., Fernandez-Cornejo, J., Unger, J., Osteen, Schimmelpfennig, D., Park, T., & Lambert, D. (2015). The economics of glyphosate resistance management in corn and soybean production. Economic Research Report No. (ERR-184). 52 pg.

Lobmann, A., Christen, O., & Petersen, J. (2019). Development of herbicide resistance in weeds in a crop rotation with acetolactate synthase-tolerant sugar beets under varying selection pressure. *Weed Research*, **59**, 479-489.

Martin, M.M., Boydston, R.A., & Davis, A.S. (2007). Wild proso millet (Panicum miliaceum) suppressive ability among three sweet corn hybrids. *Weed Science*, **55**, 245-251.

McDonald, M.R., Gossen, B.D, Kora, C., Parker, M., & Boland, G. (2013). Using crop canopy modification to manage plant diseases. *European Journal of Plant Pathology*, **135**, 581-593.

Melander, B., Liebman, M., Davis, A.S., Gallandt, E.R., Barberi, P., Moonen, A.-C., Rasmussen, J., van der Weide, R., & Vidotto, F. (2017). Non-chemical weed management. Pg. 245-270. In: Weed Research: Expanding Horizons. Hatcher, P.E., & Froud-Williams, R.J. John Wiley and Sons, Ltd. Hoboken, NJ

Mennan, H., Jabran, K., Zandstra, B.H., & Pala, F. (2020). Non-chemical weed management in vegetables by using cover crops: A review. *Agronomy*, **257**, 10.3390/agronomy10020257

Modderman, C. (2020). Managing weed seeds in manure. Online: https://www.wisfarmer.com/story/news/2020/10/29/heading-off-weed-infestation-managing-seeds-manure/3650929001/ (accessed 1/2021)

Moss, S. (2019). Integrated weed management (IWM): Why are farmers reluctant to adopt non-chemical alternatives to herbicides? *Pest Management Science*, **75**, 1205–1211.

Nakka, S., Jugulam, M., Peterson, D. & Asif., M. (2019). Herbicide resistance: Development of wheat productions systems and current status of resistant weeds in wheat cropping systems. *The Crop Journal*, **7**, 750-760.

Norsworthy, J., Ward, S., Shaw, D., Llewellyn, R., Nichols, R., Webster, T., Bradley, K.W., Frisvold, G., Powles, S.B., Burgos, N.R., Witt, W.W, & Barrett, M. (2012). Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Science,* **60**(SP1), 31-62. doi:10.1614/WS-D-11-00155.1

Owen, M., Preston, C., & Walker, S. (2013). Resistance rising across Australia. Ground Cover Issue 104- Herbicide Resistance Supplement. https://groundcover.grdc.com.au. Croplife Australia

Pieterse, P.J. (2010). Herbicide resistance in weeds- a threat to effective chemical weed control in South Africa. *South African Journal of Plant and Soil*, **27**, 66-73.

Pitla, S., Bajwa, S., Bhusal, S., Brumm, T., Brown-Brandl, T., Buckmaster, D.R., Condotta, I., Fulton, J., Janzen, T.J., Karkee, M., Lopez, M., Moorhead, R., Sama, M., Schumacher, L., Shearer, S., & Thomasson, A. (2020). Ground and aerial robots for agricultural production: Opportunities and challenges. CAST Issue Paper No. 70. Ames, IA. 20 pgs.

Powles, S.B., & Holtum, J.A.M. (1994). Herbicide Resistance in Plants: Biology and Biochemistry. CRC Press, Boca Raton, FL. 353 pg.

Powles, S.B., Preston, C., Bryan, I.B., & Justum, A.R. (1996). Herbicide resistance: Impact and management. *Advances in Agronomy*, **58**, 57-93.

Prince, J.M, Shaw, Dr. R, Givens, W.A., Newman, M.E., Owen, M.D.K., Weller, S.C., Young, B.G., Wilson, R.G., & Jordan, D.L. (2012a). Benchmark Study: II. A 2010 survey to assess grower awareness of and attitudes toward glyphosate resistance. *Weed Technology*, **26**, 531-535.

Prince, J.M, Shaw, Dr. R, Givens, W.A., Newman, M.E., Owen, M.D.K., Weller, S.C., Young, B.G., Wilson, R.G., & Jordan, D.L. (2012b). Benchmark Study: III. Survey on changing herbicide use patterns in glyphosate-resistant cropping systems. *Weed Technology*, **26**, 536-542.

Ransom, C.V., & Whitesides, R.E. (2012). Proactive EBIPM: establishing weed prevention areas. *Rangelands*, **34,** 35-38.

Ryan, G.F. (1970). Resistance of common groundsel to simazine and atrazine. *Weed Science*, **18**, 614-616.

Rice Knowledge Bank. (n.d.) Manual and mechanical weeding. http://knowledgebank.irri.org/step-by-step-production/growth/weed-management/manual-and-mechanical-weeding (accessed 1/2021)

Ruzmi, R., Ahmad-Hamdani, M.S., & Bakar, B.B. (2017). Prevalence of herbicide -resistant weed species in Malaysian rice fields: A review. *Weed Biology and Management*, **17**, 3-16.

Sarangi, D. & Jhala, A. (2018) A statewide survey of stakeholders to assess the problem weeds and weed management practices in Nebraska. *Weed Technology*, **32**, 642-655.

Schwartz-Larzaro, L.M., Norsworthy, J.K., Walsh, M.J., & Bagavathiannan, M.V. (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.

Scursoni, J.A., Forcella, F., & Gunsolus, J. (2007). Weed escapes and delayed weed emergence in glyphosate-resistant soybean. *Crop Protection*, **26**, 212-218.

Shaw, D.R., Culpepper, S., Owen, M., Price, A., & Wilson, R. (2012) Herbicide-resistant weeds threaten soil conservation gains: Finding a balance for soil and farm sustainability. CAST Issue Paper No. 49. Ames, IA. 16 pgs.

Shaw, D.R., Frisvold, G., Ervin, D.E., Sword, G.A., Jussaume, R.A. (2020) Stewardship challenges for new pest management technologies in agriculture. CAST Commentary QTA2020-2. 24 pgs.

Smith, B., & Sheley, R.L. (2012). Government success in partnerships: the USDA-ARS areawide ecologically based invasive annual grass management program. *Rangelands*, **34**, 17-24.

Smith, R. (2017) Labor, efficiency, and the future of weed control. https://www.growingproduce.com/vegetables/labor-efficiency-and-the-future-of-weed-control/ (Accessed 1/2021)

So, Y.F., Williams, M.M., Pataky, J.K., & Davis, A.S. (2009). Principal canopy factors of sweet corn and relationships to competitive ability with wild-proso millet (*Panicum miliaceum*). *Weed Science*, **57**, 296-303.

Steward, B., Gai, J., & Tang, L. (2019). The use of agricultural robots in weed management and control. In Robotics and automation for improving agriculture, Billingsley, J. (ed). Volume 44 of Burleigh Dodds Series in Agricultural Science Series. Cambridge, UK: Burleigh Dodds Science Publishing. ISBN: 9781786762726. DOI: 10.19103/AS.2019.0056.13.

Swanton, C.J., & Weise, S.F. (1991). Integrated weed management: The rationale and approach. *Weed Technology*, **5**, 657-663.

Teasdale, J. R., Brandsaeter, L.O., Calegari, A., & Neto, F.S. (2007). Cover crops and weed management. Pg 49-64. In: Non-chemical Weed Management: Principles, Concepts and Technology, Upadhyaya, M.K. & Blackshaw, R.E.(eds) CAB International

Ulloa, S. M., Datta, A., Malidza, G., Leskovsek, R., & Knezevic, S. Z. (2010). Yield and yield components of soybean [*Glycine max* (L.) Merr.] are influenced by the timing of broadcast flaming. *Field Crops Research*, **119**, 348-354.

USDA-ERS. (2016). U.S. corn and soybean farmers use a wide variety of glyphosate resistance management practices. https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=78922

Van de Stroet, B., & Clay, S.A. (2019). Management considerations for Palmer Amaranth in a Northern Great Plains soybean production system. *Agrosystems, Geosciences and Environment*, **2**, 190030 doi:10.2134/age2019.04.0030

Vencill, W., Nichols, R., Webster, T., Soteres, J., Mallory-Smith, C., Burgos, N., Johnson, W.G., & McClelland, M. (2012). Herbicide resistance: Toward an understanding of resistance development and the impact of herbicide-resistant crops. *Weed Science,* **60**(SP1), 2-30. doi:10.1614/WS-D-11-00206.1

Walsh, M.J., Harrington, R.B., & Powles, S. (2012). Harrington seed destructor: A new nonchemical weed control tool for global grain crops. *Crop Science*, **52**, 1343-1347.

Walsh, M.J., & Newman, P. (2007). Burning narrow windrows for weed seed destruction. Field *Crops Research*, **104**, 24-30.

Walsh, M.J., Newman, P., & Powles, S. (2013). Targeting weed seeds in-crop: A new weed control paradigm for global agriculture. *Weed Technology*, **27**, 431-436.

Watkins, K.B., Gealy, D.R., Anders, M.M., & Mane, R.U. (2018). Economic analysis of weed-suppressive rice cultivars in flood- and furrow-irrigated systems under reduced herbicide inputs. *Journal of Agricultural and Applied Economics*, **50**, 478-502. Doi:10.1017/aae.2018.9.

Whitehead, C.W. & Switzer, C.M. (1963). The differential response of strains of wild carrot to 2,4-D and related herbicides. *Canadian Journal of Plant Science*, **43**, 255-262.

Williams II, M.M. (2015). Stress test: identifying crowding stress-tolerant hybirds in processing sweet corn. *Agronomy Journal*, **107**, 1782-1788.

Westwood, J.H., Charudattan, R., Duke, S.O., Fennimore, S.A., Marrone, P., Slaughter, D.C., Swanton, C., & Zollinger, R. (2018). Weed management in 2050: Perspectives on the future of weed science. *Weed Science*, **66**, 275-285.

Wu, Y., Fox, T.W., Trimnell, M.R., Wang., L., Xu, R., Cigan, A.M., Huffman, G.A., Garnatt, C.W., Hershey H., & Albertsen, M.C. (2016). Development of a novel recessive genetic male sterility system for hybrid seed production in maize and other cross-pollinating crops. *Plant Biotechnology Journal*, *14*, 1046-1054.

Yeasmin, F., Yada, T., & Akimitsu, N. (2018). Micropeptides encoded in transcripts previously identified as long noncoding RNAs; A new chapter in transcriptomics and proteomics. *Frontiers in Genetics*. Apr 25:**9**:144 https://doi.org/10.3389/fgene.2018.00144 (accessed 3/2021)

Young, S.L. (2004). Natural product herbicides for control of annual vegetation along roadsides. *Weed Technology*, **18**, 580-587.

Young, S.L., Pierce, F.J., & Nowak, P. (2014). Introduction: Scope of the problem – Rising costs and demand for environmental safety for weed control. Pg. 1-8. In: Automation: The Future of Weed Control in Cropping Systems. Young, S. and Pierce, F. (ed) Springer Science Dordrecht.

Zimdahl, R.L. (2010). A History of Weed Science in the United States. Elsevier Inc. https://doi.org/10.1016/C2009-0-63984-2