Integrated Pigweed Management in Soybean and Grain Sorghum

by

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B.S., Iowa State University, 2014
M.S., Kansas State University, 2017

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Abstract

Palmer amaranth and waterhemp are among the most troublesome weeds in Kansas. The continued reliance on a single herbicide site of action has repeatedly resulted in the selection of herbicide resistant biotypes. It is likely that any anticipated future technologies will be met with the same fate as many other herbicides regarding Palmer amaranth and waterhemp if the technology is not implemented as part of an integrated system. An integrated system utilizes cultural, mechanical, and chemical control strategies to reduce the selection pressure on any one part of the system to delay the development of resistance. Field trials were implemented during 2017 and 2018 at three locations in dryland grain sorghum and soybean. The objective was to assess the control of Palmer amaranth or waterhemp with a winter wheat cover crop (CC), narrow row spacing (NRS), row-crop cultivation at 2.5 weeks after planting (WAP), and a comprehensive herbicide program to develop integrated-based management recommendations for dryland grain sorghum and soybean. Sixteen treatments were implemented in each crop to assess all possible combinations of three row spacings (76, 38, and 19-cm), CC, and row-crop cultivation. All treatments containing the herbicide program resulted in excellent Palmer amaranth or waterhemp control; therefore, these treatments were analyzed separately. Row-crop cultivation tended to offer greater than 50% reduction in density and biomass (3 and 8 WAP); whereas, mixed results were observed with CC. In about half of the site-years, CC resulted in 35 to 50% reduction in density and biomass (3 and 8 WAP), no differences were observed in one-fourth of the site-years, and approximately a 50% increase in density was observed in the remainder. The only direct benefit offered from NRS (< 76 cm) was a reduction (about 30%) in 8 WAP biomass. In conclusion, RC reduced the selection pressure placed on pigweed during POST herbicide applications through reductions in density and biomass 3 WAP; whereas RC, CC, and NRS reduced late season biomass which could reduce yield losses and subsequently weed seed production.

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Approved by:

Major Professor
Dallas E. Peterson

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Palmer amaranth and waterhemp are among the most troublesome weeds in Kansas. The continued reliance on a single herbicide site of action has repeatedly resulted in the selection of herbicide resistant biotypes. It is likely that any anticipated future technologies will be met with the same fate as many other herbicides regarding Palmer amaranth and waterhemp if the technology is not implemented as part of an integrated system. An integrated system utilizes cultural, mechanical, and chemical control strategies to reduce the selection pressure on any one part of the system to delay the development of resistance. Field trials were implemented during 2017 and 2018 at three locations in dryland grain sorghum and soybean. The objective was to assess the control of Palmer amaranth or waterhemp with a winter wheat cover crop (CC), narrow row spacing (NRS), row-crop cultivation at 2.5 weeks after planting (WAP), and a comprehensive herbicide program to develop integrated-based management recommendations for dryland grain sorghum and soybean. Sixteen treatments were implemented in each crop to assess all possible combinations of three row spacings (76, 38, and 19-cm), CC, and row-crop cultivation. All treatments containing the herbicide program resulted in excellent Palmer amaranth or waterhemp control; therefore, these treatments were analyzed separately. Row-crop cultivation tended to offer greater than 50% reduction in density and biomass (3 and 8 WAP); whereas, mixed results were observed with CC. In about half of the site-years, CC resulted in 35 to 50% reduction in density and biomass (3 and 8 WAP), no differences were observed in one-fourth of the site-years, and approximately a 50% increase in density was observed in the remainder. The only direct benefit offered from NRS (< 76 cm) was a reduction (about 30%) in 8 WAP biomass. In conclusion, RC reduced the selection pressure placed on pigweed during POST herbicide applications through reductions in density and biomass 3 WAP; whereas RC, CC, and NRS reduced late season biomass which could reduce yield losses and subsequently weed seed production.

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Chapter 1 - Literature Review

Palmer Amaranth and Waterhemp Biology

Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp (*Amaranthus tuberculatus* Moq. J.D. Saur) were ranked as the number 1 and number 4 most troublesome weeds in 2015 based on a survey of weed scientists across the United States (Van Wychen 2016). Palmer amaranth is native to the desert southwestern United States (Ehleringer 1983) whereas waterhemp was first documented in Oklahoma during 1830 (Saur 1957, 1972). While Palmer amaranth has historically been a weed in agronomic crops, waterhemp has only recently emerged as a troublesome weed in the last thirty years, presumably due to hybridization with other *Amaranthus* spp. relatives (Trucco et al. 2009).

The emergence of Palmer amaranth and waterhemp begins in the early spring and commonly extends throughout the summer (Bell et al. 2015; Hartzler et al. 2004). Drastic implications for yield loss in summer annual crops (i.e., soybean and grain sorghum) commonly occur due to the synchronous emergence of the pigweed with the crop (Dieleman et al. 1995, 1996). Palmer amaranth and waterhemp utilize the C4 photosynthetic pathway which gives these species a distinct physiological advantage over many crops when grown in high temperatures and moisture limited conditions (Chollet and Ogren 1975; Ehleringer 1983; Pearcy and Ehleringer 1984; Stoller and Myers 1989). Palmer amaranth and waterhemp commonly have rapid growth during the late spring and early summer (Hartzler et al. 2004; Horak and Loughin 2000; Klingaman et al. 1994; Sellers et al. 2003; Spaunhorst et al. 2018). Jha et al. (2008) demonstrated how Palmer amaranth has both physiological and morphological adaptations to shading from other weeds and varying soybean row widths. In addition, Ehleringer and Forseth

(1980) found that Palmer amaranth exhibits heliotropic responses to tract the sun for better light interception.

When investigating Palmer amaranth reproductive characteristics, Keeley et al. (1987) reported that Palmer amaranth began flowering in as little as three weeks after emergence, and viable seed was produced in two weeks after the onset of flowering. As a dioecious species, Palmer amaranth and waterhemp are obligate outcrossers (Franssen et al. 2001) albeit the mechanism for determining the dioecy is unknown (Ward et al. 2013). Because of genetic recombination through cross-pollination, Palmer amaranth and waterhemp possess immense genetic diversity which lends these species toward the continuous evolution of herbicide-resistant biotypes (Ward et al. 2013). Individual Palmer amaranth and waterhemp plants have robust seed producing capabilities (Bensch et al. 2003; Burke et al. 2007; Hartzler et al. 2004; Ward et al. 2013) and can compensate in terms of seeds per plant across plant densities because of their great plasticity and indeterminate growth habit (Burke et al. 2007; Jha et al. 2008; Ward et al. 2013).

Special efforts should be made to manage seed production (Barber et al. 2015). Korres et al. (2018) investigated the persistence of Palmer amaranth and waterhemp in and on the soil surface at seven locations. After three years, seed viability ranged from 4 to 5% across burial depths indicating a high mortality should be expected for Palmer amaranth and waterhemp seed after maturity; however, seed banks could easily be replenished from the few remaining viable seeds because of the robust seed production capabilities of Palmer amaranth and waterhemp.

The combination of these factors attributes the difficulty commonly encountered when controlling these species (Ward et al. 2013). Bensch et al. (2003) reported that densities of 8 Palmer amaranth m^{-2} caused a 78% yield reduction in soybean, whereas 11 waterhemp m^{-2}

reduced soybean yield by 56%. Moore et al. (2004) observed yield reductions as high as 57% when 1.6 Palmer amaranth m^{-2} were transplanted into grain sorghum at developmental stage 2.

Row Width on Palmer Amaranth and Waterhemp Management

Narrow row width has been recognized as an integrated strategy for Palmer amaranth and waterhemp management in soybean and grain sorghum (Bradley 2006, Norsworthy et al. 2012, Pester et al. 1999). The means of weed suppression through narrow rows is derived from 1) increased crop competitiveness and 2) shading of weeds through enhanced light interception (Buhler and Hartzler 2004).

Planting equipment has evolved to make narrow row planting more feasible (Bertram and Pederson 2004). Additionally, increased popularity of narrow row widths has been driven by the potential for higher soybean yields (Bertram and Pedersen 2004; Bullock et al. 1998; Cox and Cherney 2011; De Bruin and Pederson 2008; Ethredge et al. 1989; Kelley and Sweeney 2008; Thompson et al. 2015; Walker et al. 2010) and sorghum yields (Baumhardt et al. 2005; Ciampitti et al. 2014; Conley et al. 2005; Maiga 2012; Sanabria et al. 1995; Staggenborg et al. 1999; Stickler and Wearden 1965; Wiese et al. 1964).

In soybean, a yield advantage of 10% was observed with 25 cm row width over 76 cm row width in maturity group (MG) IV soybean in Georgia (Ethredge et al. 1989). Field studies in Illinois with MG II soybean observed a consistent yield advantage with 38 cm row width as opposed to 76 and 114 cm row width due to more soybean vegetative growth prior to floral initiation in the narrow row width (Bullock et al. 1998). In Wisconsin with MG 1.2 to 2.0 soybean, 19 and 38 cm row widths were found to be superior to the 76 cm row width across numerous seeding rates (Bertram and Pedersen 2004). Yield advantages of 134 to 269 kg ha^{-1} were observed in 19 and 38 cm row widths as opposed to the 76 cm row width in eastern Kansas with MG V soybean (Kelley and Sweeney 2008). Walker et al. (2010) and Thompson et al. (2015) found that 38 cm row width produced optimum yields compared to 76 cm row width with MG III soybean in Tennessee; however, no difference in economic return was observed if a MG IV or V soybean was planted (Thompson et al. 2015). Research in Iowa with MG 2.8 soybean revealed that producers require only a small amount of their total acreage in soybean production to justify the additional expense of purchasing narrow row planting equipment because of yield advantages (De Bruin and Pedersen 2008).

Other literature reveals that the benefits of narrow row soybean are much less direct. Pedersen and Lauer (2003) found no interaction of soybean row width across multiple cropping systems and tillage regimes with MG 2.3 and 2.5 soybean in Wisconsin. Meta-analysis revealed that soybean row width studies tended to only show a yield advantage in northern latitudes due to the shortened growing season (Lee 2006). Research across 25, 51, and 76 cm row widths under irrigated and rain-fed conditions in Nebraska revealed that the 51 cm row width consistently produced superior yields (Elmore 1998). Dryland soybean research in Kansas indicates that while yield was optimized with 76 cm row width and 123,500 seeds ha^{-1} in low yield (< 2000 kg ha^{-1}) environments, comparable yields with both 76 and 20 cm row widths were achieved with 247,000 seeds ha^{-1} in the same low yielding environments (Devlin et al. 1995).

Under non-moisture limited growing conditions, increased soybean yield in narrow rows is attributed to enhanced light interception (Board et al. 1992; Butts et al. 2016; Shibbles and Weber 1966) and increase in pods per unit area (Bullock et al. 1998; De Bruin and Pederson 2008; Walker et al. 2010). In rain-fed situations in Nebraska, days after planting until canopy closure were decreased as row width decreased: canopy closure differed from 62, 80, and 95 days across 25, 51, and 76 cm row widths, respectively, (Elmore 1999). Weed science research indicates that enhanced light interception by the crop not only can enhance grain yield but also can have profound impacts on weed suppression by reducing the amount of light that reaches the soil surface (Bradley 2006). Yelverton and Coble (1991) demonstrated the concept of weed resurgence on the impact of canopy closure on the development of weeds later in the growing season.

Decreasing row width in soybean has tended to result in suppression of Palmer amaranth and waterhemp (Bell et al. 2015; Butts et al. 2016; Schultz et al. 2015; Steckel and Sprague 2004; Young et al. 2001). Complex interactions exist between soybean row width and waterhemp emergence which can shift the critical period for weed control. The use of narrow row width has been demonstrated to reduce waterhemp biomass and seed production (Steckel and Sprague 2004). Waterhemp control was improved when 19 cm or 38 cm row width were implemented rather than 76 cm row width; whereas, in only one of five site-years did 19 cm row width achieve more waterhemp control than 38 cm row width 5 wk after POST herbicide applications (Young et al. 2001).

The plasticity of Palmer amaranth and waterhemp can confound various metrics (i.e., weed density, biomass, seed production) when assessing various row widths for weed suppression. Factors such as weed emergence time, population density, environmental conditions, and time of assessment can make it difficult to discern clear implications from studies aimed at quantifying the value of narrow row width as an integrated strategy. Butts et al. (2016) found that decreasing row width did not result in a reduction in pigweed density or height at the time of POST herbicide application in soybean. However, end of season assessment revealed that row widths ≤ 38 cm resulted in a reduction in pigweed height and biomass but not density or pigweed seed production for soybean in maturity group II or III compared to soybean with row width ≥ 76 cm. End of season assessment in soybean with maturity group IV revealed a reduction in pigweed biomass and seed production but not pigweed height.

Bell et al. (2015) found that the density of Palmer amaranth at soybean harvest was less in 19 and 45 cm row widths compared to 90 cm row width in the absence of an herbicide. No difference in density was observed between the 19 and 45 cm row width at grain harvest in the absence of an herbicide. In contrast, Schultz et al. (2015) found mix results in terms of waterhemp suppression in soybean with 76, 38, and 19 cm row widths: 2012 data revealed that the 19 cm row width offered significantly more waterhemp density suppression compared to 38 cm and 76 cm row widths in the absence of an herbicide when the soybean was at the R4 developmental stage. Whereas, in 2013, the 19 cm row width facilitated an increase in waterhemp density at the R4 developmental stage compared to the wider row widths. The authors did not elicit the cause of this increase in the 2013 data; however, it is likely explained from moisture conservation or enhanced thermal amplitude at the soil surface in the narrow rows which may have stimulated additional emergence (Jha and Norsworthy 2009).

Regarding grain sorghum yield, Stickler and Wearden (1965) implemented 34 trials to conclude that a 51 cm row width achieved a 10 and 7% yield advantage in eastern and central Kansas, respectively, when compared to a 102 cm row width. Staggenborg et al. (1999) found that grain sorghum yields could be increased 10% when 25 cm row width was compared to the 76 cm row width. Maiga (2012) reported a 3 to 14% yield advantage in a similar comparison. Crop modeling illustrated that in the southern High Plains, producers can anticipate a yield increase of approximately 9% in grain sorghum when a 38 cm row width is selected over 76 cm width (Baumhardt et al. 2005). Five years of research in central Texas illustrated that in the absence of weeds, row widths ≤ 51 cm tended to provide greater sorghum yields (Wiese et al.

1964). Sanabria et al. (1995) reported that grain sorghum in 40 cm row width consistently out-yield 122 cm row width across six site-years due to increased water use efficiency and higher seeding rates. An analysis of Kansas sorghum row width data from 1980-2014 revealed that row widths ≤ 25 cm resulted in a 500 kg ha^{-1} yield increase in 75% of the data points compared to row widths > 25 cm; additionally, increased yield responses to row widths ≤ 25 cm were more consistent when yields were greater than 6000 kg ha^{-1} (Ciampitti et al. 2014).

Conley et al. (2005) observed superior grain sorghum yields in one site-year with 9 cm row width as opposed to 38 and 76 cm widths. In the second site-year, no differences were observed across any of the three row widths; the authors speculated that the lack of difference was caused by droughty conditions in the second year of the study. Similar results in response to the environment were observed in Texas in which 38 cm row width improved evapotranspiration efficiency compared to 76 cm row width; however, inconsistent results were observed for grain yield (Steiner 1986). In contrast, differences were not observed in grain sorghum yield in the Coastal Bend of Texas for 38 or 76 cm row width due to favorable growing conditions (Fernandez et al. 2012, Fromme et al. 2012). The lack of consistency in many of these studies on grain sorghum row width can likely be explained with the unique interactions that exist between crop genetics, the environment, and various management strategies (i.e., fertility, planting date, seeding rate, etc.) (Ciampitti et al. 2014).

Limited research has been conducted to assess the value of narrow row width for weed suppression in grain sorghum and has been focused on weeds other than Palmer amaranth and waterhemp (Besancon et al. 2017b, Burnside et al. 1964). Besancon et al. (2017a) demonstrated that Palmer amaranth density 14 weeks after planting was not influenced by grain sorghum row width; however, a reduction in biomass was observed in the 19 and 38 cm row widths as opposed to the 76 cm row width.

Cereal Cover Crops on Palmer Amaranth and Waterhemp Management

Various agronomic benefits have been associated with cover crops (i.e., soil health, nutrient cycling, biodiversity, etc.) in recent years (Appelgate et al. 2017; De Bruin et al. 2005; Dhima et al. 2006ab; Mahama et al. 2016, Reinbott et al. 2004). In lieu of reduced efficacy of herbicides due to increasing resistance, field research has indicated that cover crops can provide weed suppression from a combination of excreted allelochemicals as well as the physical interference of cover crop residue on subsequent weeds (Foley 1999; Gallandt et al. 1999; Schulz et al. 2013). Allelopathic effects from various cover crops (i.e., cereal rye) have been documented to help with weed suppression; however, the primary mechanism of suppression has been demonstrated to be physical interference from the cover crop biomass (Mirsky et al. 2013; Norsworthy et al. 2011; Ryan et al. 2011; Teasdale 1996; Wiggins et al. 2015).

Reductions in Palmer amaranth and waterhemp biomass and density have been observed in many common crops (i.e., corn, soybean, and cotton) with the use of cover crops (Cornelius and Bradley 2017b; DeVore et al. 2013; Loux et al. 2017; Norsworthy et al. 2011; Price et al. 2012; Wiggins et al. 2015, 2016). Hairy vetch or crimson clover cover crops provided greater Palmer amaranth control prior to POST herbicide application in corn when compared to the absence of a cover crop (Wiggins et al. 2015). Cornelius and Bradley (2017) found that over wintering cover crops (i.e., Austrian winter pea, winter oat, winter wheat, and cereal rye) reduced the density of late season waterhemp in soybean compared to the non-treated check. Loux et al. (2017) found cereal rye to be superior to other cover crops (i.e., spring oat, Italian ryegrass, and forage radish) for control of Palmer amaranth in the absence of an herbicide 3 weeks after soybean planting and at grain harvest. No differences in Palmer amaranth density were observed, which indicates that the increase in visual control was likely due to possible reductions in biomass, which were not reported. Similar levels of waterhemp control were reported at the 3 and 6 weeks after planting observations in the same study. The use of cereal rye as a cover crop has been demonstrated to reduce late season Palmer amaranth emergence in Arkansas with full season soybean; however, no differences in density were observed with early season emergence (DeVore et al. 2013). Wiggins et al. (2016) found that winter cereal cover crops (i.e., winter wheat or cereal rye) should be combined with a leguminous crop to facilitate reductions in early season Palmer amaranth density as compared to the use of a single species cover crop.

While many different species and mixtures of cover crops exist, recent research has illustrated that winter cereal crops such as winter wheat and cereal rye tend to offer a superior level of Palmer amaranth and waterhemp suppression compared to other cover crop options (Cornelius and Bradley 2017b; Loux et al. 2017). Cereal rye has tended to result in greater Palmer amaranth and waterhemp suppression when compared to winter wheat, but various studies have generated mixed results. Cereal rye tended to achieve more Palmer amaranth control when compared to winter wheat, turnip or mustard in Arkansas (Norsworthy et al. 2011). In other studies, winter wheat and cereal rye offered similar levels of Palmer amaranth and waterhemp suppression (Cornelius and Bradley 2017b; Wiggins et al. 2016). Little to no research has been published to illustrate the possible utility of cover crops in grain sorghum for Palmer amaranth and waterhemp suppression.

Management implications such as planting date, nutrient application, cultivar selection, and termination timing influence the Palmer amaranth and waterhemp suppression that could be expected from the cereal cover crop. Montgomery et al. (2018) found that the emergence and growth of Palmer amaranth was influenced by cover crop termination timing; with delayed emergence, the growth of the Palmer amaranth and subsequent timing of the POST herbicide application could be delayed. Earlier terminations of winter cereal cover crops have been associated with greater control of the cover crop as compared to termination applications in later developmental stages (Cornelius and Bradley 2017a). In contrast, Palmer amaranth and waterhemp suppression increases with increasing cereal cover crop biomass, termination timing to facilitate both weed suppression and field operations (i.e., timely no-till planting) has been described as a balancing act (Balkcom et al. 2015; Mirsky et al. 2011; Nord et al. 2012; Ryan et al. 2011).

While cover crops can suppress weeds, research has demonstrated cover crops should be utilized as part of an integrated strategy using both herbicides and crop rotational systems (Price et al. 2012). The overall weed suppression that should be expected from a cover crop is linked to the density of weeds in the seedbank: as weed seed density increases, the probability of the cover crop providing acceptable control as a standalone tactic (i.e., in-place of a residual herbicide) decreases (Nord et al. 2011). When winter cereal cover crops are implemented as part of a system including herbicides, excellent control of Palmer amaranth and waterhemp is commonly observed (DeVore et al. 2013; Loux et al. 2017; Montgomery et al. 2018; Price et al. 2012; Wiggins et al. 2016).

Row Crop Cultivation on Palmer amaranth and Waterhemp Management

Mechanical weed control has long been a historical component of weed control in agriculture prior to the advent of herbicide (Triplett and Dick 2008). The effect of tillage on weeds has been classified in three distinct ways 1) uproot, dismember, and bury growing weeds, 2) change the soil environment to promote the germination and establishment of weeds, and 3) change the distribution of the weed seed in the soil which influences the timing of when the weeds will interact with the crop (Mohler 2001). The use of row-crop cultivation is a sound integrated weed management practice (Buhler and Hartzler 2004). Row-crop cultivation has been demonstrated to remove weeds from between the crop rows during critical the weed free period, thus reducing the impact of weeds on crop grain yields (Mohler et al. 2016; Peters et al. 1965), albeit row-crop cultivation must be implemented timely which can be difficult with rain delays (Hartzler et al. 1993). While providing excellent control between rows, row-crop cultivation does not control weeds in the crop row (Jordan et al. 1987, Vangessel et al. 1998). This combined with soil disturbance at the time of cultivation can cause additional weed emergence illustrating the importance of combining row-crop cultivation with banded or broadcast residual herbicide applications (Gebhardt 1981; Steckel et al. 1990). While cultivation has been effective for weed control, the implementation of row-crop cultivation has decreased in recent decades due to herbicide-resistant crops (i.e., glyphosate), personal preference, and an increased emphasis on soil and water conservation (Peterson 1999). Riar et al. (2013b) reported that only 6% of the total scouted soybean acres received a row-crop cultivation treatment per a survey of crop consultants in the Midsouth. Widespread herbicide resistance and improved row-crop cultivation equipment in recent years have prompted the combination of row-crop cultivation with cover crop systems as a robust integrated weed management approach (Keene and Curran 2016).

Because of the risk for enhanced soil erosion with sequential row-crop cultivation passes or a poorly timed pass before a rainfall event, many have discounted the use of row-crop cultivation (Buhler et al. 1995); however, it is very difficult to estimate the total soil loss from row-crop cultivation as often as little as 5 to 15% surface residue is removed with a row-crop cultivation pass (Buhler 1995; Hartzler et al. 1993). Historically, it has been very difficult to implement row-crop cultivation in a no-tillage system (Buhler 1995; Teasdale and Rosecrance 2003); however, with the advent of heavy-duty row-crop cultivators with wide sweeps, cultivation in no-tillage or cover crop systems is feasible (Hanna et al. 2000; Keene and Curran 2016).

The banding of herbicides at planting to control weeds in the row combined with a planned row-crop cultivation to control weeds between the rows has long been recognized to reduce herbicide cost and promote diverse management systems (Buhler 2002; Buhler et al. 1992, 1994; Gebhardt 1981; Mulder et al. 1993). However, the use of banded herbicide applications has dissipated along with row-crop cultivation with the advent of herbicide-resistant crops (Triplett and Dick 2008; Young 2006). Mohler et al. (2016) and Mt. Pleasant et al. (1994) demonstrated row-crop cultivation in the absence of herbicide provided 91 and 30% weed control, respectively, and was better on broadleaf weeds than established perennial weeds. High residue row-crop cultivation in no tillage system in soybean provided a 67% reduction in weed biomass (Zinati et al. 2017). The implementation of row-crop cultivation should only be on fields with moderate to low weed densities as control should be expected to decrease in high density areas (Buhler et al. 1992; Dieleman et al. 1999).

The use of row-crop cultivation has been a long-standing effective tool for weed management in grain sorghum due to the lack of available herbicides (Wiese et al. 1964). While yield losses from row-crop cultivation in grain sorghum should not be expected, yield losses are possible due to reduction in soil moisture and possible root pruning from the added tillage pass (Dickey et al. 2013), albeit Schlegel and Holman (2017) reported that if sweep tillage in fallow fields were used on occasion to control weeds, minimal yield loss should be expected. Burnside et al. (1964) found that row-crop cultivation reduced pigweed biomass and increased grain yield in sorghum.

While the use of row-crop cultivation can increase the potential for soil erosion, it must be weighed against potential integrated weed management benefits (Bates et al. 2012). Buhler (2002) reported that row-crop cultivation should only be used as part of a system involving additional means of weed control (i.e., rotary hoe or herbicide) and that it can bring much needed diversity to a weed management system. Neve et al. (2011) demonstrated that had row-crop cultivation been implemented in cotton, the risk of glyphosate resistance would have reduced. Unfortunately, very little information is available as to the Palmer amaranth and waterhemp control that can be expected from row-crop cultivation in modern soybean and grain sorghum cropping systems.

Chemical Weed Control for Palmer amaranth and Waterhemp Management

Pigweed has been confirmed resistant to eight different herbicide sites of action (Heap 2019). The onset of herbicide resistance has continued to reshape not only weed management but also alter cropping systems, facilitate the reduction of soil conservation practices, and reduce farm profitability (Foresman and Glasgow 2008; Green 2007; Scott et al. 2009; Shaner 2000, 2014; Peterson 1999; Price et al. 2011). Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type (WSSA 1998). Recently, herbicide resistance has been described as a wicked problem, one with no clear causes or solutions (Barrett et al. 2017; Shaw 2016; Jussaume et al. 2016). Albeit weed science has somewhat identified the major causes (Shaner 2014) and probable solutions for herbicide resistance (Harker et al. 2017; Norsworthy et al. 2012), the problem continues across farms on a global scale (Schroeder et al 2018).

Because of herbicide resistance, producers have limited herbicide options which can deliver a consistently high-level of control for Palmer amaranth and waterhemp in soybean and especially grain sorghum (Peterson et al. 2019; Thompson et al. 2017). In addition to herbicide resistance, commonly used herbicides can achieve poor efficacy due to reduced absorption or translocation (Ou et al. 2018) as well as enhanced metabolism (Godar et al. 2015) which can cause confusion in the field as to identifying effective herbicides. Ultimately, this leaves most of the selection pressure on just a few herbicides.

To help mitigate the risk of herbicide resistance and increase the chance of achieving good control, applications should be implemented as part of a diverse integrated weed management program (Shaner 2014). Treatments should be planned that contain multiple effective sites of action for those species that are most likely to develop herbicide resistance (i.e., Palmer amaranth and waterhemp) as a best management practice (Kohrt et al. 2017; Norsworthy et al. 2012; Schwartz-Lazaro et al. 2017a). Beckie and Rebound (2009) modeled that tank mixing multiple effective sites of action reduced herbicide resistance selection pressure when compared to rotating two different sites of action from year to year (i.e., glyphosate fb glufosinate in an herbicide resistant corn and soybean rotation). Modeling of field application history data for 500 site-years of farm data revealed that when an average of 2.5 effective sites of action were used per year compared to 1.5 effective sites of action, the selection of glyphosate resistant weeds was 83 times less likely to occur (Evans et al. 2015).

Unfortunately, producers seldom adopt herbicide resistance management strategies before herbicide resistance occurs due to the higher initial cost (Peterson 1999). Whereas, increased profitability and improved weed control have been demonstrated with tank mixes containing multiple effective sites of action, albeit at an increased cost (Weirich et al. 2011a, b).

In a survey of crop consultants in the Midsouth, respondents indicated that the use of multiple effective sites of action were implemented on more than 67% of the scouted acres, and that consultants were more likely to implement multiple effective site of action tank mixes as opposed to other cultural practices (i.e., narrow row-width and row-crop cultivation) for managing herbicide resistant weeds (Riar et al. 2013a).

Herbicide resistant crops have expanded the herbicide portfolio for numerous crops, especially soybean (Green et al. 2007, 2014). While some would attribute the rise of herbicide resistance to the adoption of herbicide resistant crops (Benbrook 2016), Kniss (2018) demonstrates that the rise of herbicide resistant weeds has been independent of the adoption of herbicide resistant crops. Because of the importance of utilizing effective herbicide mixtures in reducing the risk of herbicide resistance (Beckie and Rebound 2009; Kohrt et al. 2017; Norsworthy et al. 2012; Schwartz-Lazaro et al. 2017a), the introduction of new herbicide resistant crops in soybean (Meyer et al. 2015b, 2016a, c) and grain sorghum (Abit et al. 2011; Hennigh et al. 2010a-c) could help to facilitate new herbicide resistance management strategies.

Additionally, herbicide programs to manage difficult weeds (i.e., Palmer amaranth and waterhemp) should involve overlapping applications of residual herbicides to provide initial herbicide incorporation and sustained residual control of weeds prior to establishment (Chahal et al. 2018; Sarangi and Jhala 2018; Sosnoskie and Culpepper 2014; Steckel et al. 2002). Albeit herbicides are available which can provide control of emerged weeds in the absence of a residual herbicide (Montgomery et al. 2018), the most consistent control will be achieved when a planned preemergence followed by postemergence herbicide application is utilized (Butts et al. 2016; Reddy et al. 2013). In addition to implementing overlapping residuals, control of emerged weeds prior to the emergence of the crop is essential to reducing the risk of grain yield loss (Tharp and

Kells 2001). The primary importance of early season weed control is linked to the critical weed-free period (Knezevic et al. 2002). Van Acker (1993) demonstrated that the critical weed-free period in soybean was from the V2 through R3 developmental stages, whereas Knezevic et al. (1997) found that only when redroot pigweed emerged prior to the 5.5-leaf stage in grain sorghum were yield losses observed.

Herbicide applications must utilize herbicides applied at full, labeled rates to achieve consistent control of troublesome weeds (i.e., Palmer amaranth and waterhemp) as well as facilitate resistance management (Norsworthy et al. 2012). A push for the reduction in herbicide usage has arisen in recent decades to facilitate lower production cost and limit environmental ramifications (Mortensen et al. 2000; O'Donovan 1996). However, the use of these types of models which advocate for reduced herbicide use rates could result in the selection for resistant biotypes, especially with polygenic, non-target site resistance mechanisms (Busi and Powles 2009; Manalil et al. 2011; Neve and Powles 2005; Norsworthy 2012; Techranchian et al. 2017). By delaying herbicide applications, herbicide applications will often be below use-rate because of rapid growth from Palmer amaranth and waterhemp (Spaunhorst et al. 2018; Hartzler et al. 2004; Klingaman et al. 1994; Sellers et al. 2003) which could result in reduced control (Norsworthy et al. 2012).

Application parameters are often overlooked when making an herbicide application (Kudsk 2017) and can not only have drastic implications on weed control but resistance management as well (Butts et al. 2018, 2019; Creech et al. 2015, 2016; Meyer et al. 2015a, 2016b; Norsworthy et al. 2012). Traditional weed science has indicated that systemic herbicides (i.e., glyphosate) function regardless of carrier volume and droplet size but better efficacy with contact herbicides (i.e., paraquat is achieved with larger carrier volumes and smaller droplet sizes

(Hopkins and Grisso 2014). Butts et al. (2018) found that when glufosinate and dicamba, were assessed to determine the optimal droplet sizes and spray carrier volumes, weed control decreased as droplet size increased, while increased carrier volumes helped to buffer the overall control. While this might be expected with a contact-type of herbicide such as glufosinate, these results were surprising regarding dicamba, thereby challenging the status quo of traditional herbicide application recommendations. When a comparison of optimal droplet sizes was assessed for a premix of 2,4-D and glyphosate, it was revealed that the optimal droplet size is specific to a given weed species per environment, which further enhances the importance of utilizing proper herbicide application technology (Butts et al. 2019). Creech et al. (2015, 2016) and Meyer et al. (2015a, 2016b) revealed with droplet spectra analyses of various tank mixes that changes in product formulation, carrier volume, and adjuvants have implications for the specific droplets sizes which will comprise an herbicide application, giving an immense importance to understand the interactions of various products in the spray tank.

Integrated Weed Management for Palmer amaranth and Waterhemp

Integrated weed management is comprised of 1) the use of multiple control tactics and 2) the integration of pest biology knowledge into the management system. The implementation of integrated weed management will ultimately diversify the selection pressure on a weed community, utilize resources more efficiently, and enable a wider selection of management options (Buhler 2002). When addressing tough to control weeds (i.e., Palmer amaranth and waterhemp), a systems approach of integrated weed management must be adopted (Owen 2016). Because of the robust seed production abilities of Palmer amaranth and waterhemp (Bensch et al. 2003; Burke et al. 2007; Hartzler et al. 2004; Ward et al. 2013), the concept of zero-tolerance or no seed production has been introduced as a goal of pigweed management systems (Barber et al.

2015; Norris 1999). While this may not be realistic in all situations, at-harvest seed destructor technology has been employed in Australia (Walsh et al. 2012) and has been introduced in the United States to limit the return of Palmer amaranth and waterhemp to the soil seedbank (Schwartz-Lazaro et al. 2017b).

Twelve best management practices to reduce the risk of herbicide resistance (Norsworthy et al. 2012) have been adopted by the Weed Science Society of America to help promote integrated weed management. While several of these practices employ integrated herbicide strategies, many comprise cultural and mechanical processes that are designed to limit seed production and the return of weed seed to the soil seedbank (Norsworthy et al. 2012). Unfortunately, most of these practices have received limited adoption (Riar et al. 2013 a-c; Owen et al. 2015).

When developing weed management strategies, all farms can be placed on a continuum ranging from the mindset of “weed control” (i.e., simplistic, short term focus) to “weed management” (i.e., consideration of environmental, economic, and cultural aspects) to “cropping systems-based decisions” (complex, integrated decisions across many years) which is truly the procurement of an integrated, sustainable approach (Cardina et al. 1999). By incorporating weed management decisions at the cropping systems level, the selection for resistance to a given practice will be delayed and create a more sustainable system overall (Gallandt et al. 1999).

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Chapter 2 - Integrated Pigweed (*Amaranthus* spp.) Management in Glufosinate-Resistant Soybean with a Cover Crop, Narrow Row Widths, Row-Crop Cultivation, and Herbicide Program

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Abstract

Successful pigweed management requires an integrated strategy to delay the development of resistance to any single control tactic. Field trials were implemented during 2017 and 2018 in three counties in Kansas on dryland (limited rainfall, non-irrigated) glufosinate-resistant soybean. The objective was to assess the control of pigweed with combinations of a winter wheat cover crop (CC), three row widths (76, 38, and 19-cm), row-crop cultivation at 2.5 weeks after planting (WAP), and an herbicide program to develop integrated pigweed management recommendations. Sixteen treatments assessed all practical combinations of the four components. All treatments with the herbicide program resulted in excellent (> 97%) pigweed control and were analyzed separately. Treatments containing row-crop cultivation reduced pigweed density and biomass at 3 and 8 WAP in all locations compared to the 76-cm row width no cover crop treatment. The impact of CC was mixed: at Riley County, pigweed density and biomass were reduced, no additional pigweed control was observed at Reno County, and at Franklin County, CC had greater pigweed density and biomass compared to no crop crop-containing treatments. Narrow row widths achieved the most consistent results of all cultural components when data were pooled across locations: decreasing row widths from 76 to 38-cm resulted in a 23% reduction in pigweed biomass at 8 WAP and decreasing from 38 to 19-cm achieved a 15% reduction. In conclusion, row-crop cultivation should be incorporated where

possible as a mechanical option to manage pigweed, and narrow row widths should be used to suppress late season pigweed growth when economically feasible. Inconsistent pigweed control from CC was achieved and should be given special consideration prior to implementation. The integral use of these components with an herbicide program as a system should be recommended to achieve the best pigweed control as well as reduce the risk of developing herbicide resistance.

Introduction

Palmer amaranth and waterhemp have risen to the number one and four most troublesome weeds in production agriculture in the United States (Van Wychen 2016). Herbicide resistance is widespread within these species with many confirmed cases of multiple herbicide resistance (Heap 2019; Shergill et al. 2018). A host of morphological and physiological adaptations have given pigweed increased competitiveness over crops (Ward et al. 2013). Densities of 8 Palmer amaranth m^{-2} caused a 78% yield reduction in soybean, while 11 waterhemp m^{-2} reduced soybean yield by 56% (Bensch et al. 2003), which emphasizes the importance of controlling pigweed. Additionally, the timing of pigweed emergence was found to be even more critical than density in the prediction of yield loss in soybean (Dieleman et al. 1995, 1996).

An integrated approach encompassing more than just herbicides must be implemented to effectively manage these difficult to control weeds (Owen et al. 2014). Aspects involving ecological considerations must be made for non-herbicide weed management options in soybean (Buhler et al. 1992) in addition to understanding the biology of each weed species (Walsh and Powles 2007). While producers have little to no control over weed biology or biotypes present in a field, management practices (i.e., planting date, tillage, the use of residual herbicides, etc) can be based around the emergence pattern of the driver weed species (Norsworthy et al. 2012). Furthermore, pigweed emergence (density and timing) can be influenced by the presence of crop residues, canopy, or tillage as well as seasonal variation, which can make the prediction of pigweed emergence difficult (Jha and Norsworthy 2009; Refsell and Hartzler 2009).

Narrow row width (i.e., less than 76-cm) (NRW) has been shown to increase soybean tolerance of early season weeds when compared to wide row spacing, as well as shift the emergence pattern of Palmer amaranth (Knezevic et al. 2003; Jha and Norsworthy 2009). Using NRW has been demonstrated to increase light interception (LI) and accelerate canopy development by the crop (Elmore 1998; Shibbles and Weber 1966; Yelverton and Coble 1991) and is recognized as a means for weed suppression (Buhler and Hartzler 2004). Narrow row widths have been reported to decrease late season waterhemp density in soybean (Schultz et al. 2015). Conversely, several studies have reported mixed results in terms of pigweed suppression with the use of NRW compared to wide row widths, with only reductions in late season pigweed biomass and little to no early season benefits being reported (Bell et al. 2015; Butts et al. 2016). Productive LI by the crop has been described as cumulative intercepted photosynthetically available radiation (CIPAR). Optimal soybean yield has been achieved as CIPAR levels reach 450 MJ m^{-2} (De Bruin and Pedersen 2009). Therefore, factors that could increase CIPAR (NRW, plant density, etc) could influence grain yield through LI. In contrast, Butts et al. (2016) found that CIPAR was not correlated to end of season pigweed growth or fecundity.

Cover crops can suppress Palmer amaranth and waterhemp emergence and growth in soybean (Cornelius and Bradley 2017; DeVore et al. 2013; Loux et al. 2017). When implemented as part of a system, cover crops should be combined into a planned PRE fb POST residual herbicide program (Cornelius and Bradley 2017; Loux et al. 2017). When selecting a cover crop to manage summer annual weeds such as Palmer amaranth and waterhemp, preference should be given to cover crop species producing ample biomass to generate adequate ground cover (i.e., cereal rye or winter wheat) to reduce subsequent weed germination and emergence (Cornelius and Bradley 2017; Smith et al. 2011).

The use of row-crop cultivation in soybean is commonly recognized as an integrated weed management practice (Buhler and Hartzler 2004). Row-crop cultivation has been demonstrated to remove weeds from between the crop rows during the critical weed-free period, thus reducing the impact of weeds on crop yields (Mohler et al. 2016; Peters et al. 1965). While capable of providing excellent weed control between rows, row-crop cultivation does not control weeds as well in the crop row (Jordan et al. 1987; VanGessel et al. 1998) and is better suited to fields with lower weed densities (Buhler et al. 1992; Dieleman et al. 1999). Historically, row-crop cultivation has been linked with conventional tillage systems and could result in substantial soil erosion concerns (Buhler et al. 1995; Teasdale and Rosecrance 2003). The use of row-crop cultivation has decreased in recent decades due to herbicide-resistant crops (i.e., glyphosate), personal preference, and adoption of no-tillage with an increased emphasis on soil and water conservation (Peterson 1999; Price et al. 2011). Widespread herbicide resistance and improved equipment has prompted the combination of row-crop cultivation and cover crop residues with no-till systems as a weed management option and provide a means to mitigate soil conservation concerns (Buhler 1995; Keene and Curran 2016).

Herbicide applications to manage difficult weeds should be implemented as part of a diverse integrated weed management program (Shaner 2014) and should contain multiple components such as sequential applications of residual herbicides (Chahal et al. 2018; Sarangi and Jhala 2018; Sosnoskie and Culpepper 2014; Steckel et al. 2002). Additionally, treatments should be planned that contain multiple effective sites of action for those species that are most likely to develop herbicide resistance (i.e., Palmer amaranth and waterhemp) as a best management practice (Norsworthy et al. 2012).

Integrated systems should be utilized to manage pigweed; however, for the system to be effective at reducing the risk of resistance to any one component, the efficacy of each component of the system must be understood. The objectives of this research were to 1) understand the emergence profiles of various indigenous pigweed populations in a dryland ((limited rainfall, non-irrigated) setting in the presence of a winter wheat cover crop, and 2) evaluate four components of an integrated pigweed management system including a winter wheat cover crop, row-crop cultivation, narrow row widths, and an herbicide program on pigweed height, density, and biomass in dryland glufosinate-resistant soybean in Kansas.

Materials and Methods

Field Locations and Winter Wheat Cover Crop Establishment and Termination

Field experiments were conducted during 2017 and 2018 in Riley County near Manhattan at the Ashland Bottoms Experiment Field (39.12567, -96.613488), in Franklin County near Ottawa at the East Central Experiment Field (38.539265, -95.244301), and during 2018 in Reno County near Hutchinson at the South Central Experiment Field (37.931114, -98.029392) in Kansas, for a total of five site-years of research. Riley and Reno Counties had an indigenous population of Palmer amaranth whereas Franklin County had an indigenous population of waterhemp, with both species being collectively referenced as pigweed. “Gallagher” winter wheat was no-till drilled at 134 kg ha^{-1} in 19-cm row widths at all locations in the fall of each year (Table 2.1). “Gallagher” was selected because it is adapted to all locations used in this research as well as its dual-purpose pedigree (Edwards et al. 2014). At spring green-up, the winter wheat cover crop (CC) received a topdress application of 56 kg ha^{-1} of nitrogen in the form of urea. Termination of CC with 1065 g ha^{-1} glyphosate (Roundup PowerMAX®- Monsanto Co., St. Louis, MO) occurred at Feekes stage 10.5.1 "anthesis" (Table 2.1). Above ground biomass of CC was harvested from representative 0.25 m^2 areas at soybean planting. Samples were dried for 10 d and weighed (Table 2.2).

Pigweed Emergence Study

Adjacent to all plot areas in 2018, a pigweed emergence study was conducted on the indigenous population in the absence of soybean. The two treatments consisted of CC and no winter wheat cover crop (NCC) with four replications per site. The CC treatment received identical management as the soybean experiment. Plastic squares (50-cm by 50-cm) were placed in each plot during March. Pigweed emergence counts were taken weekly from April through September, with pigweed seedlings removed upon count. When the adjacent soybean experiment was planted, the drill was operated without soybean seed through the emergence study area to simulate the soil disturbance that would occur with soybean planting.

Pigweed emergence for each treatment was modeled with a three-parameter sigmoid regression:

$$y = \frac{a}{1+\exp(\frac{-(x-x_0)}{b})} \qquad [1]$$

where y is the proportion of the total emerged pigweed plants, x is the day of year, a is the maximum proportion of total pigweed emergence converged on 100%, b is the slope at the inflection point, and x_0 is the day of year for 50% emergence. Differences in the regression lines for CC and NCC were compared using a pairwise F-test ($\alpha = 0.05$); when no differences were detected within a location, the data were pooled across CC and NCC treatments.

Soybean Establishment

Sixteen treatments consisted of all possible, realistic combinations of a winter wheat cover crop (CC), three row widths (76, 38, and 19-cm), row-crop cultivation (76-cm row width only), and an herbicide program. Treatments were arranged in a randomized complete block design with four replications per site. Plots at all sites were 3-m wide and 9-m long. Glufosinate-resistant soybean (Credenz® "3841") was planted with a no-till drill (Model 1590, Deere and Co., Moline, IL) at all locations at a rate of 395,000 seeds ha^{-1} across all row widths with drill slots being closed to accommodate the various row widths. Dates for key field operations and site characteristics are in Table 2.1. Prior to planting, the entire plot area received an application of 841 g ha^{-1} paraquat (Gramoxone® SL 2.0- Syngenta Crop Protection, LLC., Greensboro, NC) to control any emerged pigweed. Each plot area received an application of 135 g ha^{-1} clethodim (Select Max®- Valent U.S.A., LLC., Walnut Creek, CA) to control grass weeds and 75 g ha^{-1} chlorantraniliprole (Prevathon®- E.I. du Pont e Nemours and Co., Wilmington, DE) to control insects as needed. Daily precipitation (Table 2.3) and available solar radiation measurements were recorded with weather stations located less than 2.5 km from each site.

Herbicide Program and Row-Crop Cultivation Components

The herbicide program component consisted of 2-week pre-plant, PRE, and 3 WAP POST applications. Pyroxasulfone (Zidua®- BASF Corp., Research Triangle Park, NC) at 150 g ha^{-1} plus 252 g ha^{-1} sulfentrazone and 378 g ha^{-1} metribuzin (Authority® MTZ DF- FMC Corp., Philadelphia, PA) were applied for the pre-plant and PRE applications with two-thirds of the total herbicide applied 2 weeks before planting and the remainder applied PRE. The POST application consisted of 738 g ha^{-1} glufosinate (Liberty® 280 SL- Bayer Crop Science, Research Triangle Park, NC), 1,216 g ha^{-1} *S*-metolachlor and 266 g ha^{-1} fomesafen (Prefix®- Syngenta

Crop Protection, LLC., Greensboro, NC), plus 3,364 g ha^{-1} ammonium sulfate. Herbicides were applied using a four nozzle CO_2 pressurized backpack sprayer calibrated to deliver 144 L ha^{-1} at 241 kPa. Turbo TeeJet Induction (TTI) 110015 nozzles (TeeJet Technologies, Springfield, IL) were utilized for the pre-plant and PRE applications and Air Induction Extended Range (AIXR) 110015 nozzles were utilized for the POST application. For the row-crop cultivation component, a tractor mounted three-shank row-crop cultivator (Model 6200, Bison Industries Inc., Norfolk, NE) with a 46-cm wide sweep per shank was operated 5-cm deep at 6.4 km hr^{-1} approximately 2.5 WAP.

Pigweed Data Collection and Analysis

Pigweed height, density, and biomass were recorded at 3 and 8 WAP from representative 0.25 m^2 areas within each plot. Biomass was dried at 65 C for 10 d and weighed. Pigweed data were analyzed using the Mixed Procedure in JMP Pro 14 (SAS Institute., 100 SAS Campus Drive, Cary, NC 27513-2414) and means were separated using Fisher's Protected Least Significant Difference at $\alpha = 0.05$. Treatment was considered as a fixed effect and replication as the random effect. Pigweed height, density, and biomass data were assessed for basic assumptions of ANOVA; waterhemp density data at both observation timings were log transformed to better meet assumptions of ANOVA with all means being back transformed for discussion. When no year by treatment interactions were detected within a location, year was considered a random effect with replication nested within year. Contrasts of a single degree of freedom were applied to compare groups of treatments, which excluded row-crop cultivation component, to assess the effects of NRW (i.e., 38 and 19-cm row widths) and CC within each data set. In a separate analysis, pigweed biomass data collected at 8 WAP from CC and NCC treatments were expressed as a percentage of each site-year's average pigweed biomass, pooled across site-years, and subjected to linear regression across row widths. The slope of the linear regression was compared to a slope of zero with a pairwise F-test ($\alpha = 0.05$) in GraphPad Prism 5.0 (GraphPad Software, San Diego, CA).

Soybean LI and CIPAR Assessment and Analysis

Soybean LI was assessed weekly from emergence through 91 days after emergence (DAE) to understand the influence of soybean management factors (i.e., NRW, CC, etc) on canopy development. Digital images were taken from the same area within each plot with a camera mounted on a 1.8 m pole and oriented 65 degrees from the ground (Butts et al. 2016). Light interception was only measured in plots containing the herbicide program component within each row width and CC or NCC combination. Other treatments contained pigweed plants which would interfere with soybean LI and CIPAR calculations.

Each digital image was processed in TurfAnalyzer software (Green Research Services, LLC, Fayetteville, AR) to calculate the percentage of LI in each image. Light interception from this method has been shown to produce equivalent results to those obtained from a line quantum sensor (De Bruin and Pedersen 2009; Purcell 2000). A three-parameter exponential model was fit to the LI data:

$$LI = LI_0 + \left(LI_{plateau} - LI_0\right) \times \left(1 - e^{(-Kx)}\right) \qquad [2]$$

where LI is expressed as a percent (%), x is DAE, LI_0 is the LI at x_0, $LI_{plateau}$ is the LI at $x_{infinite}$, and K is the rate constant expressed in the reciprocal DAE. Seasonal LI patterns were compared among row widths and CC vs. NCC using a pairwise F-test ($\alpha = 0.05$) in GraphPad Prism 5.0.

The ability of the soybean canopy to capture available solar radiation for photosynthesis was calculated:

$$CIPAR_t = \sum_t [Daily\ total\ solar\ radiation\ * 0.5 * Daily\ LI]$$

[3].

where CIPAR is cumulative intercepted photosynthetically active radiation in megajoule (MJ) m^{-2}, t is days after emergence, Daily total solar radiation is MJ m^{-2} of incoming radiation for each location, and *Daily LI* is the LI for the soybean canopy each day (De Bruin et al. 2009; Edwards et al. 2005; Purcell et al. 2002). To estimate LI on days when images were not taken, daily solar radiation was calculated from quadratic models from each plot. The CIPAR was summed for each treatment from soybean emergence through 91 DAE. These CIPAR data were analyzed as a two-way factorial with the fixed effects of row width and with or without CC.

Results and Discussion

Pigweed Emergence Study

In the absence of soybean, a season total emergence of 1056 and 2820 Palmer amaranth m^{-2} were observed with CC and NCC, respectively, at Riley County in 2018, indicating that CC resulted in a 62% reduction in density (Table 2.4). When the emergence patterns of Palmer amaranth were compared between CC and NCC treatments, no differences were detected (*p-value* = 0.1885). At Reno County during 2018, CC offered a 46% reduction in Palmer amaranth emergence with 844 and 1568 Palmer amaranth m^{-2} emerged throughout the season in the CC and NCC treatments, respectively. The emergence patterns between CC and NCC were different (*p-value* < 0.0001) (Figure 2.1). The CC treatment at Reno County achieved 80% emergence on June 20 whereas the NCC treatment achieved 80% emergence on July 14, which greatly extended the emergence in the absence of the winter wheat cover crop residue. Palmer amaranth emergence at Reno County was extended compared to Riley County, which could be due to differentiating rainfall, thermal amplitude, or other environmental conditions (Table 2.3) as well as differences with biotypes present at each location.

The CC treatment at Franklin County resulted in nearly a six-fold increase (4376 vs. 664 plants m^{-2}) in seasonal waterhemp emergence compared to NCC (Table 2.4). The presence of CC biomass also extended the waterhemp emergence pattern compared to the NCC treatment with 80% seasonal emergence observed by May 17 for NCC and June 14 for CC. The greater density of total waterhemp in CC is contradictory to previous research as cereal cover crops have been documented to decrease waterhemp density (Cornelius and Bradley 2017; Loux et al. 2017). Late season observations of cover crop residues compared to early season measurements have been documented to have greater weed densities compared to those taken in early season or when nitrogen was released from leguminous cover crops which may have stimulated more emergences (Cornelius and Bradley 2017; Webster et al. 2013). Franklin County produced more CC biomass (3155 kg ha^{-1}) than Reno County (2580 kg ha^{-1}) (Table 2.2). Reno County had enough biomass to reduce total Palmer amaranth emergence while CC at Franklin County could not reduce waterhemp emergence. Riley County produced a similar amount of CC biomass (3520 kg ha^{-1}) as Franklin County; therefore, the greater seasonal density was not related to the amount of CC biomass produced. This contrasts with research that attributed enhanced pigweed control when more biomass of cover crops was produced (Webster et al. 2013). Other environmental factors such as thermal amplitude interacting with the cover crop biomass, as well as soil surface moisture retention beneath the CC, could be linked to the increased emergence in the CC treatment. The soil texture at Franklin County site-years contained substantially less sand than the other locations (Table 2.1), which could have retained more moisture in the CC compared to the NCC after a rain event and encouraged more waterhemp emergence.

The paraquat application at soybean planting controlled approximately 65% of the seasonal Palmer amaranth emergence in Riley County, but less than 2% of the seasonal Palmer amaranth emergence in Reno County, simply due to emergence patterns relative to paraquat application date (Table 2.4). In Franklin County, 70 and 98% of seasonal waterhemp emergence in the CC and NCC, respectively, was controlled with the paraquat application. At Riley and Franklin Counties, this herbicide application at planting controlled the emerged weeds and substantially reduced the total number of pigweed that would emerge to compete with the soybean. Controlling emerged weeds prior to the emergence of the cash crop is recognized as a strategy to reduce early season competition and reduce the risk of herbicide resistance (Norsworthy et al. 2012).

Pigweed Height, Density, and Biomass

Treatments that included the herbicide program provided excellent pigweed control at both observation times (> 97%, data not shown). Therefore, these treatments were removed, and the remaining eight treatments were analyzed for effects of CC, row width, and row-crop cultivation on pigweed height, density, and biomass. No year by treatment interactions were detected ($\alpha = 0.05$) for Palmer amaranth height, density, or biomass for 3 and 8 WAP at Riley County. At 3 WAP, row-crop cultivation or NRW plus CC resulted in the greatest reductions in Palmer amaranth density compared to the 76-cm NCC treatment (Table 2.5). Whereas, NRW in the absence of CC did not reduce Palmer amaranth density or biomass compared to the 76-cm NCC treatment. Contrasts at 3 WAP revealed that NRW did not reduce Palmer amaranth density or biomass, while CC reduced density by 53% and reduced Palmer amaranth biomass by 76%. This suggests that a CC could reduce the selection pressure for herbicide resistant biotypes by reducing the total number of individual plants exposed to the POST herbicide application.

At 8 WAP in Riley County, treatments utilizing multiple components reduced Palmer amaranth density compared to the 76-cm NCC treatment. When individual components such as row-crop cultivation alone, NRW alone, or CC in the absence of NRW were compared to the 76-cm NCC treatment, similar high densities were observed (Table 2.5). Contrasts for density and biomass at 8 WAP indicated that the use of NRW did not improve control, albeit CC offered a 49% reduction in density and 24% reduction in biomass compared to NCC across all row widths. The reduction in late season pigweed density has been reported as a benefit of cover crops in soybean (Cornelius and Bradley 2017; Loux et al. 2017).

At Reno County, no Palmer amaranth were present at 3 WAP (data not shown), likely due to the lack of moisture to trigger emergence (Table 2.3). Even though no Palmer amaranth were present, row-crop cultivation was still implemented 2.5 WAP. By 8 WAP, no differences in Palmer amaranth density were found, which indicated that row-crop cultivation did not affect the emergence of Palmer amaranth compared to other treatments at Reno County (Table 2.6). This demonstrates that the soil disturbance caused by row-crop cultivation did not stimulate additional emergence compared to treatments that did not receive row-crop cultivation. This contrasts with prior research that indicated that row-crop cultivation could increase weed emergence because of soil disturbance (Forcella and Lindstrom 1988). This may not be the case in Kansas because of the lack of moisture and drier climate likely prevented significant pigweed emergence. Palmer amaranth was shorter by 8 WAP in treatments containing row-crop cultivation or CC. The suppression in height was expected from the physical interference with CC biomass; however, the suppression at 8 WAP from row-crop cultivation was not anticipated because no Palmer amaranth were emerged at 3 WAP. This indicates that consequences from row-crop cultivation at 2.5 WAP delayed Palmer amaranth emergence and subsequent growth when emergence finally occurred sometime between 3 and 8 WAP. It is possible that the soil disturbance from row-crop cultivation altered the emergence pattern, decreased available moisture, or facilitated other environmental interactions reducing Palmer amaranth height compared to the treatment including both 76-cm row width and no row-crop cultivation. Contrasts reveal that NRW did not reduce Palmer amaranth height, but a 42% reduction in biomass was observed when the row width was decreased from 76-cm to 19-cm (Table 2.6).

No year by treatment interactions ($\alpha = 0.05$) were observed for waterhemp height, density, or biomass at 3 and 8 WAP at Franklin County, so years were combined (Table 2.7). By 3 WAP greater waterhemp densities were observed in CC than NCC treatments, which were opposite to what was expected. No differences were detected between the 76-cm and 38-cm row widths within CC and NCC; however, the 19-cm row width plus CC resulted in greater densities than the 19-cm NCC treatment, also completely opposite to what was expected. Even though the presence of CC increased waterhemp density, similar low waterhemp densities were observed in the row-crop cultivation alone (24 plants m^{-2}) or when combined with CC (30 plants m^{-2}). Contrasts revealed that decreasing row widths did not change waterhemp density, but CC actually increased density by 67% compared to treatments that did not contain CC. Similarly, waterhemp biomass increased by 101% at 3 WAP with CC compared to NCC treatments (Table 2.7).

By 8 WAP, treatments containing row-crop cultivation resulted in the lowest waterhemp densities (15 or 16 plants m^{-2}) but did not differ from the 76-cm NCC treatment with 30 plants m^{-2} (Table 2.7). When CC was added to the 76-cm row width but no row-crop cultivation, waterhemp density was greater at 97 plants m^{-2}. The use of NRW or NRW plus CC had intermediate waterhemp densities (56 to 71 plants m^{-2}) as compared to 76-cm row width with or without CC. Contrasts indicated that NRW did not influence waterhemp density at 8 WAP and CC actually increased waterhemp density by 50% across all row widths. Within the 76-cm row width treatments, it was clear that CC facilitated additional waterhemp emergence. Cover crops have been documented to conserve soil moisture at the surface (Wells et al. 2014). Throughout the growing season, it was noted that treatments with a CC had more moisture at the soil surface compared to NCC treatments at Franklin County (personal observation). Therefore, it is possible that this created a microenvironment favoring the emergence or survival of additional waterhemp individuals. While no differences were found across treatments for waterhemp biomass at 8 WAP, the contrast comparing the 76-cm and 19-cm row widths found that NRW resulted in a 66% reduction in biomass. This indicated that even though the use of CC as an integrated management strategy failed at this location, the use of NRW could be used as an additional integrated strategy to provide some pigweed growth suppression.

Soybean LI and CIPAR

Pairwise F-tests revealed that the LI patterns for soybean in CC and NCC within each row width were different (*p-values* < 0.0001, 0.0023, and 0.0007 for the 76, 38, and 19-cm row widths, respectively). The regression curves for 38-cm and 19-cm row widths with CC or with NCC were similar (*p-values* $= 0.6757$ and 0.9666, respectively), so data were pooled across NRW with CC or NCC (Table 2.8). The regression curves for the 76-cm row width vs. NRW with CC and NCC were different (*p-values* $= 0.0003$ and 0.0055, respectively). The combination of CC and NRW influenced soybean LI (Figure 2.2) such that NRW and NCC achieved 80% LI at 57 DAE compared to the 76-cm row width and NCC, which achieved 80% LI one week later. Within the CC-containing treatments, NRW achieved 80% LI 12 days ahead of the 76-cm row width plus CC treatment (Table 2.8).

No site-year by treatment interactions were detected for soybean CIPAR data; therefore, CIPAR data were pooled. No interaction among row widths and use of CC was detected; thus, main effect of row width was not significant whereas the use of a CC was. Lower CIPAR values (533 MJ m^{-2}) were achieved in CC compared to NCC treatments (640 MJ m^{-2}). There will likely be no differences in grain yield because CIPAR values were greater than 450 MJ m^{-2} (De Bruin and Pedersen 2009). The use of a cover crop will influence soybean phenology and subsequently LI. Delays in soybean canopy development because of the presence of a cover crop could enable late season pigweed emergence or growth. In this data, if soybean were grown in the absence of a cover crop, LI would have been enhanced and pigweed emergence and growth would have been suppressed (Yelverton and Coble 1991).

Greater LI was observed consistently with NRW and sooner than with the 76-cm row width in both CC and NCC treatments. When the early season measurements were considered, all soybean canopies achieved 20% LI within a range of six days (14 to 20 DAE) (Table 2.8). Butts et al. (2016) corroborated these results as they also reported no benefit from NRW in terms of reductions in pigweed density or biomass by the time of POST application. It was likely that because of the similar level of LI for all row widths at 3 WAP, there was little to no appreciable contribution from NRW in terms of reducing pigweed height, density, or biomass across locations (Tables 2.5 to 2.7). In contrast, by 8 WAP, decreasing row widths resulted in reduced pigweed biomass for both CC and NCC (Figure 2.3). Pairwise F-test revealed that the slope was different from zero (*p-value* < 0.0001). Based on the regression, a 23% reduction in biomass was observed by decreasing the row width from 76 to 38-cm and a 15% reduction in biomass by decreasing the row width from 38 to 19-cm. This was likely due to the difference in soybean LI with NRW at 64 DAE (5 to 10% for 38 and 19-cm) compared to the 76-cm row width (Figure 2.2).

Practical Implications for Management

An integrated weed management system requires multiple tactics working in combination; therefore, when developing these systems, it is imperative to understand the contribution of each component and how it integrates as a part of the system. The herbicide program provided excellent control of pigweed and was the most effective of the four components tested. The herbicide program included multiple facets (i.e., sequential applications, overlapping residuals, multiple effective sites of action). These aspects are recognized as proven components to any successful weed management program (Norsworthy et al. 2012; Owen et al. 2014). Unfortunately, in the absence of cultural or mechanical control tactics, even a robust herbicide program, albeit more sustainable than had a single site of action being used repeatedly, will inevitably result in the selection of herbicide-resistant biotypes (Evans et al. 2016; Neve et al. 2011; Shaner 2014). Row-crop cultivation as a mechanical control tactic tended to result in better pigweed control when compared to cultural practices. The timing of row-crop cultivation when the pigweed plants were small as well as prior to POST herbicide application likely facilitated the success of this component. While the integration of CC with row-crop cultivation did not improve pigweed control as compared to row-crop cultivation alone, using a cover crop could alleviate some soil conservation concerns that have historically discouraged the use of row-crop cultivation. The use of CC as a cultural control practice achieved mixed results across multiple site-years. In 3 of the 5 site-years, CC successfully reduced late season pigweed biomass and density thereby serving as an integrated strategy. At one location during both years, CC increased pigweed biomass and density compared to NCC, which suggests that unnecessary selection pressure would have been placed on herbicides, in addition to increasing pigweed seed production at this location. This example of inconsistent performance cautions the use of CC on a large scale in addition to the economic feasibility of implementing CC. The use of NRW did not improve pigweed control at 3 WAP and subsequently would not have reduced selection pressure on pigweeds with POST herbicide applications. By 8 WAP reductions in pigweed biomass were observed with NRW, indicating that NRW should be combined as an integral strategy with other tactics as a component of an overall pigweed management system.

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Figures and Tables

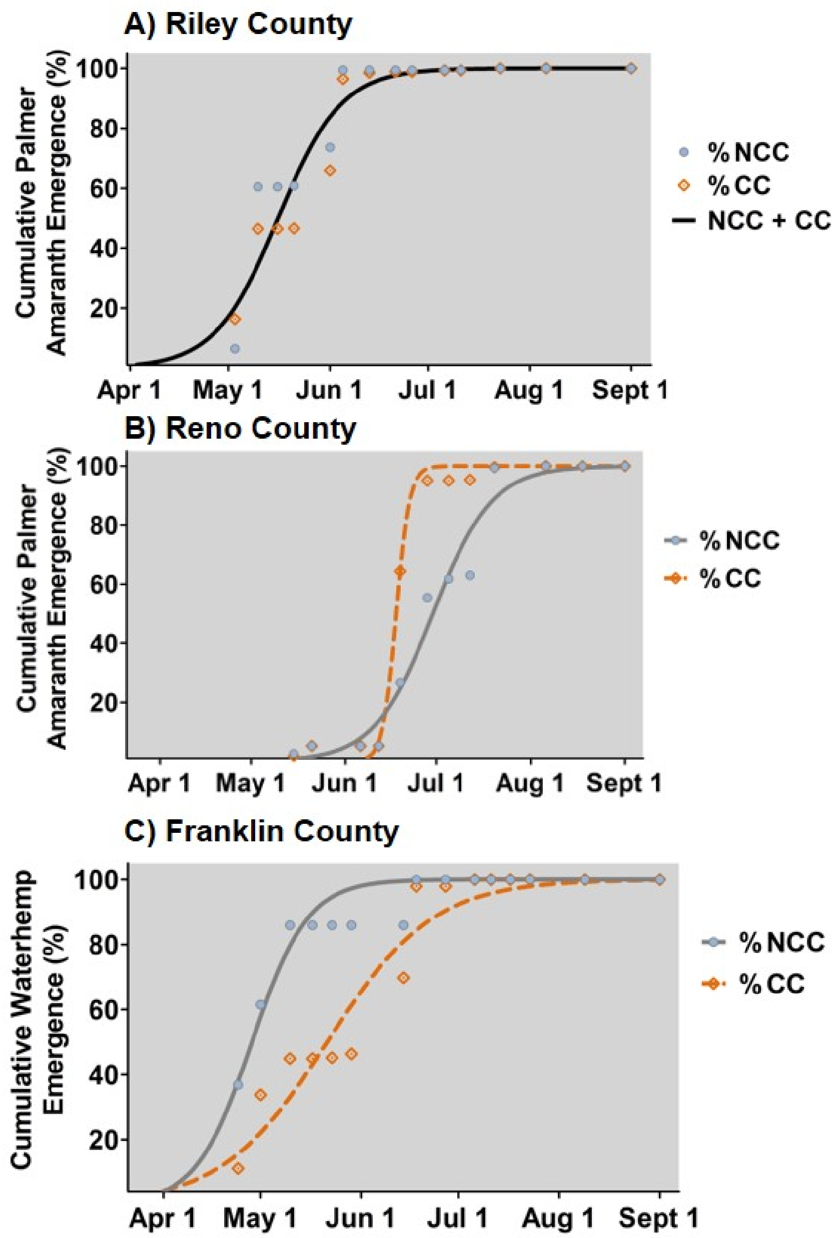

Figure 2.1 Emergence pattern for indigenous pigweed emergence study in the absence of soybean for winter wheat cover crop (CC) and no cover crop (NCC) treatments at A) Riley County with Palmer amaranth, B) Reno County with Palmer amaranth, and C) Franklin County with waterhemp. Regression parameters found in Table 2.4.

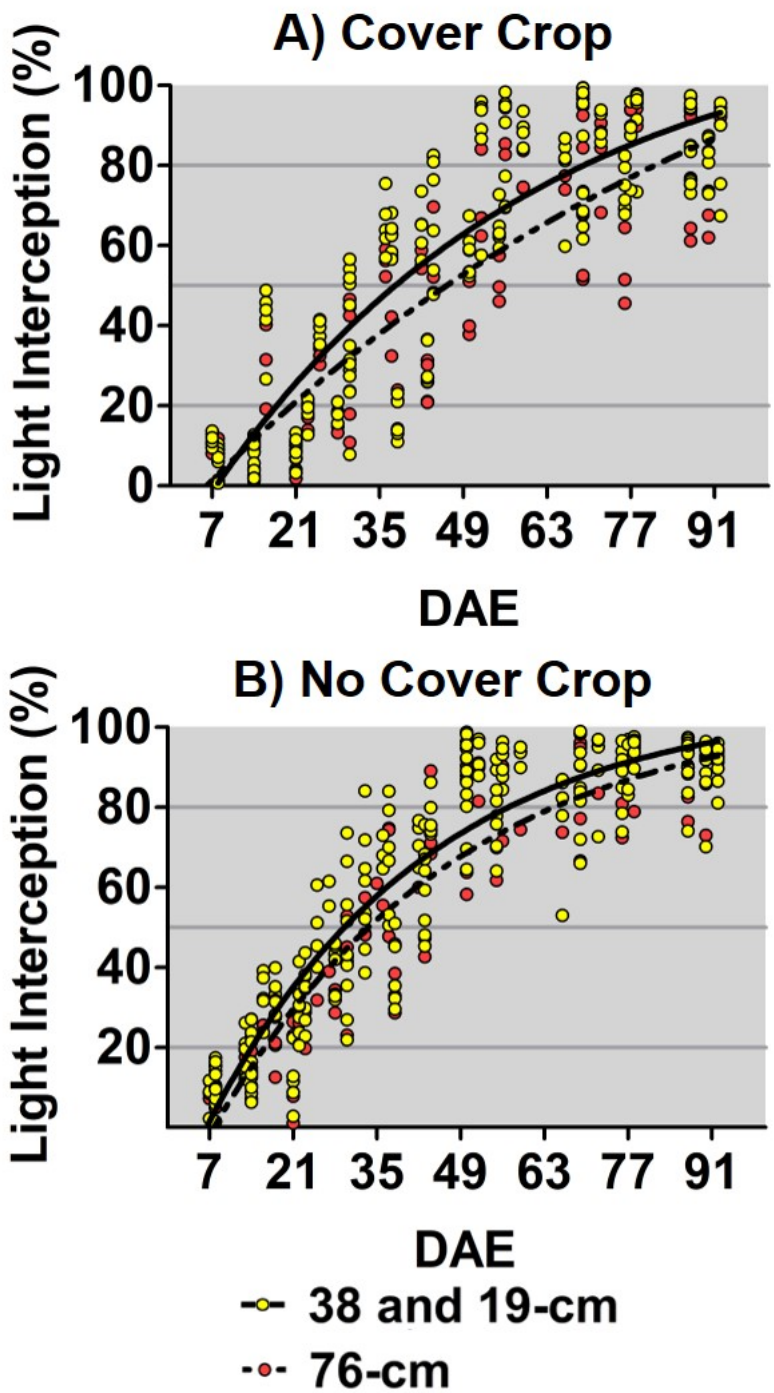

Figure 2.2 Percentage light interception (LI) by soybean days after planting (DAE) for 76-cm and 38 and 19-cm row widths and 76-cm within the A) winter wheat cover crop and B) no cover crop containing plots. Regression parameters found in Table 2.8.

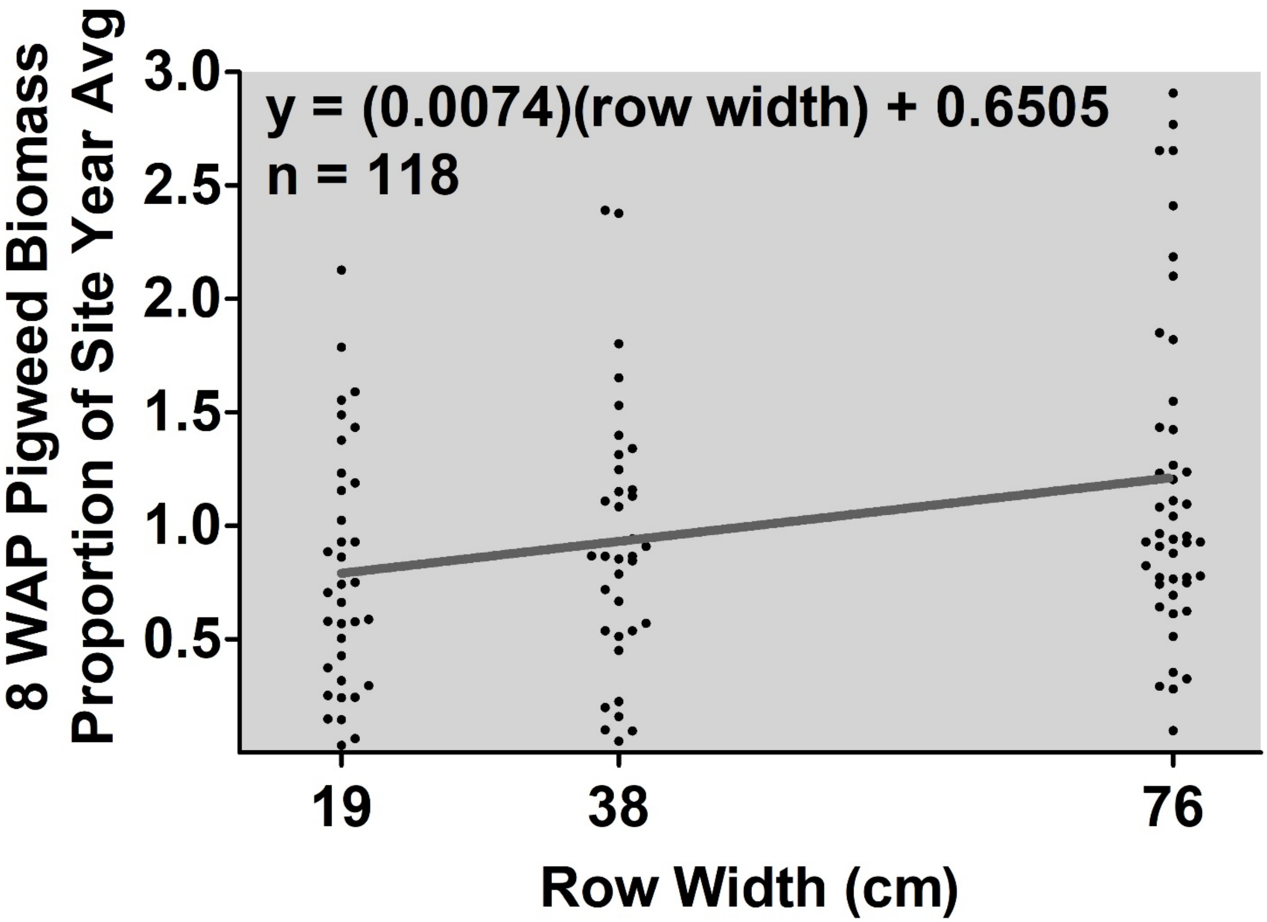

Figure 2.3 Pigweed biomass at 8 weeks after planting (WAP) as a proportion of the average for each site-year across three row widths. Data were described by linear regression pooled across site-years.

Table 2.1 Winter wheat cover crop planting and termination dates, soybean planting dates, herbicide application and row-crop cultivation dates, and site characteristics at experiment locations. [a,b,c]

	2017		2018		
Operation Dates and Site Characteristics	Riley County	Franklin County	Riley County	Reno County	Franklin County
Cover crop planting date	Early October, 2016		Late September, 2017		
Termination date	April 20		May 10		
Pre-plant application	June 7	June 8	May 12	May 12	May 21
Soybean planting date and PRE	June 21	June 22	May 22	May 22	June 4
Row-crop cultivation date	July 9	July 10	June 9	June 9	June 22
POST application	July 12	July 13	June 12	June 12	June 25
Soil series	Reading [d]	Woodson [e]	Wymore [f]	Ost [g]	Woodson [e]
Soil texture	silt loam	silt loam	silty clay loam	loam	silt loam
Soil organic matter [h] (%)	3.5	3.5	2.9	2.5	3.3
Soil pH	6.0	6.6	6.5	5.7	6.4
Soil CEC (meq/100g) [i]	21.1	17.9	15.8	18.6	18.4

[a] Abbreviations: meq, milliequivalents.

[b] Riley and Reno Counties contained an indigenous population of Palmer amaranth whereas Franklin County contained an indigenous population of waterhemp.

[c] All soil characteristics assessed from a 0 to 7.6 cm soil sampling depth.

[d] Fine-silty, mixed superactive, mesic Pachic Argiudolls

[e] Fine, smectic, thermic Abruptic Argiaquolls.

[f] Fine, smectitic, mesic Aquertic Argiudolls

[g] Fine-loamy, mixed, superactive, mesic Udic Argiustolls.

[h] Loss-on-ignition (Ball 1964).

[i] Adjusted to 7 pH (Rich 1969).

Table 2.2 Winter wheat cover crop above ground dry biomass at soybean planting.

Site-Year		Biomass (SE)
		kg ha^{-1}
2017	Riley County	5420 (777)
	Franklin County	4468 (580)
2018	Riley County	3520 (702)
	Reno County	3144 (105)
	Franklin County	2580 (360)

Table 2.3 Precipitation for each site-year during cover crop and soybean growth and development. [a]

Site	Year	Precipitation from January through April [b]		Precipitation during Soybean Growth and Development									
				Weeks after Soybean Planting									30 yr
		Accumulated	30 yr Normal	1	2	3	4	5	6	7	8	Total	Normal [c]
		mm											
Riley County	2017	270	157	4	63	0	0	10	24	95	24	220	182
	2018	81		0	38	16	3	18	5	2	43	125	231
Reno County	2018	94	179	0	9	37	0	84	50	0	67	247	218
Franklin County	2017	246	179	4	103	0	26	2	22	19	69	245	172
	2018	163		0	18	7	17	0	0	1	30	73	200

[a] 30 yr normals referenced from 1980 to 2010 for each location as recorded by the National Oceanic and Atmospheric Administration (Arguez et al. 2010).
[b] Precipitation values reflect moisture that occurred during the growth and development of winter wheat cover crop.
[c] Values calculated from 30 yr normal precipitation from the planting date for each site-year through 8 weeks after planting.

Table 2.4 Total pigweed emergence, parameter estimates and model fit values using equation 1 and predicted calendar dates for 20 and 80% pigweed emergence with (CC) or without (NCC) a winter wheat cover crop in the absence of soybean for Riley, Reno, and Franklin Counties during 2018. [a]

Location	Treatment	Total Emergence	Parameter Estimates [b]		Model Fit Values		Calendar Date for Emergence (2018)	
			b (SE)	x_0 (SE)	P-Value [c]	R^2	20%	80%
		plants m^{-2}		DOY				
Riley County	CC	1056 (587)	4.52 (0.55)	136 (1.2)	0.1885	0.95	May 2	May 30
	NCC	2820 (64)						
Reno County	CC	844 (207)	19.95 (0.29)	169 (0.3)	< 0.0001	0.99	June 15	June 20
	NCC	1568 (504)	4.50(0.59)	181 (1.4)		0.98	June 16	July 14
Franklin County	CC	4376 (644)	2.67 (0.36)	142 (2.4)	< 0.0001	0.96	April 29	June 14
	NCC	664 (328)	5.04 (0.71)	118 (1.3)		0.97	April 16	May 17

[a] Abbreviations: DOY, day of year; df, degrees of freedom; n, number of values in model; CC, winter wheat cover crop; NCC, no cover crop.

[b] Parameter estimates: *a* is the maximum proportion of total pigweed emergence set to 100%; *b* is the slope at the inflection point; x_0 is the DOY for 50% pigweed emergence.

[c] Significance of pairwise F-Test comparing the emergence patterns between the two treatments; if the regression curves were nonsignificant, the data were pooled within the location.

Table 2.5 Influence of soybean row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on Palmer amaranth height, density, and biomass in Riley County averaged across 2017 and 2018.[a,b,c]

Treatments		3 WAP		8 WAP		
Row Width	Component(s) [d]	Density	Biomass	Height	Density	Biomass
		plants m^{-2}	g m^{-2}	cm	plants m^{-2}	g m^{-2}
76-cm	CC + RC	57 e	2.8 c	8	230 c	145
	CC	563 b-d	12.0 bc	24	540 bc	186
	RC	105 de	5.3 c	17	490 bc	283
	-	1080 a	39.0 a	43	850 ab	364
38-cm	CC	380 c-e	6.7 c	31	380 c	196
	-	918 ab	28.0 ab	51	840 ab	302
19-cm	CC	359 c-e	6.8 c	25	430 c	196
	-	764 a-c	38.0 a	41	950 a	312
p-value		*0.0001*	*< 0.0001*	*0.1534*	*0. 0018*	*0.3450*
Contrasts [e,f]						
76-cm vs. 38-cm row widths		822 vs. 649 NS	26 vs. 17 NS	33 vs. 41 NS	695 vs. 610 NS	275 vs. 498 NS
76-cm vs. 19-cm row widths		822 vs, 562 NS	26 vs. 22 NS	33 vs. 33 NS	695 vs. 690 NS	275 vs. 508 NS
38-cm vs. 19-cm row widths		649 vs. 562 NS	17 vs. 22 NS	41 vs. 33 NS	610 vs. 690 NS	498 vs. 508 NS
CC vs. NCC		434 vs. 920 ***	8.5 vs. 35 ****	27 vs. 45 *	450 vs. 880 ***	248 vs. 326 **

[a] Abbreviations: WAP, weeks after planting; CIPAR, cumulative intercepted photosynthetically active radiation; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant.
[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD ($\alpha = 0.05$).
[c] 3 WAP height data for means and contrasts were found to be NS and are not shown.
[d] Hyphen indicates that no CC or RC was present in the treatment.
[e] Significance of contrast means difference: *$p = 0.1$ to 0.05, **$p = 0.05$ to 0.01, ***$p = 0.01$ to 0.0001, ****$p < 0.0001$ levels.
[f] All contrasts were conducted in the absence of RC-containing treatments.

Table 2.6 Influence of soybean row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on Palmer amaranth height and biomass at 8 WAP in Reno County during 2018.[a,b,c]

Treatments		8 WAP	
Row Width	Component(s) [d]	Height	Biomass
		cm	g m^{-2}
76-cm	CC + RC	24 c	350
	CC	27 c	330
	RC	27 c	220
	-	41 a	520
38	CC	29 bc	310
	-	33 a-c	330
19	CC	27 c	250
	-	39 ab	240
p-value		*0.0336*	*0.1171*
Contrasts [e,f]			
76-cm vs. 38-cm row widths		34 vs. 31 NS	425 vs. 320 NS
76-cm vs. 19-cm row widths		34 vs. 33 NS	425 vs. 245 **
38-cm vs. 19-cm row widths		31 vs. 33 NS	320 vs. 245 NS
CC vs. NCC		28 vs. 38 ***	300 vs. 363 NS

[a] Abbreviations: WAP, weeks after planting; ; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant.

[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD (α = 0.05).

[c] 3 WAP data are not included as Palmer amaranth was not emerged; 8 WAP density data for means and contrasts were found to be NS and are not shown.

[d] Hyphen indicates that no CC or RC was present in the treatment.

[e] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p = 0.01 to 0.0001, ****p < 0.0001 levels.

[f] All contrasts were conducted in the absence of RC-containing treatments.

Table 2.7 Influence of soybean row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on waterhemp density and biomass at 3 and 8 WAP in Franklin County averaged across 2017 and 2018.[a,b,c]

Treatments		3 WAP		8 WAP	
Row Width	Component(s) [d]	Density	Biomass	Density	Biomass
		plants m^{-2}	g m^{-2}	plants m^{-2}	g m^{-2}
76-cm	CC + RC	29 c	3.3	16 c	62
	CC	161 ab	16.0	97 a	64
	RC	24 bc	7.1	15 c	80
	-	79 bc	10.0	30 bc	64
38-cm	CC	139 a-c	11.0	71 ab	10
	-	134 a-c	12.0	58 ab	57
19-cm	CC	215 a	20.1	56 ab	24
	-	95 bc	1.5	61 ab	21
p-value		*0.0378*	*0.1206*	*0.0015*	*0.4590*
Contrasts [e,f]					
76-cm row widths vs. 38-cm row widths		120 vs. 137 NS	13 vs. 11.5 NS	64 vs. 65 NS	64 vs. 34 NS
76-cm row widths vs. 19-cm row widths		120 vs. 155 NS	13 vs. 10.8 NS	64 vs. 59 NS	64 vs. 22 *
38-cm row widths vs. 19-cm row widths		137 vs. 155 NS	11.5 vs. 10.8 NS	65 vs. 59 NS	34 vs 22 NS
CC vs. non-CC		172 vs. 103 **	15.7 vs. 7.8 *	75 vs. 50 *	33 vs. 47 NS

[a] Abbreviations: WAP, weeks after planting; CIPAR, cumulative intercepted photosynthetically active radiation; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant.
[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD (α = 0.05).
[c] Height data for means and contrasts were found to be NS and are not shown.
[d] Hyphen indicates that no CC or RC was present in the treatment.
[e] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p = 0.01 to 0.0001, ****p < 0.0001 levels.
[f] All contrasts were conducted in the absence of RC-containing treatments.

Table 2.8 Parameter estimates and model fit values for equation 2 describing light interception (LI) by soybean canopy growing in different treatments of soybean row widths and winter wheat cover crop (CC) or no cover crop (NCC) pooled across all site-years. [a]

Data Sets	P-Value [c]	Parameter Estimates [b] LI_0 (SE)	$LI_{plateau}$ (SE)	K (SE)	Model Fit Values R^2	df	DAE for Light Interception 20%	80%
38 and 19-cm CC	0.0003	-17.900 (4.979)	118.6 (11.45)	0.0183 (0.0034)	0.7806	203	17	69
76-cm CC		-9.486 (5.471)	153.4 (47.2)	0.0098 (0.0045)	0.7749	112	20	81
38 and 19-cm NCC	0.0055	-20.70 (4.090)	106.8 (4.159)	0.0274 (0.0027)	0.8522	251	14	57
76-cm NCC		-22.46 (6.451)	106.1 (8.204)	0.0246 (0.0043)	0.8575	89	16	64

[a] Abbreviations: DAE, days after planting; LI, light interception; CC, winter wheat cover crop; NCC, no cover crop.
[b] Parameter estimates: LI_0 is light interception at x_0; $LI_{plateau}$ is light interception at $x_{infinite}$; K is the rate constant expressed in reciprocal of DAE.
[c] Significance of pairwise F-Test comparing the emergence patterns between the two treatments; if the regression curves were nonsignificant, the data were pooled.

Chapter 3 - Management of Pigweed (*Amaranthus* spp.) in Grain Sorghum with Integrated Strategies

Submitted to Weed Technology on March 25, 2019*, in review*

Abstract

Pigweed is difficult to manage in grain sorghum due to widespread herbicide resistance, a limited number of registered effective herbicides, and the synchronous emergence of pigweed with grain sorghum in Kansas. The combination of cultural and mechanical control tactics with an herbicide program are commonly recognized as best management strategies; however, limited information is available to adapt these strategies to dryland systems. The objective of this research was to assess the influence of four components including a winter wheat cover crop (CC), row-crop cultivation, three row widths, and herbicide program on pigweed control in a dryland system. Field trials were implemented during 2017 and 2018 at three locations for a total of six site-years. The herbicide program component resulted in excellent control (> 97%) in all treatments at 3 and 8 weeks after planting (WAP). CC provided approximately 50% reductions in pigweed density and biomass for both timings at half of the site-years; however, mixed results were observed in the remaining site-years ranging from no attributable difference to a 170% increase in weed density at 8 WAP in one site-year. Treatments including row-crop cultivation provided reductions in pigweed biomass and density in most site-years at both observations. Narrow row width (NRW) (< 76 cm) achieved greater seasonal intercepted photosynthetically active radiation, which likely contributed to the 29% and 17% reductions in pigweed biomass 8 WAP when data were pooled; however, little benefit was observed in terms of pigweed control 3 WAP due to the similar light interception levels across all row widths early season. An herbicide

program is required to achieve pigweed control and should be integrated with row-crop cultivation or NRW to reduce the risk of herbicide resistance. Additional research is required to optimize the use of CC as an integrated pigweed management strategy in dryland grain sorghum

Introduction

The challenge of weed management in grain sorghum has continued to increase in recent years with the occurrence of herbicide-resistant weed populations (Thompson et al. 2017). Pigweed species (*Amaranthus* spp.) have been confirmed resistant to six herbicide sites of action in Kansas (Heap 2019). Yield reductions as high as 57% with 1.6 Palmer amaranth (*Amaranthus palmeri*) m^{-2} were observed when weeds were transplanted into grain sorghum at developmental stage 2 (Moore et al. 2004).

Best management practices indicate that grain sorghum should be planted by early June in Kansas (Ciampitti et al. 2017). While planting at this timing can maximize grain yield, it also synchronizes emerging sorghum with the emergence of Palmer amaranth and waterhemp (*Amaranthus tuberculatus*) as soil surface (2.5 cm depth) temperatures can often approach and exceed 25 C during the optimal grain sorghum planting time (Guo and Al-Khatib 2003; Hartzler et al. 1999; Jha and Norsworthy 2009). Synchronous emergence of grain sorghum with pigweed may be more influential than pigweed density in determining grain yield loss (Knezevic et al. 1997) and may place grain sorghum at a competitive disadvantage in contrast to other crops.

Grain sorghum producers have few effective herbicide options for controlling pigweed (Hennigh et al. 2010). A systems approach of integrated weed management must be adopted when addressing tough to control weeds (i.e., Palmer amaranth and waterhemp) (Owen 2016; Thompson et al. 2017).

Because of herbicide resistance and a limited number of registered active ingredients, cultural weed management practices such as NRW must be considered. Narrow row widths generally result in faster canopy closure and increased evapotranspiration efficiency (Steiner 1986). Staggenborg et al. (1999) reported grain sorghum yields were increased 10% with NRW compared to 76-cm row widths in favorable growing conditions. Best management recommendations for Kansas indicate that narrow row spacing should be selected over wide row spacing to increase yield (Ciampitti et al. 2017), which aligns with integrated weed management strategies to increase crop competitiveness with weeds (Norsworthy et al. 2012). The use of 38-cm and 19-cm row widths in grain sorghum has been shown to increase control of Palmer amaranth, tumble pigweed (*Amaranthus albus* L.), redroot pigweed (*Amaranthus retroflexus* L.), large crabgrass (*Digitaria sanguinalis* L. Scop.), and sicklepod (*Senna obtusifolia* L. H.S. Irwin & Barneby) when compared to wide row widths (Besancon et al. 2017; Grichar et al. 2004; Wiese et al. 1964).

The use of row-crop cultivation has been a long-standing effective tool for weed management in grain sorghum (Wiese et al. 1964); however, yield losses have been reported due to reduced soil moisture conservation and root pruning (Dickey et al. 2013). The use of row-crop cultivation can also increase the potential for soil erosion and must be weighed against integrated weed management benefits (Bates et al. 2012).

Cover crops have provided economic benefit when used as part of a rotational system with grain sorghum (Mahama et al. 2016; Reinbott et al. 2004). While cover crops have suppressed Palmer amaranth and waterhemp (Cornelius and Bradley 2017; DeVore et al. 2013; Loux et al. 2017;), little to no research has investigated the role of cover crops as an integrated pigweed management tool in grain sorghum. Maintaining adequate residue cover in a no-till dryland system can aid in weed suppression in grain sorghum (Anderson 2000; Dhuyvetter et al. 1999; Thompson et al. 1998). An extension of this is to maintain ground cover with winter wheat residue in a double-crop grain sorghum production system (Crabtree et al. 1990).

Winter wheat as a cover crop offers similar suppression of Palmer amaranth and waterhemp in cotton and soybean when compared to cereal rye (*Secale cereal* L.) (Wiggins et al. 2016). When planting a summer annual grass crop such as grain sorghum, a leguminous cover crop could be selected to avoid challenges of crop establishment and nitrogen immobilization (Mahama et al. 2016). However, leguminous cover crops seldom produce the biomass and ground cover necessary to adequately suppress Palmer amaranth and waterhemp (Cornelius and Bradley 2017; Wiggins et al. 2015). Research has indicated that with appropriate agronomic practices (i.e., adequate nitrogen fertilization), establishment of summer annual grass crops such as corn after cereal rye do not consistently reduce grain yields (Appelgate et al. 2017; Duiker and Curran 2005).

The repeated use of any one of these weed management tactics (herbicide, NRW, row-crop cultivation, or cover crops) will eventually select for tactic-resistant biotypes (Shaner 2014). Thus, a combination of these practices in pursuit of an integrated weed management plan should be implemented as a system. In developing strategies, all farmers can be placed on a continuum ranging from the mindset of “weed control” (i.e., simplistic, short term focus) to “weed management” (i.e., consideration of environmental, economic, and cultural aspects) to “cropping systems-based decisions” (complex, integrated decisions across many years), which is truly an integrated, sustainable approach (Cardina et al. 1999). By incorporating weed management decisions at the cropping systems level, the selection for resistance to a given practice will be delayed and create a more sustainable system overall (Gallandt et al. 1999). Unfortunately, limited research has investigated how to incorporate many of these best management practices into a dryland grain sorghum cropping system. The objective of this research was to assess the influence of a winter wheat cover crop (CC), row-crop cultivation, three row widths, and herbicide program, each alone and in combination, on pigweed height, density, and biomass in dryland (limited rainfall, non-irrigated) grain sorghum in Kansas.

Materials and Methods

Field experiments were conducted in Riley (39.12567, -96.613488), Reno (37.931114, -98.029392), and Franklin (38.539265, -95.244301) Counties on Kansas State University Department of Agronomy Experiment Fields during 2017 and 2018 for a total of six site-years. Riley and Reno Counties contained an indigenous population of Palmer amaranth whereas Franklin County contained an indigenous population of waterhemp. Sixteen treatments were established consisting of all combinations of four components, including an herbicide program, three row widths (76, 38, and 19-cm), CC, and row-crop cultivation (as practical by row width).

Winter Wheat Cover Crop Component Establishment and Termination

"Gallagher" winter wheat was no-till planted at 134 kg ha^{-1} in 19-cm row width at all locations (Table 3.1). "Gallagher" is a popular wheat variety in Kansas and is commonly utilized for its forage qualities as a dual-purpose wheat (Edwards et al. 2014). At spring green-up, CC received 56 kg ha^{-1} of topdress nitrogen in the form of urea. The CC was terminated with 1065 g ha^{-1} glyphosate (Roundup PowerMAX®- Monsanto Co., St. Louis, MO) at Feekes 10.5.1 "anthesis" (Table 3.1). At grain sorghum planting and maturity, soil cores were pulled to a 61-cm depth to assess nitrogen content in CC and non-cover crop (NCC) plots (Table 3.2). Above ground biomass of CC was harvested from one representative 0.25 m^2 area in each replication per site-year at grain sorghum planting, dried, and weighed (Table 3.2).

Grain Sorghum Establishment. Experiments were established in a randomized complete block design. Plots at all sites were 3-m wide and 9-m long with four replications per site. Immediately prior to planting the grain sorghum, the entire experimental area received an application of 841 g ha^{-1} paraquat (Gramoxone® SL 2.0- Syngenta Crop Protection, LLC., Greensboro, NC) to control all emerged pigweed and a broadcast application of 112 kg ha^{-1} of topdress nitrogen in the form of urea. A full season grain sorghum hybrid "7715" (Sorghum Partners®, New Deal, TX) was no-till planted at 148,200 seeds ha^{-1} using a no-till drill (Model 1590, Deere and Co., Moline, IL) at all locations. The same seeding rate was used across all row widths with drill slots being closed to accommodate the various row widths. Key operation dates and site characteristics are in Table 3.1. Daily rainfall events were recorded at weather stations located no more than 2.5 km from each site (Table 3.3). All locations received a broadcast application of 75 g ha^{-1} chlorantraniliprole (Prevathon®- E.I. du Pont e Nemours and Co., Wilmington, DE) to control unwanted insects.

Herbicide Program and Row-Crop Cultivation Components

The herbicide program component consisted of pre-plant, PRE, and 3 WAP POST applications. The split pre-plant and PRE application consisted of a premix of 1884 g ha^{-1} *S*-metolachlor, 707 g ha^{-1} atrazine and 188 g ha^{-1} mesotrione (Lumax® EZ- Syngenta Crop Protection, LLC., Greensboro, NC) with two-thirds of the total herbicide applied two weeks prior to planting and the remainder applied immediately after planting. The POST application consisted of a tank mix of 43 g ha^{-1} of pyrasulfotole and 245 g ha^{-1} bromoxynil (Huskie®- Bayer Crop Science, Research Triangle Park, NC), 280 g ha^{-1} dicamba (Clarity®- BASF Corp., Research Triangle Park, NC), 2800 g ha^{-1} acetochlor and 1389 g ha^{-1} atrazine (Degree Xtra®- Monsanto Co., St. Louis, MO), 2.5% v/v urea ammonium nitrate, plus 0.25% v/v nonionic surfactant (Activate Plus™- Winfield United, Bloomberg, MN). The herbicide applications were made using a four nozzle CO_2 pressurized backpack sprayer calibrated to deliver 144 L ha^{-1} at 241 kPa using Turbo TeeJet® Induction (TTI™) 110015 nozzles (TeeJet Technologies, Springfield, IL) for the pre-plant and PRE applications and Air Induction Extended Range (AIXR) 110015 nozzles for the POST application. For the row-crop cultivation component, a three-shank row-crop cultivator (Buffalo Model 6200, Bison Industries Inc., Norfolk, NE) with 46-cm wide sweeps was operated 5-cm deep at 6.4 km hr^{-1} approximately 2.5 WAP. Row-crop cultivation was implemented only in the 76-cm row widths.

Pigweed Height, Density, and Biomass Data Collection and Analysis

The average height of ten plants per plot as well as density was recorded and biomass harvested from representative 0.25 m^2 areas between the center rows in each plot at 3 and 8 WAP. Biomass was oven dried at 65 C for 10 d and weighed. Data were analyzed using the Mixed Procedure in JMP Pro 14 (SAS Institute, 100 SAS Campus Drive, Cary, NC) and means were separated using Fisher's Protected Least Significant Difference (LSD) at $\alpha = 0.05$. Pigweed height, density, and biomass data were assessed for basic assumptions of ANOVA. To meet these assumptions of ANOVA, Franklin County waterhemp density data observed at 3 and 8 WAP in 2017 and at 8 WAP in 2018 required natural log transformation whereas waterhemp biomass data at 3 WAP in 2017 from Franklin County required square root transformation. All values were back transformed for discussion. When no site by year by treatment interactions were detected, site-year was considered as a random effect with replication nested within the site-year (within a species). Contrasts of a single degree of freedom were applied to compare groups of treatments that excluded treatments with row-crop cultivation to assess the effects of NRW (i.e., 38-cm and 19-cm row widths) and CC. Pigweed biomass data collected at 8 WAP for both CC and NCC treatments were adjusted as a percentage of each site-year's average, pooled across site-year, and subjected to linear regression across row widths in a separate analysis. The slope of the linear regression was compared to a slope of zero with a pairwise F-test ($\alpha = 0.05$) in GraphPad Prism 5.0 (GraphPad Software, San Diego, CA).

Grain Sorghum LI and CIPAR Assessment and Analysis

Grain sorghum light interception (LI) was measured weekly from crop emergence through 80 days after emergence (DAE). The same area within each plot was photographed with a digital camera mounted 1.8 m above the soil surface and oriented 65 degrees from the soil surface. Images were taken in treatments that included the herbicide component within each row width, CC, and NCC combinations to avoid pigweed interference with the image assessment and to measure the effect of row width and presence of CC on LI.

Digital images were analyzed in TurfAnalyzer software (Green Research Services, LLC, Fayetteville, AR) to calculate the LI for each image. This methodology has been used in soybean to produce identical measurements to that of the output from a line quantum sensor (De Bruin and Pedersen 2009; Purcell 2000). A three-parameter model was used to describe the exponential relationship between grain sorghum LI through its developmental stages over time with Equation [1]:

$$\mathrm{LI} = LI_0 + \left(LI_{plateau} - LI_0\right)\left(1 - e^{(-K\mathrm{x})}\right) \qquad [1]$$

where LI is expressed as a percent (%), x is DAE, LI_0 is the LI at 0 DAE, $LI_{plateau}$ is the light interception at $x_{infinite}$, and K is the rate constant expressed in the reciprocal of DAE. Regressions of LI for various row width and CC combinations were compared using a pairwise F-test (α =

0.05) in GraphPad Prism 5.0 (GraphPad Software, San Diego, CA) to determine if there were differences.

Cumulative intercepted photosynthetically active radiation (CIPAR) links the ability of grain sorghum to capture available solar energy and was calculated with Equation [2]:

$$CIPAR_t = \sum_t [Daily\ total\ solar\ radiation\ * \ 0.5 * \ Daily\ LI] \quad [2]$$

where $CIPAR_t$ is cumulative intercepted photosynthetically active radiation in megajoule (MJ) m^{-2}, *t* is days, and *Daily LI* is the estimated LI for the grain sorghum canopy each day (De Bruin and Pedersen 2009; Purcell 2000). Estimates of LI was obtained from quadratic models for each plot, which interpolated LI for days when images were not taken. CIPAR was then summed from the time of grain sorghum emergence through 80 DAE. Daily solar radiation was measured at stations located within 2.5 km from each site. CIPAR results were analyzed as a two-way factorial with three levels of row width (i.e., 76, 38, and 19 cm) and two levels of ground cover (CC vs NCC) and were assessed for basic assumptions of ANOVA. Means were separated using Fisher's Protected LSD at $\alpha = 0.05$ with the Mixed Procedure in JMP Pro 14.

Results and Discussion

All treatments that included the herbicide program component resulted in excellent pigweed control (> 97%, data not shown); therefore, data not containing this component were extracted and analyzed separately. No interactions were detected for Palmer amaranth height, density, or biomass for site-year by treatment effects for Riley County 2017 and 2018 and Reno County 2017; therefore, data were pooled. Reno County 2018 data were analyzed separately as there was a significant year by treatment interaction with all other site-years containing Palmer amaranth. Franklin County waterhemp data were analyzed separately for each site-year as a significant year by treatment interactions were detected.

Palmer Amaranth Density and Biomass across 3 site-years (Riley and Reno Counties)

Palmer amaranth densities were similar (550 to 710 plants m^{-2}) across all row widths with NCC at 3 WAP (Table 3.4). The 76-cm row width treatment with NCC will be referred to as standard management (SM). When CC was added to the 76-cm row width, a 55% reduction in density was observed across the three site-years. Additionally, treatments with row-crop cultivation reduced density by 97% compared to SM. Both row-crop cultivation and CC were effective components to integrate in terms of reducing the selection pressure on Palmer amaranth with POST herbicide applications; this demonstrated the importance of considering both cultural and mechanical tactics when developing pigweed management strategies (Buhler 2002; Loux et al. 2017). When NRW was combined with CC, density was reduced compared to SM. Contrasts revealed that differences in Palmer amaranth density could not be attributed to NRW at 3 WAP. Treatments containing CC resulted in a 50% reduction in Palmer amaranth density across all row widths (Table 3.4).

Biomass was reduced only with the 19-cm row width compared to the 76-cm and 38-cm row width and NCC treatments at 3 WAP (Table 3.4). Combining CC plus row-crop cultivation reduced biomass by 97%, whereas row-crop cultivation alone reduced weed biomass by 83%, compared to SM. The combination of NRW plus CC reduced Palmer amaranth biomass compared to SM but NRW alone did not. When pooled across all combinations, contrasts found that NRW reduced biomass compared to the 76-cm row width. The use of a CC resulted in a

52% biomass reduction compared to NCC across all row widths by 3 WAP at these three site-years (Table 3.4).

Palmer amaranth densities were similar by 8 WAP in all NRW plus NCC and all 76-cm row width treatments (excluding row-crop cultivation-containing treatments) (Table 3.4). This indicated that CC or NRW as stand-alone tactics did not reduce late season densities. Densities in row-crop cultivation or NRW plus CC treatments were reduced compared to SM by 8 WAP. This illustrated the importance of applying a systems approach that utilizes cultural and mechanical strategies in addition to an herbicide program (Beckie 2006; Norsworthy et al. 2012; Owen 2016; Owen et al. 2014). Generally, row-crop cultivation has been associated with increasing late season weed emergence because of soil disturbance (Forcella and Lindstrom 1988); however, in some environments as in this study, increased emergence did not occur; therefore, timely row-crop cultivation could be used to control early season weeds without causing additional emergence, especially in dryland cropping systems. A combination of CC plus NRW was required to provide Palmer amaranth suppression compared to SM in these site-years – each component on its own was not enough to provide suppression. Contrasts indicated that no reduction in density could be attributed to NRW; the addition of CC across all row widths did reduce density by 50% (Table 3.4).

Palmer amaranth biomass was reduced with the CC plus 76-cm row width or 38-cm NCC treatments compared to SM by 8 WAP. Both 19-cm row width treatments (CC or NCC) produced a similar level of biomass to SM (Table 3.4). This illustrated that abiotic and biotic interactions can occur to facilitate weed growth; the 19-cm row width created a conducive environment for biomass production, whereas the 38-cm row width provided suppression. Treatments which included CC or row-crop cultivation reduced Palmer amaranth biomass compared to SM. Contrasts revealed that NRW provided 27 and 46% reductions in late season biomass with 38-cm and 19-cm row widths, respectively, compared to the 76-cm row width and the addition of CC provided a 37% reduction in late season biomass compared to NCC treatments across all row widths (Table 3.4). Butts et al. (2016) found similar results in soybean in terms of a benefit from NRW for Palmer amaranth late season biomass suppression.

Palmer Amaranth Height, Density, and Biomass in Reno County 2018

Palmer amaranth was not present by 3 WAP due to the lack of moisture to stimulate emergence (Table 3.3); regardless, all treatments were still implemented per protocol (i.e., row-crop cultivation at 2.5 WAP). Palmer amaranth height was reduced in the 19-cm row width plus CC and row-crop cultivation plus CC treatments compared to SM by 8 WAP. Contrasts indicated that NRW had no effect on height at 8 WAP; however, CC reduced height compared to NCC over all row widths (Table 3.5).

Palmer amaranth densities were greater than SM in the 76-cm row width plus CC and row-crop cultivation plus CC treatments by 8 WAP (Table 3.5). Typically, CC is expected to decrease weed density; it is possible that the density increase for CC-containing treatments was caused by moisture retained at the soil surface with other abiotic conditions occurring in this site-year (Wells et al. 2014). The row-crop cultivation treatment did not change Palmer amaranth density compared to SM, which corresponded to observations in other site-years, indicating the soil disturbance from row-crop cultivation did not stimulate more weed emergence. Densities in NRW or CC plus NRW treatments did not differ from SM. While the 38-cm row width and 19-cm row width plus CC treatments did not differ from SM, the 19-cm row width with NCC treatment reduced density compared to the 19-cm row width plus CC treatment. This indicated that the addition of CC to this row width was counterproductive. Contrasts indicated that the 38-

cm and 19-cm row widths reduced weed density by 47 and 68%, respectively, compared to the 76-cm row width. When CC and NCC treatments across all row widths were compared, use of a CC resulted in a 170% increase in weed density compared to the NCC treatments. The use of a CC may not consistently result in lower weed densities (Table 3.5).

Palmer amaranth biomass was less in the CC plus 19-cm row width and in response to row-crop cultivation compared to SM at 8 WAP in Reno County 2018 (Table 3.5). Contrasts revealed no differences in biomass were observed between the 76-cm and 38-cm row widths, while the 19-cm row width provided greater suppression. Additionally, CC provided a 40% reduction in late season biomass compared to the NCC treatments across all row widths. This could be due to increased crop-weed competitiveness which has been associated with the use of cover crops (Teasdale 1996). The weed biomass data conflict with the density data at this site-year as CC reduced biomass but increased density, likely as a function of the plasticity of Palmer amaranth (Horak and Loughlin 2000) in this dryland environment (Table 3.5).

Waterhemp Height, Density, and Biomass in Franklin County 2017

Waterhemp was shorter in treatments containing row-crop cultivation, CC or NRW plus CC compared to SM at 3 WAP (Table 3.6). No differences in waterhemp height were observed with NRW in the absence of CC as compared to SM. Waterhemp density was reduced from SM by 3 WAP by only three treatments: two with row-crop cultivation and 19-cm row width plus CC. This indicated that either row-crop cultivation or a combination of NRW plus CC was required to reduce density by 3 WAP. Contrasts indicated no overall effects on waterhemp density from NRW or CC (Table 3.6).

Waterhemp biomass was less with row-crop cultivation and with CC plus 19-cm row width treatments than SM by 3 WAP (Table 3.6). For this site-year, a combination of cultural tactics or mechanical control was required to reduce waterhemp biomass, albeit when data were pooled across row widths, CC provided a 53% reduction in biomass compared to NCC treatments (Table 3.6).

Late season waterhemp was shorter compared to SM for all CC-containing treatments at 8 WAP (Table 3.6). Row-crop cultivation plus CC reduced waterhemp height compared to row-crop cultivation alone, indicating that some level of suppression was achieved with the addition of CC. When row-crop cultivation is utilized, producers should consider the use of a cover crop or retain previous crop residues for benefits outside of weed management (i.e., soil conservation, soil moisture retention) (Keene and Curran 2016; Hartzler et al. 1993). Waterhemp was not shorter with NRW in the absence of CC compared to SM at 8 WAP. Furthermore, contrasts revealed a 29% reduction in height for CC compared to the NCC treatments (Table 3.6).

Reductions in waterhemp density from SM were only observed in row-crop cultivation treatments at 8 WAP (Table 3.6). The general lack of difference between treatments was likely due to the waterhemp emergence pattern in this specific environment. For example, the majority of waterhemp may have emerged earlier in the season, prior to the row-crop cultivation at 2.5 WAP, and thus significant proportion of emerged waterhemp were controlled. Fewer waterhemp emerged late, thereby having a reduced density at 8 WAP and CC likely provided the grain sorghum crop other competitive advantages.

Reductions in waterhemp biomass were observed for all CC or row-crop cultivation treatments as compared to SM by 8 WAP (Table 3.6). Biomass in treatments containing NRW in the absence of CC did not differ from SM, though contrasts indicated that 38-cm and 19-cm row widths contributed 49 and 46% reductions in biomass by 8 WAP compared to the 76-cm row widths. The use of NRW provided a similar benefit in soybean in terms of suppressing late season waterhemp biomass (Butts et al. 2016). Additionally, CC provided waterhemp suppression with a 64% reduction in biomass compared to NCC-containing treatments (Table 3.6).

Waterhemp Density in Franklin County 2018

No differences in waterhemp height or biomass were detected at either observation time in Franklin County in 2018 (data not shown). At 3 and 8 WAP, waterhemp density was less than SM in those treatments that contained row-crop cultivation (Table 3.7). All treatments regardless of the presence of CC or NRW resulted in similar densities. At 8 WAP in the absence of CC, the 19-cm row width reduced density compared to the 38-cm row width. The general lack of difference between NRW and CC indicate both components were ineffective at providing waterhemp suppression in this site-year. While reduced CC biomass or soil nitrogen availability could have contributed to the lack of differences at this site-year, similar biomass and soil nitrogen levels were found (Table 3.2), which indicated that environmental factors (i.e., rainfall, soil moisture, thermal amplitude at the soil surface, etc) contributed to the lack of differences.

Pigweed Biomass 8 WAP (Pooled)

To evaluate impact of row width on pigweed at 8 WAP, biomass data were calculated as a percentage of the average biomass for each site-year, and data were pooled across site-years for each row width (Figure 3.1). A pairwise F-test indicated that the slope differed from zero; therefore, trends could be discerned. Linear regression revealed that by decreasing the row width from 76-cm to 38-cm, pigweed biomass was reduced 29%, and by reducing the row width further, from 38-cm to 19-cm, a 17% reduction was observed. While reduction in late season biomass will likely have limited influence on the grain yield of the current crop, these reductions would likely reduce pigweed seed production (Webster and Grey 2015) and would serve as a strategy to impede seedbank replenishment.

Grain Sorghum LI and CIPAR

Pairwise F-tests revealed seasonal LI patterns differed for the 76-cm row width and CC treatment compared to 76-cm row width and NCC ($p = 0.0474$) (Table 3.8). Additional F-tests revealed that regression lines did not differ for the CC and NCC treatments within the 38-cm ($p = 0.2697$) and 19-cm ($p = 0.0910$) row widths. Therefore, data were pooled within the 38-cm and 19-cm row widths; regression lines for the 38-cm and 19-cm row widths were also found to be similar ($p = 0.2938$). Data were then combined across NRW regardless of presence or absence of CC (Figure 3.2). Pooled data for NRW differed from the 76-cm row width and CC treatment ($p < 0.0001$) as well as SM ($p = 0.0007$). All grain sorghum canopies reached 20% LI between 11 to 14 DAE (Table 3.8). This illustrated how NRW may not have much influence on early season pigweed emergence or growth by 3 WAP. The grain sorghum canopy reached 80% LI in the NRW treatments by 39 DAE in contrast to 43 DAE for the SM treatment, and with the addition of CC in the 76-cm row width treatment, grain sorghum reached 80% LI by 49 DAE. This demonstrated that the CC influenced the phenology of the grain sorghum and delayed leaf area development (Table 3.8). Winter cereal cover crops preceding summer annual cereal crops have been documented to influence the phenology (i.e., shoot dry weight and population) as well as the grain yield in corn (Kaspar and Bakker 2015; Martinez-Feria et al. 2016).

The grain sorghum CIPAR data were pooled across site-years with replication nested within site-year as random effects when no interactions were detected (Table 3.9). ANOVA revealed no interaction between row width and CC treatments; therefore, main effects were considered. The presence or absence of CC was nonsignificant in the summation of CIPAR, which is in contrast to LI data, albeit likely due to the pooling of data across all row widths. The main effect of row width showed that NRW accumulated more energy than 76-cm row width treatments. These data further illustrate the benefit of NRW in dryland grain sorghum in terms greater solar efficiency (Table 3.9).

Practical Implications for Management

The herbicide program component provided the most effective pigweed control in contrast to the cultural and mechanical components considered. The success of this program was likely due to the use of overlapping residuals, multiple effective sites of action in each application, and the timeliness of all applications. While this herbicide program achieved excellent pigweed control (> 97%) across all systems, this type of approach would slow the development of herbicide resistance (Godar and Stahlman 2015; Meyer et al. 2015; Norsworthy et al. 2012; Reddy et al. 2013; Sarangi and Jhala 2018; Steckel et al. 2002), albeit herbicide resistance will eventually develop in the absence of integrated strategies, even with a robust herbicide program (Shaner 2014).

The integration of other mechanical and cultural tactics must be considered to extend the life of the limited effective herbicide options that are currently available in grain sorghum (Stahlman and Wicks 2000; Thompson et al. 2017). Row-crop cultivation was the most effective component outside of the herbicide program and provided 79% reduction in pigweed density by 3 WAP when implemented at 2.5 WAP. Greater success of the row-crop cultivation component would be possible when implemented in fields with lower pigweed densities than those in this study (Buhler et al. 1992; Dieleman et al. 1999). This mechanical tactic could substantially reduce the selection pressure on pigweed imposed by POST herbicides and should be utilized when row widths are wide enough to accommodate row-crop cultivation equipment and soil conservation plans allow (Buhler 2002). Even though the integration of CC with row-crop cultivation did not consistently improve weed control, it may facilitate soil conservation (Buhler 1995; Keene and Curran 2016). Ultimately, more consideration must be given to integrate row-crop cultivation with herbicides to improve the long-term control offered by the system and to control weeds within the row (Buhler 1995; VanGessel et al. 1998).

Pigweed control with the CC component had mixed results. While half of the site-years (Riley County and Reno County during 2017, Table 3.4) resulted in approximately 50% reductions in Palmer amaranth density and biomass in both early and late season observations, the other site-years resulted in no change or greater densities of Palmer amaranth and of waterhemp. While this demonstrates the potential benefit of CC as a strategy to reduce the selection pressure on pigweed by herbicides as well as limit seedbank replenishment, more research is needed to understand other agronomic practices (i.e., termination timing, species selection, etc.) to improve the consistency of CC performance in dryland cropping systems featuring grain sorghum.

Pigweed control by 3 WAP was not influenced by NRW and would not reduce the selection pressure on pigweed from POST herbicide applications. Limited early season benefit from NRW has been reported in grain sorghum (Besancon et al. 2017) or other crops (Bradley 2006; Butts et al. 2016; Norsworthy and Oliveria 2004). By 3 WAP, LI of grain sorghum crop was similar across all row-width treatments (Figure 3.2). Reduced pigweed biomass by 8 WAP illustrated the potential benefit of NRW because less seed production is likely from pigweed escapes. The CIPAR data revealed that NRW efficiently intercepted more solar radiation compared to the widest row width by the end of the season, which could provide numerous advantages (i.e., enhanced grain yield) in addition to weed control. As result of this research, integrating the use of NRW or row-crop cultivation together with an herbicide program will achieve consistent control of pigweed and reduce the risk of evolving herbicide resistance.

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Figures and Tables

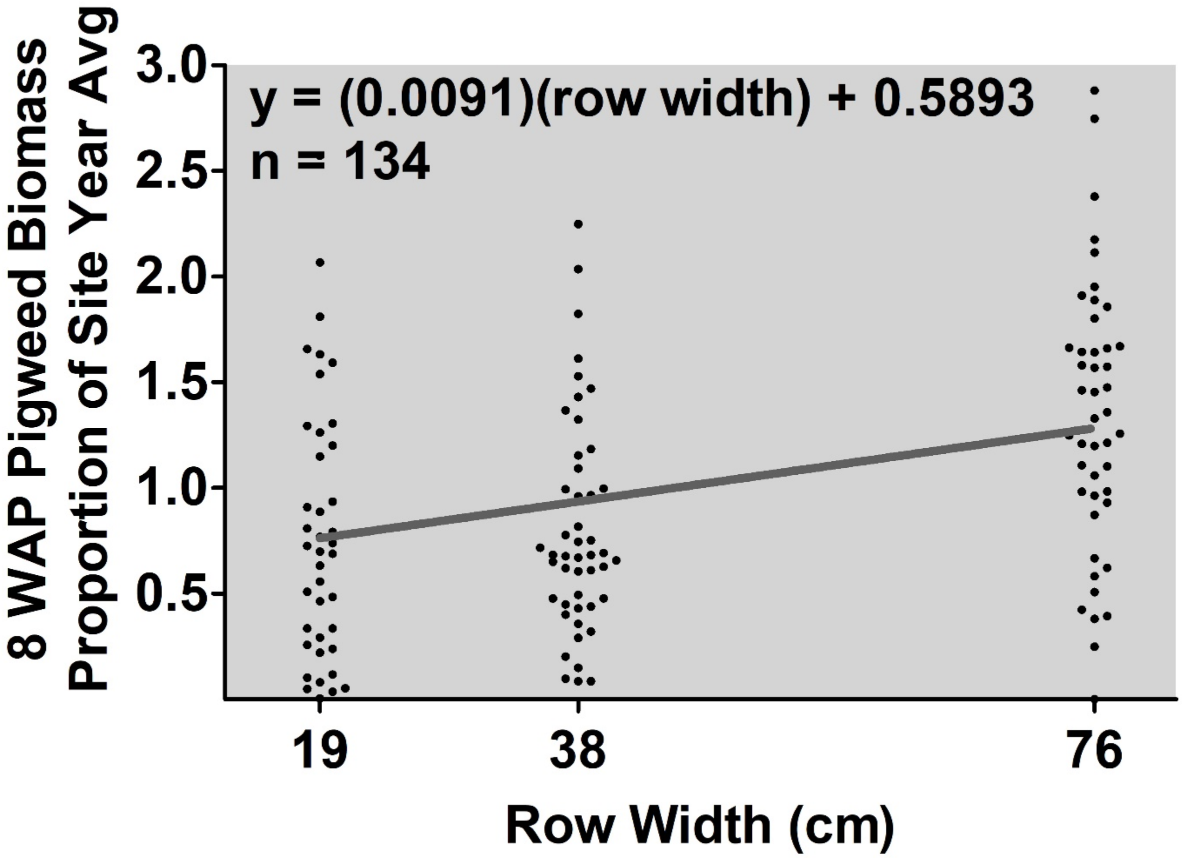


Figure 3.1 Pooled data for pigweed biomass at 8 weeks after planting (WAP) as a proportion of the average for each site-year with three row widths characterized by linear regression.

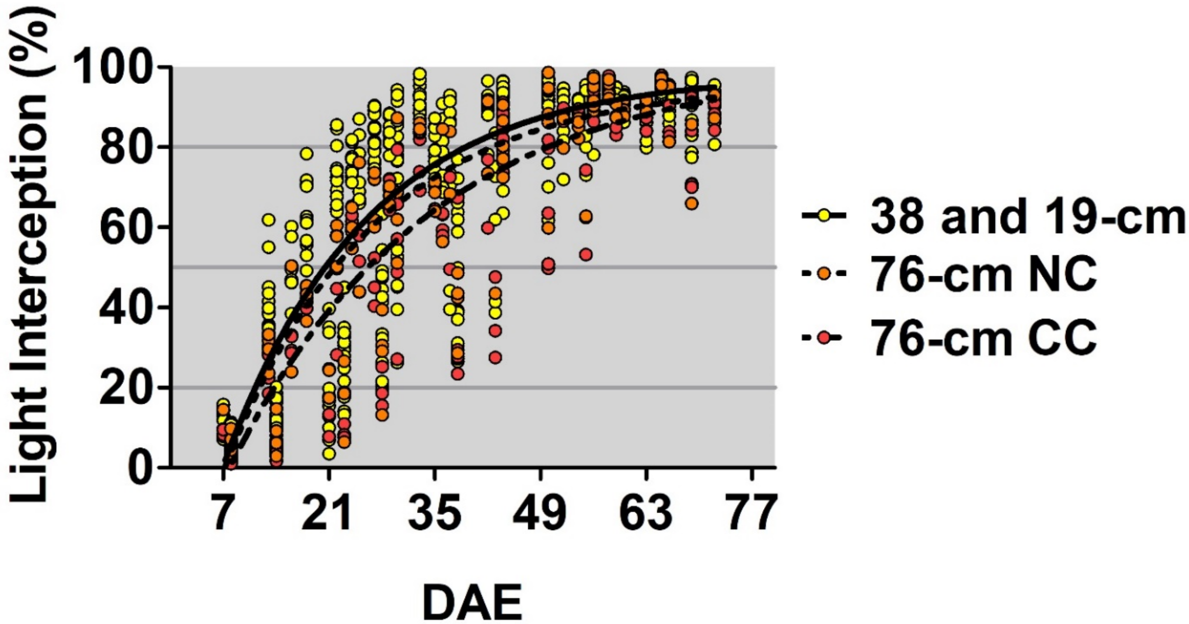


Figure 3.2 Percentage light interception (LI) by grain sorghum from emergence through 80 days after planting (DAE) for 76-cm and 38 and 19-cm row widths.

Table 3.1 Winter wheat cover crop planting and termination dates, grain sorghum planting dates, herbicide application and row-crop application dates, and site characteristics for each site-year. [a,b]

	2017			2018		
Site Characteristics and Operation Dates	Riley County	Reno County	Franklin County	Riley County	Reno County	Franklin County
Cover crop planting	Early October, 2016			Late September, 2017		
Termination	April 20			May 10		
Pre-plant application	June 7	May 30	June 8	May 12	May 12	May 21
Sorghum planting and PRE application	June 21	June 13	June 22	May 22	May 22	June 4
RC application	July 9	July 1	July 10	June 9	June 9	June 22
POST application	July 12	July 5	July 13	June 12	June 12	June 25
Soil series	Reading [c]	Ost [d]	Woodson [e]	Wymore [f]	Ost [d]	Woodson [e]
Soil texture	silt loam	loam	silt loam	silty clay loam	loam	silt loam
Soil organic matter [g] (%)	3.5	2.5	3.5	2.9	2.5	3.3
Soil pH	6.0	6.1	6.6	6.5	5.7	6.4
Soil CEC (meq/100g) [h]	21.1	20.9	17.9	15.8	18.6	18.4

[a] Abbreviations: meq, milliequivalents.

[b] All soil characteristics assessed from a 0 to 7.6 cm soil sampling depth.

[c] Fine-silty, mixed superactive, mesic Pachic Argiudolls

[d] Fine-loamy, mixed, superactive, mesic Udic Argiustolls.

[e] Fine, smectic, thermic Abruptic Argiaquolls.

[f] Fine, smectitic, mesic Aquertic Argiudolls

[g] Loss-on-ignition (Ball 1964).

[h] Adjusted to 7 pH (Rich 1969).

Table 3.2 Winter wheat cover crop above ground dry biomass at grain sorghum planting and soil nitrogen concentration at grain sorghum planting and at grain sorghum maturity. [a]

Site-Year		winter wheat biomass at planting (SE)	soil nitrogen [b,c]			
			CC Treatments		NCC Treatments	
Year	County		Planting	Maturity	Planting	Maturity
		kg ha^{-1}	ppm			
	Riley	5420 (777)	7.9	7.3	48.0	7.1
2017	Reno	4120 (461)	17.1	22.4	19.2	39.3
	Franklin	4468 (580)	27.6	2.9	30.5	2.8
	Riley	3520 (702)	26.0	9.9	12.7	12.3
2018	Reno	2580 (482)	20.3	10.2	22.9	11.7
	Franklin	3144 (410)	86.5	9.6	78.7	10.1

[a] Abbreviations: CC, winter wheat cover crop; NCC, no winter wheat cover crop.
[b] Soil sampled from 61 cm soil cores from cover crop and non-cover crop plots.
[c] PPM represents total concentration of nitrate plus ammoniacal nitrogen.

Table 3.3 Precipitation for each site-year during cover crop and grain sorghum growth and development. [a]

		Precipitation from January through April [b]		Precipitation during Grain Sorghum Growth and Development									
				Weeks after Sorghum Planting								Total	30 yr Normal [c]
Site	Year	Accumulated	30 yr Normal	1	2	3	4	5	6	7	8		
							mm						
Riley County	2017	270	157	4	63	0	0	10	24	95	24	220	182
	2018	81		0	38	16	3	18	5	2	43	125	231
Reno County	2017	287	179	25	0	19	0	8	3	12	25	93	185
	2018	94		0	9	37	0	84	50	0	67	247	218
Franklin County	2017	246	179	4	103	0	26	2	22	19	69	245	172
	2018	163		0	18	7	17	0	0	1	30	73	200

[a] 30 yr normals referenced from 1980 to 2010 for each location as recorded by the National Oceanic and Atmospheric Administration (Arguez et al. 2010).

[b] Precipitation values reflect moisture that occurred during the growth and development of winter wheat cover crop.

[c] Values calculated from 30 yr normal precipitation from the planting date for each site-year through 8 wk after planting.

Table 3.4 Influence of grain sorghum row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on Palmer amaranth density and biomass averaged across site-years in Riley County during 2017 and 2018 and Reno County during 2017 in the absence of the herbicide program component. [a,b,c]

Treatments		3 WAP		8 WAP	
Row Width	Component(s) [d]	Density	Biomass	Density	Biomass
		plants m^{-2}	g m^{-2}	plants m^{-2}	g m^{-2}
76-cm	CC + RC	20 d	0.7 e	48 c	31 e
	CC	320 bc	19 b-d	343 ab	190 bc
	RC	120 cd	10.2 de	205 bc	83 de
	-	710 a	38 a	431 a	303 a
38-cm	CC	310 bc	11 de	208 bc	108 c-e
	-	600 a	29 ab	524 a	178 bc
19-cm	CC	300 b-d	15 cd	181 bc	140 b-d
	-	550 ab	26 bc	496 a	218 ab
p-value		*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
Contrasts [e,f]					
76-cm vs. 38-cm row widths		515 vs. 455 NS	28.5 vs. 20 **	387 vs. 366 NS	246 vs. 143 ***
76-cm vs. 19-cm row widths		515 vs. 425 NS	28.5 vs. 20.5 *	387 vs. 339 NS	246 vs. 179 **
38-cm vs. 19-cm row widths		455 vs. 425 NS	20 vs. 20.5 NS	366 vs. 339 NS	143 vs. 179 NS
CC vs. NCC		310 vs. 620 ****	15 vs. 31 ****	244 vs. 484 ****	146 vs. 233 ***

[a] Abbreviations: WAP, weeks after planting; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant; NCC, no cover crop.

[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD ($\alpha = 0.05$).

[c] Height data for means and contrasts were found to be NS and are not shown.

[d] Hyphen indicates that no CC or RC was present in the treatment.

[e] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p = 0.01 to 0.0001, ****p < 0.0001 levels.

[f] All contrasts were conducted in the absence of RC-containing treatments.

Table 3.5 Influence of grain sorghum row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on Palmer amaranth height, density, and biomass at 8 WAP in Reno County 2018 in the absence of the herbicide program component. [a,b,c]

Treatments		8 WAP		
Row Width	Component(s) [d]	Height	Density	Biomass
		cm	plants m^{-2}	g m^{-2}
76-cm	CC + RC	30 c	382 a	266 b
	CC	45 ab	336 a	388 ab
	RC	40 a-c	119 bc	191 b
	-	47 a	175 bc	600 a
38-cm	CC	44 ab	114 bc	353 ab
	-	45 ab	50 c	588 a
19-cm	CC	36 bc	241 ab	216 b
	-	50 a	31 c	403 ab
p-value		*0.0115*	*0.0009*	*0.0281*
Contrasts [e,f]				
76-cm vs. 38-cm row widths		46 vs. 44.5 NS	256 vs. 82 ***	494 vs. 471 NS
76-cm vs. 19-cm row widths		46 vs. 43 NS	256 vs. 136 **	494 vs. 310 *
38-cm vs. 19-cm row widths		44.5 vs. 43 NS	82 vs. 136 NS	471 vs. 310 *
CC vs. NCC		42 vs. 47 **	230 vs. 85 ***	319 vs. 530 ***

[a] Abbreviations: WAP, weeks after planting; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant; NCC, no cover crop.
[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD (α = 0.05).
[c] 3 WAP data are not included as Palmer amaranth was not emerged.
[d] Hyphen indicates that no CC or RC was present in the treatment.
[d] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p = 0.01 to 0.0001, ****$p < 0.0001$ levels.
[e] All contrasts were conducted in the absence of RC-containing treatments.

Table 3.6 Influence of grain sorghum row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on waterhemp height, density, and biomass at 3 and 8 WAP in Franklin County during 2017 in the absence of the herbicide program component. [a,b]

Treatments		3 WAP			8 WAP		
Row Width	Component(s) [c]	Height	Density	Biomass	Height	Density	Biomass
		cm	plants m^{-2}	g m^{-2}	cm	plants m^{-2}	g m^{-2}
76-cm	CC + RC	18 b	111 b-d	7.8 b	99 c	45 b	81 bc
	CC	18 b	304 a	20 ab	101 c	205 a	110 bc
	RC	22 b	61 d	10 b	131 ab	7 c	63 bc
	-	32 a	165 a-d	36 a	146 a	93 ab	230 a
38-cm	CC	21 b	220 a-d	16 ab	101 c	71 ab	49 bc
	-	33 a	234 a-c	37 a	133 a	84 ab	123 a-c
19-cm	CC	16 b	88 cd	8 b	105 bc	62 ab	26 c
	-	33 a	261 ab	24 ab	149 a	95 ab	156 ab
p-value		*0.0033*	*0.0463*	*0.0432*	*0.0012*	*0.0026*	*0.0322*
Contrasts [d,e]							
76-cm vs. 38-cm row widths		25 vs. 27 NS	235 vs. 227 NS	28 vs. 27 NS	124 vs. 117 NS	149 vs. 78 NS	170 vs. 86 **
76-cm vs. 19-cm row widths		25 vs. 25 NS	235 vs. 175 NS	28 vs. 16 NS	124 vs. 127 NS	149 vs. 79 NS	170 vs. 91 *
38-cm vs. 19-cm row widths		27 vs. 25 NS	227 vs. 175 NS	27 vs. 16 NS	117 vs. 127 NS	78 vs. 79 NS	86 vs. 91 NS
CC vs. NCC		18 vs. 33 ****	204 vs. 220 NS	15 vs. 32 **	102 vs. 143 ****	113 vs. 91 NS	62 vs. 170 ***

[a] Abbreviations: WAP, weeks after planting; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant; NCC, no cover crop.

[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD ($\alpha = 0.05$).

[c] Hyphen indicates that no CC or RC was present in the treatment.

[d] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p= 0.01 to 0.0001, ****p < 0.0001 levels.

[e] All contrasts were conducted in the absence of RC-containing treatments.

Table 3.7 Influence of grain sorghum row width (cm), winter wheat cover crop (CC), and row-crop cultivation (RC) on waterhemp density at 3 and 8 WAP in Franklin County in 2018 in the absence of the herbicide program component. [a,b,c]

Treatments		Density	
Row Width	Component(s) [d]	3 WAP	8 WAP
		plants m^{-2}	
76-cm	CC + RC	16 b	10 c
	CC	76 a	34 ab
	RC	18 b	11 c
	-	73 a	51 ab
38-cm	CC	77 a	45 ab
	-	84 a	61 a
19-cm	CC	95 a	39 ab
	-	93 a	20 bc
p-value		*0.0093*	*0.0237*
Contrasts [e,f]			
76-cm vs. 38-cm row widths		73 vs. 81 NS	43 vs. 53 NS
76-cm vs. 19-cm row widths		73 vs. 94 NS	43 vs. 30 NS
38-cm vs. 19-cm row widths		81 vs. 94 NS	53 vs. 30 *
CC vs. NCC		83 vs. 83 NS	39 vs. 44 NS

[a] Abbreviations: WAP, weeks after planting; CC, winter wheat cover crop; RC, row-crop cultivation; NS, not significant.

[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD ($\alpha = 0.05$).

[c] 3 WAP height and biomass and 8 WAP height and biomass means and contrasts were found to be NS and are not shown.

[d] Hyphen indicates that no CC or RC was present in the treatment.

[e] Significance of contrast means difference: *p = 0.1 to 0.05, **p = 0.05 to 0.01, ***p = 0.01 to 0.0001, ****p < 0.0001 levels.

[f] All contrasts were conducted in the absence of RC-containing treatments.

Table 3.8 Parameter estimates and model fit values for equation 1 describing light interception by grain sorghum canopy growing in different treatments of soybean row widths and winter wheat cover crop (CC) or no cover crop (NCC) pooled across all site-years. [a]

		Parameter Estimates [b]			Model Fit Values		DAE for Light Interception	
Data Sets	*p-value* [c]	LI_0 (SE)	$LI_{plateau}$ (SE)	K (SE)	R^2	df	20%	80%
76-cm CC	< 0.0001	-34.23 (8.198)	101.1 (5.851)	0.0373 (0.0056)	0.8232	124	14	49
38, 19-cm CC + NCC		-42.58 (5.891)	98.21 (2.094)	0.05235 (0.0037)	0.7473	513	11	39
76-cm NCC	0.0007	-42.02 (8.955)	96.17 (3.204)	0.05039 (0.0060)	0.8604	106	12	43

[a] Abbreviations: DAE, days after emergence; df, degrees of freedom; CC, winter wheat cover crop; NCC, no cover crop.

[b] Parameter estimates: LI_0 is light interception at x_0; $LI_{plateau}$ is light interception at $x_{infinite}$; K is the rate constant expressed in reciprocal of DAE.

[c] Significance of pairwise F-Test comparing the emergence patterns between the two treatments; if the regression curves were nonsignificant, the data were pooled.

Table 3.9 Influence of grain sorghum row width and presence of winter wheat cover crop on CIPAR in the presence of the herbicide component (pooled).[a,b]

Treatment	CIPAR
	MJ m^{-2}
Presence of Cover Crop	
Cover Crop	522
None	546
Row Width	
76-cm	491 b
38-cm	564 a
19-cm	548 a
ANOVA	
Cover Crop	NS
Row Width	0.0032
CC x RW	NS

[a] Abbreviations: CIPAR, cumulative intercepted photosynthetically active radiation; NS, not significant.
[b] Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD (α = 0.05).

Chapter 4 - Epilogue: Conclusions and Implications for Management

In conclusion from the research presented in Chapters 2 and 3, the herbicide program was the most effective of all the control tactics assessed by offering greater than 97% control (personal observation) in all plots across all combinations of cultural and mechanical practices. Row-crop cultivation was very effective in reducing pigweed density and biomass early and late season, and in most site-years, did not result in additional pigweed emergence. This indicates that in dryland environments, a timely row-crop cultivation may be warranted without increasing total pigweed emergence. The addition of a cover with the row-crop cultivation did not provide a benefit in terms of pigweed control in any site-year, albeit, additional research should be implemented to discern if the inclusion of a cover crop with row-crop cultivation could be used to mitigate soil conservation concerns generally associated with the use of cultivation.

The winter wheat cover crop delivered mixed results: in half of the site-years, the cover crop resulted in 50% reductions in pigweed density and biomass in early and late season observations. In the remaining site-years, a neutral to an increase in pigweed density was observed. While this experiment was not designed to assess the causes of this phenomena, it was likely due to the variation in soil type and environmental conditions which may have favored increased emergence periods compared to areas without a cover crop. This research illustrates the importance of continuing research to develop better management recommendations to increase the success rate of cover crops in terms of pigweed suppression.

Narrow row widths (< 76 cm) had little to no benefit in terms of early season pigweed control or late season pigweed density. When data were pooled across site-year, narrow row widths reduced late season biomass production from the 76 cm row width by approximately 25%

for 38 cm rows and 35% for 19 cm rows. In turn, this illustrated the importance of using narrow row widths to possibly limit the replenishment of the soil seed bank when a few surviving plants might escape other control methods.

Overall, this research supports the use of a robust herbicide program with multiple effective sites of action applied in a layered residuals approach. When narrow row widths are not utilized, timely row-crop cultivation could be utilized to control pigweed between the rows prior to an herbicide application to control the remaining pigweed as well as layer additional residual herbicide. Cover crops could also be considered as an option to provide pigweed control early and late season. In addition to the use of a cover crop, narrow row widths could be utilized to possibly limit the fecundity of escaped pigweed as well. In addition, other integrated strategies such as crop rotation, field border management, and other best management practices should be implemented to improve overall pigweed control and reduce the risk of herbicide resistance.

Appendix A - Grain Yields for Soybean and Grain Sorghum

Grain yields for 2017 site-years. [a,b]

Row Width (cm)	CC or RC	Herbicide Program	Soybean Riley	Soybean Franklin	Sorghum Riley	Sorghum Reno	Sorghum Franklin
			kg ha^{-1} (SEM)				
76	CC + RC	Y	2338 (327)	2847 (190)	2936 (682)	4665 (360)	3759 (513)
	CC	Y	2111 (75)	2785 (116)	2992 (434	4630 (236)	4193 (929)
	RC	Y	2422 (199)	2722 (119)	4202 (453)	4212 (548)	4764 (478)
	CC + RC	-	1017 (232)	2401 (162)	3381 (470)	3572 (172)	2506 (478)
	-	Y	1964 (151)	3143 (280)	2985 (573)	4570 (400)	4502 (995)
	CC	-	554 (167)	2283 (315)	1007 (446)	2803 (367)	1422 (144)
	RC	-	402 (158)	3032 (112)	1866 (446)	3092 (597)	3922 (1036)
	-	-	1897 (283)	2282 (389)	1309 (402)	1207 (195)	2680 (518)
38	CC	Y	2656 (341)	2689 (850)	2252 (558)	4325 (161)	4512 (1187)
	-	Y	2749 (27)	3436 (362)	2531 (710)	4512 (518)	4595 (826)
	CC	-	622 (141)	3781 (880)	2038 (360)	3102 (252)	2062 (316)
	-	-	253 (138)	3097 (252)	1685 (645)	2674 (527)	2328 (293)
19	CC	Y	2916 (153)	4166 (288)	4400 (941)	5419 (368)	4088 (1423)
	-	Y	3255 (237)	3900 (217)	3972 (328)	5720 (532)	4006 (1014)
	CC	-	561 (55)	3165 (347)	1835 (401)	3527 (247)	2561 (847)
	-	-	425 (101)	4084 (509)	1868 (920)	1198 (77)	2416 (1470)

[a] Abbreviations: SEM, standard error of the mean; CC, winter wheat cover crop; RC, row-crop cultivation.

[b] Soybean grain moisture was adjusted to 13.5% and sorghum to 14.5%.

Appendix B - Integrated Weed Management, AGRON 650 Unit 1

Herbicide Site of Action 1: ALS and EPSPS-Inhibiting Herbicides, Inhibit Amino Acid Production

Video Notes for Class on January 29, 2019

I. Herbicide Introductory Material

A. Herbicide site of action

Defn:

Site of action:

Mode of action:

Family:

WSSA Group Number:

B. Herbicide residual vs. persistence

Defn:

Herbicide residual:

Herbicide persistence:

A ______________________ effective dose is the rate of herbicide required amount of herbicide to trigger a specific response.

Diagram of herbicide half-life. Be sure to label the 3 different types of doses in regards to herbicide residual/persistence (carryover, weed control, no control but still persistent).

II. Acetolactate synthase (ALS)-inhibitor WSSA SOA 2

A. History

a. Discovered in ______________ by Dow, DuPont, and American Cyanamid (BASF)

b. ALS herbicides can have ______________ and ____________ activity on plants.

c. ALS herbicides tend to have ___________ use rates and are relatively ______________ to environmental ecosystems. They also pose a low toxicity to animals.

B. Families

a. Imidazolinone were developed by ______________________ - today's BASF

i. Abbreviated as _____________.

ii. Common herbicides

Common Name	**Trade Name**	**Crop Use**
Imazethapyr	Pursuit or Newpath	Soybean and Rice
Imazaquin	Scepter	Soybean
Imazamox	Raptor or Beyond	Soybean/Alfalfa and Clearfield Crops
Imazapic	Plateau	Smooth bromegrass
Imazapyr	Arsenal	Range, bermudagrass, brush

iii. Most of these herbicides have __________ residual activity.

b. Sulfonylurea were developed by ____________________ – portfolio was split in 2017 with sale of cereal herbicides to __________________.

i. Abbreviated as __________________.

ii. Common herbicides

Common Name	Trade Name	Crop Use
Chlorsulfuron	Glean or Corsair	Small grains or Ken. Bluegrass lawns
Metsulfuron	Ally	Small grains/sorghum
Chlorimuron-ethyl	Classic	Soybean
Halosulfuron	Permit	Corn/sorghum
Nicosulfuron	Accent	Corn
Rimsulfuron	Resolve	Corn/cotton/peanuts/soybean
Thifensulfuron	Harmony	Soybean/corn/cereals/ Express Sun Sunflowers
Trifloxysulfuron	Envoke/Monument	Cotton/turf
Tribenuron	Express	Small Grains

In the above list, indicate which herbicides have the following types of residual activity .

*short residual

**very short residual

c. Triazolopyrimidine or sulfonalilides were developed by __________________________.

i. Abbreviated as __________________.

ii. Common herbicides

Common Name	Trade Name	Crop Use
Chloransulam-methyl	FirstRate	Soybean

Florasulam	Component of Quelex	Small grains
Flumetsulam	Python	Corn and soybean
Pyroxsulam	PowerFlex HL	Small grains

d. Sulfonylaminocarbonyl-triazolinone
  i. Abbreviated as _________________.
  ii. Common herbicides

Common Name	Trade Name	Crop Use
propoxycarbazone	Olympus	Small grains
Flucarbazone	Pre-Pare	Small grains (Spring market)
Thiencarbazone-methyl	Component of Corvus	Corn and small grains, fallow

e. Pyrimidinyl thiobenzoate <u>or</u> pyrimidinylthibenzoic acid
  i. Can be abbreviated "PC"
  ii. Common herbicides

Common Name	Trade Name	Crop Use
Pyrithiobac-sodium	Staple	Cotton
Bispyribac-sodium	Velocity	Turf

C. Mechanism
  a. Stops production of _________, ___________, and ____________. Classified as

  __________________ ______________ AMINO ACIDS.

  b. Required by plants – pathway not found in _____________________.

c. Secondary effect results in disruption of ____________ and ______________ synthesis and photosynthate transport.
d. Does not result in lipid peroxidation or disruption of _________________________ instead “slow, painful death”

B. Location of activity
   a. In ___________________, but does not interfere with photosynthesis.

C. Mobility in plants
   a. Phloem, primary, also xylem

D. K_{ow}
   a. Can be lipophilic or hydrophilic depending on pH (recall _______________ and ___________ examples from Absorption lecture.
   b. Some have a tendency to be more hydrophilic; most other SU’s are lipophilic at normal pH (6.0 to 7.0) values.
   c. IMI’s tend to be very ______________________.

D. Fate in soil- specific to each family
   a. SU family
      i. __________ ________________: a combination of an acid with water to destroy a chemical structure.

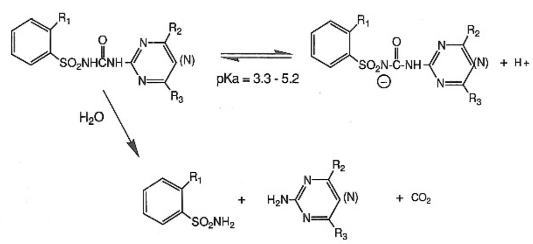
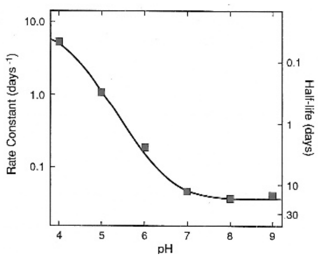


Fig. 7. Sulfonylurea herbicide ionization and hydrolysis.

1. Occurs more in __________________ soil pH values

2. Occurs ___________ in higher pH values because less acid is available



Amount of chlorimuron-methyl left in soil as result of hydrolysis in water of different pH values at a constant temperature. Adapted from Brown (1990) Pest. Sci.

Soil	pH	Graphically determined half-life including t_0
		(days)
Platner loam	6.2	38.1
Weld clay loam	7.1	60.2
Rago silty clay loam	7.7	82.0
Longmont clay	8.1	99.0

Degradation of chlorsulfuron. As pH increases, the half-life increases, meaning that there is less degradation, presumable due to less acid hydrolysis. Adapted from Thirunarayanan et al. (1985) Weed Sci.

ii. Microbial degradation

1. Microbial degradation is favored in ________ and moist conditions.
    a. Very little occurs in cool or dry soils.
    b. If herbicide is ________________, degradation cannot occur.

2. ______________ ____________ is common is PSII herbicides but does ________ occur in ALS herbicides. Instead, some soils just have more of the appropriate organisms to facilitate degradation. This is ___________ to predict.

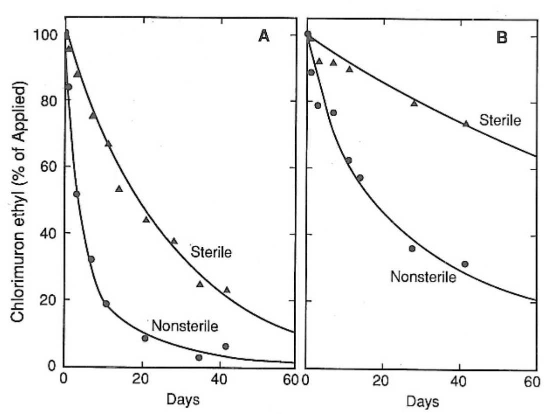
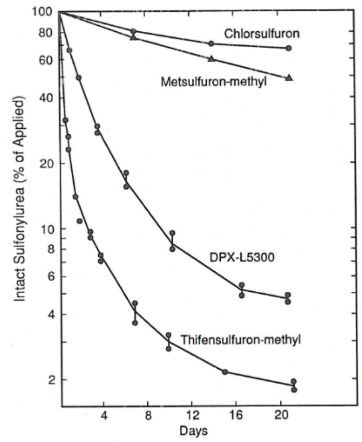


Fig. 9. Degradation of [^{14}C]chlorimuron-ethyl in (▲) ethylene oxide-sterilized and (●) non-sterilized soils at 30°C and 1 bar moisture. Treatment, extraction and HPLC analyses were performed according to Ref. 45. A, Silt loam soil, pH = 6·3, organic matter = 1·4%; B, Silt loam soil, pH = 7·8, organic matter = 1·1% (Linn, D. M., unpublished).

iii. Bridge contraction

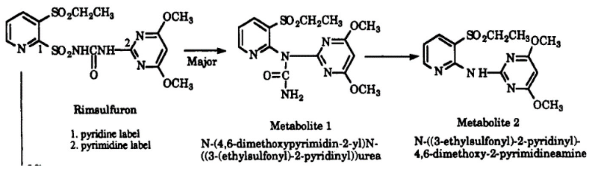
1. Special degradation mechanism of _______________.
    a. Rimsulfuron is important for early preplant treatment for _____________, _________________, ______________ crops.



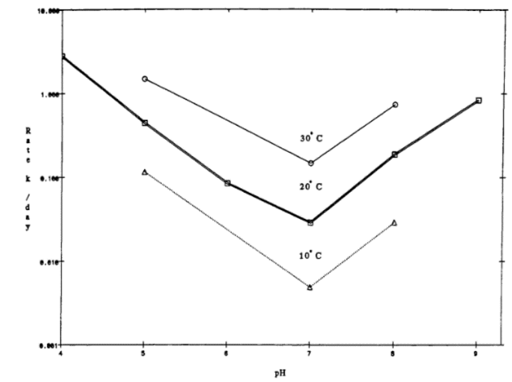
Microbial degradation of SU herbicides at 86 F. Note soil pH is 8.0, therefore little to no acid hydrolysis is facilitating degradation. DPX-L5300 is tribenuron. Adapted from Brown (1990) Pest. Sci.

    b. Strictly a chemical process- not ___________ and different from hydrolysis.
        i. Collapse of bridge between the two functional groups.
        ii. Conversion into compounds that do not have plant activity.
    c. Similar process for halosulfuron and sulfosulfuron

2. Rate of bridge contraction is ___________ and ___________ dependent
    a. Higher rates of degradation are below 6.5 and above 7.5
        i. ____________________ pH range is the stability zone
        ii. When applied to soils in this zone, we can have excellent residual activity.
    b. Rate of breakdown is about _______________ times higher at 6.0 and 8.0 than compared to the breakdown in the stability zone pH range.
    c. Rate of breakdown is about ___________ times faster at 70 degrees than 40 degrees in a 7.0 soil pH.



Bridge contraction of rimsulfuron in the soil as a chemical process independent of microbes. Notice how the "bridge" connecting the two functional groups is shortened. This results in two metabolites of rimsulfuron that do not have herbicidal activity. Adapted from Schneiders et al. (1993). J of Ag Food Chem.

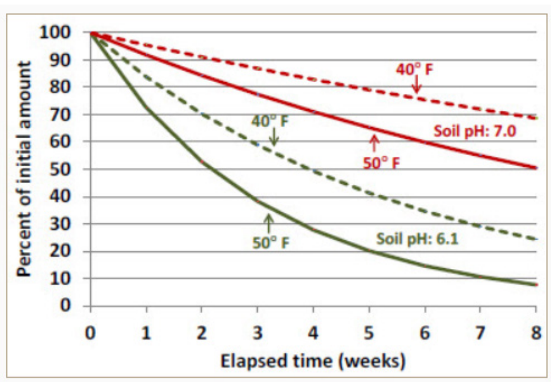


. Rate constant (k/day) for hydrolysis of rimsulfuron as affected by temperature and pH.

Effect of soil pH (x-axis) on the rate of bridge contraction (y-axis) in rimsulfuron at different temperatures. Notice that the rate of contraction is higher as temperature increases. Notice that the rate of contraction is highest at pH values outside of the 6.5 to 7.5 pH zone. Adapted from Schneiders et al. (1993). J of Ag Food Chem.

Table 1. Soil temperature and pH affect residual levels of rimsulfuron.

Soil temp (°F)	Percent of initial concentration one week after application		
	pH 6.1	pH 7.0	pH 8.1
30° F	90.9%	97.5%	93.8%
40° F	83.8%	95.4%	87.3%
50° F	72.6%	91.8%	75.8%
60° F	56.8%	85.9%	57.6%
70° F	37.5%	76.8%	34.3%



Percent of initial concentration of rimsulfuron remaining as a result of soil pH and soil temperature. Adapted from DuPont Pioneer Agronomy Library.

3. Influence of soil organic matter on residual (no effect on degradation).
    a. Rimsulfuron residual activity is reduced in soils with high organic matter because of ______________ (not available).
    b. Generally, for 1% increase in OM content, the rate of rimsulfuron must double in order to achieve similar residual activity in both soils.

b. IMI family
   i. Hydrolysis or bridge contraction _________ __________ occur.

   ii. IMI's are highly susceptible to _________________degradation.
   iii. Microbial degradation depends on availability of the herbicide in the soil.

   iv. IMI's are strongly ______________________ to the soil below pH of 6.0.
      1. Not available for microbial degradation, therefore, persistence of the herbicide____________________.
      2. In high pH soils, the persistence of the herbicide can increase because too much herbicide is in solution (microbes can't keep up).
   v. Persistence increases when conditions are not favorable to microbial degradation such as ____________ and ___________________.
      1. Depending on the concentration of the herbicide, the 50% dose may generate a strong biologic response on a susceptible species (corn).
      2. Strong adsorption in acidic or lack of adsorption in high pH could generate a crop response through increased persistence if the environment is not conducive to microbial degradation.

		Half-life	
Temperature	Water potential	Sharkey silty clay 0.12 ppmw[a]	Crowley silt loam 0.12 ppmw[a]
(C)	(−kPa)	(months)	
18	100	11.7	7.2
18	33	9.8	2.7
35	100	3.0	2.5
35	33	2.2	1.3
LSD (0.05) = 5.7			

[a]Initial imazaquin concentrations.

Half-life of imazequin as result of two temperatures and water potentials. Notice that in cool soils, the half-life increased drastically. Adapted from Basham and Lavy (1987) Weed Sci.

Table 5. Effect of pH on the sorption of imazaquin.

Soil	pH	Imazaquin in soil solution[a]
		(%)
Lucedale fine sandy loam	5.8	47 a
	6.3	48 a
	6.6	100 b
Decatur silt loam	4.7	38 a
	5.2	60 b
	5.5	75 c
Dothan sandy loam	6.0	50 a
	6.4	56 b
	6.6	65 c

[a]Means within the same soil type with the same letter are not significantly different based upon Duncan's multiple range test ($P \leq 0.05$).

Percent of Imazaquin in soil solution as result of soil pH across multiple soil textures. Notice how more herbicide is adsorbed at low pH values. Adapted from Goetz et al. (1986) Weed Sci.

c. Triazolopyrimidine <u>or</u> sulfonalilides; Sulfonylaminocarbonyl-triazolinone; Pyrimidinyl thiobenzoate <u>or</u> pyrimidinylthibenzoic acid
   i. Microbial degradation
   ii. Very similar pattern to _______ family with low pH soil adsorption
   iii. Soil incorporation (See Staple label) for details of dilution.

E. Residual characteristics
   a. Generally excellent residual properties
   b. Special considerations
      i. ________________________
      ii. _________________________
      iii. ______________________

F. Adjuvants
   a. Highly responsive to _________________ and ____________________ activator adjuvants for absorption
      i. Special label situations enable the use of a more "aggressive" adjuvant package.
         1. Two gene Clearfield wheat

Beyond®
Clearfield® Production System Herbicide

For use only on Clearfield® canola, Clearfield lentil, Clearfield rice, Clearfield and Clearfield® Plus sunflower, and Clearfield and Clearfield Plus wheat

Active Ingredient:
ammonium salt of imazamox: 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid* 12.1%
Other Ingredients: 87.9%
Total: 100.0%

*Equivalent to 11.4% 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid
1 gallon contains 1.0 pound of active ingredient as the free acid.

Crop Oil Concentrate (COC), Methylated Seed Oil (MSO), or High Surfactant Oil Concentrate (HSOC)
Petroleum-based or vegetable seed-based crop oil concentrate may be used. Methylated seed oil is recommended when weeds are under moisture or temperature stress.

DO NOT use crop oil concentrate or methylated seed oil with **Beyond® herbicide** on **Clearfield®** lentil, **Clearfield** sunflower, or **Clearfield** wheat. Crop oil concentrate or methylated seed oil may be used with **Beyond** on **Clearfield® Plus** varieties of sunflower or wheat.

Use methylated seed oil or crop oil concentrate at 1 to 2 gallons/100 gallons of spray solution (1 to 2% volume/volume [v/v]).

Use HSOC at 0.5 gallon/100 gallons of spray solution (0.5% v/v).

OR

Surfactant
Use nonionic surfactant (NIS) containing at least 80% active ingredient. Apply surfactant at 1 quart/100 gallons of spray solution (0.25% v/v). Organosilicone surfactant may be used in place of NIS.

AND

Nitrogen Fertilizer
Recommended nitrogen-based fertilizers include liquid fertilizers [such as liquid ammonium sulfate (AMS), 28% N, 32% N, or 10-34-0] at 2.5 gallons/100 gallons of spray solution. Instead of liquid fertilizer, spray-grade ammonium sulfate may be used at 12 to 15 pounds/100 gallons of spray solution.

2. Use of a more __________________ (MSO or COC containing) adjuvant package can cause undo crop response.

G. Spectrum of control
   a. Overall very broad spectrum for grasses and broadleaf weeds and sedges
   b. Some ALS herbicides offer a very narrow range of control options

      i. ________________________– sedges

   c. Some have very broad spectrum (________________ or ____________________)

H. Tank mix interactions
   a. Can be antagonistic with ____________________.

   b. Antagonism with ___________________ herbicides

      i. Tank mix of ALS herbicide (i.e., Pursuit) with ACCase (i.e., Select)
         1. Only effective on small, actively growing grasses
         2. Poor efficacy on _________________ and ______________.
         3. Fair efficacy on shattercane, giant foxtail, and corn.

      ii. Small grass weeds, high rates of ACCase, and ammonium can help overcome antagonism.

c. Crop injury with ________________ insecticides- must be considered in planning process.

Herbicide	Active Ingredients	Organophosphate Insecticides				
		Aztec® 2.1G Aztec 4.67G	Counter® 15G Counter 20G	Fortress® 5G	Lorsban® 15G	SmartChoice™ 5G
Accent®/Accent Q	nicosulfuron	■	●	■	▲	■
Balance® Pro/Flexx	isoxaflutole	■	■	■	■	■
Basis®	rimsulfuron, thifensulfuron	■	●	■	▲	■
Beacon®	primisulfuron	▲	●	▲	▲	▲
Callisto®	mesotrione	■	▲	■	▲	■
Callisto Xtra	mesotrione, atrazine	■	▲	■	▲	■
Camix®	mesotrione, metolachlor	▲	▲	▲	▲	▲
Capreno®	thiencarbazone, tembotrione	■	●	■	●	■
Corvus™	thiencarbazone, isoxaflutole	■	●	●	●	●
Halex™ GT	mesotrione, glyphosate, metolachlor	●	●	●	●	●
Hornet®	flumetsulam, clopyralid	▲	●	▲	▲	▲
Impact®	topramezone	■	■	■	■	■
Laudis®	tembotrione	■	■	■	■	■
Leadoff™	rimsulfuron, thifensulfuron	■	●	■	▲	■
Lexar®	mesotrione, atrazine, metolachlor	▲	▲	▲	▲	▲
Lumax®	mesotrione, atrazine, metolachlor	▲	▲	▲	▲	▲
Northstar®	primisulfuron, dicamba	▲	●	▲	▲	▲
Option®	foramsulfuron	■	●	■	▲	■
Permit®	halosulfuron	■	●	■	■	■
Prequel®	rimsulfuron, isoxaflutole	■	●	■	▲	■
Priority®	carfentrazone, halosulfuron	■	■	■	■	■
Python®	flumetsulam	▲	●	▲	▲	▲
Radius®	flufenacet, isoxaflutole	■	■	■	■	■
Realm™ Q	rimsulfuron, mesotrione	■	●	■	●	■
Require® Q	rimsulfuron, dicamba	■	●	■	▲	■
Resolve® Q	rimsulfuron, thifensulfuron	■	●	■	▲	■
Sharpen®	saflufenacil	■	●	■	●	■
Spirit®	prosulfuron, primisulfuron	▲	●	▲	▲	▲
Steadfast® Q	nicosulfuron, rimsulfuron	■	●	■	▲	■
Stout®	nicosulfuron, thifensulfuron	■	●	■	▲	■
Surestart®	flumetsulam, clopyralid, acetochlor	▲	●	▲	▲	▲
TripleFLEX®	flumetsulam, clopyralid, acetochlor	▲	●	▲	▲	▲
Verdict™	saflufenacil, dimethenamid	■	●	■	●	■

■ No restrictions specified on herbicide label when using insecticide within product guidelines.
▲ Restrictions on application method or timing and/or risk of crop injury. Refer to herbicide label for specific instructions.
● Application is not recommended; significant risk of crop injury.

Adapted from DuPont Pioneer Agronomy Library.

i. ALS and organophosphates are ___________________ via the same pathway in certain crops (i.e, corn) and will cause crop response as the herbicide will accumulate at toxic levels.

III. 5-enolypyruvyl-shikimate-3-phospate synthase (EPSPS) inhibitors WSSA SOA 9

A. History

a. Invented in ____________by Swiss chemist Dr. Henry Martin, Cilag Pharmaceutical.

i. Never used as it had no pharma applications

ii. In 1959, Cilag was purchased by Johnson and Johnson which sold glyphosate to Aldrich chemical.

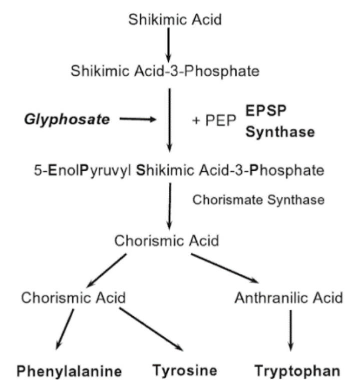
iii. Monsanto aquired glyphosate in a group of 100 other compounds fpr the development of______________________________ from Aldrich.

1. Dr. Phil Hamm screened for herbicidal activity with poor results.
2. Dr. John Franz developed various analogs and derivatives of the original molecule. The 3rd attempt yielded glyphosate as we recognize it.

3. First synthesized in May of ______________, available in ____________.
    a. Non selective, no soil residual
    b. Very unique, very expensive when introduced.

B. Families
    a. Glycine (sometimes none)

C. Mechanism
    a. Affects ______________ acid pathway



        i. 3 ____________________ acids ______________, ________________, and __________________________.
        ii. Secondary products (thus inhibits formation of) lignins, coumarins, alkaloids, IAA)
        iii. Pathway found in plants, fungi, and bacteria (not animals).
        iv. _________________ of total fixed carbon moves through this pathway

    b. Replaces PEP (carbon substrate for amino acid synthesis (binds 115 fold tighter)
    c. Does not inhibit ____________________or cause lipid peroxidation directly
    d. Shikimic acid pathway not found in animals

D. Location of activity
    a. ____________________ organelle.

E. Mobility in plants
    a. Primarily phloem mobile, very systemic

F. K_{ow}
    a. Hydrophilic
    b. Absorption can be difficult; however, most species are ____________ susceptible so very little needs to be absorbed for excellent control.

G. Fate in soil
    a. Binding as a _________________ (dipolar ion; positive and negative properties)

    b. _______________________ _______________converts to phosphoric acid and amino groups.
H. Residual characteristics- none
I. Adjuvants
    a. Non-ionic surfactant required for _________________ formulations.

    b. Ammonium sulfate required; UAN does not substitute

        i. AMS needed for ________________ and ___________ adjuvant functions.
            1. _____________ (utility) tie-up cations in water and leaf surface
            2. ______________ (Activator) complex with glyphosate for better uptake through plasmalemma.

        ii. Equation to calculate the required amount of AMS
            1. Lbs of AMS/100 gallons = (0.002 x ppm K) + (0.005 x ppm Na) + (0.009 x ppm Ca) + (0.014 x ppm Mg) + (0.042 ppm Fe).

            2. _____ to ____________ lbs AMS/100 gallon general rate range.

            3. Minimum of _______________ lbs AMS/100 gallon for uptake and leaf surfaces.
            4. Beware of AMS replacement products.
J. Spectrum of control
    a. Very broad spectrum
    b. Grass, broadleaf, and perennials
    c. Need 1-2 days of temps in 50 F to achieve early or late season control.
K. Tank mix interactions
    a. Very difficult to tank mix with certain formulations of 2,4-D amine
    b. Never tank mix with paraquat.
    c. Can have antagonism with PPO herbicides
    d. Metribuzin antagonizes glyphosate.

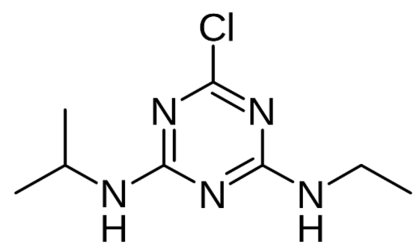
Herbicide Site of Action 2: Photosynthesis Review, PSII-Inhibiting, and PSI Electron Diverter Herbicides

Video Notes for Class on January 31, 2019

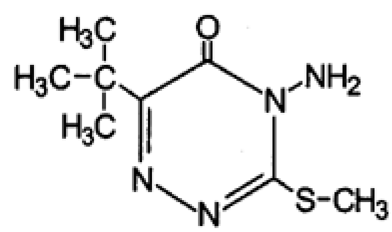
I. Photosystem II (PSII) inhibitor WSSA SOA 5,6,7

A. History
  a. Developed in the _____________ by J.R. Geigy Lab (precursor to Ciba-Geigy, now ____________.
    i. Key aspect was the triazine ring because of its weed control potential

  b. Simazine registered in ____________, atrazine in _________.
  c. Essential to weed management due to efficacy and selectivity
  d. Safety of triazines has come into question
    i. Reproductive ability of ____________ in Mississippi River basin
    ii. Not deemed a threat to human health; topic continues to arise



atrazine

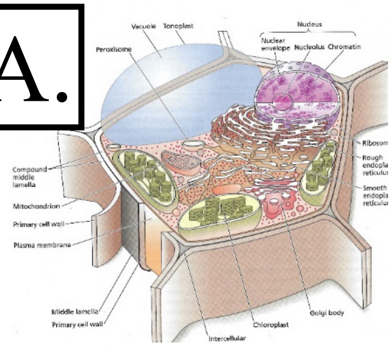


metribuzin

B. Families
  a. SOA 5
    i. Triazine **or** s-triazine (atrazine [Aatrex], simazine [Princep])- symmetrical
    ii. Triazinone (metribuzin [Dimetric/Sencor])- ________________triazines.
  b. SOA 6
    i. Benzothiadiazinone or benzothiadiazole (bentazon [Basagran])
    ii. Nitrile (bromoxynil [Buctril/Brox])
  c. SOA 7
    i. Urea (diuron [Direx/Karmex], linuron [Linex/Lorox], flumeturon [Cotoran])

Images adapted from Taiz and Zeiger (2006).

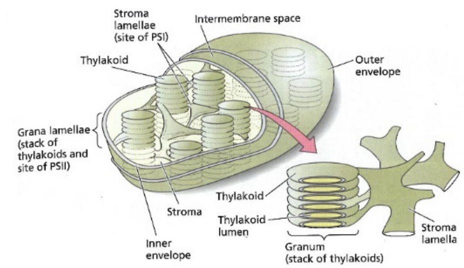
A.



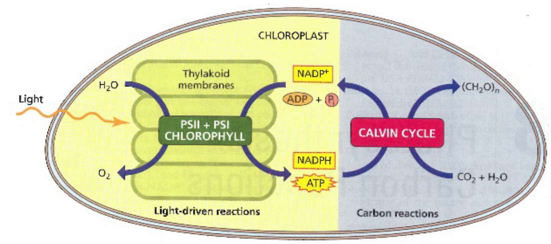
The plant cell contains the sites of action of all herbicides. Notice key organelles that we have discussed such as the plasmalemma and chloroplast.

B.

This is the chloroplast extracted from the plant cell. Notice a membrane (inner and out envelope) encases the chloroplast. This is membrane is destroyed in lipid peroxidation. The chloroplast contains granum comprised of the thylakoid membrane. The open "space" within the chloroplast is the stroma.

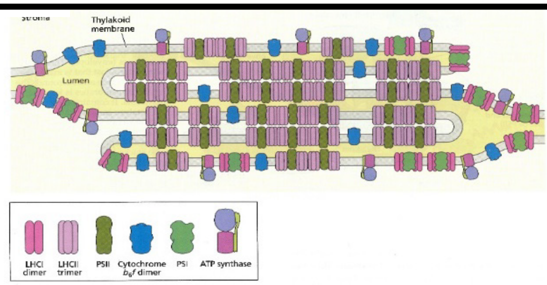


C.



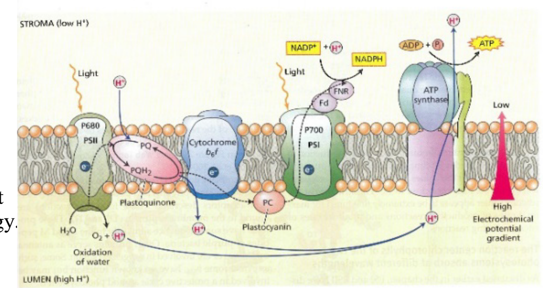
This describes the two overarching processes occurring in the chloroplast that facilitate photosynthesis. Notice the light reactions (light splits water to make ATP and NADPH) occur in the thylakoid membrane whereas the Calvin Cycle (CO_2 is converted to sugar, powered by the ATP and NADPH from light reaction) occurs in the stroma.

D.



The thylakoid membrane forms stacks (called grana). Imbedded in this membrane are the protein complexes that facilitate the light reactions. Certain herbicides interfere with these proteins and can cause lipid peroxidation which destroys this membrane.

E.



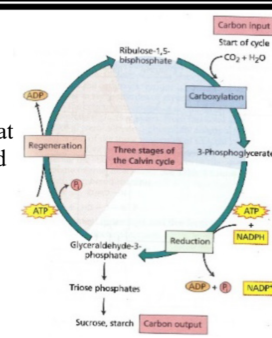
This is a close-up the protein complexes contained in the thylakoid membrane. Notice that PSII splits water with light energy. Follow the flight of the electron through the membrane.

Notice that PSI uses light energy to share the electron with ferredoxin which then uses the electron to reduce NADP to NADPH.

When PSII split water, it left protons in the lumen. ATP synthase uses the proton gradient to change ADP to ATP. When PSII stops, all products (NADPH and ATP) of the light reactions stop production.

F.

The Calvin Cycle is light independent but is dependent on input products (ATP, NADPH, and CO_2). Notice that the cycle regenerates itself and is therefore continuous. Respiration depends on the sugar produced in the Calvin Cycle for metabolic function.



A. Mechanism
   a. Introduction/refresh on photosynthesis
      i. Plant Cell **(PICTURE A)**
         1. Contains many organelles
         2. Herbicides penetrate the plasmalemma into ______________ during absorption.
         3. Must find _________________ enzyme, protein, etc in an organelle to facilitate its mechanism of plant death. (this is SOA).

      ii. Chloroplast contains the SOA of many herbicides but not all.

      iii. Grana stacks are comprised of _______________membranes inside the chloroplast (**PICTURE B)**.
         1. Thylakoid membrane contains protein complexes for light reactions.

         2. Light splits water into 3 parts in PSII protein complex **(PICTURE C)**
            a. __________________

            b. __________________

            c. __________________

         3. Electrons are moved from protein to protein until it arrives at ___________protein complex **(PICTURES D AND E)**.

         4. Electrons are passed from PSI to ____________ where they are used to reduce NADP+ to NADPH.

         5. Protons are used in formation of ATP. This process is known as __________________.

      iv. ATP and NADPH are used to power _______________ Cycle **(PICTURE F)**.

1. Occurs in __________ of chloroplast.

2. Converts Water and CO_2 into ____________.

3. Without Calvin Cycle, plants would not have _____________.

v. Photosynthesis is _________ __________ inhibited by herbicides.
   1. Photosynthesis is comprised of hundreds of reactions, proteins, and enzymes.

   2. Herbicides stop ____________protein or enzyme
   3. This leads to destructive activates that then stop photosynthesis.

b. Each SOA (5,6,7) has a slightly different __________ ________ on the _________ protein within the PSII protein complex.

   SKETCH OF D1 BINDING NICHE

c. ______________ flow inhibited in PSII.

d. ______________production reduced.
   i. Due to limited products to power ________ ________.

e. Light reactions continue, resulting production of free radicals from oxygen.

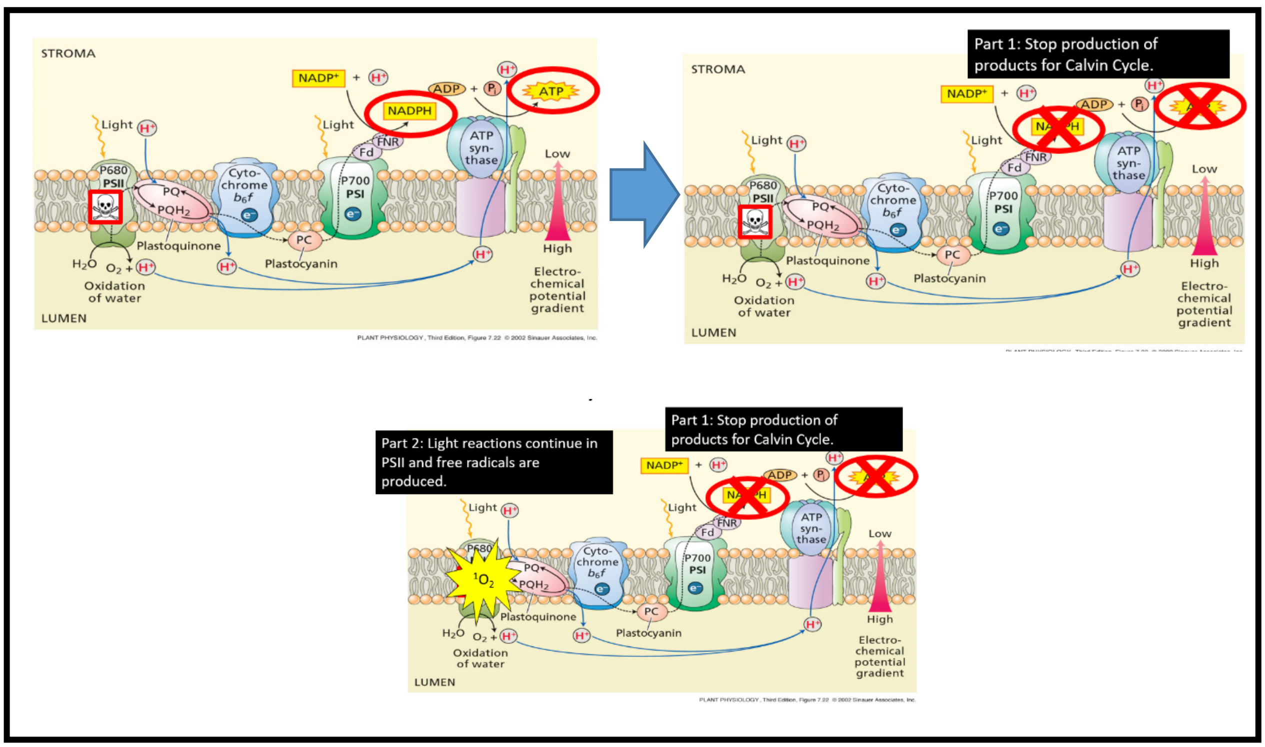
f. Free radicals destroy cell membranes in a process known as __________ ______________ and result in plant death.

i. Lipid peroxidation

1. Oxidative degradation of ________________.
2. Free radicals scavenge electrons from lipids resulting in membrane destruction

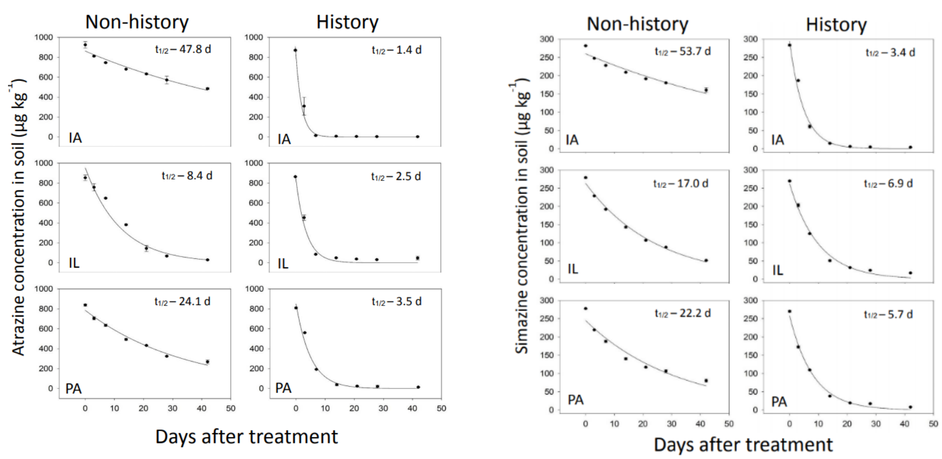
a. Singlet oxygen
b. Reactive oxygen species (ROS)

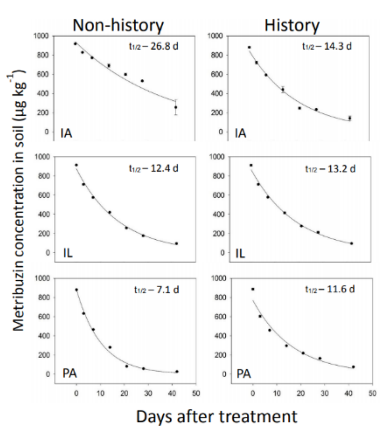
c. Triplet chlorophyll



B. Location of activity
    a. In thylakoid membrane of chloroplast; __________________ membrane destruction followed by plasmalemma.
C. Mobility in plants
    a. ________________ mobile
D. Kow
    a. Highly lipophilic herbicides (weak _____________ – special, not weak acids).

E. Fate in soil
    a. Microbial degradation
        i. ________________ microbial degradation





PSII inhibitor degradation as influenced by soils with a history of atrazine use. Notice that simazine had a similar reduction in activity when compared to atrazine; however, metribuzin was not as adversely influenced by the same microbial population. Adapted from Parker et al. (2017) Univ. of Tenn. Dissertation.

b. If strongly ______________ at low soil pH, microbial degradation may be slowed.
    i. RECALL: weak base herbicides have _________ charge at low pH and ______ charge at high pH.
    ii. This is difference from weak acid herbicides.
c. Photolysis is possible, not a main component.
d. Chemical degradation (amination of s-triazines) or hydrolysis of others.

    i. Hydrolysis prevalent mechanism for ____________ family.

e. Can be susceptible to leaching in ____________ soils and run-off in ___________ soils for SOA 5
    i. SOA 7, leaching only problem in sandy soils.

F. Residual characteristics
  a. SOA 5, excellent residual properties. Sensitive at high pH due to neutral charge; therefore, highly available. Use rate must be ______________and crop rotation ________________.

  b. SOA 6, almost ______ _______________ properties.

  c. SOA 7, very good residual properties. These herbicides are ________________; therefore, not influenced by pH. Sorption to OM and clay as well as solubility can determine rate.
  d. Excellent reach back for SOA 5 and 7. Primary mechanism in residual situations.
G. Adjuvants
  a. Oil activator adjuvant is required for foliar activity. ______________ has shown less of a benefit for absorption of these herbicides.
H. Spectrum of control
  a. Primarily broadleaf weeds, but have activity on grass species as well – fairly broad-spectrum.
I. Tank mix interactions.
  a. Can be antagonistic to glyphosate (especially MTZ + Gly)
  b. Highly synergistic to ___________________ herbicides (PRE and POST) and ___________________.
J. Comments
  a. Label revision in early 2000's reduced amount of triazines that were applied to net 2.5 #/ac/year.
    i. Special label for ______________ lbs/yr if used in the fall in Kansas.

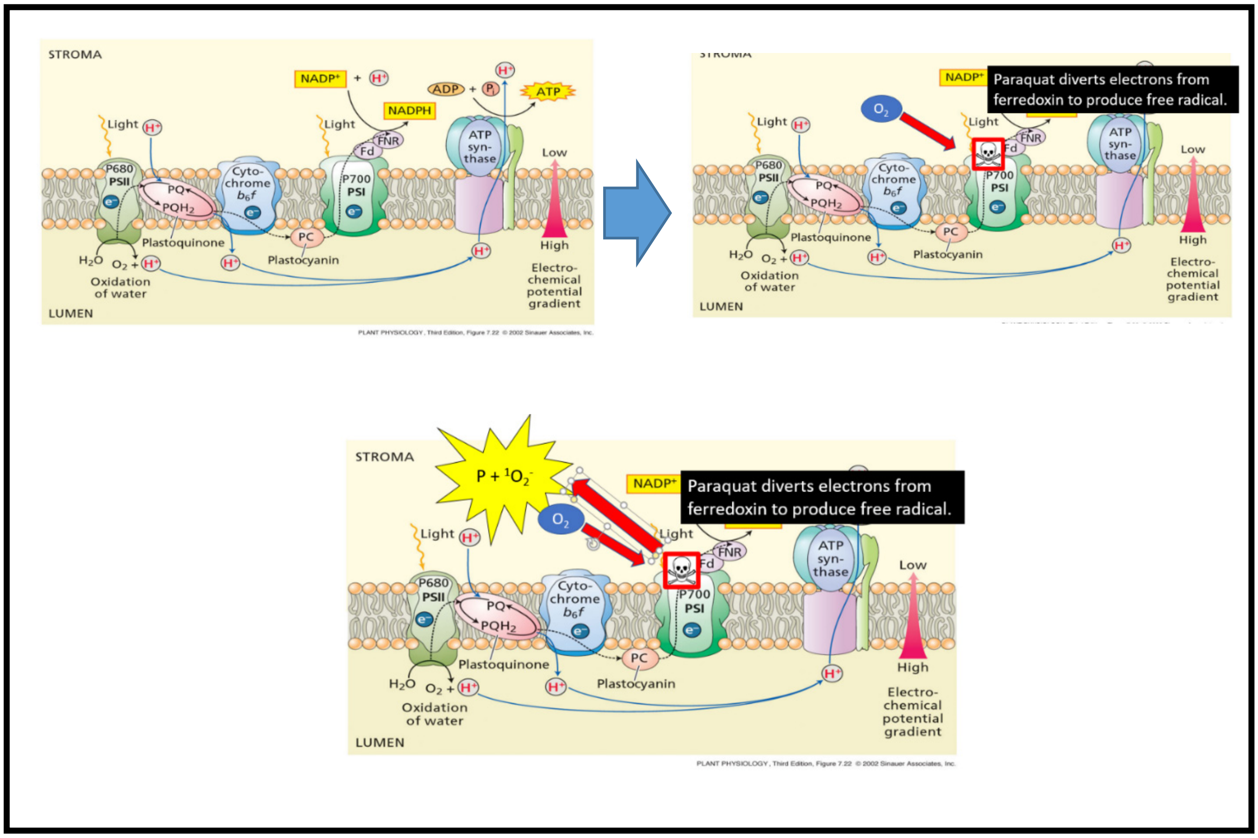
b. Excellent tank mix partner; seldom a good stand-alone herbicide
c. Special considerations must be given to crop rotation restrictions in high pH areas.

II. Photosystem I (PSI) electron diverter WSSA SOA 22

A. History
   a. First synthesized (paraquat) in ____________ for unique properties as a divalent cation in bench chemistry.
   b. Recognized as an herbicide in 1955 by Jealott's Hill Research in UK. Purchased by ICI, marketed in 1962. Modern day ________________.

B. Families
   a. Bipyridylium (paraquat [Gramoxone], diquat [Reglone]).

C. Mechanism
   a. Does ______________ ______________ electron flow.
   b. Binds to ________________ (a protein outside of PSI).
   c. Electrons are intercepted from ferredoxin
      i. Ferredoxin uses an electron to reduce NADP+ to NADPH
   d. Because of electron diversion from ferredoxin, paraquat begins reducing O_2 to form free radical singlet oxygen resulting in ___________________ __________________.
   e. Very rapid compared to other herbicides



D. Location of activity
   a. Thylakoid membrane in chloroplast; thylakoid membrane is destroyed first followed by plasmalemma.

   b. _______________ is required for activity.

E. Mobility in plants
   a. Not mobile in vascular system

F. K_{ow}
   a. Hydrophilic

G. Fate in soil
   a. Adsorption. K_{oc} is so high that paraquat is biologically _________________________ for degradation or leaching. Also, problem with dust in air or on leaf surface.

H. Residual characteristics- none

I. Adjuvants- _____________.

   a. Make a recommendation to suit tank mix partner.

b. ___________ can be beneficial if hot and dry.

c. _____________ may be warranted if applying paraquat in an early spring burndown.

J. Spectrum of control
   a. Non-selective
   b. Paraquat better than diquat on _____________; but still not good.
K. Tank mix interactions
   a. Synergistic with ____________ inhibitors
   b. Antagonistic with glyphosate, ALS herbicides, some formulations of 2,4-D and dicamba.

Herbicide Site of Action 3: PPO, HPPD, and Glutamine Synthetase Inhibiting Herbicides

Video Notes for Class on February 5, 2019

I. Protoporphyrinogen Oxidase (PPO) inhibitor WSSA SOA 14

A. History
   a. Pentachlorophenol was the first compound synthesized that would become a PPO herbicide.
      i. Commercially available in ____________ in 1959 with many agricultural and industrial uses.
      ii. Useful for _____________________ control in rice; 2,4-D and MCPA were for broadleaves.
      iii. Problems with __________________ toxicity and ______________ kills.
      iv. Only available in the United States as an industrial product for treating powerline poles and rail road ties.
         1. Threshold of 1 ppb in water; must be reported and remediated.

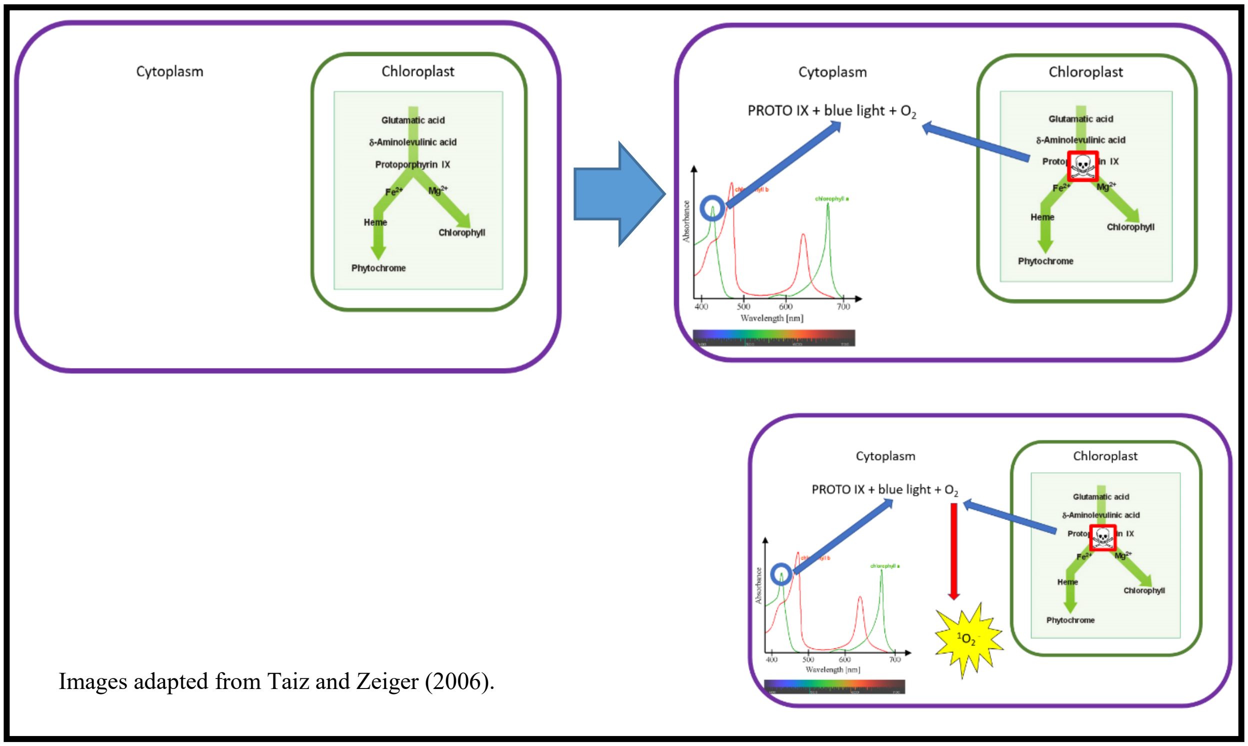
   b. ______________ _____________ synthesized nitrofen in _____________as a precursor for the more widely used as oxyfluorfen (Goal) herbicide for United States; safer for environment and less toxicity.

B. Families
   a. Aryl triazinone <u>or</u> triazolinone (sulfentrazone [Spartan], carfentrazone [Aim])
   b. Diphenylether (lactofen [Cobra], fomesafen [Flexstar].
   c. N-phenylphthalimide (flumioxazin [Valor].
   d. Pyrimidinedione (saflufenacil [Sharpen])
   e. Oxadiazole (oxadiazon [Ronstar]).

C. Mechanism
   a. ________________ is required for this SOA.

   b. ________________ pathway (abbreviated as ____________) is stopped in chloroplast.

      i. Chlorophyll production stops
      ii. Instead of producing chlorophyll, PPO produces ________________ which can become toxic.
      iii. PROTO IX is moved out of chloroplast into _____________ where it reacts with blue light and oxygen to produce singlet oxygen which facilitates ______________ __________________.



Images adapted from Taiz and Zeiger (2006).

D. Location of activity
   a. Initially in ______________________, final step in _______________; plasmalemma is first membrane to be destroyed.
   b. Light is required for activity.

E. Mobility in plants
   a. Not mobile in foliar applications
   b. In residual applications, ________________ mobility is thought to move herbicide to target site.

F. K_{ow}
   a. Lipophilic

G. Fate in soil
   a. __________________ ________________.
      i. Aerobic degradation with exception of ________________________, which is anaerobic.
         1. This can result in herbicide carryover problems for fomesafen.
            a. Hot, dry
            b. Sandy, low organic matter soils
      ii. Hot and dry conditions do not favor degradation.
   b. Continues with less influence of soil ___________.

H. Residual characteristics
   a. Excellent residual properties with ______________________ reach back.
   b. Light sorption to clays and organic matter
   c. Solubility increases with________________ soil pH.
   d. Flumioxazin is not affected by pH (non-ionizable) .
   e. More adsorption is expected with increasing CEC
      i. Many herbicides have incorporated this into the label- consider Spartan

Herbicide	pKa	Solubility at pH
Sulfentrazone	6.56	6.0 is 110 mg/L
		7.0 is 780 mg/L
		7.5 is 1600 mg/L
Saflufenacil	4.41	5.0 is 30 mg/L
		7.0 is 210 mg/L
Fomesafen	2.7	7.0 is 50 mg/L
Flumioxazin	Non-ionizable	1.79 mg/L

SUNFLOWERS (22.0)
Table 8

Spartan 4F Use Rate Table (Sunflowers) Fall, Early Spring Preplant, Preemergence, and Preplant Incorporated Applications			
Broadcast Rate	Fluid Ounces Spartan 4F per acre		
	Soil Texture		
% Organic Matter	Coarse	Medium	Fine
<1.5	3.0 - 3.75	3.0 – 4.5	3.75 – 5.25
1.5-3.0	3.0 – 4.5	3.75 – 6.0	4.5 – 6.75
>3	3.75 – 6.0	4.5 – 6.75	6.0 – 8.0

Refer to the previous information on soil types under the COARSE, MEDIUM, and FINE categories
Use higher rates for soils of pH less than 7.0 and lower rates for pH greater than 7.0 within the rate range.

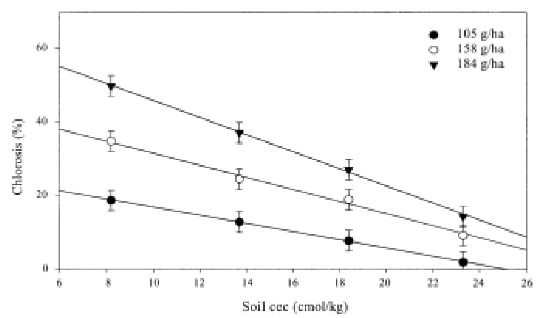


Figure 2. Effects of sulfentrazone rate and soil cation exchange capacity on sunflower leaf chlorosis 12 d after planting. Fitted equations, n = 8: 184 g/ha, y = −2.3x + 69, r^2 = 0.75; 158 g/ha, y = −1.6x + 48, r^2 = 0.62; 105 g/ha, y = −1.1x + 28, r^2 = 0.45. Vertical bars represent standard errors.

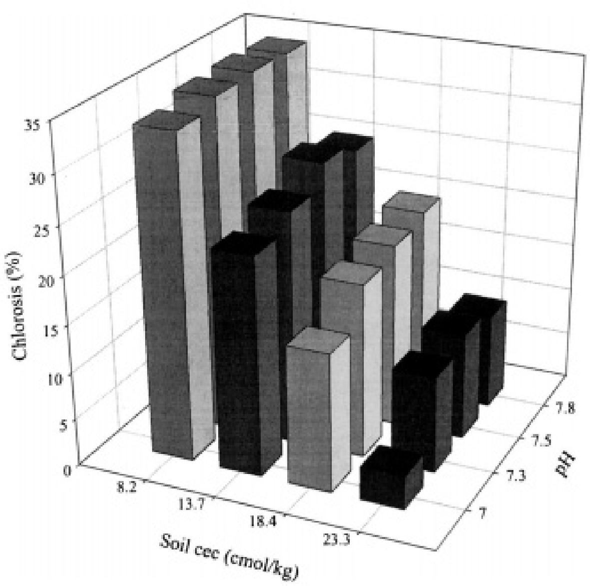


Figure 1. Sunflower leaf chlorosis 12 d after planting as affected by soil pH and cation exchange capacity averaged over sulfentrazone rates of 105, 158, and 184 g/ha.

Sulfentrazone was applied at several rates to sunflower PRE. Notice that as CEC increases, injury decreases. Soil pH was not a factor in this as the pH was above the pKa for sulfentrazone. A similar trend of sorption could be expected for other residual PPO herbicides. If a lower pH (such as 6.0) it would be reasonable that injury would have decreased dramatically across all CEC values. Adapted from Kerr et al. (2004) Weed Technol.

I. Adjuvants
   a. Highly responsive to oils and ammonium nitrogen for solubilizing wax and complexing with herbicide for uptake.
   b. Some ______________ the use of oils (Ultra Blazer, aciflorofen, to reduce crop response.)
   c. ________________ requires __________ and _________ for any foliar activity.

J. Spectrum of control
   a. Mainly broadleaves; however, can have special cases of high grass efficacy.

K. Tank mix interactions
   a. Most are antagonistic to glyphosate

   b. ______________________ or __________________ + glyphosate with HSOC and AMS can improve the efficacy of some grass species such as burndown of annual ryegrass.

II. 4-hydrophenylpyruvate dioxygenase (HPPD) inhibitor WSSA SOA 27

A. History
   a. Reed Gray in _________________, scientist at Western Research Center of Stauffer Chemical in California, notice fewer weeds under the bottlebrush plant (*Callistemon citrinus*)
      i. Synthesized into leptosperone, good grass activity at _____________ g ai ha^{-1}
   b. Triketone family developed as result of acquisition of Stauffer Chemical, ICI, and Ciba-Geigy for modern day ____________________
   c. Commercialized in late 1990’s, early 2000’s.

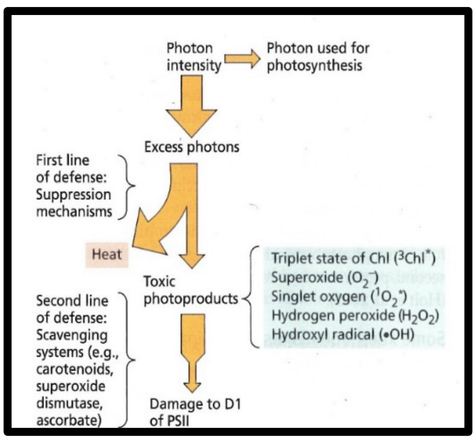
B. Families
   a. Isoxazole, (isoxaflutole [Balance])
   b. Pyrazole, (pyrasulfotole [Huskie])
   c. Pyrazolone, (topramezone, [Armezon])
   d. Triketone

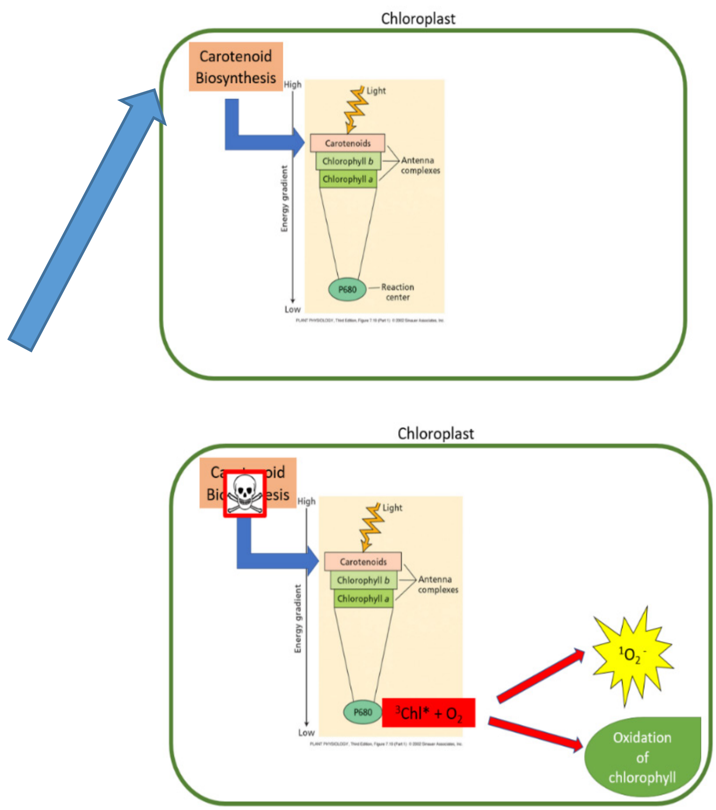
Herbicide	**Trade Name**
Mesotrione	Callisto
Tembotrione	Laudis
Bicyclopyrone	Acuron, component

C. Mechanism
   a. Inhibit ______________________ biosynthesis
      i. Carotenoids protect plants from “extra” light energy

   b. Because of extra light energy, chlorophyll can become ____________ (triplet chlorophyll).
   c. Reacts with O_2 to produce free radicals and cause ____________ ______________.

   d. Secondary mechanism, results in loss of chlorophyll (bleaching), less photosynthesis, damage to ___________________ protein.





Images adapted from Taiz and Zeiger (2006).

D. Location of activity
   a. Chloroplast, thylakoid membranes destroyed from lipid peroxidation.
E. Mobility in plants
   a. Xylem and phloem mobile
F. Kow
   a. Generally lipophilic

G. Fate in soil
   a. Microbial degradation
      i. Suitable environmental conditions for enough time (warm and moist)
      ii. Must not be adsorbed; If adsorbed, ____________ ____________ to degradation.

H. Residual characteristics
   a. _____________________ reach back
   b. Adsorption to organic matter and sorption by soil pH are driving factors; lesser extent clay content.
      i. ________________ soil pH, _________ organic matter increase persistence.

      ii. ________________ soil pH, _________ organic matter decrease persistence.
      iii. This has been incorporated into many HPPD residual herbicides labels where rate structure is primarily based on OM%, with a slight emphasis on texture.
      iv. ___________________ is a popular Group 27 residual herbicide that is non-ionizable.

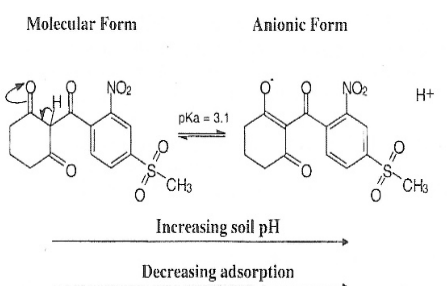
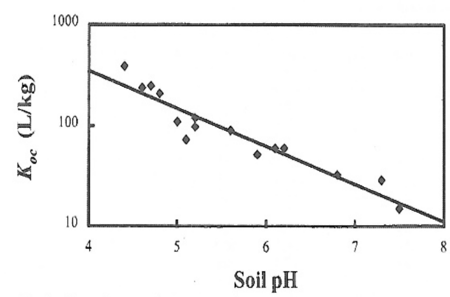


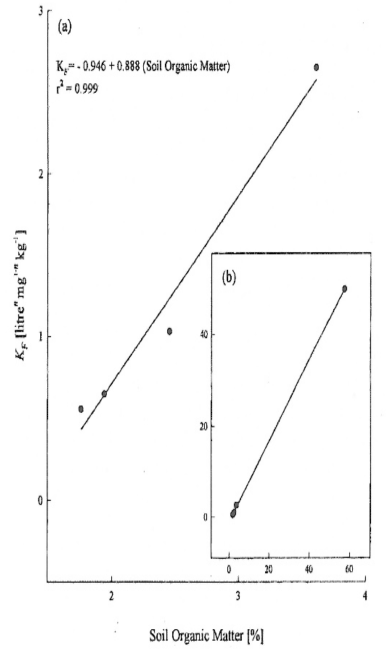
Fig. 1. The dissociation of mesotrione with rising pH.



HPPD herbicides are weak acids. Mesotrione has a pKa of 3.12. As pH increases above 3.12, more of the herbicide will be in the anionic form (See above left figure). This decreases the adsorption of the herbicide. Notice that as the soil pH increases, the Koc of mesotrione decreases. This will make the herbicide more available for plant uptake, more prone to crop response (bleaching in grain sorghum), and more susceptible to microbial degradation as pH increases. The half-life of mesotrione would follow a similar trend as seen in the above right figure. Adapted from Dyson et al. (2002) J of Environ Quality.

The sorption coefficient Kf (similar to Koc) is graphed as a response of soil organic matter content. Notice that as organic matter content increases, sorption increases. Notice that the MN-A and CO soils have similar clay content but different organic matter levels. Four soils listed in “graph a” and all five soils are listed in “Graph B”. Adapted from Mitra et al (1999) Pest Sci.

Soil	pH	Texture	Clay %	OM %	CEC
MN-A	7.04	Silty clay loam	30	3.61	33
CO	6.55	Clay loam	34	2.45	17
MN-B	6.71	Sandy clay loam	10	1.76	16
MA	6.18	Silty loam	8	1.94	4.9
MI	5.27	Muck	43	57.4	36



I. Adjuvants
  a. HPPD-inhibiting herbicides are generally __________________.
  b. Label specific information must be considered.
    i. _____________ requires MSO for POST applications in corn.
    ii. _____________ requires NIS or COC for POST applications in corn.
    iii. MSO or COC should be used for all applications outside of POST.
  c. All are very responsive to_______________ for enhanced absorption.
    i. Some labels prohibit the use of nitrogen fertilizer to mitigate crop response.

J. Spectrum of control
  a. Broad spectrum for grass and broadleaf weeds
  b. Particular herbicides have specialty focuses
    i. Better on small or large seeded broadleaves, better on grasses, etc
    ii. Some have __________________ residual

K. Tank mix interactions
    a. ______________________ provides synergy with HPPD on PRE and POST.
    b. Moderate to good tank mix partner with glyphosate.
    c. Dicamba + mesotrione can reduce grass activity.

III. Glutamine Synthetase (GS) Inhibitor WSSA SOA 10

A. History
    a. Developed from phosphinothricin, produced from _________________________ (biological) in 1970's.
        i. "Biologically based"
    b. Hoechst Ag, acquired by Aventis, modern day _________________________.
    c. Recently sold to BASF pending Bayer-Monsanto acquisition.

B. Families
    a. Organophosphorus

C. Mechanism
    a. Inhibits the activity of glutamine synthetase (GS)
        i. Enzyme that converts ______________________ and ammonia to glutamine.

        ii. Glutamine serves as an essential amino acid
            1. Required in ________________________.
            2. Basis for the formation of many other amino acids through ________________.

    b. Because GS is inhibited, _______________ __________ continues to produce ammonia.

        i. ________________ also produces ammonia that was primarily added to glutamate with GS.

    c. Ammonia can bind with _______________ or stop _____________ __________ in light reactions.
        i. When ammonia binds with PSII, ________________ ______________ results similarly to the PSII-inhibiting herbicides.
        ii. Increased ammonia levels can cause _____________________closure.
        iii. NH_4^+ can diffuse membranes and result in net pH imbalance by converting to NH_3 in high pH areas. This can stop ATP synthase.

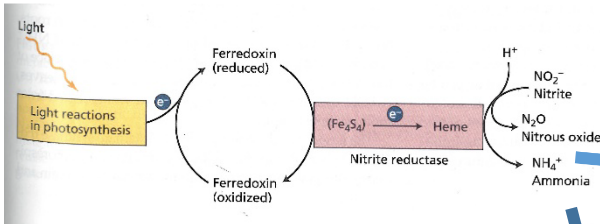
    d. Deficiency of glutamine impedes ______________________________.
        i. While photorespiration is bad, it happens about 25% of time in C3 plants and still some in C4 plants.

ii. Rubisco must be regenerated in photorespiration or a net loss of rubisco will result.
iii. With a shortage of glutamine, _________________ is not regenerated; therefore Calvin Cycle is stopped.

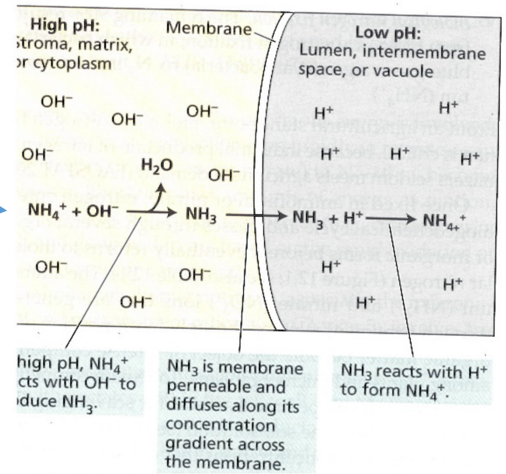
e. Summary of plant death

i. _______________ _____________________________ as result of inhibition of PSII from NH_3 (fast)
ii. Inhibition of ATP synthase and slowing of Calvin Cycle (slow)
iii. Inhibition of Calvin Cycle as result of lack of rubisco regeneration in photorespiration. (slow)

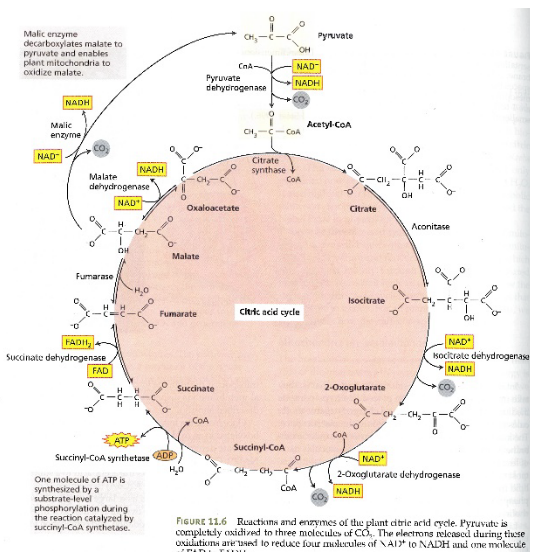
Nitrite reductase reduces nitrite to ammonia. Ammonia will convert to ammonium based on the pH of the solution. Nitrogen is essential in the building of amino acids.



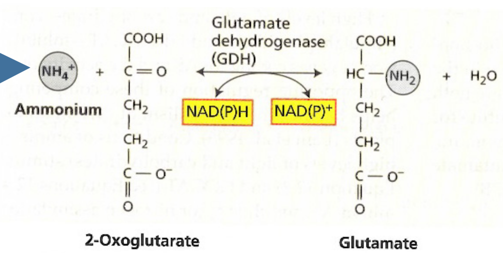
When GS is inhibited with glufosinate, ammonia can move freely through membranes causing a pH imbalance (stopping ATP synthase) and can bind with PSII causing the production of free radicals and lipid peroxidation.

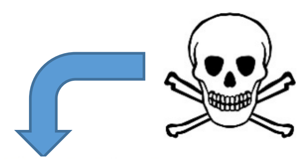


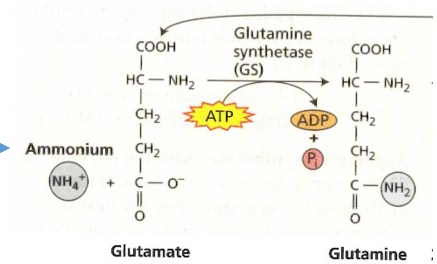
Oxoglutarate is a carbon skeleton that serves as the basis for glutamate. It is produced in the Citric Acid Cycle (aka CREBS Cycle) of respiration (located in mitochondria).



Glutamate dehydrogenase combines ammonium with oxoglutarate to produce glutamate. GS adds a second ammonium to produce glutamine. When glufosinate GS, ammonium accumulates and glutamine deficiency in photorespiration occurs.







Images adapted from Taiz and Zeiger (2006).

D. Location of activity
    a. ____________________________
        i. Thylakoid membrane destroyed via lipid peroxidation followed by chloroplast and plasmalemma.
        ii. Sugar production reduced through limited ATP slowing Calvin Cycle
        iii. Sugar production reduced through inhibition of Calvin Cycle because lack of rubisco.

E. Mobility in plants- not mobile in vascular system.

F. K_{ow}- hydrophilic

G. Fate in soil- microbial degradation

H. Residual characteristics- none, very short half-life

I. Adjuvants
    a. All current formulations of glufosinate contain a ____________________ adjuvant
    b. ________________is beneficial for absorption in low humidity situations (3 lbs AMS/acre)
        i. A lesser benefit of AMS has been demonstrated in Mid-South region.
    c. ________________utility modifier required in most situations.

J. Spectrum of control
    a. Broad spectrum, non-selective

K. Tank mix interactions
    a. Tank mixes well with paraquat- improves grass control
    b. Synergized by ___________________ herbicides
    c. Tank mixes well with HPPD herbicides
    d. Tank mixes very well with 2,4-D
    e. Antagonistic to glyphosate and dicamba.
        i. When tank mixed with glyphosate, _______________ performance is relatively unaffected, and glyphosate can still control highly susceptible _______________.

Herbicide Site of Action 4: ACCase, VLCFA, Microtuble-Inhibiting and TIR1 Auxin Receptor Herbicides

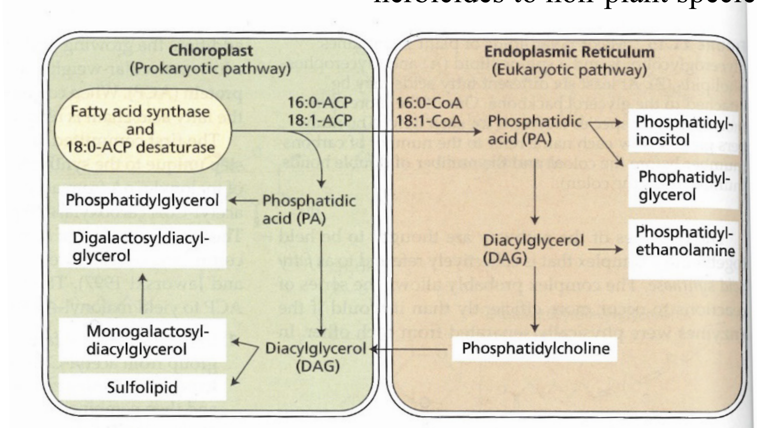
Video Notes for Class on February 7, 2019

I. Acetyle-coenzyme-A carboxylase inhibitors (Acetyl CoA Carboxylase (ACCase) inhibitor) WSSA SOA 1

a. History _________________ (grass control)
   i. Discovered/launched in 1970's.
   ii. Original purpose was __________________ grass control
      1. Had toxicity issues
   iii. Now POST only, but can have ______________ in soil.
      1. 30-day plant back to corn or sorghum with most applications.

b. Families
   i. Arloxyphenoxypropionates (fops) (fluaxifop, quizalofop)
   ii. Cyclohexanedione (dims) (clethodim, sethoxydim)
   iii. Phenylpyrazolin (requires safener ie, cloquintocet-mexyl in Axial XL (pinoxaden)

c. Mechanism of action
   i. Inhibition of ________________ ____________ leads to plant death due to loss of membrane integrity.
      1. Results in leaky membranes.
         a. Reduction in phosphoglyerides, triglyerides reduces inputs to build ______________________ bilayers.
      2. 2 categories of ACCase enzymes
         a. ___________________ (cytosol, mitochondria, ER)
         b. ____________________
            i. Found in chloroplast (plastidic) = chlorplast
            ii. More active in plants (provides safety of herbicides to non-plant species).



Images adapted from Taiz and Zeiger (2006).

ii. Selection of grasses in dicots
   1. Prokaryotic ACCase enzyme in grasses is ____________________ (provides a niche).
   2. Prokaryotic ACCase enzyme in dicots is ____________________ (not a clear target site. Herbicide is very specific; therefore, lipid synthesis is not stopped).

      This provides for ___________selectivity in

      _____________.

iii. What ACCase inhibitors **do not** directly cause
   1.
   2.
   3.

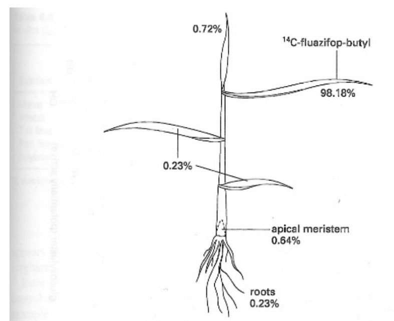


Figure 8.5 Percentage ^{14}C-activity recovered from plants of *Setaria viridis* 72h after treatment with radiolabelled fluazifop-butyl (modified from Carr *et al.*, 1986).

d. Location of activity
   i. ___________________ region of plants in chloroplasts
      1. Apical bud (growing point differentiation region in grasses) "Dead heart"

e. Mobility
   i. Xylem and phloem mobile

f. Kow
   i. Generally lipophilic. As solution pH increases, they become more ______________________.
      1. This has more to do with absorption in the plant than spray tank solution.

g. Fate in soil
   i. ______________ ____________ and ____________ hydrolysis
      1. Carryover problems will likely occur in _______ pH soils.

h. Residual herbicide characteristics
   i. Minimal with 2-14 day half life, low use rate

ii. Rotational restrictions back to grass crops are 30-60 days for most; _______________ has a 6 day replant on corn with low use rates.
iii. Reach back in terms of persistence is severe.

i. Adjuvant recommendations
   i. ___________________ source required for uptake.

   ii. ____________ generally perform best; however, __________may be required to reduce phytotoxicity.

j. Spectrum of activity
   i. All grasses; not broadleaves
   ii. Not all ACCase-herbicides have similar levels of control on all grasses.

k. Tank mix interactions
   i. Highly antagonistic to growth regulator herbicides (or antagonized by them).
      1. In ability to apply AMS in ______________ _______________ soybean reduces efficacy even more.
   ii. Highly antagonized by _______________ ____________ herbicide formulations such as found in ___________________ herbicide.
   iii. Can antagonize _________________herbicides. Higher rate required to overcome rate. Many herbicide specific interactions. Troubles appear when we have poor coverage, poor growing conditions, low use rates, big weeds.

II. Very long change fatty acid (VLCFA) synthesis inhibitor WSSA SOA 15

L. History
   a. Discovered in _______________ by ___________________; commercially available in 1956, first time herbicide could be applied _______________ to a crop.

M. Families
   a. Chloroacetamide (metolachlor [Dual], acetochlor [Warrant or Harness])
   b. Pyrazole (pyroxasulfone [Zidua])

N. Mechanism
   a. Absorbed by seedlings during ______________________ elongation
      i. Radicles in dicots and coleoptiles in grasses.
   b. Inhibit VLCFA biosynthesis
      i. Reduction in VLCFA's and build-up of medium and long chains
      ii. Reduced functionality of plasmalemma
      iii. ____________________ never emerge.

O. Location of activity
   a. Cells in internodes of emerging seedlings

P. Mobility in plants
   a. Movement is not classified in emerged plants, but in seedlings it is believed to be phloem.

Q. Kow
   a. Lipophilic

R. Fate in soil
   a. _______________ ___________________ and _________________

S. Residual characteristics
   a. Excellent residual properties
   b. __________________ in soil (no pKa)
   c. Adsorption dictates herbicide rate, length of residual
   d. Heavy ____________________ can reduce herbicide concentrations
   e. No _________________ _____________ properties

   f. Differences exist in precipitation required for activation and potential for length of residual.

Herbicide	Solubility (mg/L)	K_{oc}
Acetochlor	223	165
Dimethenamid	1174	55
s-metolachlor	488	200
pyroxasulfone	3.49	60

T. Adjuvants- none
   a. When applied POST to crop, some will say that it is an "oil" activator adjuvant; however, it is difficult to replace the need for COC or MSO with a Group 15 (i.e., Dual)

U. Spectrum of control
   a. Grasses and broadleaf weeds and sedges
      i. Plants must be able to absorb herbicide. (diagram shattercane uptake).

   b. Selectivity due to seed size or _______________ metabolism in certain weeds.

c. Safeners allow use in new crops
   i. Fluxofenin [Concept Seed Treatment] for VLCFA application in ________________.
   ii. Benoxacor (II part of some formulations) for metolachlor in corn ______.

d. Encapsulation increases crop safety and length of residual for acetochlor.
   i. Encapsulation can increase the amount of _________________ needed for activation.
   ii. Table

Herbicide	**Encapsulation**	**Crops (PRE)**
Harness	None	Corn
Degree	Encapsulated	Corn and Sorghum
Warrant	Micro-encapsulated	Corn, Sorghum, Cotton, Soybean. (Rate reduced in cotton and soybean).

e. Isomer revisions for dimethenamid to dimethenamid-*P* and metolachlor to *s*-metolachlor.
   i. *S*-metolachlor contains a ______________ ratio of *S*:*R* isomers
      1. *S* is biologically active. Original metolachlor contains ________ ratio of S:R isomers.
      2. Generally, it takes a ___________ more metolachlor to result in same efficacy as *S*-metolachlor.
   ii. Must check label to know what you are using.
   iii. May need to adjust rate structure to allow optimal control.

   iv. Table

Herbicide	7:1 Ratio of S:R	Benoxacor safener for PRE Corn
Dual	No	No
Dual II	No	Yes
Parallel II	No	Yes
Dual Magnum	Yes	No
Dual II Magnum	Yes	Yes
Bicep	No	No
Bicep II Magnum	Yes	Yes
Halex	Yes	No
Acuron or Lumax	Yes	Yes

V. Tank mix interactions- none; excellent tank mix partners.
    a. Formulation influences droplet size

III. Microtubule Inhibitor WSSA SOA 3

A. History
    a. Discovered in 1950's by Eli Lilly and Co (______________________ today).
    b. Trifluralin screened in 1960, launched in 1964 (3.5 yrs)
    c. Commonly referred to as the "_______________________ herbicides"
B. Families
    a. Dinitroaniline

C. Mechanism

a. Microtubule definition- component of cell cytoskeleton mitotic spindle, player in orientation of microfibrils in cell wall.
b. Important during _________________ of mitosis.
c. Stops the function of microtubules, thereby inhibiting cell division.
d. Tubulins in animals are different than plants, giving SOA 3 herbicides increased safety.

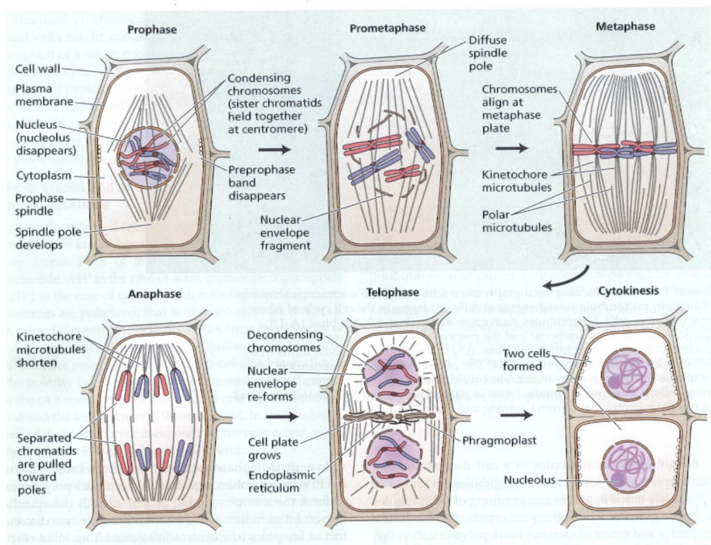


FIGURE 1.27 Diagram of mitosis in plants.

Images adapted from Taiz and Zeiger (2006).

D. Location of activity
   a. ________________________ of plant cells
   b. Areas of cell division (seedlings).
E. Mobility in plants
   a. Locally mobile in emerging seedlings, thought to be phloem mobile.
F. Kow
   a. Lipophilic
G. Fate in soil
   a. Adsorption to soil
   b. ____________________ (can also provide herbicidal properties)
   c. Chemical degradation
H. Residual characteristics
   a. Relatively _____________________ and highly adsorbed.

Herbicide	Solubility (mg/L)	K_{oc}
Pendimethalin	0.275	17,200
Trifluralin	0.3	8765

   b. ____________________ reach back

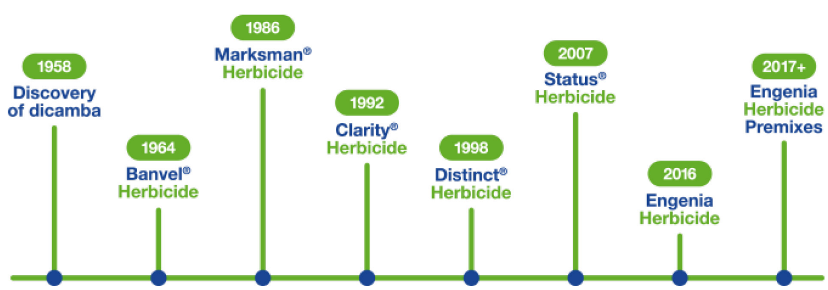
c. Requires ________________________ of trifluralin because of volatility and photodegradation

d. Prowl and Barricade are less volatile than Treflan
e. Incorporation ______________ performance (needs plenty of water, consistent wetting).
f. Very difficult to achieve good efficacy with these herbicides in the Great Plains.

I. Adjuvants- none
J. Spectrum of control
   a. More grasses than broadleaf.
   b. Poor control of ________________;_____ with pendimethalin in K-State trials.
K. Tank mix interactions- none

IV. TIR1 Auxin Receptor WSSA SOA 4

A. History
   a. Discovery of 2,4-D as result of WWII, commercialized in 1946 by Dow Chemical
   b. Discovery of dicamba in 1956.



B. Families
   a. Benzoic acid- dicamba (Clarity, Banvel, Engenia, Xtendimax, Status)
   b. Pryidine-Carboxylic acid- clopyralid (Stinger), flouroxypyr (Starane), picloram (Tordon)
   c. Quinoline-carboxylic acid- quinclorac (Facet, Drive) – offers grass control
   d. Phenoxy-carboxylic acid- dichlorprop, MCPA, 2,4-D
C. Mechanism
   a. Mimics indole-3-acetic-acid (__________________)
   b. Binds to the ________________ auxin receptor to trigger a gene(s)
      i. ________________ of genes

ii. ________________ of genes
iii. _________ or _______ response genes

c. 3 step process
   i. ________________ phase (0-5 hours after application)
      1. Curling, swelling
      2. Gene activation, expression
   ii. ________________ phase (24 hours after application)
      1. Reduced growth
      2. Reduced photosynthesis
      3. Production of reactive oxygen species
   iii. ______________ phase
      1. Ethylene production triggered
      2. Lipid peroxidation

d. Note- times are for *Galium aparine* in a greenhouse. Results are generally much more extended in the field. Final weed control with Group 4 herbicides should not be determined until ___________________ weeks after application.

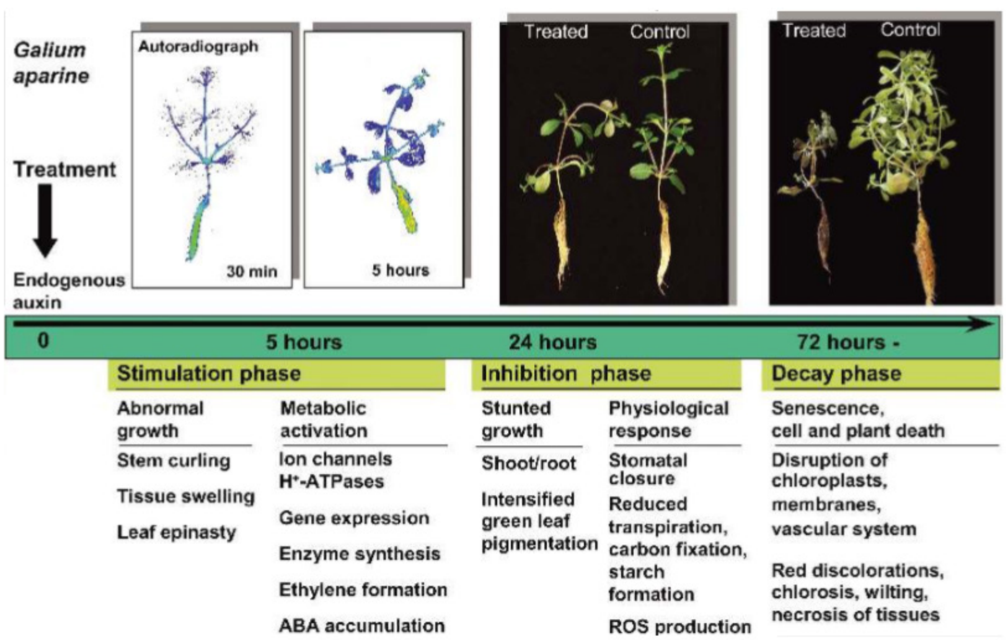


Figure 2. Three-phase response in auxin herbicide action exemplified for the dicot weed *Galium aparine* after root uptake and distribution in the plant (shown by coloration in autoradiographs using labelled compound) against the background of reported data in the literature. Modified from Grossmann.[40]

D. Location of activity
   a. In __________plant cells
E. Mobility in plants
   a. Highly mobile in ________________.
F. K_{ow}

a. Depends on herbicide
    i. 2,4-D and MCPA are _________________ (as is diflufenzopyr SOA 19)
    ii. Dicamba, quinclorac, and clopyralid are _______________.
    iii. Ester forms (i.e., 2,4-D or MCPA) are more easily ______________.
        1. Higher volatility
        2. Dicamba has more volatility than 2,4-D inherently.

G. Fate in soil
    a. _______________ _____________.
    b. Increased as soil temperatures increase above ___________ degrees F.

H. Residual characteristics
    a. All have residual activity if available for uptake.
        i. _______________ temperatures can cause microbial degradation and shorten residual
    b. Special considerations must be given to the ____________formulations as they have increased solubility for plant back restrictions.

Herbicide	Solubility (mg/L)
2,4-D Amine	729,000
2,4-D LV ester (not a salt)	0.0867
2,4-D Choline	768,000
Dicamba (all salt formulations)	4500

    c. Very seldom does 2,4-D or dicamba enter ground water due to its high solubility. Rapid degradation eliminates this concern.
    d. Consider label restrictions for plant-back to corn and soybean after an application of 2,4-D or dicamba.
        i. 2,4-D ester should be used in burndown treatments due to reduced solubility.
            1. 7-10 days for 1 pt/ac of LV-4 to corn or soybean
            2. 30 days if using AMINE formulations of 2,4-D

3. 10 days plant back to corn or sorghum is using 8 oz of dicamba to corn or sorghum.
4. 30 days plus 1-inch of rain rain required plant back to non-Xtend soybean.

e. Dicamba PRE to Xtend soybean could be a good fit requiring ___________ _____________.

I. Volatility

a. ________________ have been formulated to reduce the volatility of 2,4-D and dicamba.

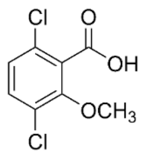
b. _________________spray solution pH can cause the salt to ____________________ into the free acid.

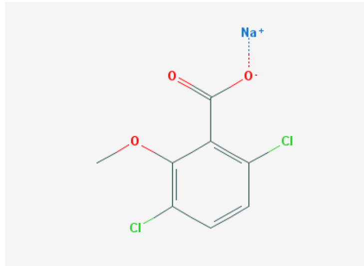
c. Different salts exist to increase the ____________________ weight of the herbicide and therefore decrease the volatility assuming the salt doesn't dissociate.

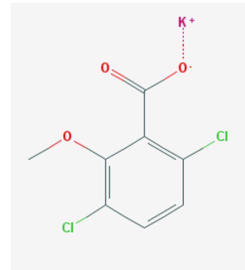
i. ___________________of the ionic bond is very important to prelude dissociation.

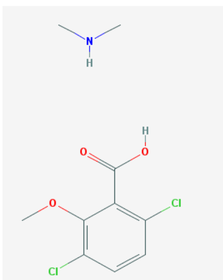
Herbicide	Salt	Molecular weight (g/mol)
Vision	None- just acid	221
Dicamba XP, Distinct, Status	Sodium	243
Marksman	Potassium	259
Banvel	Dimethylamine (DMA)	266
Clarity	Diglycoamine (DGA)	326
Xtendimax w/ Vaporgrip	Diglycoamine (DGA)	326
Engenia	N,N-bis(3-aminopropyl)methylamine (BAPMA)	366

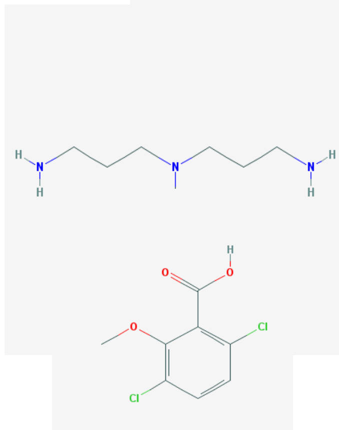
ii. The molecular weight becomes irrelevant if the salt dissociates. This results in the free _____________ which is ______________.

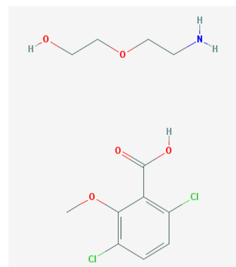












J. Adjuvants

a. An adjuvant is generally not required for __________________.

i. _________________ source required for diflufenzopyr uptake; however this could result with increased _________________.

ii. ______________ adjuvants could be used as substitutes in these situations though not as good.

b. 2,4-D is responsive to ____________ based activator adjuvants.

i. Crop response can be concern when these are used.

ii. 2,4-D ___________________ has a built-in adjuvant system

K. Spectrum of control

a. Mostly broadleaf weeds

b. Quinclorac has activity on _____________weeds by inducing early ____________ production.

c. Can cause injury to grass crops when used at incorrect stage of development or adjuvant package results with increased absorption.

d. _______________________ is labeled POST on conventional soybeans; however, generally poor weed efficacy is observed due to poor herbicide absorption.

L. Tank mix interactions
    a. 2,4-D LV or Choline is an excellent tank mix partner
        i. Glyphosate, paraquat
        ii. Amine formulations can antagonize paraquat
    b. Dicamba and glyphosate tank mix can be antagonistic to kochia
        i. Generally fine with most other species
    c. Dicamba tank mixes well with HPPD herbicides
    d. Dicamba is antagonistic to
        i. ACCase herbicides
        ii. Glufosinate

Exam 1 February 14, 2019

_______1. Which of the following statements is true about "contact" herbicides?

A. Contact herbicides have no movement in the plant.
B. Contact herbicides move in the xylem but not the phloem.
C. Contact herbicides move in the leaf by not the vascular system.
D. Contact herbicides require minimal coverage of the leaf surface.

______ 2. Which of the following could be included with a PRE herbicide?

A. Herbicides with residual activity.
B. Herbicides with foliar activity.
C. Herbicides that can only be applied PRE to the crop.
D. Herbicides that can be applied PRE or POST to the crop.
E. All of the statements are true.

______ 3. Which of the following is not a method of herbicide selectivity?

A. Crop/weed genetics
B. Herbicide persistence in the soil
C. Herbicide rate of absorption
D. Altered physiological target site

______ 4. Which of the following chemical constants are used to characterize if an herbicide is lipophilic or hydrophilic?

A. Koc
B. Kow
C. pKa
D. Kd

______ 5. Which of the following is a hydrophilic herbicide?

A. atrazine
B. 2,4-D
C. dicamba
D. saflufenacil

_____ 6. Which of the following components of the leaf is considered to be the polar entry route?

A. wax
B. cutin
C. plasmalemma
D. cuticle

_____ 7. Which of the following processes are required to move lipophilic herbicides across the plasmalemma?

A. Passive Movement
B. Ion Trapping Theory
C. Active Movement
D. None of these

_____ 8. What is the approximate pH of the cytosol?

A. 5.0
B. 6.0
C. 7.5
D. 8.5

_____ 9. Which category would best describe a compatibility agent type of adjuvant?

A. activator adjuvant
B. utility modifier adjuvant
C. a type of nonionic surfactant
D. a type of water conditioner

_____ 10. Which of the following is the primary objective of including a COC with a lipophilic herbicide?

A. increase spray droplet retention on the leaf
B. increase canopy penetration
C. spread the droplet across the leaf surface to create a better deposit
D. solubilize the leaf cuticle and wax to speed absorption

_____ 11. Which of the following best describes the function of adding 2.5% v/v UAN to the spray tank?

A. The ammonium will help with herbicide absorption and translocation.
B. This will help to condition the water by forming salts with various cations.
C. This should not be used as a substitute for AMS when spraying glyphosate.
D. This should never be used as a substitute for AMS when spraying herbicides.
E. All of these statements are true.
F. None of these statements are true.
G. Only A and C are true.
H. Only A, C, and D are true.

_____ 12. You would expect a weak acid herbicide to have ________ charge in an acidic soil.

A. a negative
B. a positive
C. no charge
D. None of these options.

____ 13. Assuming you are dealing with either a weak acid or weak base herbicide in a soil pH of 8.3. You would expect which of the following?

A. The herbicide will not be held to the soil at all because it would have a negative charge or be nonionized.
B. The herbicide would still be somewhat held to the soil because of its K_{oc} albeit more available that if it were in an acidic soil.
C. The herbicide would be strongly adsorbed and not available.
D. A tremendous amount of crop injury as could terrible environmental ramifications occur as result of using residual herbicides on these soils.

_____ 14. Which of the following is not a fate of herbicides in the soil?

A. permanent adsorption
B. run-off/leaching
C. enzymatic degradation
D. volatilization

_____ 15. Which of the following best describes an herbicide's site of action?

A. The mechanism by which the herbicide causes plant death.
B. The location (protein, enzyme, pathway) where the herbicide binds.
C. The chemical classification of the herbicide.
D. None of these options.

_____ 16. Which of the following families belong to the Group 2 herbicides?

A. Organophosphorus
B. Triazine
C. Imidazolinone
D. Aryl triazinone

_____ 17. Which of the following is the fate of the IMI herbicides in the soil?

A. acid hydrolysis
B. microbial degradation
C. bridge contraction
D. all of these are true for the IMI herbicides.

_____ 18. In which of the following scenarios would you expect acid hydrolysis to contribute to herbicide degradation?

A. Wet soil condition, soil pH 8.0
B. Wet soil condition, soil pH 7.0
C. Soil pH 5.5
D. It will not occur in any of these situations.

_____ 19. If an herbicide that commonly uses acid hydrolysis as a means of degradation is applied to a soil in which acid hydrolysis does not occur, what will happen to the herbicide?

A. It will persist indefinitely.
B. Microbes will degrade the herbicide.
C. Bridge contraction will degrade the herbicide.
D. The herbicide will slowly leach away because it will not be adsorbed.

______ 20. At which of the following pH values would you expect the length of residual from rimsulfuron to be the greatest?

A. 5.0
B. 6.5
C. 7.5
D. 8.5

______ 21. Which of the following adjuvant packages would most likely result in the best weed control with an ALS-inhibiting herbicide?

A. 2.5% v/v NIS
B. 1 pt/ac COC
C. 1 pt/ac MSO
D. 5 gallon/ac UAN
E. 3 lb/ac AMS
F. 1 pt/ac COC plus 2.5% v/v UAN
G. 1 pt/ac MSO plus 8.5 lb/100 gallon AMS

______ 22. Glyphosate inhibits the production of three aromatic amino acids. Which of the following is one of the amino acids that glyphosate inhibits?

A. tyrosine
B. valine
C. leucine
D. isoleucine
E. B, C, and D are correct.

______ 23. Which of the following adjuvants should be included with the glyphosate label pictured?

A. 0.25% v/v NIS
B. 0.5% v/v NIS
C. 1 pt/ac COC
D. 1 pt/ac MSO
E. None of these adjuvants.

______ 24. Assume a producer has given you the following water test:

pH: 7.1

Ca: 250 ppm

Mg: 300 ppm

Fe: 110 ppm

Na: 27 ppm

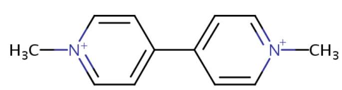
K: 56 ppm

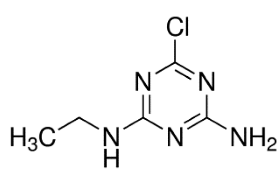
Use the following formula to calculate the lbs of AMS/100 gallon of spray solution that you should recommend he use: (0.002 x ppm K) + (0.005 x ppm Na) + (0.009 x ppm Ca) + (0.014 x ppm Mg) + (0.042 x ppm Fe).

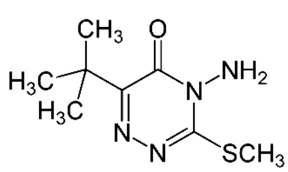
Which of the following rates of AMS in lbs of AMS/100 gallons of spray solution should you recommend for his glyphosate applications?

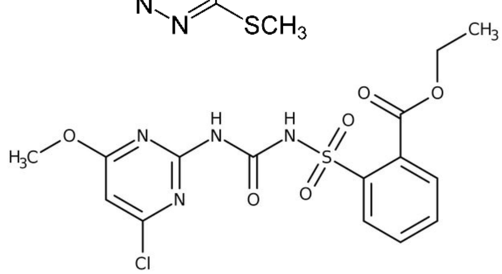
A. 8.5
B. 11.5
C. 15
D. 17
E. No AMS is needed.

______ 25. Which of the following structures is metribuzin?

A. 

B. 

C. 

D. 

______ 26. Which of the following is an output of the light reactions?

A. sugars
B. carbohydrates
C. ATP
D. $NADP^+$

______ 27. Which of the following statements are true about herbicide Groups 5, 6, and 7?

A. They all have the same site of action.
B. They all have different sites of action
C. They all have the same mode of action.
D. A and B are true.
E. A and C are true.
F. None of these are true.

______ 28. Which of the following is true about the mobility of PSII-inhibitors in plants?

A. They are xylem mobile.
B. They are phloem and xylem mobile.
C. They are phloem mobile.
D. They are not mobile in the vascular system.

______ 29. Which of the following herbicides would not be susceptible to enhanced microbial degradation?

A. atrazine
B. metribuzin
C. simazine
D. All of these are susceptible to enhanced microbial degradation.

______ 30. Assuming you have been in a crop rotation with a heavy load of atrazine each year. The soil pH is 5.2. Which of the following would most likely describe the persistence of atrazine in your field?

A. There has likely been a lot of atrazine leaching, and therefore, persistence is not a concern.
B. Most of the atrazine will be adsorbed, and therefore, persistence is a significant concern.
C. Most of the atrazine will have been degraded by microbes, and therefore, persistence is not a concern.
D. None of these are true.

_____ 31. The atrazine label states that no crop other than corn or sorghum may be planted until the following year after an application of atrazine; however, the Acuron label indicates that wheat may be planted after 4 months. Why is there this discrepancy?

Herbicides for Corn

Herbicide* and lb active ingredient needed/acre	Formulated product/acre*	Comments and limitations
POSTEMERGENCE		
S-metolachlor (15) + Bicyclopyrone (27) + Mesotrione (27) + Atrazine (5) 1.34 to 1.61 + 0.038 to 0.045 + 0.15 to 0.18 + 0.63 to 0.75	2.5 to 3 qt **Acuron**	Acuron is a premix of 2.14 lb *S*-metolachlor, 0.06 lb bicyclopyrone, 0.24 lb mesotrione, and 1 lb atrazine (restricted use herbicide); and may be applied early post to field, silage, and seed corn prior to corn attaining 12 inches tall. The addition of NIS at 0.25% v/v is recommended. COC not to exceed 1% v/v can be used; however, crop injury may occur. When applying Acuron POST do not tank mix with MSO or nitrogen products including UAN or AMS. POST applications will not provide adequate control of emergence grasses thus an additional herbicide with grass activity should be tank mixed with the early post application. Use rates are 2.5 qt when soil organic matter is less than 3% and 3 qt when organic matter is 3% or greater. The addition of bicyclopyrone will enhance control of large seeded broadleaf weeds. Rotational restrictions include wheat, rye, or barley 4 months; cotton, soybeans,
Atrazine (5) 1 to 2	1 to 2 qt **Atrazine* 4L** or 1.1 to 2.2 lb **Atrazine* 90 DF**	A restricted-use pesticide. The 2 lb/a rate is permissible only when no atrazine was applied before corn emergence. Apply with COC in water before grasses, broadleaf weeds, and corn exceed 1.5, 4, and 12 inches in height, respectively. Do not apply in liquid fertilizer carrier after corn emerges because injury can occur. Do not plant treated field to crops other than corn (or sorghum in northeastern Kansas) during the same season. Postemergence atrazine rates over 1 lb/a are not considered best management practices because of high runoff potential in surface water in sensitive watersheds (see K-State Research and Extension publication MF-2208). See label for directions, rates, recropping, and feeding limitations.

A. Acuron contains a safener that allows shorter rotational restrictions.
B. Acuron contains a different formulation of atrazine that has enhanced degradation.
C. The atrazine label is out of date.
D. Acuron contains a lower use rate of atrazine; therefore, persistence is less of a concern.
E. None of these are correct.
F. All of these are correct.

_____ 32. Which of the following best describes the site of action for paraquat?

A. PSI-inhibitor
B. PSI electron diverter
C. Cell membrane disruptor
D. None of these.

_____ 33. Which of the following herbicides should always be included with paraquat so long as rotational restrictions allow?

A. mesotrione
B. *S*-metolachlor
C. atrazine
D. metribuzin
E. glyphosate
F. C and D are correct.

_____ 34. Which of the following adjuvants should be used assuming you are using a mixture of paraquat plus atrazine plus *S*-metolachlor to provide foliar and residual control of pigweed in normal growing conditions?

A. NIS
B. COC
C. AMS
D. UAN
E. No adjuvant needed.

_____ 35. Where in the cell does a Group 14 cause activity?

A. chloroplast
B. chloroplast followed by the cytosol
C. cytosol
D. nucleus
E. mitochondria

_____ 36. Which of the following toxic compounds is produced by PPO inhibiting herbicides?

A. PROTO VIII
B. PROTO IX
C. PROTO X
D. PROTO XI
E. None of these.

______ 37. What is the mechanism of activity for PPO-inhibiting herbicides?

A. Stop light reactions
B. Stop the production of amino acids.
C. Strop the production of lipids.
D. Cause lipid peroxidation.

______ 38. Which of the following herbicides require anerobic microbial activity for degradation?

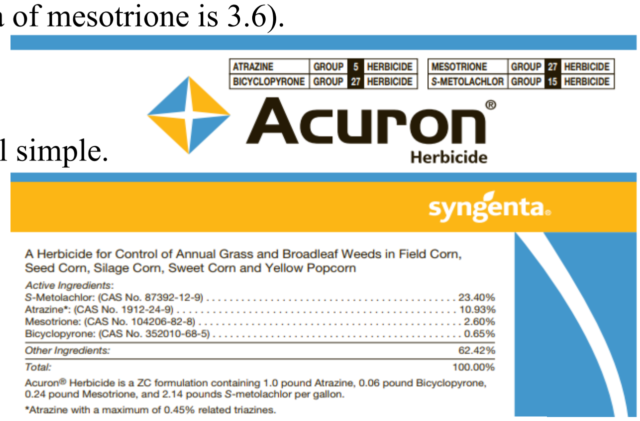
A. saflufenacil
B. aciflurofen
C. lactofen
D. fomesafen
E. All of these options.

______ 39. Assume that you applied a residual application of sulfentrazone. Two days after application you received 0.15” of rain, and 6 days after application you receive 0.8” of rain. You scout the field one week after application and find emerged pigweed in the cotyledon to 1-leaf stage. Do you expect the sulfentrazone to provide control of these?

A. Yes.
B. No.
C. Some, but not many.
D. Hard to tell. Call the agronomist.

______ 40. Why does the Acuron label use only organic matter to determine the use rate instead of soil pH and texture? (Note: the pKa of mesotrione is 3.6).

A. The pKa of mesotrione is low.
B. The pKa of mesotrione is high.
C. Syngenta wanted to make the label simple.
D. None of these reasons.



SOIL ORGANIC MATTER

Determine the organic matter of the soil on which the application is to be made prior to application. The use rate of Acuron Herbicide is based on percent soil organic matter.

_____ 41. Which of the following herbicides should always be included with foliar and residual applications of an HPPD-inhibitor when rotational restrictions allow?

A. mesotrione
B. *S*-metolachlor
C. atrazine
D. metribuzin
E. glyphosate
F. C and D are correct.

_____ 42. Which of the following describes the site of action for glufosinate?

A. glutamate synthase
B. glutamine synthase
C. glutamate synthetase
D. glutamine synthetase

_____ 43. How does glufosinate cause lipid peroxidation via PSII?

A. It directly binds to PSII.
B. It inhibits the process that fixes ammonia with amine groups, and the ammonia becomes toxic to PSII.
C. It causes that production of ammonia which is toxic to PSII.
D. It inhibits nitrate reductase which is the plants mechanism of fixing toxic ammonia which in turn causes a toxic build up of ammonia to inhibit PSII.
E. Glufosinate inhibits the Calvin Cycle which limits energy production.

_____ 44. Which of the following adjuvants should be used with glufosinate?

A. UAN
B. AMS
C. defoamer
D. UAN plus defoamer
E. AMS plus defoamer
F. None of these options.

_____ 45. Which of the following families is not included in the ACCase-inhibitors?

A. Arloxyphenoxypropionates
B. Cyclohexanediones
C. Phenylpyrazolin
D. Triazolopyrimidine

_____ 46. Group 1 herbicides bind to this type of ACCase enzyme.

A. eukaryotic, homomeric
B. eukaryotic, multimeric
C. prokaryotic, homomeric
D. prokaryotic, multimeric
E. It binds to neither of these.
F. It binds to both of these.

_____ 47. What benefit(s) might ammonium provide Group 1 herbicide efficacy?

A. Water conditioning
B. Absorption
C. Translocation
D. All of these are true.
E. B and C are true.
F. A and B are true.

_____ 48. Which of the following herbicides would most likely produce antagonism with a Group 1 herbicide?

A. dicamba
B. 2,4-D
C. glyphosate
D. paraquat

_____ 49. Dicot seedlings absorb Group 15 herbicides via the

A. radicle
B. coleoptile
C. cotyledon
D. hypocotyl
E. All of these options are true.

_____ 50. Which of the following describe the fate of Group 15 herbicides in the soil?

A. microbial degradation
B. adsorption
C. acid hydrolysis
D. volatilization
E. A and B are correct.

_____ 51. Which of the following herbicides may be applied PRE to corn?

A. Halex GT
B. Dual
C. Dual Magnum
D. Dual II
E. All of these may be applied PRE to corn.

_____ 52. SOA 3 herbicides inhibit this phase of mitosis.

A. prophase
B. metaphase
C. telophase
D. anaphase
E. They inhibit all phases of mitosis.

_____ 53. Which of the following is not phase of the Group 4 herbicide response?

A. Stimulation
B. Inhibition
C. Senescence
D. Decay

_____ 54. Which of the following salts of dicamba has the lowest molecular weight?

A. BAPMA
B. DGA
C. DMA
D. potassium
E. sodium
F. acid

_____ 55. You are preparing to apply some atrazine as residual in the fall. No weeds are emerged. Which of the following adjuvants should you consider using?

A. None
B. 0.25% v/v NIS
C. 1 pt/ac COC
D. AMS

_____ 56. You have applied 1.5 qt/ac Bicep Lite II Magnum to your grain sorghum, and you are preparing to rotate to corn the following year. You would like to apply Aatrex 4L in the fall for marestail residual and then Harness Xtra PRE to your corn next spring with 1.5 qt/ac Acuron POST. Assuming you are using no-till and your soils are not erodible, which of the following rates of Aatrex 4L and Harness Xtra should you apply?

A. 1.25 qt Aatrex; 2.5 qt Harness Xtra
B. No Aatrex allowed; 2.5 qt Harness Xtra
C. 2 qt Aatrex; 3 qt Harness Xtra
D. No atrazine should be used in this system.

HARNESS XTRA
Herbicide by Monsanto
GROUP 5 15 HERBICIDE

100.0%
*Contains 516 grams/liter or 4.3 pounds/gallon of acetochlor and 204 grams/liter or 1.7 pounds/gallon of atrazine and related compounds.

Bicep Lite II Magnum®
Herbicide
syngenta

For weed control in corn and grain or forage sorghum

Active Ingredients:	
Atrazine (CAS No. 1912-24-9)	28.1%
Atrazine related compounds	0.6%
S-metolachlor (CAS No. 87392-12-9)	35.8%
Other Ingredients:	35.5%
Total:	100.0%

Bicep Lite II Magnum contains 2.67 lb atrazine + relateds per gallon and 3.33 lb of *S*-metolachlor active ingredient per gallon.
Bicep Lite II Magnum Herbicide is formulated as a suspension concentrate (SC).

ATRAZINE	GROUP 5 HERBICIDE	MESOTRIONE	GROUP 27 HERBICIDE
BICYCLOPYRONE	GROUP 27 HERBICIDE	S-METOLACHLOR	GROUP 15 HERBICIDE

Acuron®
Herbicide

Acuron® Herbicide is a ZC formulation containing 1.0 pound Atrazine, 0.06 pound Bicyclopyrone, 0.24 pound Mesotrione, and 2.14 pounds *S*-metolachlor per gallon.

syngenta **AATREX® 4L HERBICIDE**
FIFRA
Section 24(c) Special Local Need Label

AAtrex 4L Applied Alone - Row Crop Stubble To Be Planted To Corn or Sorghum (Grain or Forage) the Next Spring

Soybeans - Corn or Sorghum - Soybeans Rotation on Medium and Fine Textured Soils

AAtrex 4L may be applied to untilled soybean stubble following soybean harvest for control of fall germinating weeds and control of early spring germinating weeds. Broadcast 3.2 to 4.0 pts./A in a minimum of 10 gals. of spray mixture for ground application, with or without crop oil concentrate, depending on soil texture classification and the percent of soil covered with plant residue. On soils not highly erodible, apply 3.2 to 4.0 pts./A. On highly erodible soils where conservation tillage is practiced, leaving at least 30% of the soil covered with plant residues, apply 3.2 to 4.0 pts./A as a broadcast spray. If the soil coverage with plant residue is less than 30%, a maximum of 3.2 pts./A of AAtrex 4L may be applied. In the following spring if supplemental weed control is needed, up to 1.5 lb. a.i./A of atrazine may be applied as AAtrex 4L (1 pint of AAtrex 4L contains 0.5 lb. atrazine active ingredient) or atrazine in registered prepack products. If weeds are present at application which are not on the product label(s), use a tank mixture of AAtrex 4L with an approved foliar applied herbicide.

_____ 57. Spartan 4F is a liquid formulation of sulfentrazone which indicates there is a 10 month rotational restriction to corn regardless of use rate. Spartan Charge is premix of carfentrazone (a PPO-inhibitor with no residual) and sulfentrazone. See the rate conversion chart for Spartan Charge to Spartan 4F. Spartan Charge allows corn to be planted after 4 months. Assuming 8.5 fl oz/ac of Spartan Charge and that sulfentrazone has a pKa of 6.8, in which of the following situations should the rotational restriction to corn be increased?

A. silt loam soil
B. soil organic matter 2.1%
C. soil pH > 7.5
D. clay loam soil

RATE CONVERSION CHART

SPARTAN CHARGE HERBICIDE		CARFENTRAZONE-ETHYL		SULFENTRAZONE	
Product fl oz/A	lb ai*	Product fl oz/A**	lb ai*	Product fl oz/A***	lb ai*
3.75	0.10	0.65	0.01	2.9	0.09
5.75	0.15	1.0	0.015	4.5	0.14
8.50	0.23	1.5	0.02	6.7	0.21
10.20	0.28	1.8	0.03	8.0	0.25
15.25	0.41	2.7	0.04	12.0	0.37

* Total pounds active of sulfentrazone + carfentrazone-ethyl
** Based on Aim 2EC formulation
*** Based on SPARTAN 4F formulation

INFLUENCE OF CLAY, SOIL TYPE, AND PH ON SPARTAN CHARGE HERBICIDE USE RATES AND CROP RESPONSE

Following an application of SPARTAN CHARGE HERBICIDE to soil, germinating seeds and seedlings take up SPARTAN CHARGE HERBICIDE from the soil solution. The amount of SPARTAN CHARGE HERBICIDE in the soil solution, and available for weed uptake, is determined primarily by soil type, organic matter, and soil pH. SPARTAN CHARGE HERBICIDE adsorbs to the clay and organic matter fractions of soils; effectively limiting the amount of active ingredient immediately available to control weeds. Soils typically increase in clay content through the series from coarse to fine as noted in the following Soil Classification Chart (Table 1).

Table 1. SOIL CLASSIFICATION CHART

COARSE	MEDIUM	FINE
Sand Loamy sand Sandy loam	Sandy clay loam Sandy clay Loam Silt loam Silt	Silty clay loam Silty clay Clay loam Clay

Soil organic matter content can vary widely and independently of soil type and requires an accurate analysis of representative soil samples to determine its content.

Do not use this product on coarse soils classified as sand which have less than 1% organic matter.

Soil pH also exerts a dramatic affect on SPARTAN CHARGE HERBICIDE availability in the soil solution. As soil pH increases, SPARTAN CHARGE HERBICIDE availability increases. Accurate soil pH information will require an accurate analysis of representative soil samples.

The total amount of SPARTAN CHARGE HERBICIDE available, in any given soil, is determined by the interaction of soil type (clay content), % organic matter, and pH. The application timing (relative to the emergence of the crop and weeds) and amount of rainfall and/or irrigation received will ultimately determine, in conjunction with the soil parameters and pH, the amount of SPARTAN CHARGE HERBICIDE in soil solution.

Irrigation with highly alkaline water (high pH) following a SPARTAN CHARGE HERBICIDE soil application can also significantly increase the amount of SPARTAN CHARGE HERBICIDE available in the soil solution. Irrigation with water having a pH greater than 7.5 could result in adverse crop response. This response will ultimately depend on initial SPARTAN CHARGE HERBICIDE application rate, timing, amount and pH of irrigation water and sensitivity of the crop and its growth stage when irrigated. The risk of adverse crop response will lessen with the advance in growth stage among most crops.

The following Crop Specific Use Directions have been designed with specific SPARTAN CHARGE HERBICIDE instructions for each crop based on the soil type, soil organic matter, and soil pH interactions described above. The user is cautioned that crop tolerance and weed control performance are based on strict adherence to these use directions.

_____ 58. Imazethapyr has an 18 month rotational restriction to grain sorghum. In which of the following situation should you consider increasing the rotational restriction?

A. Soil pH of 5.5
B. Warm and wet summer following application
C. Droughty summer following application
D. All of these options are problems and the interval should be increased.
E. A and C warrant the increase of the rotational restriction.

_____ 59. You have been called to the field in response to poor efficacy of clethodim on volunteer corn. The application was made 21 days ago to 18 inch tall corn in soybean. The producer is upset because the corn is still green. What should you do?

A. Issue the farmer a refund for the herbicide and pay for a respray.
B. Demonstrate the corn is actually dead.
C. Contact a third-party consultant to investigate.
D. Analyze the clethodim that was used to certify the viability of the active ingredient.

_____ 60. You are a new agronomist working at a retailer in eastern Kansas. A customer calls you to discuss fall herbicide options to control marestail ahead of soybean. He indicates that he has historically applied 1 lb ai/ac atrazine as a fall treatment. You share with him that this is an off-label treatment. He responds by asking why he has been achieving excellent soybean yields with this off-label practice. Why is the soybean not injured in this case?

A. The producer must have high pH soils, and the atrazine is leaching away over the winter.
B. The producer must have a low pH soil, so the atrazine is adsorbed and not available for soybean uptake.
C. The producer must have enhanced populations of microbes on his farm to facilitate rapid atrazine degradation.
D. Soybean is very tolerant to atrazine.
E. None of these are plausible causes, and you should report him to the EPA and KDA.

Appendix C - Integrated Weed Management, AGRON 650 Unit 2

Herbicide Resistant Crops

Video Notes for Class on February 19, 2019

I. Herbicide Resistant vs. Tolerant.

a. Many crops are tolerant to herbicides.
    i. Reduced ____________.
    ii. Narrow _________________ windows.
    iii. _________________ of crop injury.
b. Few crops are resistant.
    i. Full to higher rates.
    ii. Generally allows _________________ over the top applications of herbicide that was not otherwise labeled.
    iii. Wider application windows.
    iv. Low risk for crop injury.
    v. Source of resistance.
        1. Other plants or ____________________.
        2. Generally ______________ or ________________ genes.
        3. Can be __________ or _______________ (if _________, likely metabolism).
        4. Can be from GMO or Non-GMO.
c. Registration of HR crops.
    i. Requires review by ____________ and _______________.
        1. For HR trait.
        2. New herbicide/label expansion.
    ii. Export approval preferred (not required).

II. Integration of Resistant Crops

a. Part of a __________________ system.

    i. Utilize _______________ SOA that were not otherwise available.
    ii. Increase yields through better weed control.

b. Improper use.
    i. Over-reliance as a _________________ only program.

    ii. Help to facilitate disregard for ____________________.

    iii. Some argue helped to facilitate the rise of ____________________________.

III. HR Corn

a. Current Products.
    i. Roundup Ready Corn.
        1. GMO.
        2. Applied VE through _______________________ tall.
            a. If RR2 (enhanced) apply to 30 to 48-inch tall corn with drop nozzles.

    ii. Liberty Link Corn
        3. GMO.
        4. Apply ______________ through ___________________.

    iii. RR2 stacked with Liberty.
        5. GMO.

    iv. Enlist Corn.
        6. GMO.
        7. Stacked with glyphosate, ________________.

a. 2,4-D can be applied to ____________________corn POST until 8 inches tall with drop nozzles after 8-inches.
    i. High potential for crop response.
    ii. Low rate (ineffective w/o tank mix partner).

b. Enlist Duo or Enlist One can be applied until _______________ with drop nozzles up to 48-inches.
    i. Higher rate.
    ii. No crop response.
    iii. More effective because of tank mix partners.
    iv. Enlist One may be tank mixed with ________________ on Enlist SmartStax.
    v. Very limited on tank mix options in corn.
    vi. Indirect resistance to __________________ (will not be labeled POST).

v. Clearfield Corn.
1. Allows application of ______________________ POST in corn.

2. Also reduces _________________ ______________ from Beyond applications to immediate plant back from 8.5 months to non-Clearfield corn.
3. Very few hybrids available on the market.

b. Future Products.

vi. Xtendflex Corn
1. GMO.
2. Not on market (5 to 10 years from launch).
3. Provide resistance to glyphosate, dicamba, and ______________.

a. __________________ is currently labeled in corn.
    i. Xtendimax can be applied 0.5 lb ai/ac until _________ tall or 0.25lb ai/ac until 36-inches or 15 days before tassel.
        1. High potential for crop response.
        2. Lower rate on bigger corn.

    ii. ___________ (cyprosulfamide safener) can be applied 0.5 lb ai/ac from PRE to V10 or 36-inches tall.

iii. __________ (isoxadifen safener with diflufenzopyr for reduced amount of dicamba) can be applied from V2 or 4-inches tall through V8 or 36-inches tall.

b. Xtend corn will provide option for a rate increase and use of non-safened product (Xtendimax).

4. Next generation incorporates resistance to _________ and _____________.

vii. ___________-resistant corn.

5. GMO.
6. Not on market (5 to 10 years from launch).
7. Provide increased spectrum of resistance to POST and PRE PPO inhibiting herbicides.

c. ________________ POST.
d. ________________ potentially PRE or POST.
e. New active ingredient (trifludimoxazin).

IV. HR Soybean.

a. Current products.
  i. Roundup Ready.
    1. GMO.
    2. Two events (RR and RR2).
    3. PRE through R1 stage.

  ii. Liberty Link.
    1. GMO.
    2. PRE up to ____________________ stage.

  iii. Xtend.
    1. GMO.
    2. Two events (RR2 and ___________________).
    3. PRE applications to __________________.
    4. Must use Xtendimax, Engenia, Fexipan, Tavium.
      a. Very restrictive application parameters.

b. Limited tank mix options.

iv. Enlist Soybean.
1. GMO.
2. Three events (glyphosate, 2,4-D, __________________).
3. Applied PRE through _____________ stage.
4. Must use Enlist Duo or Enlist One.
   a. Enlist One may be tank mixed with ___________________.
   b. Very restrictive on tank mix partners (website).

v. STS and BOLT Soybean.
1. Non-GMO.
2. STS is one-gene resistant to sulfonyl-urea herbicides.
3. BOLT is two-gene resistant to SU herbicides.
4. Allows for shorter plant-back from SU herbicides in wheat (chlorsulfuron).

b. Future Products.

i. ___________________ soybean.
1. GMO.
2. 3 to 5 years from launch.
3. Resistant to glyphosate, dicamba, and ________________.

ii. Balance Beans.
1. GMO.
2. 1 to 3 years from launch.
3. Isoxaflutole PRE and glyphosate POST.
4. Second generation will have ____________________ POST as well.

iii. MGI soybean.
1. GMO.
2. 3 to 5 years from launch.
3. Resistant to mesotrione, glufosinate, and _________________.
   a. HPPD will be PRE only.
   b. Potential for mesotrione _________________ in second generation.
   c. Potential for ___________ POST in second generation.

iv. PPO-resistant soybean.
1. GMO.
2. 5 to 10 years from launch.
3. Similar event as discussed in corn.

v. 5 and 6 stack soybean.
    1. GMO.
    2. 8 to 10 years from launch.
    3. Combinations of many HR traits in one soybean.
    4. Opportunities for flexible management and less risk of damage from off-target movement.

V. HR Cotton.

a. Current Products.
  i. Roundup Ready Cotton.
    1. GMO.
    2. Original trait in cotton.
    3. Low use rate (22 fl oz of PowerMax).
    4. From VE through ___________________.

  ii. Roundup Ready ____________ Cotton.
    1. GMO.
    2. Higher rates.
    3. Very wide application window.

  iii. Liberty Link Cotton.
    1. GMO.
    2. Stacked with glyphosate.
    3. Applications from VE through __________________ allowed.

  iv. XtendFlex Cotton.
    1. GMO.
    2. Stacked with dicamba, glyphosate, and ____________________.
    3. Sequential application of dicamba plus glyphosate fb glufosinate are common.
    4. Still susceptible to ____________________ injury.

  v. Enlist Cotton.
    1. GMO.
    2. Stacked with glyphosate, 2,4-D, and ____________________.
    3. Applied from VE through mid-bloom.

b. Future Products
   i. Integrating XtendFlex Cotton with ______________ cotton.
   ii. Incorporating _____________ resistance (similar to corn and soy)
   iii. Incorporating HPPD herbicides.

VI. HR Canola.

a. Current products.
   i. Glyphosate resistant winter canola.
      1. GMO.
      2. Applied from PRE- through prior to ___________________ in spring.

   ii. Clearfield resistant winter canola.
      1. Non-GMO.
      2. Beyond applied VE up to ______________________.
      3. NIS must be used; MSO could cause additional injury to canola.

b. Future products.
   i. Liberty-Link winter canola for Great Plains.
      1. Currently available in spring market and in _________________.

VII. HR Winter Wheat.

a. Current products.
   i. Clearfield Winter Wheat.
      1. Non-GMO.
      2. Allows for POST applications of _______________.
      3. One-gene (Clearfield) requires ________________ and an application window of tiller initiation through jointing.
      4. Two-gene (Clearfield Plus) can have _________________ and an application window of 2-leaf through second joint.

   ii. CoAXium Winter Wheat.
      1. Non-GMO.
      2. Allows for POST applications of quizalofop (Aggressor herbicide).
      3. Apply at 4-leaf stage to prior to _________________.

4. Option for control of _______________ brome populations.

b. Future products.
   i. Liberty Link or glyphosate resistant wheat.
      1. GMO.
      2. Has been developed; however, not launched due to poor market adoption.

VIII. HR sunflower.

a. Current products.
   i. Clearfield sunflower.
      1. Non-GMO.
      2. Allows for POST applications of Beyond.
      3. One-gene (Clearfield) requires NIS and an application window of V2 through V8 stage and rate limit of 4 oz/ac Beyond.
      4. Two-gene (Clearfield Plus) can have MSO and ____________ application rate of 6 oz/ac Beyond.

   ii. ExpressSun Sunflower.
      1. Non-GMO.
      2. Allows for POST applications of Express (_______________ ALS herbicide).
      3. Applied from V2 through ____________________ stage.
      4. MSO required.

IX. HR Grain Sorghum.

a. Future Products.
   i. Inzen Grain Sorghum.
      1. Non-GMO.
      2. Resistant to SU herbicides POST.
         a. _________________ POST.
      3. Potential to decrease rotational restrictions from SU herbicides in winter wheat.
      4. Currently under development. No timeline for launch of commercial hybrids.

   ii. IMI-Resistant Grain Sorghum
      1. Resistant to _____________ herbicide.
      2. Currently under development. No timeline for launch of commercial hybrids.

3. Could pose rotational restriction concerns.
4. Generic Pursuit will likely be labeled, not Beyond.

iii. ACCase-resistant grain sorghum.
1. Non-GMO.
2. Resistant to _____________ herbicides.
3. Currently scrapped due to trait sourcing law suits.

Herbicide Efficacy

Video Notes for Class on February 21, 2019

I. Herbicide Efficacy

A. Why study efficacy?
   a. Not all ________________control all weeds
   b. Not all herbicides are labeled in all crops
      i. Some herbicides can be used in multiple crops but require different application ____________________ (adjuvants, nozzles, etc).
      ii. Herbicide ___________________ issues

B. Efficacy on driver weeds from a _________ perspective (may be POST to crop, but residual for weeds).
   a. Palmer amaranth and waterhemp residual
      i. ALS herbicides (SOA 2)
         1. ____________ (If not resistant; most are resistant)
         2. ____________ (If not resistant; most are resistant
      ii. Growth Regulator (SOA 4)
         1. _____________ (when cool and dry)
            a. Need at least 0.5 # active/acre
            b. If rain, then very little residual
      iii. PSII (SOA 5,6,7)
         1. __________ (5)
            a. If not resistant; __________ are resistant PRE and POST.
            b. Requires more than 0.25 # ai/ac
         2. __________ (5)
            a. No resistant populations confirmed
            b. Requires at least 0.25 # ai/ac (less in sandy soils)
         3. ___________ (7)
            a. Not well suited to Kansas cropping systems.
      iv. PPO (SOA 14)
         1. PPO _______controls all PPO ___________populations in Kansas
            a. New mechanism of resistance in Illinois, Arkansas, Tennessee where efficacy is reduced to 80%.
         2. ___________
            a. Watch rotational restrictions to corn and sorghum
            b. Need at least 1 pt/ac of Flexstar

3. ____________
    a. Need at least 3 oz or 2 oz as planned early program
4. ___________
    a. Need at least 6 to 7 fl oz/ac Spartan 4L
5. ____________
    a. High rates. 10 days per oz of Sharpen.

v. VLCFA (SOA 15)
1. _____________
    a. 1.5 to 3 oz/acre Zidua
    b. ___________ inches of rain for good activation.
2. ____________________
    a. Consider conversion from metolachlor to *s*-metolachlor
    b. Need at least 1.33 pts/ac Dual Magnum
3. _____________________
    a. Need high rates (more than 1 pt/ac Outlook)
4. ________________
    a. More rain needed for encapsulated and microencapsulated, but residual may last longer.
    b. Rate structure reduced for soybean and cotton.

vi. HPPD (SOA 27)
1. All populations are controlled by HPPD ______________that are resistant to HPPP _____________.
2. PSII should still be used on PSII and HPPD resistant populations for _____________ and ___________ synergy.
3. ______________
    a. Need at least 3 oz Callisto/ac
    b. Maybe more like 6 oz/ac
4. ______________
    a. Consider conversion between Balance PRO/Balance Bean (_______ product) and Balance Flex (_________ product).

b. Kochia PRE
    i. ALS (SOA 2)
    1. ___________________ (historically but all are resistant)
    ii. Growth Regulator (SOA 4)
    1. ______________
        a. Need at least 0.25 # ai/ac
        b. Best during early season. Warm and wet reduces activity.

iii. PSII (SOA 5)
    1. _____________
        a. Need at least 0.5 # ai/ac for short residual, more for longer.
        b. Potential for target site resistance
    2. ____________
        a. Generally not as good as ATZ
        b. Potential for same resistance as ATZ

iv. PPO (SOA 14)
    1. _____________
        a. More than 4 oz/ac Spartan
        b. May only be used in fallow, soybean, and corn systems
        c. Longer rotational restrictions to sorghum
    2. _____________
        a. More than 2 oz/ac (2 weeks/oz)
        b. Much more flexible on rotational restrictions than sulfentrazone, but not as good on kochia unless high rates.

v. VLCFA (SOA 15)
    1. ____________
        a. Requires 1 inch of rain for activation
        b. More than 3 oz/ac Zidua can provide good long season control.

vi. HPPD (SOA 27)
    1. Must use a _______ herbicide in combination even on PSII resistant populations.
    2. ______________
        a. Flexible to corn or sorghum
        b. Need at least 3 oz/ac for 1 week per oz of Callisto, need about 6 oz/ac.
    3. _____________
        a. Restrictive to corn, 6 months to sorghum

c. Pigweed POST
    i. ALS (SOA 2)
        1. Responsive to _______ activator adjuvants and ___________.
        2. _______________ (likely resistant)
        3. ___________, ______________ (likely resistant)

ii. EPSPS (SOA 9)
    1. __________________ (Likely resistant)
        a. Requires ____________ water conditioner
        b. Requires __________for non-loaded formulations
iii. Growth regulator (SOA 4)
    1. ________________
        a. Ammonium increases volatility
        b. Need 0.5 # ai/ac
            i. Low rates are no longer _____________.
            ii. Possible __________; likely reduced ____________ in warm temperatuers.
        c. Or diflufenzopyr
        d. Low rates are not good
    2. ________________
        a. Must be combined with glyphosate even on glyphosate resistant populations
        b. Responsive to oil activator adjuvants.
iv. PSII (SOA 5, 7)
    1. COC or MSO required for absorption.
    2. Less responsive to _________________.
    3. ______________ (will ______ control ATZ resistant populations)
    4. ______________ (will control _________ resistant populations)
    5. _______________ (need a fairly high rate)
    6. _____________

v. ____________ (SOA 10)
    1. Must include AMS
    2. Responsive to high humidity

vi. PPO (SOA 14)
    1. Responsive to COC or MSO
        a. Concerns of crop response
    2. Responsive to ammonium
    3. Will not control PPO resistant populations
    4. ______________
    5. Aciflurofen
    6. _____________
    7. Flumioxazin
    8. _____________

9. Normally do not list what offers _______ control but….
    a. _______________Cadet
    b. _______________Resource

vii. PSI (SOA 22)
1. __________________
2. Always tank mix with a __________ even on ATZ-R populations.
3. NIS preferred; however, an oil may be used with a tank mix partner.
4. Ammonium may be beneficial during hot and dry weather.

viii. HPPD (SOA 27)
1. Ammonium beneficial for absorption
2. MSO preferred with many, but limited for crop response purposes.
3. Will not control HPPD resistant populations POST.
4. Always use a PSII herbicide as a tank mix partner.
5. ____________________ (at least 3 oz/ac Callisto)
6. __________________ (MSO required)
7. _____________________ (MSO required)
8. _____________________
9. _______________________

d. Kochia POST
i. ALS (SOA 2)
1. Responsive to MSO activator adjuvants and ammonium
2. Imazethapyr (likely resistant)
3. Chlorsulfuron, thifensulfuron (likely resistant)

ii. EPSPS (SOA 9)
1. Glyphosate (Likely resistant)
    a. Requires AMS water conditioner
    b. Requires NIS for non-loaded formulations

iii. Growth regulator (SOA 4)
1. Dicamba
    a. Ammonium increases volatility
    b. Need 0.25 # ai/ac
    c. Or diflufenzopyr
    d. Low rates are not good
    e. Could be ____________
        i. Dicamba _______ controls populations that are resistant to dicamba ____________.
2. Fluroxypyr

            a. Resistance is starting to appear.

    iv. PSII (SOA 5)
        1. COC or MSO required for absorption.
        2. Less responsive to ammonium
        3. Atrazine (will not control ATZ resistant populations)

    v. PPO (SOA 14)
        1. Responsive to COC or MSO
            a. Concerns of crop response
        2. Responsive to ammonium
        3. ________________

    vi. PSI (SOA 22)
        1. ______________
        2. Always tank mix with a PSII even on ATZ-R populations.
        3. NIS preferred; however, an oil may be used with a tank mix partner.
        4. Ammonium may be beneficial during hot and dry weather.

    vii. HPPD (SOA 27)
        1. Ammonium beneficial for absorption
        2. MSO preferred with many, but limited for crop response purposes.
        3. Always use a PSII herbicide as a tank mix partner.
        4. Mesotrione (at least 3 oz/ac Callisto)
        5. Tembotrione (MSO required)
        6. Topramezone (MSO required)
        7. Pyrasulfatole
        8. Bicyclopyrone

e. ACCase-inhibiting herbicides
    i. Not all have good efficacy on all grass species.
    ii. _______________
        1. Poor on volunteer corn
            a. Higher rate required with heavy adjuvant load.
        2. Fair on other annual grasses
    iii. _______________
        1. Excellent on annual grasses
    iv. _______________
        1. Excellent on volunteer corn and perennial grasses.

II. Use of Adjuvants

A. Important to consider the absorption process for an herbicide (reflect on previous lectures)
B. Focused on POST herbicides with foliar activity
    a. Research has yet to show benefits of adjuvants for _______________ herbicides
C. Beware of AMS ____________________ products or other convenience features.
    a. If it is cheap, it is likely too good to be true.
    b. Only use ________________ approved adjuvants
        i. No regulation in adjuvant sales business.
        ii. Seek out university testing or in-field comparisons for adjuvant recommendations.
D. Use rates for Oil Adjuvants
    a. Historically based on % v/v
        i. This can result in not enough oil to solubilize cuticle and wax to allow herbicide to diffuse through plasmalemma.
            1. Especially problem with _______________ carrier volumes.
        ii. See chart from NDSU.
        iii. Generally, we need 1 to 2 pt/ac of COC or MSO
        iv. COC is ________________ based.
        v. MSO is ________________ based.
    b. Even more confusion arises with HSOC
        i. Based on _____________ or ________________.
        ii. Contains about 20% surfactant
        iii. Ideal for tank mixing lipophilic and hydrophilic herbicides
            1. Such as _____________ with lipophilic herbicides.
        iv. Recommended at 0.5% v/v (not enough)
        v. MSO based products are preferred.

Oil adjuvant rates
volume vs. area

Volume rate (v/v rate)	Spray volume (gpa)	Area rate (pt/A)
1%	25	2
1%	19	1.5
1%	12.5	1
1%	9.4	0.75
1%	5 (aerial)	0.375

Oil adjuvant volume rates: % v/v vs. area

E. Always follow label instructions when making an adjuvant selection.
    a. Consider the implications of use rate.

III. Concept of Nozzle Selection

A. Spray nozzle droplet size

a. Each nozzle produces ______________ sizes of droplets

b. The "average droplet size" is described as a nozzle's

____

c. ASABE characterizes nozzles based on this criteria.

Category	Symbol	VMD Range (µm)	Color
Extremely Fine	XF	< 60	
Very Fine	VF	61 - 105	
Fine	F	106 - 235	
Medium	M	236 - 340	
Coarse	C	341 - 403	
Very Coarse	VC	404 - 502	
Extremely Coarse	XC	503 - 665	
Ultra Coarse	UC	> 665	

Table 1. Spray droplet classification chart as derived from ASABE (2009) standards. Based on the VMD of a particular nozzle at a given pressure and spray solution, the nozzle can be classified based on the range of droplet spectrum. A symbol as well as color code for classification is also designated.

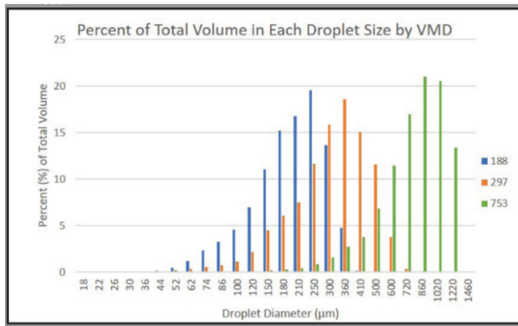


Figure 2. Spray droplet spectrum as a percentage of the total spray volume contained in each size of droplet diameter. Colored bars indicate droplet size distribution for three different nozzles each having a corresponding VMD. Notice that the nozzle with the VMD of 753 (ultra coarse classification) still produced droplets classified as Fine which could be subject to physical drift.

B. Optimal Droplet Size Selection

a. Each herbicide has an optimal droplet size to maximize _____________.

b. Much more _____________

i. Optimal range is an interaction of droplet size and carrier volume

1. Dicamba is 20 GPA at __________ VMD

2. Glufosinate is _____to __________VMD regardless of GPA

3. Paraquat is about _________ VMD regardless of GPA

AIXR TeeJet® (AIXR)

	PSI										
	15	20	25	30	35	40	50	60	70	75	90
AIXR110015	XC	XC	VC	C	C	C	C	M	M	M	M
AIXR11002	XC	XC	XC	VC	VC	C	C	C	C	M	M
AIXR110025	XC	XC	XC	XC	VC	VC	C	C	C	C	C
AIXR11003	XC	XC	XC	XC	VC	VC	C	C	C	C	C
AIXR11004	UC	XC	XC	XC	XC	XC	VC	VC	C	C	C
AIXR11005	UC	XC	XC	XC	XC	XC	VC	VC	C	C	C
AIXR11006	UC	XC	XC	XC	XC	XC	VC	VC	VC	C	C

Figure 8. It is important to consider the interaction of orifice size and operating pressure. Notice how the VMD decreases as the orifice size increases. As the pressure increases, droplet size decreases and the potential for driftable fines increases. Adapted from TeeJet (2014).

C. Many factors influence droplet size for a given nozzle.

a. Spray carrier ______________

b. Spray ________________

c. Adjuvants

d. Tank mix partners and formulations

D. Coverage of target

a. Research demonstrates that penetration into a canopy is not facilitated with ___________ ___________ nozzles.

b. Should consider one or more nozzles oriented down rather than at an angle.

Nozzle	DRA Yes	DRA No
	VMD (µm)	
AITTJ11005	509	602
AIXR11005	509	485
TTI11005	645	803
XR11005	319	252

† All droplet spectra were measured at 40 psi using the same spray solution with and without the DRA in a carrier volume of 20 GPA. Droplet spectra was assessed using a wind tunnel equipped with laser diffraction technology. Cell color indicates droplet size classification.

Table 3. Herbicide solutions were applied through different nozzle types with and without a DRA (In-Place, Wilber-Ellis Company, Fresno, CA 93755). The addition of a DRA did not consistently increase droplet sizes. In certain nozzles such as the TTI, droplet size was actually decreased and could increase the risk for physical drift. It is important to consider the interaction of a DRA with nozzle type before implementing the use of a DRA. Adapted from Creech et al. 2009.

Treatment	AIXR 10 GPA	AIXR 20 GPA	TTI 10 GPA	TTI 20 GPA
	VMD (µm)			
Engenia + Liberty	459	515	743	757
Engenia + Roundup PowerMax	385	487	665	746
Engenia + Liberty + Roundup PowerMax	560	501	800	789
Engenia + Liberty + Roundup PowerMax + Dual Magnum	399	490	589	568

† All droplet spectra were measured at 40 psi using a 11003 and 11005 nozzles for the 10 and 20 GPA treatments, respectively. Droplet spectra was assessed using a wind tunnel equipped with laser diffraction technology. Field use rates of all herbicides were utilized. Cell color indicates droplet size classification.

Table 2. Various tank mixes of different herbicides were applied at field use rates with different nozzles (AIXR and TTI) at different carrier volumes. Notice how the additions of certain herbicides influenced droplet size. Notice how increasing carrier volume tended to increase droplet size, but not always. It is important to consider the interaction of herbicide formulation, nozzle type, and carrier volume on droplet size. Adapted from Meyer et al. 2016.

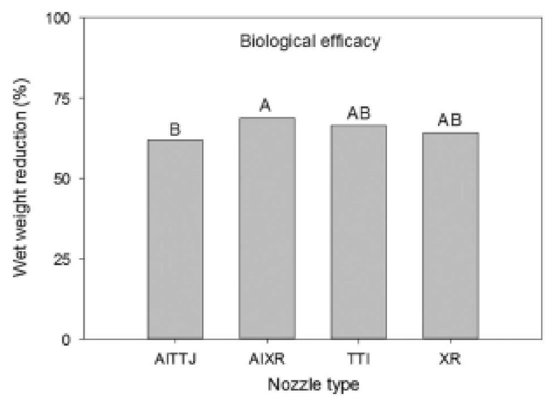
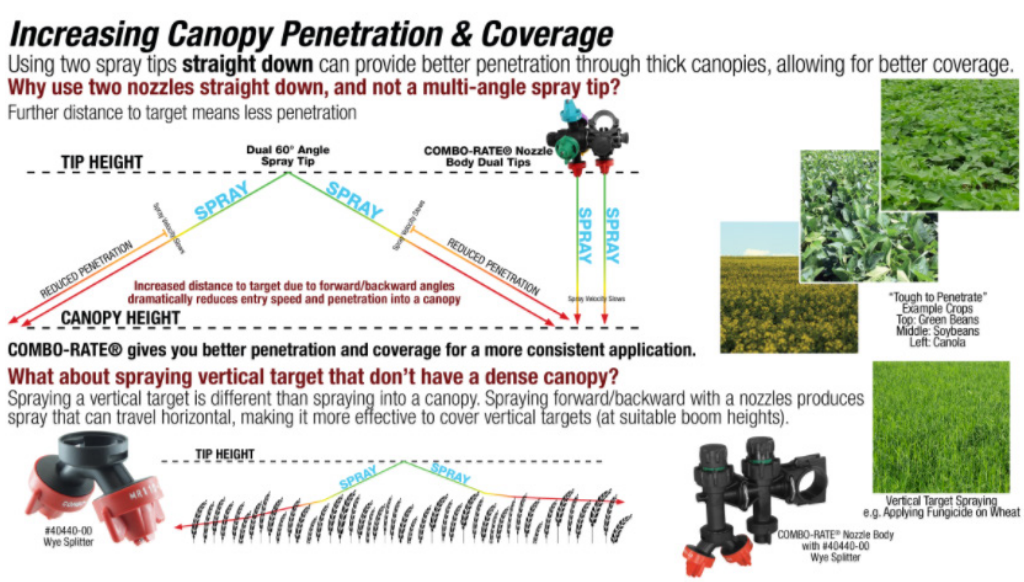


Figure 8. Wet weight reduction of soybean used as a biological indicator plant as influenced by nozzle type in a corn canopy. The spray mixture included two carrier volumes with and without a drift reduction adjuvant (DRT). Letters indicate significant differences (α = 0.05) across nozzle type.



Developing Simple Herbicide Recommendations

Video Notes for Class on February 26, 2019

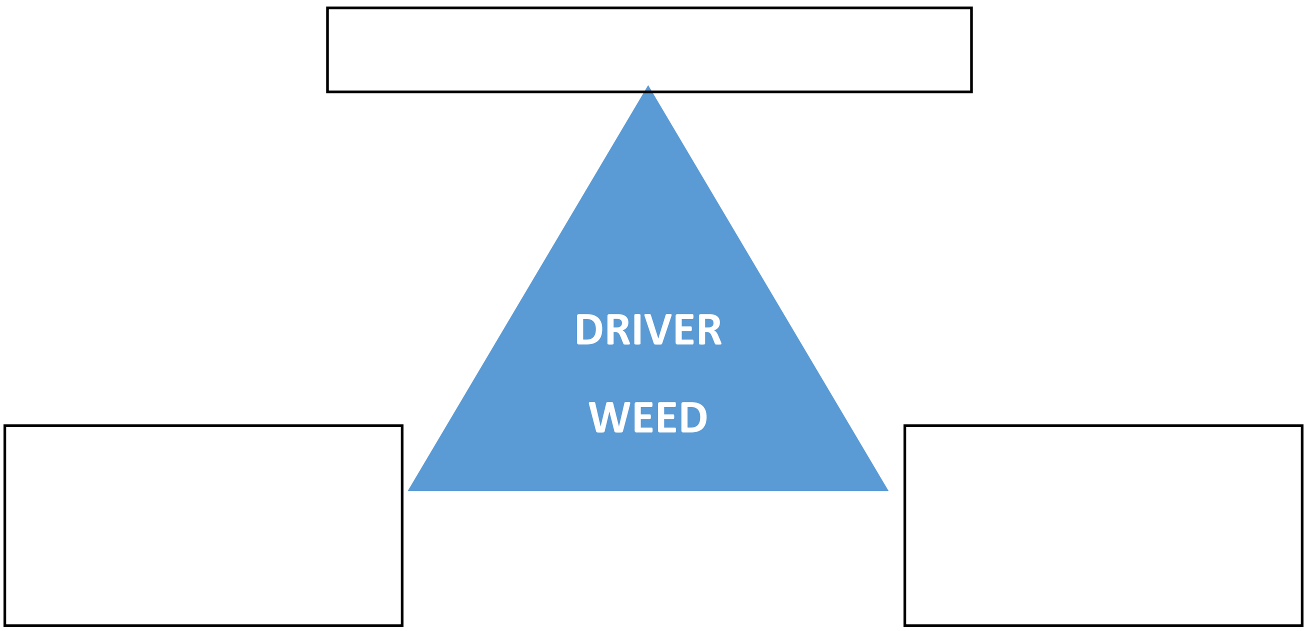
I. Aspects to Consider when Selecting Herbicides

1. __________________weed control efficacy
   a. Using ________________________products on target species
      i. What is the spectrum of control?
      ii. Efficacy on driver species?
   b. Appropriate herbicide ______________________
      i. Low ________________ vs._____________ efficacy
   c. Desirable weed ________________ (germinating or few true leaves)
      i. Spraying __________________ weeds does not end well
   d. Application parameters (GPA, speed, nozzle, droplets)
      i. Very specific interactions exist
      ii. Minimize driftable fines
      iii. Provide adequate _________________
         1. This historically has been overstated
         2. Do not use _____________ nozzles for anything other than residual herbicides or dicamba POST in soybean/cotton.
      iv. Assess the implications for small things such as speed changes
   e. Adequate ______________ package.
      i. Appropriate adjuvants
      ii. ________________of adjuvants
   f. Applied at appropriate ______________ (not middle of August or during a freeze).
      i. Applications during hot temperature can result in enhanced metabolism, reduced translocation, or reduced absorption.
         1. HPPD herbicides applied POST above 85 degrees Fahrenheit
         2. Auxinic herbicides applied POST result in reduced translocation
         3. PPO herbicides applied POST result in poor absorption.
2. Facilitate crop safety
   a. Safety to ________________crop
      i. Phytotoxicity
      ii. Yield preservation
      iii. Harvest management
   b. Safety to _____________________ crops
      i. Rotational restrictions
      ii. Must consider the "specific situation"
         1. May need to increase rotational restriction

II. Develop the Plan

1. "Failing to plan is planning to fail," quote from Benjamin Franklin.
    a. It is amazing how many people do not have a _______________
        i. Old views have caused this problem (_____________ _______________).
        iii. Concept of using ______________ ___________________ to "save" an herbicide pass.

2. Three-part program



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III. Starting Clean

a. Do not plant a crop into a field with actively growing __________________.
    i. Leads to early season ____________________.
    ii. ____________________ _________________.
    iii. Limited herbicide options and reduced efficacy if _________________ not implemented.
b. Difficult to implement with a "_______________ _______________" cover crop system.
c. _______________________is a key component of starting clean.
d. Can be difficult to implement with high ________________ with __________ herbicides.

e. Use effective herbicides to facilitate burndown.
    i. Consider April 20 grower example for burndown ahead of corn, soy, sorghum.
        1. Marestail (3-inch) (glyphosate resistant).
        2. Various mustards.
        3. Henbit.
        4. 2-inch Palmer amaranth (glyphosate resistant).
        5. Downy brome.

Herbicide	Rate	Target Weed Species	Comments
Roundup Powermax	32 oz/ac		
2,4-D LV-6	8 oz/ac		
Clarity	6 oz/ac		
Elevore	1 oz/ac		

    ii. Consider controlling downy brome in winter wheat
        1. Utilizing a burndown approach in no-till or ________ _______approach.
        2. ____________________ is the main herbicide of choice.

f. Sticky situations with the spring burndowns can be _________________ to facilitate and very ________________________ with a high risk of ______________________.
    i. Find ways to avoid these situations by using a preventative rather than reactive approach with ________________ _____________________
        1. Plan starts with identifying species
            a. _________________ (may be ALS-resistant)
            b. _________________(may be glyphosate or ALS-resistant)
            c. _________________ (may be ALS-resistant)
            d. ______________(tansy/bushy wallflower may be ALS-resistant)

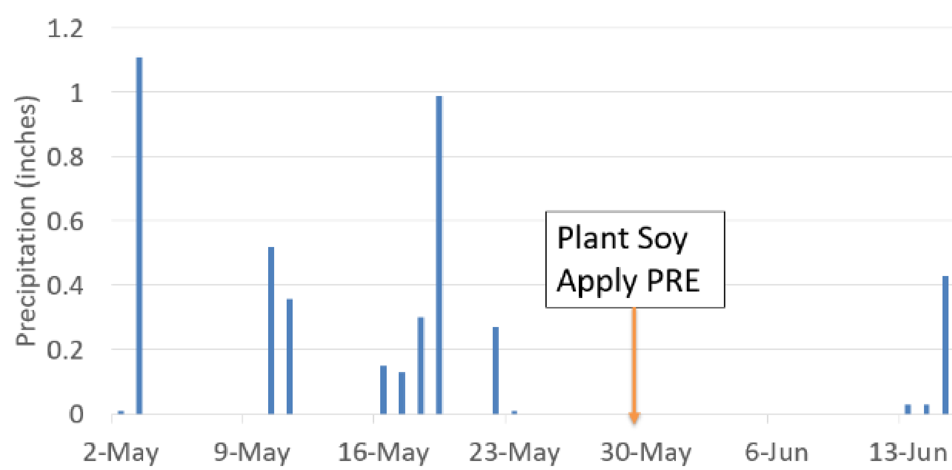
2. Fall treatments must accomplish both burndown and residual.
    a. May be extended into winter treatment (no snow or frozen soil)
    b. Key fall burndown herbicides (foliar activity requires good temps at least _____________days above _________ F).
        i. __________________ (26 oz/ac PowerMax)
            1. _____________ on Bromus
            2. _____________on henbit and mustards
        ii. ______________ (1 pt/ac LV-4)
            1. ______________ on mustards
            2. ______________ on henbit and marestail
        iii. _______________ (8 oz/ac Clarity)
            1. ________________ on marestail
            2. ________________ on henbit
            3. _________________on mustards
        iv. _____________ or __________ (requires COC for foliar)
            1. Excellent tank mix partner with Group 4 herbicides for broadleaf weeds.
            2. Poor on grasses
        v. Finesse, Autumn Super, Rave, Chlorimuron-ethyl
            1. ______________ on ALS-susceptible marestail and henbit.
            2. Must watch ___________ _________________
                a. ____________________ is very flexible
    c. Fall residuals
        i. Dicamba (> 8 oz/ac Clarity)
            1. _____________ broadleaf weed control
            2. Requires dry, cool conditions
        ii. Atrazine, Simazine, Metribuzin
            1. _________________ marestail, dicot control
            2. _____________ Bromus control
            3. _______________= corn only
            4. _______________ = soybean or corn only
            5. ______________ = all crops but must watch rotational restrictions, high pH, and use rate for corn or sorghum
        iii. _____________________

1. _________________marestail and dicot control
2. ______________ grass control
3. Flexible to ___________________

iv. Finesse, Autumn Super, Rave, Chlorimuron-ethyl
1. Excellent on ALS-susceptible marestail and henbit.
2. Must watch rotational restrictions.
   a. Autumn Super is very flexible

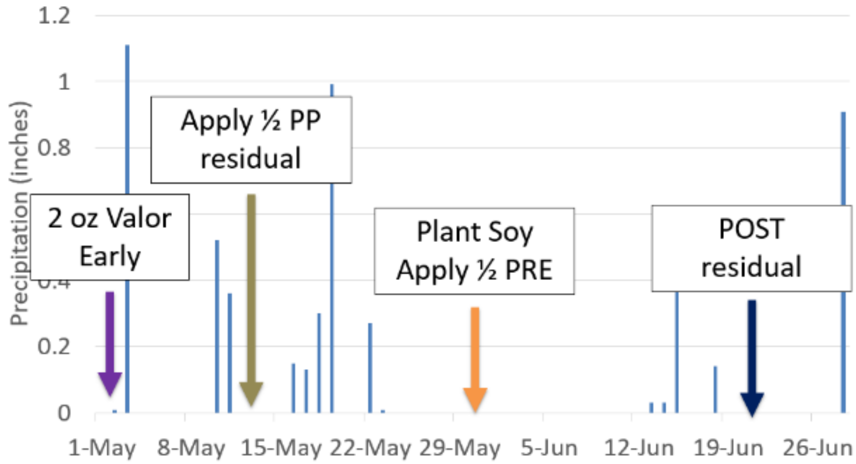
IV. Utilize Overlapping Residuals.

a. Case study of Hutch $30/acre PRE program (Fierce MTZ).
   i. Why did the expensive PRE fail?



   ii. What value does the $30/acre PRE program bring to the table?

   iii. What does a split-shot, overlapping program facilitate?



iv. Why maintain a split-shot program rather than apply all residual 2 weeks preplant?

b. Planned residual programs
   v. Include a split-shot pre-plant followed by PRE Planned POST program.
      3. Could utilize _______________ treatment residual as well
      4. Planned POST should be timed on the calendar.
         a. Do not ___________________to spray or wait for more weeds to _____________ to save on applications.
      5. Automatically apply more residual _______________ days after planting.
         a. Utilize POST products that have residual and foliar activity where possible.
            i. ________________ (corn).
            ii. ________________ (corn and sorghum).
               1. 11-inch tall crop cut off timing.
            iii. ________________ (soybean).
         b. Always use a __________________in POST applications.
            i. Contains no POST activity.
            ii. Consider cut off timing for specific products and crops.

Introduction to Herbicide Resistance

Video Notes for Class on February 28, 2019

I. Rise of Herbicide Resistance

a. 2,4-D was developed as a result of ___________ and commercialized in __________.

   i. Revolutionized agriculture.

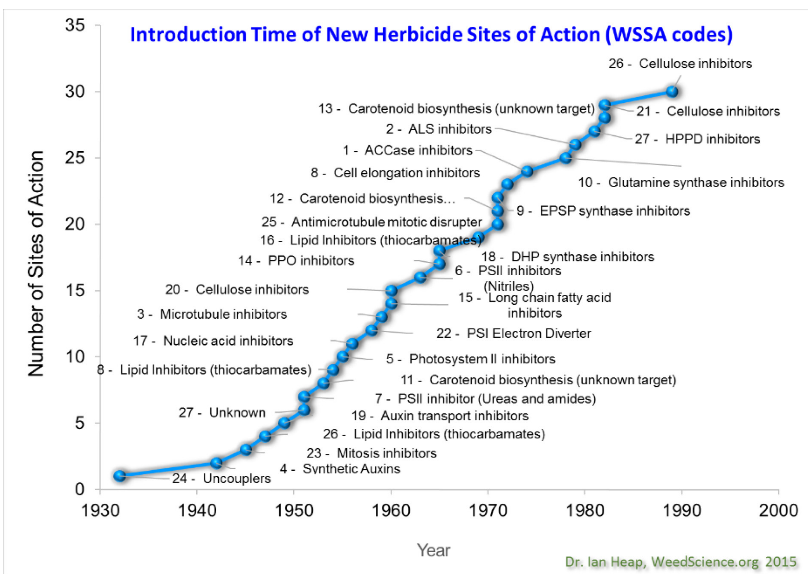
   ii. Beginning of ____________ ______________ in herbicide industry.

   iii. Gave rise to weed science.

b. VLCFA herbicides discovered in 1952 and commercialized in 1969

   i. First time an herbicide could be applied ____________ a crop.

c. Introduction of new sites of action



   i. ____________________was the last new site of action discovered in _________ for agricultural applications.

   ii. 1970's and 1980's were a very exciting time for herbicide introductions.

   iii. Created the culture of "industry will provide something new to use to manage my weeds."

d. Resistance arrives
    i. ___________________ (*Daucus carota*) was confirmed resistant to _________.
        1. 1957
        2. 12 years after the introduction of 2,4-D

    ii. ____________________ (*Senecio vulgaris*) confirmed resistant to triazine herbicides in Washington in 1968.

e. Resistance is overlooked
    i. Herbicide resistance was overlooked until _________________.
        1. Limited number of cases (41 by 1980).

        2. _______________ resistance discourage concern about herbicide resistance.
            a. Rise of insecticide resistance (17 cases per year from 1954 to 1960).
            b. Weeds were considered ______________ to resistance (seed bank, life cycle, etc).

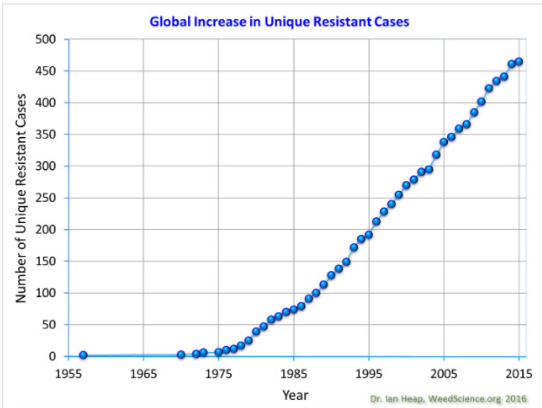
        3. ________________ of triazine resistance
            a. Fitness penalty associated with resistance.
            b. Maternally inherited gene.
            c. Ultimately not understood until recently.

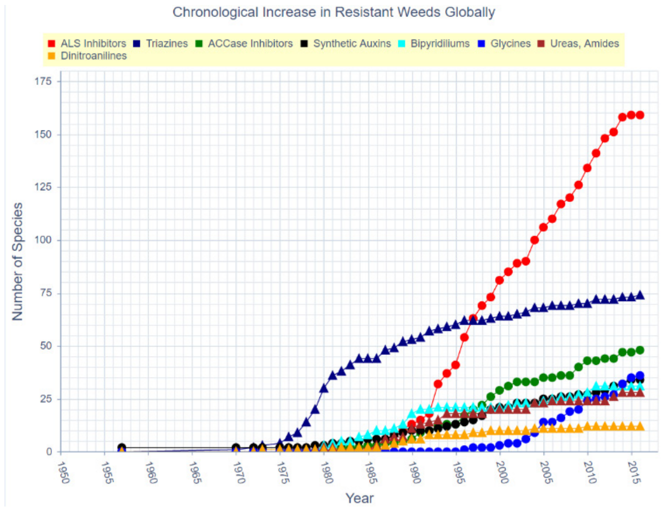
f. Resistance becomes reality
    i. ______________ confirmed resistant in ridged ryegrass in 1982.
    ii. _______________ confirmed resistant in ridged ryegrass and blackgrass in 1982.
    iii. 3 reasons for resistance "wake-up call"
        1. ______________ of resistance
            a. Paternal inheritance, Target-Site based
            b. No fitness penalty

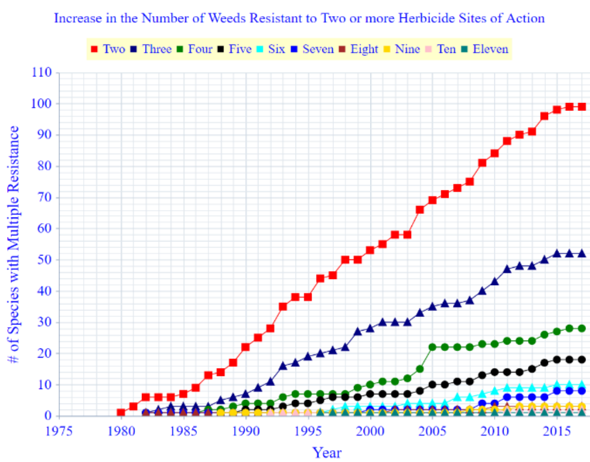
        2. ______________________ _________ of the mutation.

        3. Reported within _______________ years of introduction of the herbicides.

g. Expansion of Resistance







Adapted from Heap 2018

h. Resistance as of December 10, 2018

i. ___________ unique cases (species x SOA) of herbicide resistant weeds globally.

ii. ______________ herbicide resistant species (148 dicots, 106 monocots)

iii. Resistance confirmed to ________ of ________ known sites of action.

iv. Confirmed across 163 different herbicides of approximately 310 registered today.

II. Causes of Herbicide Resistance

i. WSSA definition of resistance

   i. Herbicide resistance is the ____________ _________ of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type.

   ii. Herbicide tollerance is the inherent ability of a species to survive and reproduce after herbicide treatment. This implies that there was no genetic selection or manipulation to make the plant tolerant; it is ____________tolerant.

j. ________________ selection is key

   i. Single or multiple genes

   ii. Resistance gene(s) is usually dominant or semi-dominant.

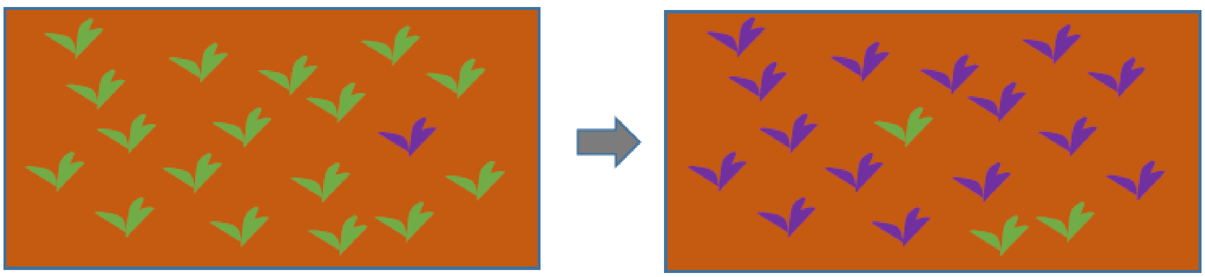


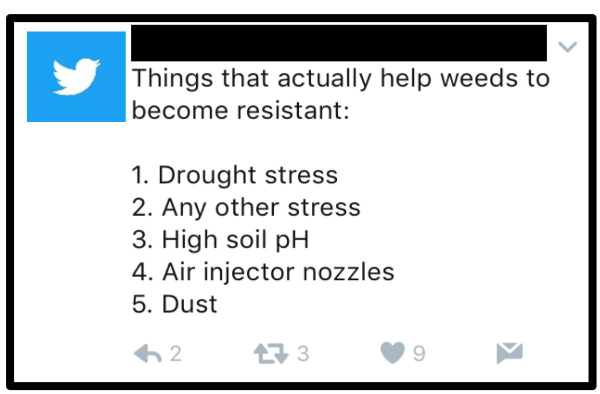
Figure 2: Consider the left image as a representation of weeds in the field. The purple specimen is the biotype that has inherent resistance. The image on the right shows the increased number of resistant biotypes after sequential herbicide applications.

k. Factors that do not cause resistance

   i. _____________ do not cause genetic mutation.

   ii. ___________________doses of herbicide.

   iii. ________________ does not influence resistance



l. Examples of resistance outside of herbicides

i. _________________resistant downy brome (Fenesi et al. 2016).

ii. Weeds resistant to _______________ _________ (Gould 1991).

iii. Tillage resistance?

III. Characterization of Resistance

a. Resistance is specific to _____________ and ________________ of resistance.

b. Generally, resistance applies to an entire ____________, but can be _______ specific.

c. Two Types of Resistance

iv. __________ ___________ (TS)

1. __________ dose response
2. Major gene or genes
3. ___________time to develop
4. Spreads rapidly if paternal (pollen)

v. Non-Target Site (NTS)

1. ________________response (metabolism based)

2. __________to develop

3. ___________resistance to other SOA's is likely
4. Potentially resistant to new herbicides

Species	ALS (2)	Auxin (4)	PSII (5)	EPSPS (9)	PPO (14)	HPPD (27)
P. amaranth	TS, NTS		NTS	TS		TS, NTS
waterhemp	TS		NTS	TS	TS	
kochia	TS	TS, NTS	TS	TS		
horseweed	TS			NTS		
c. ragweed				?		
g. ragweed				?		
shattercane	TS					
cheat	TS					

d. Types of cross resistance

vi. Type I cross resistance refers to one or more resistance events working on different ___________________ within a site of action .

1. Cross resistance to SU and IMI herbicides within the ALS site of action from a single resistance event.

vii. Type II cross resistance refers to a single resistance event that enables resistance across ________________ sites of action.

1. PSB gene in PSII inhibiting herbicides in ______________
2. ALS and HPPD resistant _________________

e. Multiple resistance
    viii. Refers to the ___________ of individual resistance events into a single biotype.
    ix. Multiple resistance can occur with most resistance mechanisms resulting in a biotype with many resistance mechanisms to many sites of action.

Overview of Resistance Classification in Kansas

Species	Herbicide or SOA	TS or TNS	Type of Cross Resistance	Comments
	Glyphosate	TS	None	
	HPPD	NTS		
Pigweed (Palmer amaranth and Waterhemp)	HPPD	TS	None	
	PSII	NTS	None	
	ALS (SU)	TS or NTS	None	
	ALS IMI	TS or NTS	None	
	ALS	TS or NTS		
	PPO	TS	None	
Kochia	Glyphosate	TS	None	
	Dicamba	NTS and TS	None	
	Fluroxypyr	TS	None	
	PSII	TS		
Bromus Species	ALS	TS		

Developing HR Management Recommendations

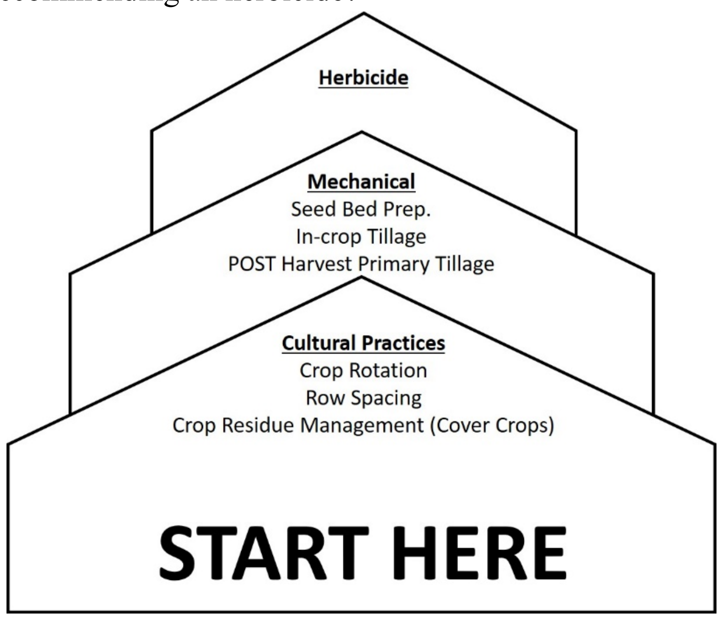
Video Notes for Class on March 5, 2019

I. Keys to Consider in a Recommendation

A. The hierarchy of strategies.

i. Have you ________ how you can implement all aspects of the hierarchy?

ii. Have you fully ________ the benefits of the hierarchy before recommending an herbicide?



B. Outcomes from this hierarchy

i. Good ___________ control

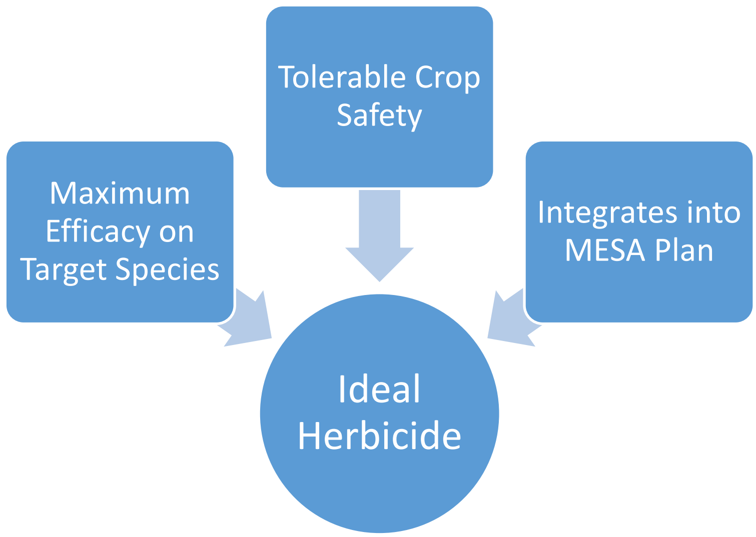
ii. Reduced _______ production

iii. Long term __________

iv. Long term ___________

II. Herbicide are Part of the Hierarchy

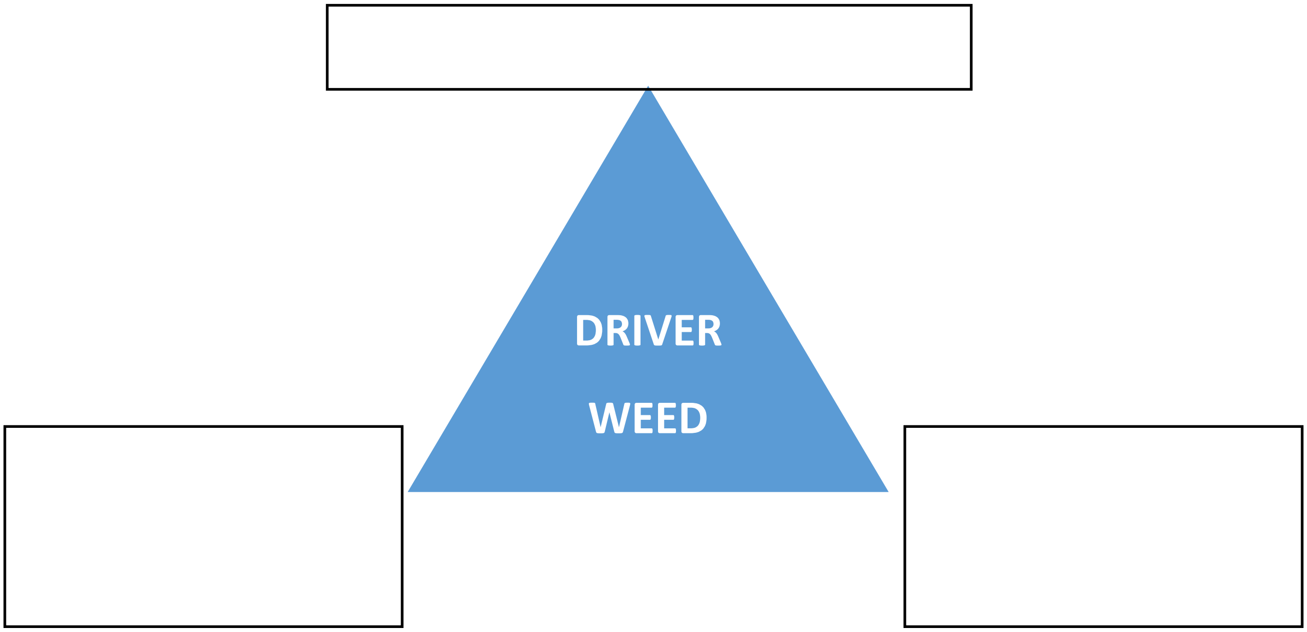
A. Select an ideal herbicide based on the 3 fundamentals.



i. Many would say that ________________and ________________________ impact should be included in this selection.

1. Herbicide prices are generally dictated by what the market will facilitate. There will always be "bargains" however, agronomists should never choose to comprise agronomic practices to facilitate price. Common examples include:
    a. ______________________ herbicide rates.
    b. Using poor ___________________________practices (low carrier volumes, improper nozzles).
    c. Using an inappropriate ______________________ package.
2. Herbicide ________________________ must adhere to strict environmental scrutiny upon registration and through a continual review process. As an agronomist, you should consider the potential for negative environmental effects; however, best practices will be achieved through adherence to the ______________________.

B. The herbicide program must have all three parts (Review)



C. MESA

1. Introduction to MESA
    a. Good herbicide efficacy is ______________ resistance management.

    b. Long term _________________________ ____________________ must be considered
        i. Mike Owen quote, "Manage your weeds like they are resistant, because if you don't, they will soon become resistant."

        ii. Use multiple effective sites of action (_______________) in ________________ _______________and in rotation.

        iii. Important question to ask when developing herbicide recommendations: Ask, "Which herbicide am I using to impose the _______________ _____________________?"
            1. If you are continually selecting with only ________ herbicide _________________, this is not a good strategy.

2. Use of MESA as part of a plan.
    a. MESA (multiple effective sites of action) on ______________________ weeds.

b. Requires that ____________ sites of action have activity on driver species.

   i. Must be applied in __________________ (sequential is not as good).
   ii. Must be compatible.

c. Types of responses.
   i. ________________ or additive activity.
      1. One controls a biotype that is resistant to other SOA in tank mix.
      2. Must be used preventatively.
      3. Reactively is too late (don't see resistance until it has become 30% of the population).
   ii. _________________ is similar to previous except that control is better than would be expected with either compound alone.
      1. HPPD, parquat, glufosinate, with a ____________ herbicide.
   iii. ___________________ responses should be avoided.

d. Kochia example from Wallace County.

   Kochia is glyphosate resistant. The producer is applying Clarity and Roundup Powermax in a tank mix.

   i. How many SOA were in the tank mix?

   ii. How many SOA were effective on the kochia?

e. What about the value of rotating herbicides?
   i. Example of dicamba on corn and glufosinate on soybean as a rotation.

   ii. What key components caused the rotation to fail?

f. The ideal program should contain MESA in a rotation.
    i. Corn followed by soybean example.

Corn	Soybean
Mesotrione	Glufosinate
Dicamba	Fomesafen

g. MESA applies to POST applications as well as ______________________applications.

    i. Can lead to excessive pressure on ___________________ herbicides.

    ii. Residuals must contain ____________________.
        1. Challenges with anticipating degradation, length of residual, adsorption, leaching.
            A. High rates.
            B. Overlapping program (as mentioned above).

    iii. Burndown and fallow programs must contain MESA.

        1. Abuse of ________________________ in burndown and fallow.
            A. Will result in resistance (likely NTS).

h. MESA is difficult to implement.
    i. Many weeds are resistant (multiple resistant biotypes).

    ii. Increases ______________ of herbicide program (but will result in greater efficacy and long-term sustainability).

iii. Not practical for all ______________species.
   1. Focus on _____________ species.

i. Implications for future herbicide resistant crops.
   i. Future herbicide resistant crops will contain multiple herbicide resistance events (up to 5-way trait stacking).

   ii. Example of _______________________-resistant soybean.
      1. Multiple way stack to use HPPD, glufosinate, dicamba, 2,4-D, and glyphosate POST.

      2. Many think this will cause more ____________________.
         A. Only if used inappropriately.

      3. Can make ____________________ easier to implement.

Exam 2, March 7, 2019

______1. Which of the following would best describe an herbicide resistant crop?

E. Reduced herbicide rates are required for crop safety.
F. Narrow application window.
G. High probability of crop injury.
H. An aggressive adjuvant package can likely be utilized without crop injury.

_____ 2. Which of the following situations prohibit a POST broadcast application of glyphosate in Roundup Ready corn?

F. Corn at stage V7 .
G. Corn at stage V5.
H. Corn at stage V4.
I. Corn at stage V2.
J. Glyphosate can be applied in all of these situations.

_____ 3. You would expect Enlist Corn to be resistant to

E. glufosinate
F. glyphosate
G. 2,4-D
H. dicamba
I. glyphosate + 2,4-D
J. glyphosate + dicamba
K. glyphosate + 2,4-D + glufosinate

_____ 4. Which of the following herbicides can be used to control grasses in Enlist Corn?

E. Assure II
F. Fusilade
G. Select Max
H. Enlist One

______ 5. Which of the following herbicides will likely be labeled for POST applications in corn in the future?

E. lactofen
F. paraquat
G. saflufenacil
H. metribuzin

______ 6. Which of the following situations prohibit a POST broadcast application of glyphosate in Roundup Ready soybean?

E. R3 stage
F. V18 stage
G. R1 stage
H. V4 stage

______ 7. Which of the following situations prohibit a POST broadcast application of glufosinate in Liberty Link soybean?

E. R1 stage
F. V3 stage
G. V6 stage
H. None of these allow glufosinate

______ 8. Enlist cotton is resistant to which of the following herbicide combinations?

E. Glyphosate + glufosinate
F. Glyphosate + glufosinate + dicamba
G. Glyphosate + glufosinate + 2,4-D
H. Glufosinate + 2,4-D

______ 9. Which of the following adjuvants can be used with Beyond in Clearfield Plus winter wheat but not Clearfield winter wheat?

E. MSO
F. COC
G. NIS
H. All of these options

_____ 10. CoAxium winter wheat allows the POST application of?

E. quizalofop
F. fluazifop
G. clethodim
H. imazamox

_____ 11. Which of the following herbicides would have the least efficacy on volunteer corn?

I. clethodim
J. fluazifop
K. quizalofop
L. these all have very similar efficacy

_____ 12. When applying atrazine as a residual herbicide, you should

E. include an adjuvant to improve the coverage of the soil.
F. include a crop oil to help the herbicide penetrate the soil.
G. include an adjuvant that protects the herbicide from photodegradation.
H. include some non-ionic surfactant to keep the screens on the sprayer clean.
I. not include an adjuvant.

____ 13. You are preparing to make an herbicide recommendation to a producer to control jointed goatgrass in winter wheat. Which of the following herbicides would have the best efficacy?

A. Chlorsulfuron
B. Imazamox
C. Propoxycarbazone
D. Pyroxsulam

_____ 14. Which of the following statements is true regarding crop oil concentrate?

E. It is derived from plant-based oils.
F. It is derived from petroleum-based oils.
G. It is an excellent water conditioner.
H. It should always be tank mixed with glyphosate.

______ 15. Which of the following would be an appropriate use rate for MSO?

E. 1% v/v
F. 1 pt/ac
G. 0.5 pt/ac
H. 0.5% v/v

______ 16. Which of the following would you use to assess a nozzle's average droplet size?

E. Dv90
F. VWD
G. DMV
H. VMD

______ 17. Which of the following spray classifications would be best suited for paraquat applications to control pigweed?

E. Fine
F. Medium
G. Very Coarse
H. Very Fine

______ 18. If you were selecting nozzles to spray POST applications in corn, you should give preference to

E. A nozzle with multiple angles
F. Nozzles that can be oriented forward and backward, alternating from one nozzle to the next.
G. Nozzles that are oriented straight down
H. Nozzles that are air inducted

______ 19. If you were to tank mix an oil-based herbicide such as Dual Magnum, you would expect the average droplet size to

E. Increase
F. Decrease
G. Increase and decrease
H. Not change

_____ 20. You are considering the use of an oil-based DRA. Which of the following nozzles would be not compatible with this DRA?

E. XR
F. AI
G. AIXR
H. TTI

_____ 21. If you were given 8 oz/ac Clarity (4-pound ae dicamba) which of the following weeds would it have the best efficacy on?

H. blue mustard
I. bushy wallflower
J. rosette marestail
K. pinnate tansy mustard
L. It would be excellent on all of these.

_____ 22. TTI and similar nozzles that produce Ultra Coarse droplets should only be used for

F. Dicamba applications in soybean and cotton
G. All POST applications in all crops
H. Only in broadcast fertilizer applications
I. Only when applying residual herbicide
J. A, C, and D are correct

_____ 23. You have applied an HPPD-inhibiting herbicide POST in grain sorghum to control pigweed and achieved poor control. While the pigweed could be resistant, what else could have caused poor control?

F. Reduced herbicide absorption
G. Reduced herbicide translocation
H. Enhanced herbicide metabolism
I. A combination of these
J. None of these

_____ 24. A producer is planting corn in central Kansas. Rain is forecast in the next day. The producer usually plants and sprays his own corn. The producer does not have any residual herbicide on the corn fields that have been planted. What should the producer do?

F. Continue corn planting to maximize yield
G. Rely on a POST-only program
H. Hope to miss the rain so that he can apply the PRE before the corn emerges.
I. Stop planting and apply the PRE before it rains.

_____ 25. How should a POST be timed in corn, sorghum, or soybean?

A. By timely scouting to save money by not having to apply a POST.
B. A POST with foliar activity should be applied 21 days after planting.
C. A POST with foliar and residual activity should be applied 21 days after planting.
D. A POST with only residual activity should be applied 21 days after planting.
E. Timely scouting should be used to include an herbicide with foliar activity with the planned residual herbicide 21 days after planting.
F. POST herbicides should be applied 28 days after planting.

_____ 26. A producer has glyphosate-resistant marestail that is 6-inches tall. Liberty-Link soybean needs to be planted in 15 days. Which of the herbicides listed would provide the best control of the marestail and facilitate the plant-back interval?

E. Dicamba
F. 2,4-D
G. Paraquat
H. Elevore

_____ 27. A producer is looking for advice on herbicides for a late fall treatments to provide control of various winter annual broadleaf weeds, especially marestail and henbit. He is uncertain if corn or soybean will be planted. Which will provide the greatest flexibility while providing excellent residual control?

G. Atrazine
H. Flumioxazin
I. Dicamba
J. Finesse Cereal and Fallow
K. Glyphosate

_____ 28. You are preparing to apply paraquat + atrazine to burndown some pigweed. Which would be the best adjuvant recommendation?

E. 0.25% v/v NIS
F. 3-pounds per acre AMS
G. UAN 2.5% v/v
H. COC 1% v/v
I. COC 1 pt/ac

_____ 29. You have applied a full rate of Finesse Cereal and Fallow prior to planting winter wheat. You have historically applied chlorsulfuron in winter wheat for approximately 20 years. Which of the following could be missed by this application? (hint- see page 85)

E. bushy wallflower
F. blue mustard
G. field pennycress
H. Finesse Cereal and Fallow has poor residual control of all of these.

_____ 30. You have purchased enough Authority MTZ to apply 20 oz/ac on all of your soybean acres for 2019. About how much should you apply in a 2 wk pre-plant treatment? (hint- see page 73)

E. 20 oz/ac
F. 10 oz/ac
G. 5 oz/ac
H. 0 oz/ac

_____ 31. Which of the following herbicides have foliar and residual activity and can be applied POST to a crop?

A. Fomesafen
B. Mesotrione
C. Flumioxazin
D. Atrazine
E. *S*-metolachlor
F. All of the options
G. A, B, and D are correct

_____ 32. Which of the following was the last herbicide SOA to be discovered?

E. Group 15
F. Group 27
G. Group 10
H. Group 9

_____ 33. Which of the following weeds was the first confirmed case of herbicide resistance?

G. common groundsel
H. wild carrot
I. wild parsnip
J. smooth groundsel
K. blackgrass

_____ 34. Resistance to Group 1 and 2 herbicides was confirmed within ________ years of launch.

F. 2
G. 3
H. 5
I. 10

_____ 35. Which of the following herbicide/weed combinations would not be classified as "herbicide resistance?"

F. Dicamba/kochia
G. Glyphosate/pigweed
H. 2,4-D/kochia
I. Atrazine/kochia
J. Imazamox/downy brome

_____ 36. Which of the following combinations is most true describing herbicide resistance genes?

F. Paternally inherited, dominant
G. Maternally inherited, dominant
H. Paternally inherited, recessive
I. Maternally inherited, recessive

_____ 37. Which of the following does not correspond with non-target site resistance?

E. Slow to develop
F. Responsive to dose
G. Not likely to have cross resistance
H. All of these represent non-target site resistance.

_____ 38. A population of waterhemp is found to be resistant to both chlorsulfuron and imazethapyr. Further investigation finds that a single gene conveys the resistance. This is likely

F. Type I cross resistance
G. Type II cross resistance
H. Type III cross resistance
I. Multiple resistance
J. Regular resistance by SOA

_____ 39. A population of pigweed is resistant to a foliar application of mesotrione and fomesafen. Which of the following statements is true?

E. Mesotrione and fomesafen will no longer provide residual control of this population.
F. This population is also resistant to PSII-inhibitors.
G. Mesotrione and fomesafen will provide residual control of this population.
H. This population is also resistant to metribuzin.

_____ 40. A population of kochia is found to be resistant to atrazine. Which of the following statements is true?

E. Atrazine will still provide residual control.
F. Metribuzin will provide residual control.
G. Diuron will provide foliar control.
H. This population is likely resistant to all PSII-inhibitors.

_____ 41. A population of pigweed is found to be resistant to foliar applications of atrazine. Which of the following statements is true?

A. Atrazine will still provide residual control.
B. Metribuzin will provide residual control.
C. This population will be cross resistant to mesotrione.
D. This population is likely resistant to all PSII-inhibitors.

_____ 42. When making an herbicide resistance management-based recommendation, consideration should first be given to

E. Which adjuvant should be used.
F. How many herbicide sites of action can be utilized.
G. How timing of planting can be leverage.
H. If a row-crop cultivator is hiding in the hedge row.

_____ 43. Which of the following is not part of MESA?

F. Two effective sites of action on driver species.
G. Sequential applications in a season.
H. Tank mixing
I. Synergistic responses

_____ 44. A producer is applying Valor XLT (pg 65) PRE to soybean with a POST application of Prefix (pg 76) plus Xtendimax plus Roundup Powermax. The pigweed is glyphosate and PPO resistant. How many sites of action are in this system? How many effective sites of action are in this system?

G. 5 total; 2 effective residual and 1 effective foliar.
H. 6 total; 1 effective residual and 1 effective foliar.
I. 4 total; 2 effective residual and 1 effective foliar.
J. 5 total; 2 effective residual and 0 effective foliar.

_____ 45. A producer is applying Liberty plus Zemax (pg 44) POST in corn and Liberty + *S*-metolachlor POST in his soybean to control his HPPD-resistant pigweed. This is a corn fb soybean rotation. How many sites of action are used across both crops and which herbicide(s) is bearing the most selection pressure?

E. 4 SOA; glufosinate
F. 4 SOA; glufosinate and *S*-metolachlor
G. 3 SOA; glufosinate
H. 3 SOA; glufosinate and *S*-metolachlor

_____ 46. A producer is applying a burndown application of paraquat and metribuzin. COC at 1 pt/ac was utilized. This pigweed is resistant to atrazine. **2 part question:** How many effective sites of action are in this application? How many effective sites of action would be in this application if NIS had been substituted for the COC?

G. 1, 1
H. 1, 2
I. 2, 1
J. 2, 2

_____ 47. A producer is planning to rotate SOA by spraying glyphosate POST in his corn and glufosinate POST in his soybean. His pigweed is glyphosate and glufosinate susceptible. This will likely result in

G. No herbicide resistance.
H. Resistance to both herbicides
I. Resistance to glyphosate
J. Resistance to glufosinate

_____ 48. A producer is making an application of Acuron plus Clarity plus Roundup Powermax plus AMS POST in corn to control pigweed that is resistant to HPPD-inhibitors, atrazine, and glyphosate. **3 part question**: How many sites of action are in this application, how many effective foliar sites of action are in this application, and how many effective residual sites of action are in this application for the pigweed?

E. 6; 4; 2
F. 7; 1; 2
G. 6; 1; 2
H. 7; 4; 3

_____ 49. Which of the following is not an outcome of using MESA?

F. Greater short-term cost.
G. Reduced herbicide usage short-term.
H. Reduced long-term cost.
I. Reduced weed seed bank.

_____ 50. Using the correct use rate is essential to achieving MESA. Which of the following would be the correct use rate for Callisto POST in corn?

F. 0.3 oz/ac
G. 3 oz/ac
H. 3 pts/ac
I. 3 qts/ac

51 and 52. Develop a management recommendation for each of the scenarios to control the driver species in the crop of interest. Do not make recommendations for the other crops in the rotation or other weeds. You may start your program whenever you see fit (i.e., fall, winter, spring, etc). Full credit will be given for overlapping residuals, implementation of a start clean approach, and MESA. Rotational restrictions, product names, use rates, and adjuvants must be appropriate for full credit.

51. Kochia control in Corn (4 pts)

Cropping System: 2 year rotation of corn and soybean

Management: No-tillage, corn will be planted on May 15

Location: Northwest Kansas silt loam irrigated.

Herbicide Resistance: Glyphosate, ALS, dicamba, and ATZ-resistant

Emergence pattern for driver weed:

Application Timing/Crop Stage/Days after planting	**Products**	**Rates**

Describe your approach and why you selected the products you chose (be sure to discuss all timings and products):

Describe a scenario in which your plan could achieve poor control of the driver weed? Other weeds?

Which one or two herbicides are at most risk of developing resistance and why?

52. Pigweed and marestail control in soybean (4 pts)

Cropping System: 2 year rotation of corn and soybean

Management: No-tillage, soybean will be planted on May 20

Location: South Central Kansas silt loam dryland.

Herbicide Resistance: Pigweed: Glyphosate, ALS, PPO, and ATZ-resistant; Marestail: Glyphosate and ALS-resistant

Emergence pattern for driver weeds:

Application Timing/Crop Stage/Days after planting	Products	Rates

Describe your approach and why you selected the products you chose (be sure to discuss all timings and products):

Describe a scenario in which your plan could achieve poor control of the driver weed? Other weeds?

Which one or two herbicides are at most risk of developing resistance and why?

53. Complete the recommendation to control the specified weeds in winter wheat. You do not need to utilize overlapping residuals or MESA. A burndown would likely be very useful. **You are limited to the following products: Finesse Cereal and Fallow, Roundup Powermax, Dicamba, MCPA, and 2,4-D.** You have unlimited resources for adjuvants, but are restricted to these products.

53. Downy brome, marestail, and various mustards in winter wheat (2 pts)

Management: No-tillage, winter wheat planted on October 5

Location: South Central Kansas silt loam dryland.

Herbicide Resistance: downy brome: ALS-resistant; marestail: ALS-resistant

Emergence pattern for driver weeds:

Application Date	**Wheat Stage**	**Products**	**Rates**

Describe your approach and why you selected the products you chose (be sure to discuss all timings and products):

Describe specifically how you addressed the downy brome since you have no good POST herbicide option. Provide an example of how this may be 'okay' as well as an example how this might not be so good.