Use of 2,4-D and Other Phenoxy Herbicides in Field Corn, Soybean, Sorghum, and Peanut Production in the United States

Wesley J. Everman, North Carolina State University

- While the acreage treated with 2,4-D has declined since the introduction of glyphosate resistant crops, it remains an important weed management tool, particularly in no-tillage systems.
- Weeds are much less likely to develop resistances to 2,4-D than other herbicides, meaning 2,4-D use will likely increase as weed resistance becomes problematic.
- 2,4-D is an inexpensive and effective option, particularly for producers of low-acreage crops. Such crops are often not worth the cost of developing new herbicides, so the loss of 2,4-D would significantly hinder production in those sectors.

Introduction

Phenoxy herbicides are currently used in field corn, soybean, sorghum, and peanut production in the United States to control broadleaf weeds. Growers have used 2,4-D, a phenoxy herbicide, for 70 years, as an integral part of weed management programs. 2,4-D use peaked in corn with over 50% of the acreage being treated in the 1950's, and has declined with the introduction of other herbicide options. An increased interest in no-till corn and soybean production has led to an increase in use of 2,4-D for control of existing weeds and cover crops prior to planting. In soybean, 2,4-DB is used postemergence to a limited extent. In sorghum, 2,4-D is used as a postemergence treatment in the crop and for preplant weed control in no-till systems. In peanut production, 2,4-DB is widely used as a postemergence treatment. In all four crops, phenoxy herbicides have been effective in providing economical control of many annual and perennial broadleaf weeds, providing a low cost weed control option when compared to alternative herbicides. If phenoxy herbicides were no longer available, growers may respond by increasing tillage; however, farmers and regulators alike are striving to reduce tillage rather than increase it. The increasing number of ALS and glyphosate-resistant weed species necessitates the use of a range of alternative sites of action in burndown and in crop applications. If phenoxy herbicides were lost, weed management costs would increase with reduced efficacy on several annual and perennial weed species.

Losses from Broadleaf Weeds

Weed competition in field corn has been widely researched and well documented (Zimdahl 2004). Yield losses due to weed competition have been reported to range from 40 to 74% in a recent survey (Dille et al. 2015). Broadleaf weeds are among the most competitive with corn, with several of the most troublesome broadleaf weeds now developing resistance to the most widely used herbicide, glyphosate. The potential loss of corn production across the Midwest US due to weed competition totals 10 billion bushels worth approximately $131 billion in 2014. These figures illustrate the importance of managing weeds in corn, and the potential impact on the agricultural economy if weed management options are lost.

Soybean is one of the most competitive and resilient crops in relation to weed infestation. There has been limited research on weed competition starting prior to soybean planting, but research investigating weed emergence with the crop or shortly after has indicated that broadleaf weeds are the most competitive with soybean (Hock et al. 2006; Zimdahl 2004). For weeds that emerge with the soybeans, density is a major factor in determining impact on yield. In glyphosate-tolerant soybean systems, total postemergence weed management programs are common. Studies have shown a wide response to time of weed removal, with most soybeans showing little or no yield response when weeds were controlled by V2 or V3 growth stages, but up to 27% yield loss was experienced when control was delayed to the V4 stage (Fickett et al. 2013). Additionally, cultural practices have been shown to impact soybean competitive ability with weeds, making yield loss predictions difficult. Soybeans grown in narrow rows are more competitive than those grown in wide rows (Knezevic et al. 2003; Hock et al. 2006; Arce et al. 2009).

Weed control is also a major challenge for sorghum producers worldwide as the percentage of grain sorghum yield lost from weed competition exceeds that of most other grain crops (Stahlman and Wicks 2000). Grain sorghum is especially sensitive to weed competition during the first 3 weeks after planting when crop growth is slow (Burnside and Wicks 1969; Everaarts 1993; Stahlman and Wicks 2000). Research has shown a greater reduction in grain sorghum yield when grown in competition with broadleaf weeds compared to grain sorghum grown in competition with grass weeds or in competition with a mixture of broadleaf and grass weeds (Feltner et al. 1969a; Feltner et al. 1969b). Palmer amaranth, an increasingly difficult to control weed in soybean, can dramatically reduce grain sorghum yield. Sorghum yield reduction due to competition with Palmer amaranth ranged from 1.8% to 3.5% when Palmer amaranth density was increased by one plant per 15 m of row. Yield reduction increased to 9.1% with an increase of 1 kg of Palmer amaranth dry weight per 50 m2 (Moore et al. 2004). Another Amaranthus species, redroot pigweed, causes significant sorghum yield losses when emerging before the 5.5 leaf stage of sorghum (Knezevic et al. 1997). In addition, it has been demonstrated that the competitive influence of tall waterhemp on sorghum yield was higher under high rainfall and supplemental fertility conditions (Feltner et al. 1969a).

Peanuts are low growing plants that are often shorter than broadleaf weeds. Therefore, they are at a distinct competitive disadvantage requiring higher levels of weed control than most other crops. Yield losses occur not only due to competition, but also decreased digging efficiency. Weeds must be controlled season-long to ensure optimal yields in peanuts, especially when competing with broadleaf weeds (Everman et al. 2008). The most competitive broadleaf weeds are common ragweed and common cocklebur (Clewis et al. 2001; Royal et al. 1997). Studies designed to determine the competitive effects of broadleaf weed species in peanut production have shown that interference of one plant of common cocklebur, common ragweed, or jimsonweed per meter of row resulted in yield losses of 70%, 40%, and 40%, respectively (Clewis et al. 2001; Royal et al. 1997; Price et al. 2006).

Current Weed Control Methods

The introduction of glyphosate-tolerant crops in the mid-90s reduced the number of in-crop applications of selective herbicides for both corn and soybeans, and effectively eliminated the use of 2,4-DB on most soybean acres. Currently, 2,4-D is used primarily in a burndown application prior to planting no-till field corn and soybean. A commonly used combination in corn and soybean is glyphosate at 0.75 lb/A plus 2,4-D at 0.5 lb/A, especially where glyphosate-resistant horseweed is a concern. Early postemergence applications or directed applications are still commonly used in field corn to control difficult annual and perennial broadleaf weed species, or to manage glyphosate-resistant weeds. Soil-applied 2,4-D applications in corn are virtually non-existent, relegated to extreme situations where an application is needed to manage emerged weeds at planting. Preharvest 2,4-D applications in corn are more common in Southern states to manage vining weeds and aid harvest. These applications are made as needed with high-clearance equipment, and may be applied aerially, however aerial application is less common where sensitive plants are growing nearby and are even banned in some cotton producing areas.

The use of 2,4-DB has steadily decreased in soybean both prior to planting and postemergence due to the risk of soybean injury. Over 95% of soybeans are treated with glyphosate in the US. The introduction of glyphosate for use in soybean changed grower perceptions on acceptable injury, with more injurious selective herbicide use diminishing rapidly. Glyphosate only applications are still widely used where resistance is not an issue. The increase in glyphosate-resistant weeds across the South and in the Midwest has led to a renewed interest in selective herbicide use with emphasis on protoporphorin-inhibiting herbicides including flumioxazin, fomesafen, sulfentrazone, lactofen, and acifluorfen; applied either preemergence, postemergence, or in some cases, both. The use of PSII-inhibiting herbicides, such as metribuzin and linuron, as preemergence products has increased in areas to combat resistance and to provide an alternative site of action to control troublesome weed species. In addition, many acres receive an application of metolachlor, acetochlor, pyroxasulfone, or dimethenamid, used to control small seeded broadleaf weeds such as Palmer amaranth or waterhemp. Premix combinations that include 2,4-DB do exist, but their use is limited in soybean.

2,4-D is an important herbicide in sorghum production across the US. It is an important component in burndown programs prior to planting in no-till situations, and is low cost management option for in crop weed management.

2,4-D is an important herbicide in sorghum production across the US. It is an important component in burndown programs prior to planting in no-till situations, and is a low cost management option for in-crop weed management. Burndown applications must be made 30 days prior to planting. Postemergence herbicide options are limited to a handful of products in sorghum. PSII-inhibiting Herbicides such as atrazine, basagran, and bromoxynil are widely used to manage emerged broadleaf weeds in sorghum, with the ALS-inhibitor prosulfuron and HPPD-inhibitor pyrasulfotole recently coming on the market. Dicamba is also used to control broadleaf weeds, however crop injury and yield reduction can occur following application. 2,4-D is one of the most commonly used postemergence herbicides in sorghum due to its wide weed control spectrum and low cost. Sorghum sensitivity appears to be varietal, with yield losses ranging from 12% to 27% (Burnside and Wicks 1972). Herbicide formulation also plays a role in grain sorghum tolerance to 2,4-D with greater injury observed following treatment with low-volatile ester formulations (Phillips 1960). More recent research has shown that grain sorghum productivity and lodging are sensitive to the rate of 2,4-D as well as phenological stage at which it is applied (Dan et al. 2010; Petter et al. 2011; Rosales-Robles et al. 2014).

Unlike corn, sorghum, and soybean, tillage is a major component in early season weed control in peanuts. Primary tillage followed by light cultivation reduces weed competition and allows peanuts to get established. Preemergence herbicides including alachlor, pendimethalin, flumioxazin, metolachlor, dimethenamid, and diclosulam are used at planting. Postemergence broadleaf herbicides are limited to 2,4-DB, paraquat, lactofen, acifluorfen, bentazon, imazethapyr, and imazapic. Broadleaf weed control is critical to maximizing yields; however, combinations of these herbicides must be used multiple times to achieve acceptable control.

Cost of Control Methods

Application cost for 0.5 lb/A of 2,4-D amine is approximately $3 to $5 per acre while 0.5 lb/A of the ester formulation costs between $4 and $6 per acre, making 2,4-D one of the most economical herbicides. Typical use rates for burndown application are 0.5 lb/A to 1.0 lb/A for a cost between $3 and $12 per acre depending on formulation and rate. Glyphosate was a more expensive burndown option through the early 2000's, but quickly dropped in price after going off patent. Although 2,4-D and glyphosate are comparably priced at approximately $6 per acre, they are increasingly being applied together for resistant weed management.

In-crop applications of 2,4-D amine in corn or sorghum cost between $4 and $12 per acre. -Costs of other broadleaf herbicides are often greater in both corn and sorghum, making 2,4-D a desirable management option. Similarly, applications of 2,4-DB cost between $3 per acre in soybean up to $6 per acre for 0.38 lb/A applied in peanut.

Impact of the Loss of 2,4-D or All Phenoxy Herbicides

The loss of 2,4-D would negatively impact corn and soybean production, particularly in no-till. Although 2,4-D and 2,4-DB are not used as extensively for weed control postemergence, the increased use in no-till acres has had a very significant impact on reduced tillage's success. Effective preplant weed management has allowed farmers to reduce tillage, reduce fuel and equipment costs, and also reduce labor expenses. Loss of 2,4-D in no-till crop production would have a significant environmental and economic effect.

There are other herbicides that can be used in burndown application, however their higher cost-- and their often reduced efficacy when compared to 2,4-D -- make them less than desirable options. Standard burndown herbicides include paraquat and glyphosate. Paraquat is typically 4 times more expensive when compared to 2,4-D at 0.5 lb/A. Paraquat is effective for burndown weed control, however 2,4-D provides better control of horseweed, prickly lettuce, hairy vetch, and alfalfa. Paraquat also has the distinction of being labeled with a Danger/Poison classification, making 2,4-D safer when mixing and handling.

If 2,4-D were lost for postemergence control of weeds in corn, it would lead to a marked increase in cost of weed management programs. Effective herbicide options are available in corn, however cost per acre can be up to 5 times more expensive than 2,4-D.

Glyphosate is comparable in price to 2,4-D ester at 0.5 lb/A, but with the increase in glyphosate-resistant weeds, particularly horseweed, and difficult to control weeds such as cutleaf evening primrose, a combination of glyphosate plus 2,4-D is commonly used for effective control. Few other herbicides give the burndown control of broadleaf weeds that 2,4-D does alone or in combination with glyphosate. For both corn and soybean, triazines, and PPO-inhibitors have limited use as burndown products; they instead provide residual control in a burndown application.

If 2,4-D were made unavailable for postemergence control of weeds in corn, it would lead to a marked increase in the cost of weed management programs. Effective herbicide options are available in corn, however cost per acre can be up to 5 times more expensive than 2,4-D. Few options provide the same level of control of morning glory species in pre-harvest applications. Losing 2,4-D for directed and pre-harvest applications would lead to reduced harvest efficiency and reduced yield due to weed competition.

Alternative herbicides exist for broadleaf weed management in sorghum. The loss of 2,4-D would result in the increased use of products such as atrazine, bromoxynil, and others. In 2011, 2,4-D was used on 38% of sorghum acres, with only atrazine and metolachor used on more acres. The loss of 2,4-D would result in increased weed management costs because at $3 to $5/A, it is much less expensive than any other postemergence option.

In peanut, the loss of 2,4-DB would lead to an increase in the use of bentazon, acifluorfen, and ALS-inhibitors imazethapyr and imazapic, which would increase the cost of weed control. The shift in herbicide use would in turn affect control of difficult to manage weeds such as sicklepod and common cocklebur, and reduce overall peanut yields.

Weed Control Alternatives If Either 2,4-D or All Phenoxy Herbicides Were Lost

Alternative corn herbicides for postemergence control of broadleaf weeds include atrazine, dicamba, bromoxynil, bentazon, prosulfuron, nicosulfuron, halosulfuron, mesotrione, tembotrione, isoxaflutole, and topramezone. Premixes of these herbicides exist and are becoming increasingly common. There are concerns for the various herbicide options. For instance, there are groundwater restrictions for the use of atrazine, isoxaflutole, and topramezone. Many of these herbicides are also the replacements that would be used in sorghum if 2,4-D were lost. Rate restrictions for atrazine limit the amount used for postemergence application due to the majority of atrazine being applied preemergence in both corn and sorghum. Dicamba is a likely herbicide to replace 2,4-D in both corn and sorghum if it were lost, however there are greater risks of herbicide movement after dicamba application, causing injury to susceptible plants. Bromoxynil and bentazon are effective products on small weeds. The ALS-inhibitors used in corn and sorghum, prosulfuron and nicosulfuron, have a narrow spectrum of broadleaf weed control. The cost of these ALS-inhibitors is also greater than 2,4-D while providing less control. In sorghum, pyrasulfotole is a relatively new herbicide that provides good control of broadleaf weeds, but at a greater expense than 2,4-D.

Glyphosate has been the most common herbicide used in soybean, and has been increasingly used on corn acres over the past 15 years for postemergence weed control. Glyphosate-resistant weeds have necessitated the increased usage of alternative modes of action in both crops. Alternatives in soybean include the use of paraquat or saflufenacil in preplant applications to control horseweed. Saflufenacil is effective on small weeds, but like paraquat, is a contact herbicide that is dependent upon environmental conditions for effective burndown control. Postemergence herbicide alternatives to 2,4-DB in soybean include glyphosate, glufosinate, acifluorfen, laftofen, fomesafen, flumiclorac, imazethapyr, chlorimuron, cloransulam, and thifensulfuron. Resistance is a concern with glyphosate, imazethapyr, chlorimuron, cloransulam, and thifensulfuron, therefore increased PPO-inhibitor usage has occurred.

There would be few changes in peanut if 2,4-D were lost, with a slight increase in burndown cost to control horseweed and other weeds that are difficult to manage with products such as glyphosate, paraquat and saflufenacil. Peanut weed control would, however, become substantially more expensive if 2,4-DB were lost. Alternative herbicides for use in peanut would include acifluorfen, lactofen, bentazon, and imazapic. 2,4-DB effectively controls several difficult weed species that lactofen, acifluorfen, and bentazon do not. A higher proportion of peanut acres would receive applications of imazapic at a higher cost than 2,4-DB. In addition to increased weed control costs, alternative herbicides from the ALS-inhibiting family have a history of resistance that could limit effectiveness. Another consideration with imazapic is crop rotation. Many peanuts are grown in areas where cotton, potatoes, sorghum, or sweet potato are grown. Rotation restrictions for these crops range from 18 to 40 months after imazapic application, severely limiting the crops that can be grown and potential revenue sources.

Compelling Reasons to Maintain the Phenoxy Herbicides

Field corn

1. Application of 2,4-D provides one of the lowest cost broadleaf weed controls.
2. The timing of application for 2,4-D is quite broad from before emergence to about tassel stage and resuming at dough stage.
3. Because it is translocated to weed roots, 2,4-D provides control of perennial as well as annual weeds to a greater extent than many other herbicides.
4. Use of 2,4-D prior to planting no-till corn has helped to assure success of no-till crop production, resulting in significant conservation of soil, water, fuel, equipment, and labor resources. With 2,4-D as a key component, no-till production is maintaining or increasing corn yields, while leaving more land undisturbed for wildlife. No-till also allows grain lost during harvest to remain on the soil surface where it is readily available as food for wildlife.
5. Because persistence of 2,4-D in the environment is relatively short, there is little concern about residual effect on crops grown in rotation with corn or groundwater contamination.
6. Many species of broadleaf weeds are controlled by 2,4-D.

7. After seventy years of use, 2,4-D has been shown to have relatively low risk from an animal or human toxicology viewpoint.

Soybean

1. Use of 2,4-D for preplant application for no-till soybean production has been a major factor in the success and rapid adoption of this production method, because it conserves both soil and energy resources.
2. The use of 2,4-D for preplant application for no-till soybean production has been critical for controlling glyphosate-resistant and tolerant weeds, preventing the reintroduction of tillage on many acres.
3. Other than glyphosate, 2,4-D is about the only translocated herbicide available to control broadleaf perennial weeds prior to planting no-till soybean. The combination of 2,4-D and glyphosate provides more economical and effective broad-spectrum weed control than glyphosate alone. Currently, there are few other alternative herbicides for broad spectrum weed control prior to planting no-till soybean production fields.

Sorghum

1. Although some care is needed with use of 2,4-D to avoid injury to sorghum and to reduce potential for movement outside the target area, 2,4-D is still one of the main herbicides for sorghum.
2. As with other crops, 2,4-D provides one of the keys to success for no-till, providing control of many major weeds associated with no-till sorghum production. Rather than being replaced by dicamba or glyphosate, 2,4-D is needed in combination with these compounds to economically broaden the spectrum of weed control in no-till production.
3. Significant cost savings are made possible by 2,4-D as the lowest cost herbicide available for sorghum. Since sorghum is not a high value crop, limiting weed control costs are very important to profitable production.

Peanut

1. The only phenoxy herbicide used in peanut production, 2,4-DB, is still widely used on peanut acres in the US.
2. For peanuts, 2,4-DB provides a relatively low cost postemergence treatment for control of broadleaf weeds, and it controls many of the weeds commonly found in the peanut production areas.
3. Some alternative herbicides would cost three to five times more than 2,4-DB for controlling weeds in peanut production.
4. One of the few herbicides for control of sicklepod in peanut is 2,4-DB, and it is also very effective on common cocklebur.

5. Because of the rather limited acreage of peanut, herbicide manufacturers are often reluctant to invest in research, development, and registration of herbicides for this high value, low acreage, edible crop. So highly effective and economical alternatives for 2,4-DB in peanut production are not likely to be available soon.

Weed Resistance Management

Development of weed resistance has become a significant concern with some common herbicides such as glyphosate, the triazines, sulfonylureas, and the imidazolinones. Use of 2,4- D can be quite beneficial for programs to help manage weeds that have developed resistance to some of these other herbicides. Where glyphosate is used for no-till, 2,4-D is considered almost essential to provide control of horseweed and cutleaf evening primrose. 2,4-D can broaden the spectrum of control as well as help in managing weed resistance. Long-term use of 2,4-DB in peanut production in conjunction with standard crop rotations has resulted in few weed resistance problems.

Although 2,4-D has been used for 70 years, only 37 species have been identified as resistant with 7 of those found in the US (Heap 2015). LeBaron and Gressel (1982) indicated that there has been very little concern about development of weed resistance with 2,4-D. Regehr and Morishita (1989) attribute this to 2,4-D being a hormonal-type herbicide that interferes simultaneously with many growth processes, whereas some other herbicides have primarily a single site of action. They also indicate that because 2,4-D is degraded rather rapidly, it exerts only moderate, temporary selective pressure on weeds. Although true resistance has not been much of a problem with 2,4-D, various species-- and biotypes within a species -- can vary considerably in tolerance to 2,4-D.

Future Weed Management Options

There have been no new herbicide sites of action discovered for use in corn, soybean, sorghum, or peanut in the past 20 years. This is a trend that will continue for the foreseeable future. The lack of new herbicide sites of action means we will continue to rely on herbicides available, and resistance management will be a prominent issue. In field corn, HPPD-inhibiting herbicides, ALS-inhibitors, and PSII-inhibitors will continue to be used for the majority of acres. In addition, dicamba and 2,4-D will continue to be critical components for broadleaf weed control in both conventional and no-till corn production. Due to a lack of new herbicide options, developers have explored methods to reduce risks and extend the use of current herbicides. Accordingly, corn with enhanced tolerance to postemergence applications of 2,4-D has been developed. As an alternative, dicamba products have been introduced with agents that allow a wider window of post-emergence application without crop injury, allowing greater flexibility. The cost of 2,4-D will continue to a major factor in its use, making it an economical option for controlling many broadleaf weeds.

Broadleaf weed control in soybean has become a major concern for many growers. The introduction of glyphosate-tolerant soybean allowed growers to easily control many weeds postemergence. However, the selection of glyphosate-resistant weeds, through repeated use of a single herbicide, has created a need for alternative control options. For several species, including those in the Amaranthus and Ambrosia genus, herbicide options in soybean are limited primarily to the PPO-inhibitors and ALS-inhibitors. Several populations of common ragweed, giant ragweed, waterhemp, and Palmer amaranth around the US are now resistant to these families as well, adding to the challenges facing soybean growers. Currently dicamba, 2,4-D, and HPPD-tolerant soybeans are being developed for use across the US. These new technologies, combined with currently available glufosinate-tolerant soybeans, will allow growers to again control these resistant weeds with postemergence applications. Although difficult to predict future adoption of these individual technologies, 2,4-D may be used on a greater number of acres as need for broadleaf control dictates.

The cost of herbicide development and marketing often preclude companies from evaluating new products for use in sorghum or peanut. As such, it will be increasingly important to protect the herbicides currently used to manage weeds in these crops.

Although lack of new herbicide sites of action in corn and soybean is troubling, minor crops such as sorghum and peanut are in a more difficult situation. The cost of herbicide development and marketing often preclude companies from evaluating new products for use in sorghum or peanut. As such, it will be increasingly important to protect the herbicides currently used to manage weeds in these crops. 2,4-D is still widely used in sorghum due to cost and efficacy, and will likely continue to be one of the most commonly used products barring significant changes to regulations. The use of 2,4-DB will also continue to be a critical component in broadleaf weed management in peanuts. No new herbicides are on the horizon in these small crops, and growers continue to need 2,4-D and 2,4-DB to control weeds in their respective niche markets.

LITERATURE CITED

Anonymous. 2015a. Weedone LV4 EC herbicide product label. Burr Ridge, IL:Nufarm. 14p.

Anonymous. 2015b. 2,4-DB 200 herbicide product label. St. Paul, MN: Winfield Solutions,13p.

Arce, G.D, P. Pederson, and R.G. Hartzler. 2009. Soybean seeding rate effects on weed management. Weed Technol. 23:17-22.

Burnside, O.C. and G.A. Wicks. 1969. Influence of weed competition on sorghum growth. Weed Sci. 17:332-334.

Burnside, O.C., and G.A. Wicks. 1972. Competitiveness and herbicide tolerance of sorghum hybrids. Weed Sci. 20:314-316.

Clewis, S.B., S.D. Askew, and J.W. Wilcut. 2001. Common ragweed interference in peanut. Weed Sci. 49:768–772.

Dan, H.A., L.G.M. Dan, A.L.L. Barroso, R.S. Oliver Jr, N. Guerre, and C. Feldkircher. 2010. Tolerance of grain sorghum to 2,4-D applied post-emergence. Planta Daninha 28:785-792.

Dille, A., P.H. Sikkema, V.M. Davis, I.C. Burke, and W.J. Everman. 2015. Perspectives on corn yield losses due to weeds in North America. Proc. Weed Sci. Soc. Amer. 70:82.

Everaarts, A.P. 1993. Effects of competition with weeds on the growth, development and yield of sorghum. J. Agric. Sci. 120:187-196.

Everman, W.J., I.C. Burke, S.B. Clewis, W.E. Thomas, and J.W. Wilcut. 2008. Critical period of grass versus broadleaf weed interference in peanut. Weed Technol. 22:63–67.

Feltner, K.C., H.R. Hurst, and L.E. Anderson. 1969a. Tall waterhemp competition in grain sorghum. Weed Sci. 17:214-216.

Feltner, K.C., H.R. Hurst, and L.E. Anderson. 1969b. Yellow foxtail competition in grain sorghum. Weed Sci. 17:211-213.

Fickett, N.D., C.M. Boerboom, and D.E. Stoltenberg. 2013. Soybean Yield Loss Potential Associated with Early-Season Weed Competition across 64 Site-Years. Weed Sci. Vol. 61:500-507.

Heap, I. 2015. The International Survey of Herbicide Resistant Weeds. Online. Internet. Friday, June 5, 2015. Available www.weedscience.org

Hock, S.M.; S.Z. Knezevic, A. Martin, and J.L. Lindquist. 2006. Soybean row spacing and weed emergence time influence weed competitiveness and competitive indices. Agronomy & Horticulture -- Faculty Publications. Paper 375.

Knezevic, S.Z., S.P. Evans, and M. Mainz. 2003. Row spacing influences the critical timing for weed removal in soybean (Glycine max). Weed Technol. 17:666-673.

Knezevic, S.Z., M.J. Horak, and R.L. Vanderlip. 1997. Relative time of redroot pigweed (Amaranthus retroflexusL.) emergence is critical in pigweed-sorghum [Sorghum bicolor(L.) moench] competition. Weed Sci. 45:502-508.

LeBaron, H.M. and J. Gressel. eds. 1982. Herbicide Resistance in Plants. John Wiley & Sons, New York, NY.

Moore, J.W., D.S. Murray, and R.B. Westerman. 2004. Palmer amaranth (Amaranthus palmeri) effects on the harvest and yield of grain sorghum (Sorghum bicolor). Weed Technol. 18:23-29.

Petter, F.A., L.P. Pacheco, F. Alcantara Neto, A.M. Zuffo, S.O. Procopio, and F.A. Almeida. 2011. Agronomic performance of sorghum as a response to 2,4-D application, dosage, and times. Planta Daninha 29:1091-1098.

Phillips, W.M. 1960. Weed Control in Sorghums. Manhattan, KS: Kansas Agricultural Experiment Station.

Price, A.J., I.C. Burke, W.B. Askew, M. Schroeder, W.J. Everman, and J.W. Wilcut. 2006. Interference and seed-rain dynamics of jimsonweed (Datura stramonium L.) in peanut (Arachis hypogaea L.). Peanut Sci. 33:142–146.

Regehr, D.L. and D.W. Morishita. 1989. Questions and answers on managing herbicide-resistant weeds. MF-926, Coop. Ext. Service, Kansas State Univ., Manhattan, KS.

Rosales-Robles E., R. Sanchez-de-la-Cruz, and L.A. Rodriguez-del-Bosque. 2014. Tolerance of grain sorghum to two herbicides. Revista Fitotecnia Mexicana 37:89-94.

Royal, S.S., B.J. Brecke, and D.L. Colvin. 1997. Common cocklebur (Xanthium strumarium) interference in peanut (Arachis hypogaea). Weed Sci. 45:38–43.

Stahlman, P.W. and G.A. Wicks. 2000. Weeds and their control in grain sorghum. Pages 535-590 in C. W. Smith and R.A. Frederiksen eds. Sorghum: Origin, History, Technology, and Production. New York: Wiley.

USEPA. 2005. United States Environmental Protection Agency Reregistration Eligibility Decision for 2,4-D. EPA 738-R-05-002. June 2005.

Widholm, J.M. 1977. Selection and characterization of biochemical mutants. in W. Barz, E. Reinhard, and M.H. Zenk, eds. Plant Tissue Culture and Its Bio-Technological Application. Springer-Verlog, Berlin, Germany.

Zimdahl, R.L. 2004. Weed-Crop competition. A Review, 2nd Edition, Blackwell publishing Ltd., Oxford, UK, 220.

Wesley Everman is an Extension Weed Specialist and Assistant Professor at North Carolina State University. He conducts research and extension activities for weed management in corn, soybean, sorghum, and small grains. In addition, he has conducted research and published on weed management in cotton, peanut, potato, and bioenergy crops during his career. When not in the field, Dr. Everman also teaches Weed Management in Field Crops.