

Integrated weed management strategies for soybean (*Glycine max*) with different planting dates

by

Salina Raila

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Approved by:

Major Professor
Sarah Lancaster

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Abstract

Weed is a major challenge in Kansas soybean production, particularly with rising herbicide resistance and a shift toward earlier planting dates. While farmers and researchers continue to adopt integrated weed management (IWM) strategies to address herbicide resistance, the changing trend of planting soybeans raises questions about its influence on weed control and yield. This thesis integrates findings from a field experiment and a farmer survey to evaluate how planting date, row spacing, and herbicide programs affect weed control and yield, and how these research insights align with on-farm practices. The field experiment was conducted at Kansas State University research sites in Manhattan, Ottawa, Scandia (2022–2023), and Parsons (2023), using a split-block design with four replications. Treatments included a factorial combination of two planting dates (early and normal) with two row spacings (38 cm and 76 cm) and four herbicide programs: two preemergence combinations, sulfentrazone + metribuzin and flumioxazin + metribuzin, followed by two postemergence applications: 2,4-D choline + glyphosate with or without S-metolachlor. One weed-free and one non-treated control plot were also included within each row spacing for comparison. Data were collected for visual weed control and percent light interception at four weeks after pre- and postemergence herbicide applications, weed biomass at the R7 stage of soybean, and soybean yield. Data were analyzed in R using ANOVA and Tukey's HSD. Results indicated that early planting generally improved weed control, although its impact on yield was inconsistent and appeared to depend on environmental conditions. Narrow row spacing (38 cm) and the flumioxazin + metribuzin combination offered greater early-season weed suppression. Weed control after postemergence application was consistent across locations and planting times for all herbicide programs. To contextualize these results with current on-farm practices, a survey was conducted from 2024 to

2025 using an online questionnaire. Responses were collected from 60 soybean farmers across 37 Kansas counties, representing management of approximately 352 hectares respondent-1. The survey captured information on planting practices, problematic weed species, herbicide use, and decision-making processes. Findings revealed that *Amaranthus* species (pigweeds) are the most troublesome weeds. Early planting practices and adoption of IWM practices were also common among the respondents. IWM practices mostly included herbicide rotation, cover crops, and manipulating row spacing. Most respondents expressed satisfaction with their current strategies but also recognized the need for adjustments in response to increasing herbicide resistance and changing planting windows. Practices identified as effective in the current field study (early planting and narrow rows) were also commonly adopted by surveyed farmers. However, variable yield responses in the experiment suggest that effective weed control does not always translate into consistent yield benefits. In summary, both the field experiment and survey underscore the importance of weed control for Kansas farmers. While their strategies often align with research findings, continued Extension efforts are needed to address knowledge gaps in herbicide terminology and to support informed, site-specific decision-making.

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Dedication

I want to dedicate my work to my family, my fiancé, my professor and Kansas State University.

Chapter 1 - Literature Review

Soybean

Soybean (*Glycine max* (L.) Merr.) is one of the major oilseed crops in the world (Carter & Hartwig, 1962), mainly due to its use in versatile applications (Tehulie et al., 2021). It serves as a key source of protein for animal feed, particularly in livestock and poultry diets (Hartman et al., 2011). For human consumption, soybeans are primarily consumed as vegetable oil (often in processed foods) and in plant-based products like tofu, soy milk, soy sauce, and soy flour. Beyond direct consumption, soybeans are also processed into products like soap, paints, and resins, highlighting their role in non-food industrial applications (Thakur & Dhiman, 2016). Modern-day soybean is believed to have been domesticated in East Asia 6,000–9,000 years ago from its wild relative (Carter et al., 2004). Tracing the history of soybean cultivation in the United States, soybeans are believed to have been introduced in 1804 (Howell, 1983), and as of the 2023/24 season, USDA reported that 33.78 million hectares of soybeans are planted in the U.S., with a yield forecast of 3,497 kg ha⁻¹. The north-central part of the U.S. is the major producer of soybean, producing approximately 82% of the total U.S. soybean production (Edreira et al., 2016). Kansas is one of the major contributors to the soybean production system in the north-central region, ranking 10th nationally (2,850,716,480 kg; FAO, 2017).

Weeds

Weeds, unwanted plants at a given place and time, are the biggest challenge in crop production (Hamuda et al., 2016). Weeds compete with field crops for water, sunlight, nutrients, and living space (Hongbo et al., 2020). In soybeans, weeds can cause 40% (Soliman et al., 2015) to 80% yield loss (Daugovish et al., 2003), and this loss depends upon the intensity and duration of crop–weed competition (Tehulie et al., 2021). The growth stages at which weeds have the

greatest negative influence on crop yield and/or quality are called the critical period for weed control. In soybean, the critical period for weed control ranges from V0 (cotyledon stage) to V4 (four trifoliate) growth stage for both broadleaf and grass weeds (Van Acker et al., 1993).

Troublesome weeds

During the critical period of weed control in soybean, weeds like Palmer amaranth (*Amaranthus palmeri*), waterhemp (*Amaranthus tuberculatus*), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), velvetleaf (*Abutilon theophrasti*), morningglory (*Ipomoea* spp.), and cocklebur (*Xanthium strumarium*) are problematic. Among these weeds, *Amaranthus* species (Palmer amaranth, waterhemp) and large crabgrass are consistently ranked as the most troublesome weeds across the U.S. (Van Wychen, 2022)

Palmer amaranth

Palmer amaranth is a small-seeded, C4, summer annual broadleaf plant adapted to hot and dry weather conditions, such as those in Kansas. Its optimum range for extensive growth is between 25°C–35°C / 30°C (day/night) (Guo & Al-Khatib, 2003). Palmer amaranth produces 200,000 to 600,000 seeds per plant; thus, farmers should pay attention to controlling this weed before it sets seed (Keeley et al., 1987; Sellers et al., 2003; Webster & Grey, 2015). Palmer amaranth is a robust plant that competes with soybean and reduces its yield. Literature suggests that, in Kansas, Palmer amaranth at a density of 8 plants m⁻¹ can cause 38 to 76% yield loss in soybean. Additionally, the same research also indicated that yield loss can increase when Palmer amaranth emerges earlier than soybean (Bensch et al., 2003). Furthermore, Palmer amaranth's dioecious nature (Steckel, 2003; Ward et al., 2013) facilitates wind pollination (Menges, 1987), which ultimately increases the rate of outcrossing, leading to substantial genetic variability

within the species (Franssen et al., 2001). This genetic variability in Palmer amaranth might have been a factor in the development of herbicide resistance.

Waterhemp

Waterhemp, like Palmer amaranth, is a dioecious, small-seeded, summer annual broadleaf weed, commonly found along riverbanks and floodplains (Buhler, 1992; Buhler et al., 1996; Mosyakin et al., 2003). It is native to the north-central region of the United States and has remained a problematic weed in the Midwest since the 1980s (Hager et al., 1997). In soybean production, waterhemp can cause yield loss of up to 73% (Steckel, 2003); thus, this weed has become a challenge for farmers. When compared to other summer annuals, waterhemp exhibits a delayed and prolonged emergence pattern (Hager et al., 1997; Hartzler et al., 1999). This enables the weed to evade management practices, particularly in fields with limited or no herbicides with residual properties (Hager et al., 1997). Additionally, its high reproductive potential (15,000 to 32,000 seeds per plant) and herbicide resistance have made it increasingly difficult to manage in agricultural habitats since the 1990s (Knezevic, 2007; Steckel, 2003; Tranel & Trucco, 2009). Moreover, qualities like prolific seed production, wind pollination, genetic diversity, and fast adaptation to herbicides have given ecological advantages to waterhemp over agricultural crops (Bell & Tranel, 2010; Montgomery et al., 2019).

Other summer annual broad-leaved weeds of soybean

Common cocklebur is another challenging weed in soybean fields. This weed emerges simultaneously with soybean and surpasses the growth rate of soybean, limiting the light reaching the crop. Thus, it puts the crop at a competitive disadvantage and reduces its production potential (Henry & Bauman, 1989). In soybean fields, common cocklebur is reported to cause a yield loss of up to 80% (Bloomberg et al., 1982).

Velvetleaf is another troublesome weed of soybean. It belongs to the Malvaceae family and is a hardy weed (Warwick et al., 2002). Literature suggests that when velvetleaf grows 1.5 m apart from each other in a full stand of soybean (26 plants row⁻¹), it can reduce the crop yield by 34%–45% (Marwat & Nafziger, 1990). Additionally, this weed has a unique canopy architecture that allows it to achieve high phenotypic plasticity depending on the intensity of light it receives (Bazzaz et al., 1989; Wang & Zhou, 2021; Warwick et al., 2002). Along with phenotypic plasticity, allelopathic properties, prolific seed production, and genetic variability give this weed a competitive advantage over crops and hence deplete the production and productivity of crops (Colton & Einhellig, 1980; Lindquist et al., 1996; Warwick et al., 2002).

Morningglory species are also problematic for soybean growers. Morningglory vines wind around the soybean shoots, causing potential lodging, reduced harvest efficiency, and increased weed seeds in the harvested produce (Barker et al., 1984; Stoller et al., 1987; Wilson & Cole, 1966). This weed also causes yield loss. Two to eight plants per square meter can reduce crop yield by 25% to 90% (Howe III & Oliver, 1987; Stoller et al., 1987).

Summer annual grass weeds of soybean

Three foxtail species (green foxtail (*Setaria viridis*), yellow foxtail (*Setaria pumila*), and giant foxtail (*Setaria faberi*)) are troublesome weed of soybean (VanWychen, 2022). All three species are self-pollinating, cosmopolitan, C4 weed species of temperate region of North America that were introduced to North America from Eurasia in the 1970's (Wang et al., 1995). A mixed population of the three species were found to decrease the yield of soybean by increasing the shading effect and imposing competition for soil moisture (Clay et al., 2006). Giant foxtail is highly competitive, reducing up to 60% yield in soybean (Knake & Slife, 1969).

and shows rapid directional evolution to adjust with changing environments (Ethridge et al., 2023).

Large crabgrass is a common and competitive grass weed of broadleaf cropping systems of the U.S. (Basinger et al., 2022; Van Wychen, 2022). This weed has high fecundity of 900 to 3100 seeds per plant (King & Oliver, 1994). It can reduce soybean yield by 37% (Basinger et al., 2019). Although using effective herbicides has reduced large crabgrass weed to a certain extent in the U.S., the evolution of herbicide resistance, especially ALS- and PSII- inhibitor resistance, across the globe has been a matter of concern to farmers (Heap, 2017).

Herbicide resistance

Several weed management techniques are used to control weeds in soybean fields. In small-scale agriculture, farmers rely on weeding or spot spraying, while in large-scale agriculture, they are more dependent on using herbicides to control weeds (Wiggins et al., 2015). The continuous use of herbicides in large-scale agriculture might be because herbicides are more economical and show immediate results compared to cultural or mechanical methods. While using herbicides is an easy and economical option, it has some side effects. The repeated use of herbicides with the same site of action can cause weeds to develop resistance (Beckie, 2006). Reports suggest that herbicide resistance in weeds is becoming a global problem (Heap, 2010). Moreover, herbicide resistance is a bigger problem in no-till systems compared to tilled fields because no- or reduced-till systems rely more on herbicides. This practice increases the probability of evolution of resistance or tolerance in weeds (Sarangi & Jhala, 2018). The evolution of herbicide-resistant biotypes is a matter of concern in soybean production because it limits farmers' ability to control the weeds (Wiggins et al., 2015).

Multiple cases of herbicide resistance have been reported in major weed species (Owen et al., 2007). Some weed characteristics associated with developing herbicide resistance include factors that promote genetic variability, such as prolific seed production, obligate outcrossing, and efficient and long-distance seed movement (Liu et al., 2012). Some of the most common examples are resistance to ALS-, PSII-, and EPSPS-inhibitors (Heap, 2010). According to the International Survey of Herbicide Resistant Weeds, 262 weeds have developed resistance to 23 out of 26 sites of herbicide action (Heap, 2017). As of now, 534 (273 dicot and 117 monocot) unique cases of herbicide-resistant weeds have been documented in 101 crops across 75 countries. These weeds have evolved resistance to 168 different herbicides that belong to 21 (out of 31) known sites of action (Heap, 2025).

Weeds like Palmer amaranth and waterhemp are better able to transfer herbicide-resistant alleles through pollen-mediated gene flow (Jhala et al., 2021; Ward et al., 2013). As of 2020, 65 cases of resistance to eight sites of action were reported in Palmer amaranth, including resistance to six sites of action in Kansas (Heap, 2020). Furthermore, one Palmer amaranth population has been reported to be resistant to ALS-, PPO-, PSII-, EPSPS-, and HPPD-inhibiting herbicides, as well as synthetic auxin herbicides, in Kansas (Shyam et al., 2021). Additionally, in Kansas, Palmer amaranth resistance to acetolactate synthase (ALS)-inhibitors, hydroxyphenylpyruvate dioxygenase (HPPD)-inhibitors, microtubule (PSII)-inhibitors, protoporphyrinogen oxidase (PPO)-inhibitors, synthetic auxins, and 5-enol-pyruvylshikimate-3-phosphate (EPSPS) synthase inhibitors has been documented (Burgos et al., 2001; Culpepper, 2006; Gaedert et al., 1997; Heap, 2015, 2020; Horak & Peterson, 1995; Shyam et al., 2021). Similarly, 54 cases of resistance have been reported in waterhemp to herbicides such as ALS, triazine, and glyphosate (Heap, 2017, 2020). Among these resistant populations, glyphosate resistance has been the

greatest concern for farmers in the U.S., likely due to its extensive use resulting from its simplicity, affordability, and efficiency. Furthermore, common cocklebur biotypes resistant to ALS-inhibiting herbicides have been observed in 12 states of the U.S. (Heap, 2025). Similarly, giant foxtail has also developed resistance to several groups of herbicides, including photosystem II inhibitors (Ethridge et al., 2023) and ACCase inhibitors (Hidayat et al., 1997; Menendez et al., 1993; Volenberg & Stoltenberg, 2002). The prevalence of herbicide-resistant weeds suggests a need to adopt a diverse and sustainable weed management system (Johnson & Lessy, 1985). Similarly, understanding the interactions between crops and weeds, the potential impact of weeds on crops, and the concept of economic threshold is crucial in developing effective weed management strategies (Bassinger et al., 2019).

Integrated Weed Management practices (IWM)

Integrated weed management (IWM) offers a sustainable solution by combining chemical, mechanical, cultural, and preventive methods to keep weed densities below economic thresholds (Knezevic, 2014; Oerke, 2006). In the case of herbicide-resistant weeds, the economic threshold is zero. This is because the seeds produced by just one herbicide-resistant plant can cost a lot of money in the future. Thus, it becomes necessary to adopt IWM approaches and maintain a zero-tolerance threshold (Norsworthy et al., 2014). Additionally, by reducing reliance on herbicides, IWM reduces the economic and ecological impact of weeds while preserving agroecosystems. For effective implementation, IWM also prioritizes enhancing crop competitiveness, managing seed bank dynamics, and incorporating education and extension services into weed management planning (Knezevic, 2014; Tehulie et al., 2021; Thill et al., 1991). Additionally, IWM might include maintaining field sanitation, using certified seeds, managing herbicide-resistant weed patches (spraying herbicides only at the spots where weeds

are present, i.e., spot spraying), cleaning equipment, planting cover crops, crop rotation, and applying herbicides at the correct dose and time (Knezevic, 2014; Thill et al., 1991).

Cultural management: Managing canopy to increase crop competitiveness

Light plays a vital role in regulating crop performance. For example, C4 weeds like waterhemp and Palmer amaranth thrive when light intensity and duration are increased (Hand et al., 1993). Thus, changing management practices to manipulate the intensity or duration of the photosynthetic period can be a good strategy to manage weeds. This manipulation can be achieved by changing agronomic practices like row spacing and planting date of the crop. When a crop is planted earlier relative to weed emergence or in narrow row spacing, crop canopy formation is accelerated. When crops establish their canopy earlier, they shade the soil surface and reduce the availability of light for weeds. This not only limits germination and growth of weeds but also suppresses dry matter accumulation in weeds and reduces fecundity (Oliveira et al., 2022). Soybean is a poor competitor during its early stages of development. Thus, integrating management practices like narrow row spacing and early planting can increase competitive ability during early growth stages and increase soybean production potential (Heneghan & Johnson, 2017). Additionally, these practices help suppress the late-emerging cohorts of weeds under the canopy (Heneghan & Johnson, 2017). This is because under low-irradiance environments, pigweeds translocate more photosynthates to leaves instead of reproductive parts, reducing weed seed production potential (Heneghan & Johnson, 2017; Schwartz et al., 2016).

However, even under shaded conditions, weeds like Palmer amaranth manage to produce seeds (Jha et al., 2008). The reason behind this is the unique architecture some plants possess. Waterhemp has phenotypic plasticity, which means it can change its architecture based on the direction of light incidence (McLachlan et al., 1993). If we use only cultural management

practices, seeds will be added to the seed bank and will potentially be a problem in the future. Therefore, cultural practices alone are insufficient, and there is a need to integrate other weed management strategies into our plan.

Chemical control

While devising an integrated weed management system, farmers often try to minimize the application of herbicides. Having said that, we cannot deny the fact that it is the most dependable and economical option for farmers all over the world. This might be due to a shortage of labor or machinery, ease of herbicide availability and application, and the cost of herbicides (Gianessi, 2013). Despite using various management practices like early soybean planting, reducing row spacing, planting cover crops, and other mechanical methods, weeds often adapt and escape control measures (McLachlan et al., 1993). In such cases, it is smart to integrate herbicides into the field.

In soybean cultivation, farmers often use herbicides to burndown the weeds before planting and to control the weeds that emerge throughout the growing season. Herbicides like EPSPS- and PSII-inhibitors are used as burndown herbicides to kill everything that is present in the field. Similarly, preemergence herbicide applications (before the crop emerges) control the flush of weeds that would coincide with the emergence of the crop. Moreover, some preemergence herbicides also provide residual weed control throughout the critical period of weed control (Loux et al., 2013). For example, a report suggested that when sulfentrazone (a residual herbicide) was applied as a preemergence herbicide, it increased the weed control of summer annuals from 51% to 89% (Knezevic et al., 2009). Similarly, another report suggested that residual herbicides like sulfentrazone or flumioxazin can control weeds 95%–99% up to nine weeks after planting soybeans without causing crop injury (Harre et al., 2021). Additionally,

residual herbicides are particularly important in no-till soybean fields, like those in Kansas. This is because the most popular herbicides like glyphosate and 2,4-D do not have residual properties, and when these herbicides are mixed with residual herbicides and applied as preemergence herbicides, they can provide a longer period of weed control (Whitaker et al., 2010). Thus, these residual herbicides can be used with other herbicides in burndown applications to increase weed control.

However, the effect of herbicides ends after some time, and weeds can escape management practices. This is because the burndown or preemergence herbicide applications may fail to control a large percentage of weeds due to extended or later emergence patterns (Jha & Norsworthy, 2009; Myers et al., 2004). Thus, growers should also include postemergence herbicides as part of their integrated weed management plan (Vollmer et al., 2019).

Postemergence herbicides are necessary to control weeds that escape preemergence applications. For example, Palmer amaranth control increased from 68%–80% to 90%–97% when applying a postemergence herbicide after a preemergence herbicide (Shyam et al., 2021). Additionally, including a residual herbicide in postemergence application mixtures (post crop emergence) can improve weed control throughout the cropping season. This process of applying residual herbicides one after another is called layering of residual herbicides. Layering residual herbicides helps reduce the germination of new weed flushes and thus gives the crop a competitive advantage during its early growth period. Furthermore, it reduces late-season weed growth, which can interfere with harvesting, deteriorate seed quality, and damage farm machinery. Reports suggest that applying a preemergence herbicide (co-application of sulfentrazone and metribuzin, herbicides with residual properties) followed by a postemergence herbicide (co-application of glufosinate and one of the very long chain fatty acid (VLCFA)-

inhibitors; VLCFA inhibitors have residual properties) can control summer annual broadleaf weeds at rates greater than 90% (Aulakh & Jhala, 2015). Similar results were observed in research conducted by Miller and Norsworthy (2016), who found better control of Palmer amaranth with mixtures that contained residual herbicides in their postemergence applications compared to when they were absent.

Trend of soybean cultivation in Kansas

From 1980 to 2022, soybean planting dates in the U.S. have gradually shifted earlier, with 50% of soybeans planted approximately 0.33 days earlier per year on average (USDA-NASS, 2023). Additionally, research suggests that the adoption of cultural practices like narrow row spacing is increasing to improve early canopy closure, enhance soybean competitiveness, and suppress weed growth in the U.S. (Heneghan & Johnson, 2017; Oliveira et al., 2022; Schwartz et al., 2016). In Kansas, soybean planting has also advanced, with farmers shifting planting dates earlier by approximately one-third of a day per year (Ciampitti et al., 2017). This change may be driven by various factors, including efforts to fit corn into the crop rotation, responses to shifting climatic conditions, or a desire to capture potential yield and management benefits associated with earlier planting.

However, despite these trends, little is known about how earlier planting dates interact with weed emergence and weed control efficacy. This gap underscores the importance of studying the relationship between early planting and weed management practices to ensure sustainable soybean production under changing agronomic conditions.

Conclusion

Soybean is an important crop in Kansas, and weeds are one of the biggest challenges in soybean fields, especially herbicide-resistant weeds. Farmers have been trying to control these

weeds using different combinations of integrated weed management practices, and many of these have shown good results in research fields. At the same time, there is a trend of planting soybeans earlier than the normal calendar date, and this shift might affect how well some weed management practices work. Thus, there is a need to determine how planting dates interact with other weed management strategies like row spacing, pre- and postemergence herbicides, and residual herbicide applications in Kansas. To explore this, a field experiment was conducted in 2022 and 2023, and a survey was conducted in 2024 with soybean farmers across Kansas. This helped in understanding how on-farm practices are aligned with the research results. Additionally, it helped us understand what practices farmers are using, what influences their decisions, and how they manage weeds on their farms. This study will help provide useful information for farmers who are thinking about changing their soybean planting date or improving their weed management plan.

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Chapter 2 - Exploring integrated weed management strategies for soybean (*Glycine max* (L.) Merr) with different planting dates

Abstract

Soybean (*Glycine max* (L.) Merr.) is an important crop in Kansas, where weed management remains one of the primary production challenges. Weeds compete with soybeans for sunlight, water, and nutrients, reducing yield. To manage these challenges, Kansas farmers use integrated weed management (IWM) strategies that combine cultural, mechanical, and chemical methods. In recent years, however, there has been a shift toward earlier soybean planting, raising questions about how planting date affects weed control and yield. This study aimed to evaluate the effect of planting date on weed control effectiveness and soybean productivity. Field experiments were conducted at Kansas State University research farms in Manhattan, Ottawa, and Scandia (2022 and 2023), and Parsons (2023) using a split-block design with four replications. The main plots included two planting dates: early (four to seven weeks before the normal date) and normal (late May to late June). Subplots were a factorial combination of two row spacings (38 cm and 76 cm) and six herbicide programs. These included two preemergence herbicides: sulfentrazone + metribuzin and flumioxazin + metribuzin, followed by two postemergence treatments: 2,4-D choline + glyphosate, with or without S-metolachlor. Weed-free and non-treated controls were also included. Data were collected for visual weed control ratings at four weeks after preemergence (WAPR) and postemergence (WAPR) applications, weed biomass at the R7 stage, and soybean yield. ANOVA and Tukey's HSD were used for statistical analysis ($\alpha = 0.05$). Results showed that early planting generally improved weed control; however, its impact on yield was inconsistent. In one site-year, early planting increased yield; in two site-years, normal planting produced higher yields; and in the

remaining three, yields were similar. This suggests that environmental factors had a greater influence on yield than planting date. Weed control was similar for both row spacings in five of seven site-years but was greater in 38-cm rows in two. Likewise, soybean yield was greater for 38-cm rows in two site-years and similar in the rest. The preemergence herbicide flumioxazin + metribuzin treatment resulted in better weed control at 4 WAPR in three site-years compared to sulfentrazone + metribuzin, though this did not lead to consistent differences in R7 weed control or yield. Both postemergence treatments provided similar weed control (86–99%) and yields across all locations. Returns over selected costs mirrored yield trends. Mixed results for yield and profitability suggest that annual environmental variation plays a more critical role in soybean performance than planting date, row spacing, or herbicide program. This study highlights that IWM strategies incorporating narrow rows and flumioxazin + metribuzin, followed by postemergence herbicide application, improve weed control and may enhance yield and profitability under certain conditions.

Introduction

Soybean (*Glycine max* (L.) Merr.) is an important crop in the U.S. Midwest, particularly in Kansas. In 2022 and 2023, soybeans were planted on 35,238,885 hectares and 33,842,730 hectares, respectively, across the United States (USDA, 2023/2024). The corresponding average productivity was 3,337 kg/ha in 2022 and 3,407 kg/ha in 2023. In Kansas, soybean was planted on 2,043,666 hectares in 2022 and 1,792,768 hectares in 2023, with an average productivity of 1,849 kg/ha and 1,748 kg/ha, respectively. Kansas ranks 10th in soybean production (5,564.7 kg) nationwide (FAO, 2017). Several factors influence the production potential of soybean, among which weeds are an important one. Weeds hinder production by competing with soybeans for nutrients, space, and water (Hongbo et al., 2020). Depending on the intensity and duration of weed interference (Tehulie et al., 2021), weeds are reported to cause 40% (Daugovish et al., 2003) to as much as 80% yield loss in soybeans (Soliman et al., 2015).

Among all the weeds, those belonging to the *Amaranthaceae* family, especially Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus*), are the most common and troublesome in soybean fields (Van Wychen, 2022). In Kansas, it is reported to reduce soybean yield by 78% and 56%, respectively (Bensch et al., 2003).

Palmer amaranth and waterhemp are very competitive weeds. Their competitive nature is due to ecological advantages such as a dioecious reproductive system, wind pollination, extensive outcrossing, rapid evolution, prolific seed production, and robust plant structure (Culpepper, 2006; Franssen et al., 2001; Knezevic, 2007; Sellers et al., 2003; Steckel, 2003; Tranel & Trucco, 2009; Ward et al., 2013). These ecological advantages facilitate the rapid development and spread of herbicide resistance, making it a matter of concern to farmers (Liu et al., 2012). Apart from *Amaranthus* species, summer annual broadleaf weeds such as velvetleaf,

morning glory, and cocklebur, and summer annual grasses such as giant foxtail and large crabgrass are also problematic in Kansas soybean fields. These weeds can potentially reduce soybean yield by 66% (Eaton et al., 1976), 25% to 90% (Howe III & Oliver, 1987; Stoller et al., 1987), 80% (Bloomberg et al., 1982), and 37% (Basinger et al., 2019), respectively.

With the rise of herbicide-resistant weeds, farmers are increasingly turning to integrated weed management (IWM) programs as a more sustainable and effective control strategy. IWM combines chemical, mechanical, cultural, and preventive methods to manage herbicide-resistant weeds and keep them below the economic threshold (Knezevic, 2014; Oerke, 2006), defined as the point at which the cost of controlling weeds equals the value of the additional crop yield (Weersink et al., 1991). In the case of herbicide-resistant weeds, the economic threshold is considered to be zero, meaning that even a small population warrants immediate action (Norsworthy et al., 2014). This is because allowing resistant weeds to persist, even at low levels, can cause long-term economic consequences by adding seeds to the soil seed bank, ultimately accelerating the need for new herbicides. As part of an effective IWM strategy in soybean production, farmers often adopt cultural practices such as early planting and narrow row spacing to give crops a competitive advantage over weeds (Arbuckle & Lasley, 2013). These proactive measures help suppress weed emergence and reduce reliance on herbicides, contributing to more resilient and cost-effective weed management (Knezevic, 2014; Oerke, 2006).

Light plays a vital role in regulating plant growth and development, and any disruption in light reaching plant surfaces can influence the growth patterns of both crops and weeds (Holt, 1995). In agricultural systems, competition for light between crops and weeds is inevitable; however, strategic manipulation of light availability can reduce this competition and favor crop performance (Donald, 1961). Cultural practices like narrow row spacing (Wax & Pendleton,

1968) and early planting (Buhler & Gunsolus, 1996) optimize light interception by the crop canopy and suppress weed growth (Yelverton & Coble, 1991). Accelerated crop canopy formation helps shade the soil, reducing weed germination potential and thus decreasing weed biomass accumulation (Oliveira et al., 2022). Reports suggest that planting soybean earlier facilitates earlier canopy formation compared to weeds (Arbuckle & Lasley, 2013). Overall, these cultural practices give soybean a competitive advantage in its early growth stages and help the crop suppress weeds (Heneghan & Johnson, 2017).

In Kansas, farmers have been planting soybeans approximately one-third of a day earlier each year (Ciampitti et al., 2017). According to USDA-NASS (2023), from 1980 to 2022, 50% of soybeans were planted an average of 0.33 days earlier each year. The reason behind this shift may include changing environmental conditions, a desire to integrate another crop into the rotation, or potential benefits associated with earlier cultivation.

Along with cultural practices, herbicide application is an integral part of an IWM system. Current weed management programs emphasize the role of residual herbicides in preventing weed emergence. Applying preemergence herbicides with residual properties such as sulfentrazone, flumioxazin, and metribuzin not only provides early-season control (Aulakh & Jhala, 2015; Knezevic et al., 2009) but also improves the effectiveness of postemergence herbicides like 2,4-D and glyphosate (Whitaker et al., 2010). In addition, layering, or overlapping residual herbicides (which involves adding residual herbicide in postemergence applications), has proven helpful in managing herbicide-resistant species (Lammers, 2025; Norsworthy et al., 2012; Striegel et al., 2021). Some residual herbicides labeled for postemergence use in soybean include those from groups like VLCFA inhibitors (e.g., acetochlor, S-metolachlor), ALS inhibitors (e.g., chlorimuron-ethyl, chloransulam-methyl,

imazethapyr), and PPO inhibitors (e.g., fomesafen). However, the timing and method of their use as layered herbicides depend on product labels and crop growth stage (Striegel et al., 2021).

Researchers also recommend incorporating layered residual herbicides into IWM programs to improve control of herbicide-resistant weeds (Norsworthy et al., 2012; Sarangi & Jhala, 2019; Steckel et al., 2002), such as Palmer amaranth and waterhemp. Moreover, using herbicide-tolerant soybean varieties like Enlist E3, which are resistant to 2,4-D, glyphosate, and glufosinate, can further enhance weed control options (Craigmyle et al., 2013; Hay et al., 2019; Merchant et al., 2013; Smith et al., 2019).

Similarly, adopting a two-pass herbicide program, a preemergence application followed by a postemergence application, can help maintain season-long control and reduce the chance of herbicide-resistant weed escapes (Smith et al., 2019). However, for any weed management practice to be widely accepted, it must also be economically viable. This viability can be assessed through crop yield data, partial budget analysis, or net and gross return evaluations. According to the literature, practices like narrow row spacing (Harder et al., 2007; Nelson & Renner, 1999) and a two-pass herbicide system (Sarangi & Jhala, 2019) have proven to be both effective and economically sound.

Despite this, a knowledge gap still exists regarding the integration of residual herbicide applications with cultural practices such as narrow row spacing and early planting. To address this, a study was conducted to examine how planting date affects the efficacy of weed management combinations in weed control and soybean yield. Specifically, the primary objective was to evaluate the interaction between soybean planting date, row spacing, and herbicide programs on overall weed management and crop productivity in Kansas soybean fields.

Materials and methods

The experiment was conducted at four Kansas State University Agronomy Experiment fields: Manhattan, KS (39°07'06"N, 96°38'08"W) in 2022 (MHK22) and 2023 (MHK23); Ottawa, KS (39°32'21"N, 95°14'36"W) in 2022 (OTT22) and 2023 (OTT23); Parsons, KS (37°22'03.5"N, 95°17'09.8"W) in 2023 (PAR23); and Scandia, KS (39°50'01"N, 97°50'22"W) in 2022 (SC22) and 2023 (SC23). Thus, there were a total of seven site-years. All the locations were under rainfed conditions. Soils at Manhattan, Ottawa, Parsons, and Scandia were Reading silt loam, Woodson silt loam, Dennis silt loam, and Crete silt loam, respectively.

Each field was tilled twice (a pass with a field cultivator followed by a pass with a vertical tillage implement) prior to planting, following conventional tillage practices to ensure a clean start. Enlist E3 soybeans (Pioneer Hi-Bred International, P.O. Box 1000, Johnston, IA) were planted. In OTT22, a Kinze 3000 interplant planter (Kinze Manufacturing, Williamsburg, IA) was used, and a John Deere split-row vacuum planter (Deere & Company, Moline, IL) with double-disk openers was used at the remaining site-years (Table 2.1). Using these planters, a target seeding rate of 120,000 seeds ha⁻¹ was achieved at each site-year.

In each site-year, the experiment was conducted using a split-block design, with main plots comprising early (four to seven weeks before the normal planting date) and normal planting dates (Table 2.1). Each planting date included subplots featuring factorial combinations of two row spacings (38 cm and 76 cm) and six herbicide programs. The herbicide programs included two preemergence herbicides: sulfentrazone + metribuzin (Authority MTZ, FMC Corporation, Philadelphia, PA) and flumioxazin + metribuzin (Dimetric Charged, WinField United, Arden Hills, MN); two postemergence herbicide treatments: 2,4-D choline (Enlist One, Corteva Agriscience, Indianapolis, IN) + glyphosate (Roundup PowerMax 3, Bayer CropScience, St.

Louis, MO), and 2,4-D choline + glyphosate + S-metolachlor (Dual II Magnum, Syngenta Crop Protection, Greensboro, NC); one weed-free treatment; and one non-treated control (Table 2.2). Weed-free plots were hand-weeded throughout the cropping period. Each subplot measured 9 m by 3 m, and each treatment was replicated four times.

Data collection and analysis

For each location, temperature and precipitation data throughout the soybean cropping period (Table 2.1) were collected from the Kansas Mesonet (mesonet.k-state.edu) weather data library (Appendix Table A-10). Then, data were collected for four parameters: visual rating of percent weed control, weed biomass, photosynthetically active radiation (PAR), and crop yield. Weed control ratings were visually estimated every four weeks following herbicide applications and again at the R7 soybean growth stage, using a scale from 0% (no control) to 100% (complete control). Photosynthetically active radiation was measured in 2023 at Manhattan and Ottawa using a LI-COR Light Sensor Logger (LI-COR Biosciences, Lincoln, NE) at four and eight weeks after planting. At the soybean R7 growth stage, weed biomass was sampled randomly between the center rows of each plot using two 0.25 m² quadrats, resulting in a total sampling area of 0.5 m² per plot. Biomass samples were then dried at 50°C until a constant weight was achieved. Soybeans planted in 38-cm and 76-cm rows were harvested by collecting the middle five rows and two rows, respectively, using a plot combine equipped with a platform head. At Manhattan, a Delta model Wintersteiger combine (Wintersteiger Inc., Salt Lake City, UT) and Harvest Master 800 grain gauge (Juniper Systems Inc., Logan, UT) were used. At Ottawa, a model E Gleaner (AGCO Corporation, Duluth, GA) with a Harvest Master 800 grain gauge (Juniper Systems Inc., Logan, UT) was used. At Parsons, a K-2 Gleaner (AGCO Corporation, Duluth, GA) with an HM800 Harvest Master system (Juniper Systems Inc., Logan, UT) was

used. At Scandia, a model E Gleaner combine (AGCO Corporation, Duluth, GA) with a Single High-Capacity Grain Gauge (Juniper Systems Inc., Logan, UT) was used. Yield was adjusted to 13% moisture, and 100-seed weights were recorded.

Data analysis was conducted using RStudio. The data on weed control, weed biomass, and soybean yield were analyzed using R packages such as lme4 (for fitting linear mixed models), lmerTest (for obtaining p-values and degrees of freedom), emmeans (for calculating least-square means), and multcomp (for multiple comparison procedures like Tukey's test) (Fox et al., 2019; Graves et al., 2019; Hothorn et al., 2008; Kuznetsova et al., 2017; Lenth, 2022; Wickham et al., 2019). Normality assumptions were tested using the Shapiro-Wilk test (shapiro.test) and visualized using QQ plots (Fox et al., 2019).

All models for soybean yield and return over selected cost met normality assumptions. However, most of the data for weed control (seven out of ten cases) and all data for weed biomass were highly non-normal, and transformations did not improve normality. The QQ plots often resembled horizontal lines, likely due to many similar values: weed control was frequently close to 99%, and weed biomass hovered near 0 g m⁻², with minimal variation when values did differ. Similar results were observed for normality assumptions in a separate study conducted in 2020 and 2021 in Manhattan, Ottawa, and Scandia, Kansas (Lammers, 2025).

Despite the lack of normality in some variables, literature suggests that F-tests are robust even when normality assumptions are violated (Blanca et al., 2017), so the data were analyzed using analysis of variance (ANOVA) at a significance level of $\alpha = 0.05$. A linear mixed-effects model (lmer) was used, with planting date, row spacing, and herbicide program as fixed effects and replication as a random effect. Each parameter was analyzed separately for each location due

to differences in weed species. Means were separated using Tukey's HSD ($\alpha = 0.05$) when appropriate according to the ANOVA results.

Photosynthetically active radiation was measured at Manhattan and Ottawa in 2023. The data for control and weed-free plots were removed. Then, the percentage of light interception by the soybean canopy was calculated as the difference between light incidence above and below the canopy, expressed as a percentage of the above-canopy light incidence. Regression analyses were performed using percent weed control or weed biomass as dependent variables and percentage light interception as the independent variable for Manhattan and Ottawa, in R^2 at a 5% level of significance (Kansas State University, 2023), to better define the role of canopy light development on weed management in the experiments.

A partial budget analysis was conducted for the economic analysis of the integrated weed management combinations used in the system. A partial budget analysis is used to quantify and compare the effects of using a proposed technology for crop production (Alimi, 2000). Similar costs in all plots (tillage, seeds, and herbicide application) were kept constant, and only variable costs such as herbicide prices and planting expenses (labor, fuel, and fixed costs associated with planters, especially when soybeans were planted at different row spacings) were included. Herbicide prices were taken from the Chemical Weed Control Guide (Lancaster et al., 2022, 2023), planting costs were obtained from AgManager.info (Kansas State University, 2024), and the price received for soybean sale was taken from Quick Stats (USDA, 2022; 2023). We calculated the return over selected costs for this analysis and analyzed the data using ANOVA.

Results

Weed species and density varied by location. Palmer amaranth was the dominant species in Manhattan, waterhemp in Ottawa, and cocklebur in Parsons. Scandia, on the other hand, had

very low weed pressure. Similarly, rainfall and temperature differed across the site-years (Figure 2-1 to 2.4; Kansas State University, 2022; National Climate Data Center, 2021). The 30-year average rainfall during the soybean growing season in Kansas is 62.9 cm. In comparison, Manhattan received 63.65 cm in 2022, which was slightly above average, and only 34.77 cm in 2023, which was nearly half. Ottawa received 41.05 cm in 2022 and 39.17 cm in 2023. Parsons received 59.92 cm in 2023. Scandia had 31.85 cm in 2022 and 45.03 cm in 2023. Overall, rainfall ranged from 31.85 to 63.65 cm. In some locations, it was consistent with the 30-year average, while in others it was much lower.

The optimum temperature for soybean cultivation is around 26°C, and soybean productivity tends to decline if temperatures exceed this threshold. During the growing period, the minimum temperature ranged from 5.9°C to 15.8°C. In Manhattan, it was 15.3°C in 2022 and 15.2°C in 2023. In Ottawa, it was 5.9°C in 2022, which was relatively cold, and 15.5°C in 2023. Parsons recorded 15.8°C in 2023, while Scandia had 13.7°C in 2022 and 14.3°C in 2023. The maximum temperature ranged from 28.5°C to 30.1°C. Manhattan recorded 28.7°C in 2022 and 29.7°C in 2023. Ottawa had 30.3°C in 2022 and 30.1°C in 2023. In Parsons, the maximum temperature was 28.9°C in 2023. Scandia recorded 28.5°C in 2022 and 28.9°C in 2023. These observations highlight the environmental variability across the research locations, particularly in terms of rainfall and temperature.

Weed Control

Manhattan. In 2022, Palmer amaranth control was similar when pooled across planting date and preemergence herbicides four weeks after the application of preemergence herbicide (4WAPR). A two-way interaction was observed between planting date and preemergence herbicide (Table 2.3). Palmer amaranth control was similar for both planting dates (Table 2.3)

when flumioxazin + metribuzin was applied (83–92%), while the lowest control was observed when soybeans were planted at the normal calendar date and treated with sulfentrazone + metribuzin as a preemergence herbicide, achieving only 62% control (Table 2.4). Palmer amaranth control was also similar across planting dates and postemergence herbicide applications four weeks after the postemergence herbicide was applied (4WAP0). Similar to 4WAPR, a two-way interaction between planting date and preemergence herbicide was observed (Table 2.3). Palmer amaranth control was $\geq 96\%$, except for soybeans planted at the normal time and treated with sulfentrazone + metribuzin as a preemergence herbicide, which showed slightly less control at 94% (Table 2.4). Additionally, there was a main effect of row spacing at 4WAP0, where Palmer amaranth control was greater in 38-cm row spacing (98%) compared to 76-cm row spacing (96%) (Table 2.5).

In 2023, results followed a similar trend. Palmer amaranth control remained consistent across row spacings and postemergence herbicides at 4WAPR, and a two-way interaction between planting date and preemergence herbicide was again observed (Table 2.6). Palmer amaranth control was $\geq 95\%$ in most cases, except for soybeans planted at the normal time and treated with sulfentrazone + metribuzin as a preemergence herbicide, which resulted in 79% control (Table 2.4). At 4WAP0, Palmer amaranth control was consistent across all treatment combinations, maintaining $\geq 96\%$ control.

Contrary to these results, another study conducted in Arkansas suggested that flumioxazin alone and sulfentrazone + chloransulam provided similar Palmer amaranth control (94–98%) when applied as preemergence herbicides and evaluated 14 days after application (Miller & Norsworthy, 2016). The difference in results may be attributed to the herbicide combinations and the timing of data collection. Additionally, these two locations differ

significantly in environmental conditions, which may have influenced the outcomes. However, similar broadleaf control (velvetleaf, Pennsylvania smartweed, common cocklebur) was reported at seven weeks after planting (WAP) in central Missouri, when sulfentrazone (92–97%) and flumioxazin (89–96%) were applied preemergence without metribuzin (Niekamp et al., 1999)

Ottawa. In 2022, waterhemp control was similar ($\geq 98\%$) across all treatment factors at both 4WAPR and 4WAP0 (Table 2.7). In 2023, the results were similar for 4WAPR ($\geq 86\%$). However, at 4WAP0, a two-way interaction was observed between planting date and row spacing (Table 2.8), where all combinations were equally effective in controlling waterhemp ($\geq 98\%$) except for the combination of 76-cm row spacing and early planting, which achieved 94% control (Table 2.9). This could be attributed to the fact that narrow row spacing enhances faster crop canopy interception, improving weed suppression. This aligns with the findings of a study where greater soybean planting density improved weed control (Liebert & Ryan, 2017).

Parsons. At Parsons in 2023, cocklebur control was similar for all treatments at 4WAPR (Table 2.10) ($\geq 72\%$) and 4WAP0 ($\geq 74\%$). Contrary to our results at Parsons, research conducted in central Missouri reported that sulfentrazone and flumioxazin, when applied separately, provided more than 89% control of cocklebur (Niekamp et al., 1999). This difference in control might be due to weather patterns. In Missouri, the conditions were cold and wet after herbicide application, whereas in Parsons, the fields received less than 25.4 cm of rainfall up to May, and temperatures ranged from 4°C to 27°C. Also, the herbicide programs used in both studies were different. Our herbicide combinations were primarily targeting *Amaranthus* species. However, only common cocklebur emerged in this field, even in the control plots, so the herbicides might not have been as effective in controlling it.

Scandia. At 4WAPR, the data from visual estimation of percentage giant foxtail control at Scandia in 2023 showed a main effect of row spacing (Table 2.11), where 38-cm row spacing resulted in greater foxtail control ($\geq 98\%$) compared to 76-cm row spacing ($\geq 82\%$) (Table 2.12). The herbicide programs and planting date did not influence giant foxtail control in Scandia. These results are consistent with the literature, where planting crops in narrow row spacings promotes faster canopy formation and increases the competitive ability of soybean against grass weeds (Datta et al., 2017). Similar foxtail control by herbicides was observed in research conducted at the same location in 2021 (Lammers, 2025).

Overall, the weed control results from this study suggest that planting date likely interacts with row spacing and preemergence herbicide programs. In most cases, early planting resulted in better weed control, which aligns with findings from the north-central U.S. (Heneghan & Johnson, 2017). In our study, weed control was generally similar between the two row spacings, but in some cases, the 38-cm spacing had fewer weeds than the 76-cm spacing. This is consistent with results from earlier research at the same locations, where row spacing had little effect on weed control (Lammers, 2025). However, other studies, such as one conducted in Michigan (Harder et al., 2007), showed that narrow rows closed the canopy faster, which helped suppress weeds—similar to what was observed when narrow rows had slightly fewer weeds in Scandia in 2023 in this study. Another study conducted in Ohio and Indiana also reported similar findings, where narrow row spacings resulted in greater weed control (Loux et al., 2013).

Among the preemergence herbicides tested, the combination of metribuzin and flumioxazin provided better weed control than metribuzin with sulfentrazone. Finally, weed control across all site-years was similar at four weeks after postemergence application (4WAPR), indicating that a two-pass herbicide program is necessary for consistent and effective

weed management. This is also supported by previous studies. For example, a study in Ontario, Canada, demonstrated that two-pass programs provided 98–100% control across all weed species (Soltani et al., 2017). Likewise, research from Wisconsin evaluating 11 different pre- and postemergence herbicide combinations in corn found that carefully selected herbicide programs can effectively control both broadleaf and grass weeds (Mobli et al., 2023). Our results, along with findings from other studies, highlight the importance of selecting the right combination of pre- and postemergence herbicides for effective weed control. However, it is important to note that weed control ratings at 4WAPR and 4WAP0 might not fully capture the actual effectiveness of the weed management strategies. Measuring weed biomass at the R7 growth stage can provide a better understanding of how well the weeds were controlled throughout the season (Dhakal et al., 2024) and help assess whether we are moving toward zero tolerance for herbicide-resistant weeds.

Weed Biomass at R7 Soybean

Manhattan. In 2022, there was a three-way interaction for Palmer amaranth biomass between planting date, row spacing, and preemergence herbicides. All combinations were equally effective in keeping weed biomass below 3.26 g m^{-2} , except for soybeans planted at the normal calendar date in 38-cm row spacing and treated with the preemergence herbicide combination of metribuzin with sulfentrazone, where biomass reached 27 g m^{-2} (Table 2.13). In 2023, all combinations were equally effective in keeping weed biomass below 0.01 g m^{-2} . The difference in treatment efficacy between 2022 and 2023 may be attributed to differences in rainfall. In 2022, total rainfall was 63.65 cm, while in 2023 it was only 34.77 cm (nearly half) which may have caused the herbicides to behave differently in controlling weeds.

Ottawa. In 2022, there was a two-way interaction between row spacing and postemergence herbicide for waterhemp biomass, where the combination of 76-cm row spacing with the postemergence treatment of 2,4-D choline + glyphosate + S-metolachlor (below 0.61 g m⁻²) and 38-cm spacing with 2,4-D choline + glyphosate (below 0.14 g m⁻²) resulted in higher weed biomass than the other two combinations (Table 2.14). However, for Ottawa in 2023, weed biomass was similar across all treatment combinations. The difference in efficacy of weed management combinations between the two years may be attributed to differences in temperature. In 2022, temperatures ranged from 5.9°C to 30°C, while in 2023 they ranged from 15.5°C to 30°C which might have caused the weeds to escape herbicide applications in 2022. Additionally, literature suggests that cooler temperatures, as in 2022, treatment efficacy may be reduced (Derr & Serensits, 2016).

However, it is important to note that although results in 2022 were statistically different, the recorded biomass levels were still low relative to the non-treated check. At the observed densities, the weeds would not likely reduce soybean yield. A similar implication was noted in a review paper on the impact of climate change factors on weeds and herbicide efficacy (Varanasi et al., 2016). Additionally, these differences were only observed in interaction effects, while the main effects showed negligible differences. The small waterhemp biomass observed may also be due to late-season weed escapes.

Parsons. In Parsons, there was negligible difference between the common cocklebur biomass (below 0.01g m⁻²).

Scandia. In both years, weed biomass was negligible (below 0.01 g m⁻²) across all treatment combinations. Additionally, temperature trends at Scandia were consistent across both

years, and this consistent temperature pattern may have contributed to the similar herbicide efficacy observed in controlling weeds (Derr & Serensits, 2016).

Overall, the results for weed biomass at the R7 soybean growth stage suggest that the herbicide program was equally effective in controlling all weeds except for those requiring a “zero tolerance” approach, i.e., *Amaranthus* species. The biomass of Palmer amaranth ranged from 3 to 27 g m⁻², and waterhemp ranged from 0.14 to 0.61 g m⁻². Research conducted in dry beans in Nebraska suggests that as Palmer amaranth biomass increases, seed production also increases; 1 g of dry biomass can produce between 270 and 7,290 seeds (Miranda et al., 2021). Additionally, another experiment conducted in cotton in Arkansas reported that the male-to-female sex ratio of Palmer amaranth ranged from 1.3:1 to 1.9:1 in crowded conditions, but dropped to 0.6:1 to 0.8:1 at low densities (Norsworthy et al., 2016). These findings suggest that even a few escapes of *Amaranthus* species are capable of producing substantial seed quantities, potentially including viable female plants that could further contribute to the herbicide resistance problem. Thus, literature indicates that the weed biomass observed in this research trial could contribute to the soil seedbank and does not confirm zero escapes of *Amaranthus* species.

Soybean Yield

Manhattan. In 2022, yield varied with planting date, early planted beans yielded less than (1115.94 kg ha⁻¹) soybeans planted at normal calendar date (2889.18 kg ha⁻¹) (Table 2.5). In 2023, yield data could not be accessed due to technical problems that occurred during harvest.

Ottawa. Soybean yield at Ottawa in 2022 showed a three-way interaction among planting date, row spacing, and preemergence herbicide. Early-planted soybeans produced greater yields (2,371 to 2,663 kg ha⁻¹) than those planted at the normal calendar date (1,245 to 1,606 kg ha⁻¹), regardless of row spacing or preemergence herbicide treatment (Table 2.15). However, within

each planting date, there was no difference between row spacings or preemergence herbicide programs. In other words, both 38-cm and 76-cm row spacings yielded similarly within the early and normal planting dates, but yields differed between planting dates. Applying a preemergence herbicide did not significantly affect soybean yield when planting date was held constant. These results indicate that planting date was the dominant factor influencing soybean yield in Ottawa in 2022. In 2023, there was a main effect of planting date on soybean yield. Yield was greater in soybeans planted at the normal date (2,510 kg ha⁻¹) compared to those planted early (2,150 kg ha⁻¹) (Table 2.16).

Parsons. Yield was similar for all treatment combinations (760 to 1060 kg ha⁻¹) in Parsons.

Scandia. In 2022, there was a main effect of row spacing for soybean yield (Table 2.17). Yield was greater in 38 cm row spacing (4394 kg ha⁻¹) compared to 76 cm (3612 kg ha⁻¹) (Table 2.18).

Similarly, in 2023, yield was greater in 38-cm row spacing (4,448.46 kg ha⁻¹) compared to 76-cm (3,459.44 kg ha⁻¹) (Table 2.18). Additionally, there was a two-way interaction between planting date and preemergence herbicides, where soybeans planted early and sprayed with the preemergence herbicide combination of metribuzin with sulfentrazone had the greatest yield (4,509 kg ha⁻¹) compared to the other treatments ($\geq 3,717$ kg ha⁻¹) (Table 2.19).

Overall, soybean yield was greater with early planting in one site-year, similar in three site-years, and greater with normal planting in two site-years, indicating a mixed effect of planting date on soybean yield. Previous research suggests that environmental factors influenced by planting dates greatly affect the growth and development of soybean (Andales et al., 2000; Chen & Wiatrak, 2010). Among these factors, temperature can impact crop performance, with

reports indicating that increased temperature may either positively or negatively impact yield (Bellaloui et al., 2011). Similarly, change in precipitation also has mixed effects on soybean yield (Heatherly & Elmore, 1983; Muchow et al., 1994). Additionally, in the Midwest region of the U.S.A., when soybean is planted after the critical date, yield rapidly decreases, and this critical date can vary in different site-years, which is similar to our results (Egli & Cornelius, 2009).

In our study, the mixed yield response for planting date could be explained by differences in rainfall and temperature from ideal conditions for soybean growth. Ideal soybean yield conditions generally involve cumulative precipitation between 45–65 cm during the growing season and moderate temperatures, typically around 25–29°C for maximum and 15–20°C for minimum temperatures. In 2022 in Manhattan, temperatures (maximum 28.7°C; minimum 15.3°C) and rainfall (63.7 cm) closely matched these ideal conditions, potentially explaining better overall yields at normal planting. However, in Ottawa in 2022, the maximum temperature was suitable (30.3°C), but the minimum temperature was notably cooler (5.9°C), combined with less rainfall (41.1 cm), creating suboptimal conditions that might have limited soybean yield. In contrast, Scandia experienced relatively low rainfall (31.9 cm), potentially stressing the crop and influencing yield results for planting date in 2022. In sum, these comparisons emphasize that environmental conditions, especially deviations from ideal temperature and rainfall, may have had a more pronounced effect on soybean yield than planting date alone in our study.

Additionally, yield was greater in narrow row spacing for two site-years (Scandia 2022 and 2023), consistent with the findings of research conducted in Michigan which evaluated similar row spacings (Harder et al., 2007), while it remained similar for the other site-years. The similarity in the two site-years might be due to the cooler temperature conditions in Michigan

and Scandia (Scandia had comparatively cooler temperatures compared to other site-years, except Ottawa 2022), which may favor faster canopy closure in narrow rows and might improve light interception. Both Scandia and the Michigan sites also had similar maximum temperatures (around 28.5–29°C), which may have reduced moisture stress and allowed narrow-row soybeans to express their full yield potential. In contrast, there were warmer conditions and lower rainfall in southern Kansas sites like Parsons and Ottawa (except for Ottawa in 2022). Additionally, these sites are located at lower latitudes, where high temperature and moisture stress may have reduced the benefits of narrow row spacing. Manhattan, although closer in latitude to Scandia, had more variable rainfall compared to these two sites, which might explain its inconsistent yield response to row spacing compared to the consistent results observed in Michigan.

This indicates that planting soybeans in narrow row spacing is either beneficial or at least comparable to wider row spacing depending on environmental conditions. Furthermore, in this experiment, all the herbicide combinations had similar effects on soybean yield. All in all, similar to our experimental results, the literature suggests that environmental conditions have a greater influence on soybean yield than planting date.

Soybean canopy light interception

Weed Control. The regression analysis between percent weed control and canopy light interception showed that R^2 values ranged from 0.0009 to 0.033 (Figure 2-5). This indicates that the models explained less than 4% of the variability in weed control, suggesting that canopy light interception is not a strong predictor of weed control in this dataset. Additionally, all p -values were above 0.05, indicating that the slopes were not statistically significant and the observed trends could be due to random variation. However, examining the regression equations reveals a slight positive trend in weed control when soybeans are planted earlier. While this trend is not

statistically strong, it suggests that early canopy development may contribute somewhat to improved weed suppression.

Weed Biomass. In Manhattan, no weed biomass was observed in early-planted soybeans, resulting in a flat regression line. For soybeans planted at normal calendar dates, the regression showed a very weak positive slope. In Ottawa, there was a very weak negative slope for early-planted soybeans and a very weak positive slope for normally planted soybeans. The extremely low R^2 values (ranging from 0.001 to 0.044) across all cases suggest that canopy interception (Figure 2-6) explains very little of the variability in weed biomass, and the trends observed may simply be random. These results suggest that the differences in canopy light interception among treatments were not substantial enough to establish a clear relationship with weed control or biomass. Moreover, very few weeds emerged in the treated plots, likely due to effective two-pass herbicide programs. This limited weed emergence may have resulted in insufficient variation to detect meaningful trends.

Overall, the findings imply that other factors (beyond canopy interception) may have played a more influential role in determining weed outcomes in this study. Similar implications can be derived from research in which light interception provided by wheat on weed suppression was not as pronounced as other factors such as wheat height and vigor (Mwendwa et al., 2020).

Economic Analysis

The analysis of variance of the return over selected cost indicated interaction of site year and treatment, therefore data were analyzed separately for each site year. The differences in yield among site years were the key factor in calculating returns, and that is why the results for site-years varied with yield.

Manhattan. At Manhattan in 2022, there was a main effect of planting date (Table 2.20) and the return over selected cost was greater for normal-planted soybeans (1280.67 US \$ ha⁻¹) compared to early planted beans (369.58 US \$ ha⁻¹) (Table 2.21). As yield data was discarded for Manhattan 2023, return over selected cost was not calculated.

Ottawa. At Ottawa 2022, there was a three-way interaction between planting date, row spacing and preemergence herbicide for return over selected cost (Table 2.20). There was a clear difference between the return for planting dates where early planted soybeans (1006-1185 US \$ ha⁻¹) had a greater return over selected cost compared to the soybeans planted at normal times (403-613 US \$ ha⁻¹) (Table 2.22). Results for Ottawa 2023 were similar to Manhattan 2022, with a main effect of planting date. Normal-planted soybeans resulted in a greater return over selected cost (1227.53 US \$ ha⁻¹) compared to early planted soybeans (1012.48 US \$ ha⁻¹) for Ottawa 2023 (Table 2.21).

Parsons. At Parsons 2023, all the management practices had similar return over selected cost (235-482 US \$ ha⁻¹).

Scandia. At Scandia, for both years there was a main effect of row spacing for return over selected cost and in both years 38 cm row spacing gave a greater return compared to the 76 cm row spacing (Table 2.23). In 2022, 38 cm gave 2041 US \$ ha⁻¹ and 76 cm gave 1664 US \$ ha⁻¹ and in 2023, 38 cm gave 2206 US \$ ha⁻¹ and 76 cm gave 1689 US \$ ha⁻¹ (Table 2.24).

Similar to yield, there was a mixed result for return over selected cost. Additionally, at all the site years, the greater yield, the greater the economic return. Moreover, identical main effects and interactions were observed suggesting the direct relationship of yield with the economic return. Similar relationships between yield and return over selected cost was observed in a research where yield and return over selected cost were greater in preemergence herbicide

treatment compared to pre followed by postemergence herbicide application in Ottawa, Kansas (Lammers, 2025).

Management considerations

Planting date

From a weed management standpoint, similar to previous research reports, early planting generally offers better weed control across most locations and years in our research (Arsenijevic et al., 2022). Additionally, there is a consistent interaction between planting date, row spacing, and herbicide programs for weed control. This suggests that while planting date alone is not the only determinant, it can play a significant role in determining weed control when combined with other management practices.

Soybean yield told a different story. There was a mixed effect of planting date on yield at different site-years. Previous experiments reported that early-planted soybeans might yield more (Chen and Wiatrak, 2010; Heatherly, 2005) or less (Andales et al., 2000; Kane et al., 1997; Steele and Grabau, 1997) than later-planted soybeans. The variability in yield observed across our study sites suggests that environmental conditions may have played a greater role in determining soybean yield than planting date alone. Furthermore, in previous research, environmental factors during reproductive stages are often found to be more critical for yield than those during vegetative growth. This is because stress at pod-filling stages directly affects seed set, pod filling, and ultimately crop yield (Egli and Bruening, 2004). Similar to yield results, the return over selected costs also showed mixed outcomes across planting dates.

Row spacing

In this experiment, narrow row spacing (38 cm) provided better weed control (especially Palmer amaranth and giant foxtail) compared to wider row spacing (76 cm). Furthermore,

soybean yield was greater or similar at 38 cm compared to 76 cm. These results suggest that limiting light interception in weeds (via faster canopy formation in soybean) using cultural practices like narrow row spacing can help achieve greater weed control and soybean yield (Heneghan & Johnson, 2017; Oliveira et al., 2022; Schwartz et al., 2016). Additionally, 38 cm row spacing was more profitable than 76 cm row spacing. Similar results were reflected in research in which gross margin was calculated for 38 and 76 cm row spacings in Michigan (Harder et al., 2007).

Herbicide programs

Among the preemergence herbicides, flumioxazin + metribuzin provided equal or better weed control compared to sulfentrazone + metribuzin in the early crop growth stages. Additionally, both postemergence herbicides were equally effective in controlling weeds at all location. This suggests that a two-pass herbicide program i.e., preemergence herbicide followed by a postemergence herbicide application is an effective strategy in integrated weed management (Aulakh & Jhala, 2015; Miller & Norsworthy, 2016). Overall, all the herbicide programs used in this experiment gave similar return over selected cost.

Final recommendation

The most effective weed management practices in Kansas can vary from location to location and year to year, depending on environmental conditions. However, based on this research, early planting combined with narrow row spacing generally improved overall weed control, likely due to quicker canopy closure and shading of emerging weeds, which increases the competitive ability of soybeans over weeds. In a few site-years, early-planted soybeans and those grown in narrow rows also produced greater yields compared to normal planting dates and wider rows.

This study also found that using flumioxazin plus metribuzin as a preemergence herbicide provided more consistent early-season weed control. Therefore, farmers might consider including this combination in their weed management programs. Regardless of the choice of preemergence herbicide, a two-pass herbicide program was found to be beneficial in maintaining effective, season-long control.

Lastly, the presence of *Amaranthus* species (Palmer amaranth and waterhemp) at the R7 stage suggests that some populations may still escape management practices. Even a few weed escapes can contribute significantly to the soil seedbank and herbicide resistance. Thus, it is critical for farmers to adopt a zero-tolerance approach when designing their weed management programs.

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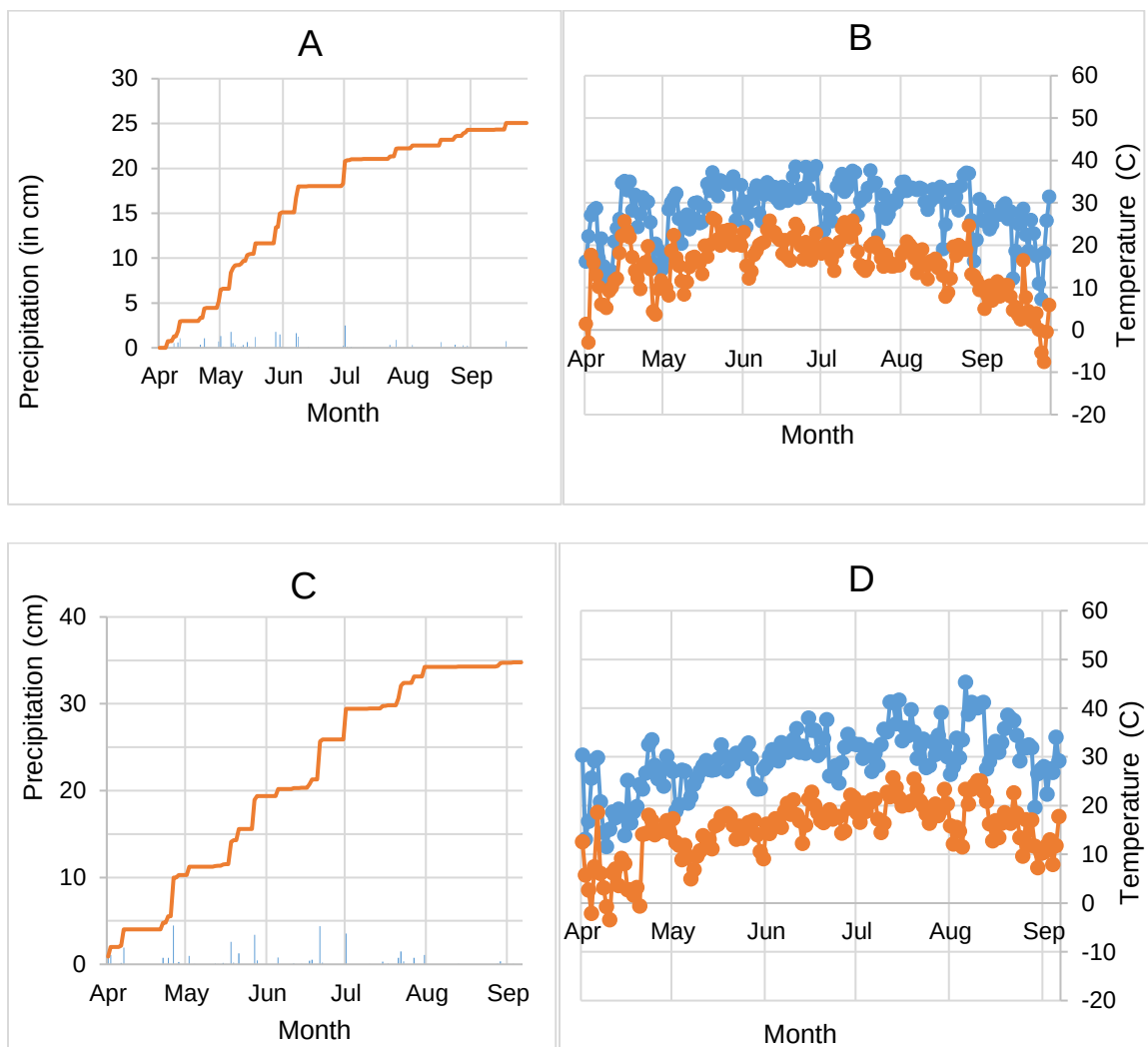


Figure 2-1. Precipitation and temperature throughout the cropping season in Manhattan
A. Cumulative and daily precipitation during 2022; B. Daily maximum and minimum
temperatures during 2022; C. Cumulative and daily precipitation during 2023; D. Daily
maximum and minimum temperatures during 2023.

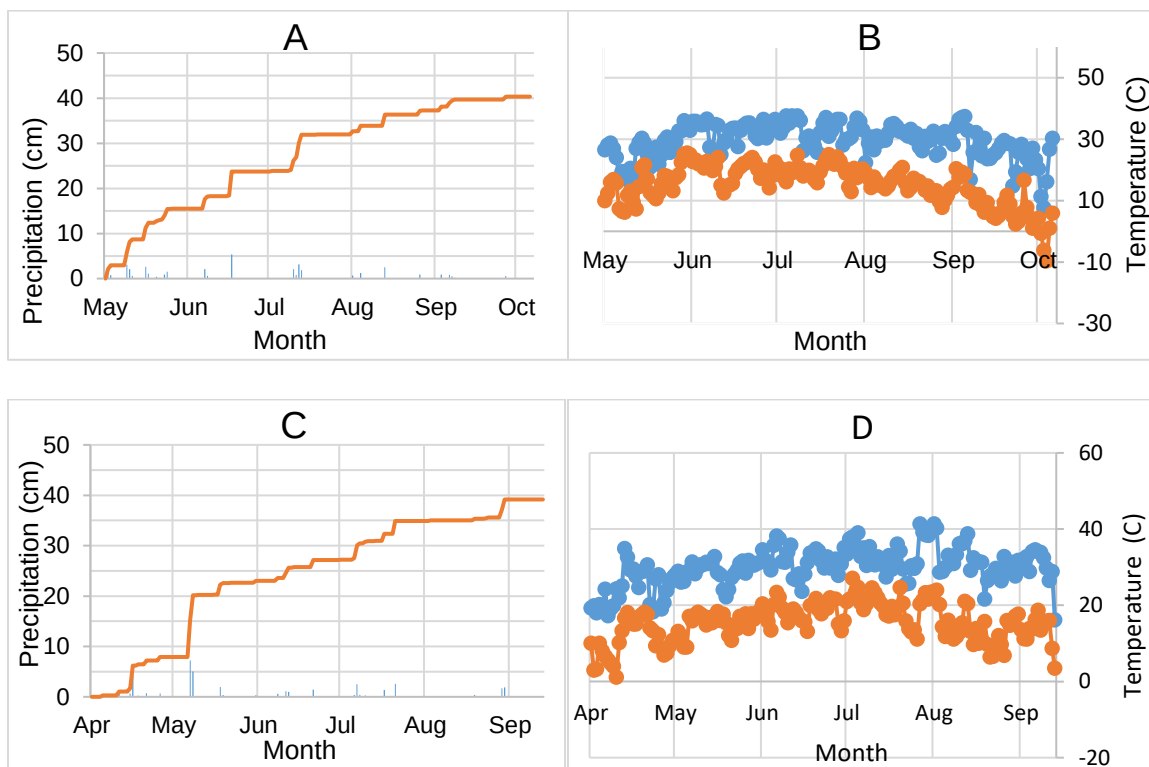


Figure 2-2. Precipitation and temperature throughout the cropping season in Ottawa A. Cumulative and daily precipitation during 2022; B. Daily maximum and minimum temperatures during 2022; C. Cumulative and daily precipitation during 2023; D. Daily maximum and minimum temperatures during 2023.

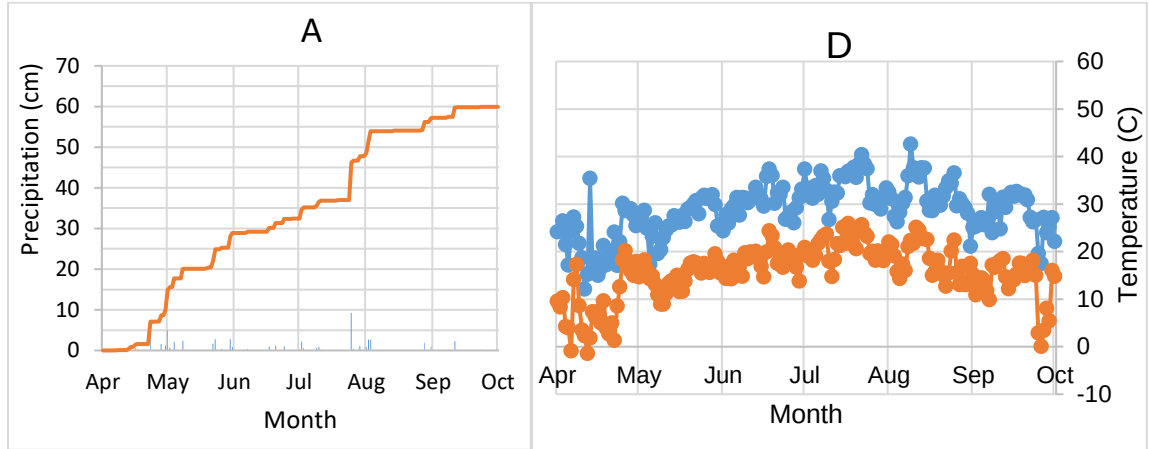


Figure 2-3. Precipitation and temperature throughout the cropping season in Parsons A. Cumulative and daily precipitation during 2023; B. Daily maximum and minimum temperatures during 2023.

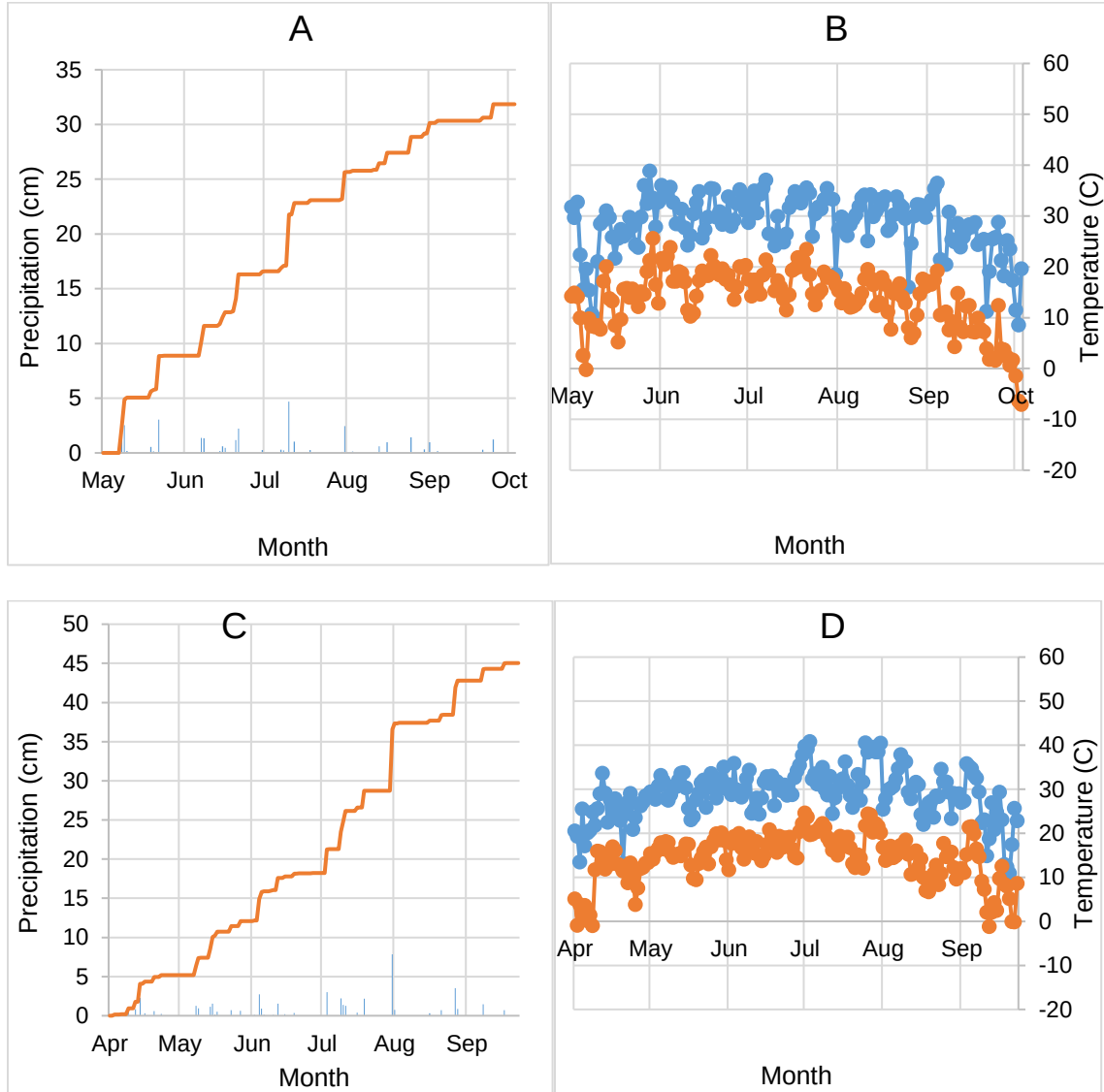


Figure 2-4. Precipitation and temperature throughout the cropping season in Scandia A. Cumulative and daily precipitation during 2022; B. Daily maximum and minimum temperatures during 2022; C. Cumulative and daily precipitation during 2023; D. Daily maximum and minimum temperatures during 2023.

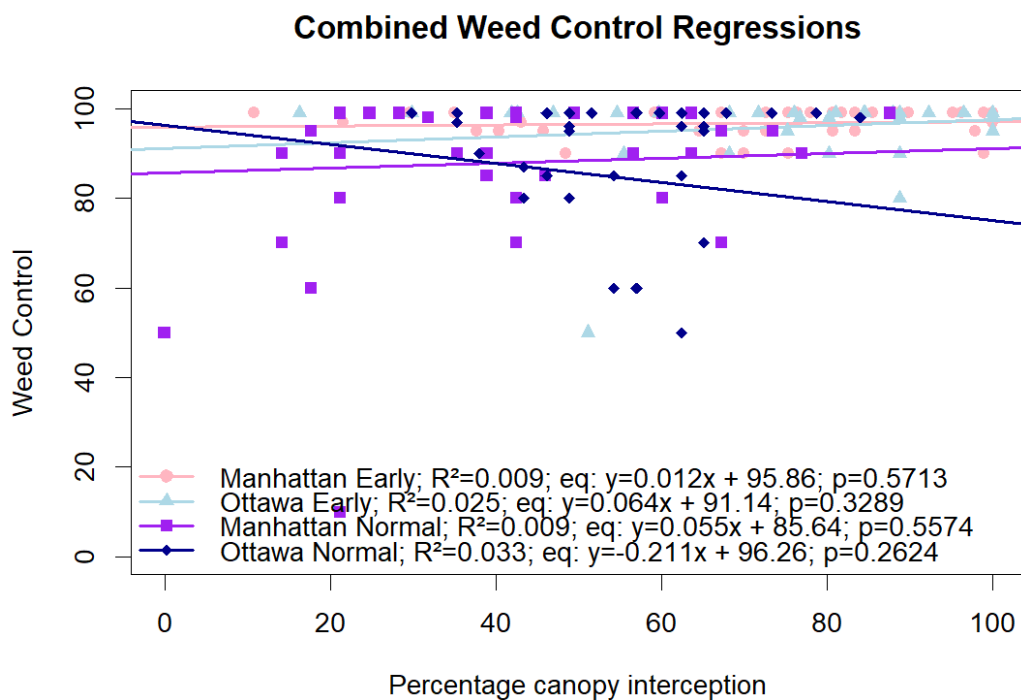


Figure 2-5. Regression of percent weed control at 4WAPR and percent light interception in Manhattan (light blue triangle, early; dark blue diamond, normal) and Ottawa (light red circle, early; dark red squares, normal) in 2023.

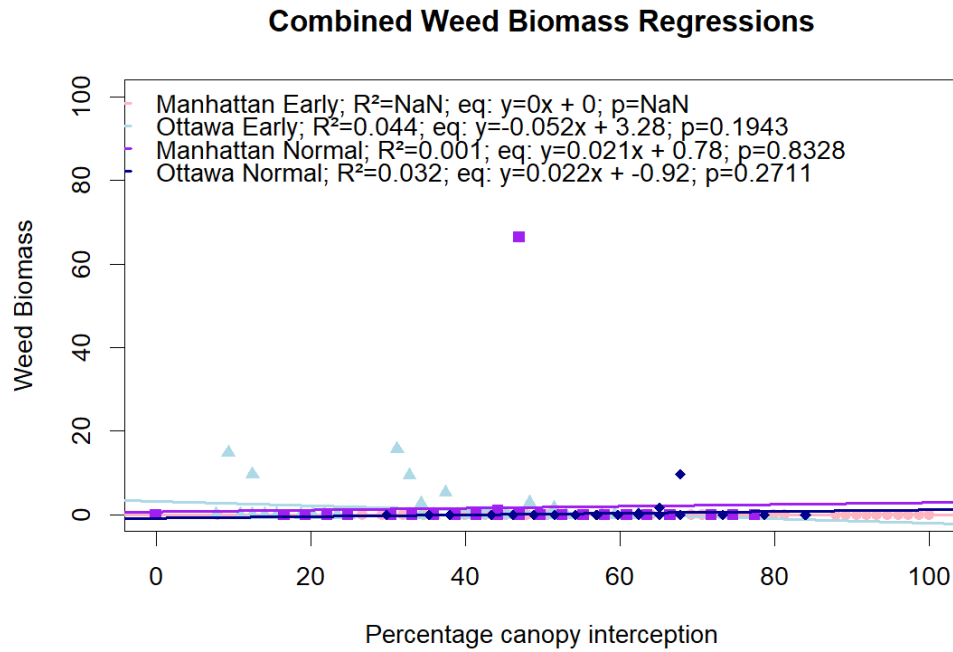


Figure 2-6. Regression between weed biomass (g m⁻²) at R7 soybean and percent light interception at 4WPO in Manhattan (light pink circle, early; purple square, normal) and Ottawa (light blue triangle, early; dark blue diamond, normal) in 2023.

Table 2-1. Site year information: Enlist® variety, planting dates, tillage/burndown application previous crop and harvest date of Soybean

Location	Enlist® variety	Planting dates		Tillage/Burndown	Previous crop	Harvest Date
		Early	Normal			
MHK22	38A54E	4/25	5/22	Tillage	Corn	10/21
MHK23	GH4093 E3	4/14	5/22	Tillage	Corn	9/19
				Roundup Powermax (1qt acre) + AMS		
OTT22	38A54E	6/15	6/29	(17lb/100 gal) (at 4/17) + Tillage	Corn	10/21
OTT23	GH4433 E3	4/24	5/24	Tillage	Corn	10/06
PAR23	GH4433 E3	4/12	5/26	Tillage	Corn	10/12
						Early: 10/10,
SC22	38A54E	5/17	6/14	Tillage	Corn	Normal: 10/19
SC23	GH 3774 E3	4/26	6/1	Tillage	Corn	10/18

Abbreviations: Manhattan, KS, 2022; MHK22, Manhattan, KS, 2023; MHK23, Ottawa, KS, 2022; OTT22, Ottawa, KS, 2023; OTT23, Scandia, KS, 2022; SC22, Scandia, KS, 2023; SC23 and Parsons, KS, 2023; PAR23.

Table 2-2. Herbicide application timings, active ingredients, trade names and rates

Application timings ^{ab}	Active ingredients	Trade names	Rates (g ai ha ⁻¹)	Manufacturer
At planting (preemergence herbicide) ^a	sulfentrazone + metribuzin	Authority MTZ	126+189	FMC ^c
	flumioxazin + metribuzin	Dimetric Charged	394+189	Winfield United ^d
		Enlist One +RoundUp		Corteva ^e +
Four weeks after planting (postemergence herbicide) ^b	2,4-D choline + glyphosate	PowerMax 3	1066+841	Bayer Crop Science
		Enlist One +RoundUp		Corteva+
	2,4-D choline + glyphosate + S-metolachlor	PowerMax 3+ Dual II Magnum	1066+841+1598	Bayer Crop Science ^f + Syngenta ^g

Abbreviations: ^{ab}All preemergence and postemergence herbicide mixtures were applied with a CO₂-pressurized backpack sprayer equipped with an AIXR 11002 nozzle, calibrated to deliver 187 L ha⁻¹.

^cFMC Corporation, Philadelphia, PA

^dWinfield United, St. Paul, MN

^eCorteva Agriscience, Wilmington, DE

^f Bayer Crop Science, St. Louis, MO

^gSyngenta, Greensboro, NC

Table 2-3. Analysis of variance of fixed effects and all treatment interactions for Palmer amaranth control at four weeks after preemergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAPO), palmer biomass at R7 stage of soybean and soybean yield in Manhattan, Kansas in 2022

	4WAPR			4WAPO			Biomass (gram m ⁻²)			Yield (kg ha ⁻¹)	
	df	F-value	P-value	d f	F-value	P-value	df	F- value	P-value	F-value	P-value
Fixed effects											
Planting date	1	11.77	0.00	1	0.92	0.34	1	9.72	0.00	79.87	<0.01
Preemergence herbicide	1	53.21	0.00	1	10.27	0.00	1	7.96	0.01	0.69	0.41
Postemergence herbicide				1	0.00	0.95	1	0.42	0.52	0.78	0.38
Row spacing	1	2.94	0.09	1	7.95	0.01	1	4.70	0.04	0.21	0.65
Planting date*Preemergence herbicide	1	17.02	0.00	1	4.21	0.05	1	6.20	0.02	0.03	0.85
Planting date*Post emergence herbicide				1	1.48	0.23	1	0.14	0.71	0.40	0.53
Preemergence herbicide*Post emergence herbicide				1	1.33	0.25	1	1.57	0.22	1.07	0.31
Planting date*Row spacing	1	1.53	0.22	1	0.26	0.61	1	3.66	0.06	4.02	0.05.
Preemergence herbicide*Row spacing	1	2.38	0.13	1	2.99	0.09	1	7.57	0.01	2.68	0.11
Post emergence herbicide*Row spacing				1	0.15	0.70	1	0.62	0.44	0.21	0.65
Planting date*Preemergence herbicide*Post emergence herbicide				1	0.02	0.90	1	0.97	0.33	0.16	0.69
Planting date*Preemergence herbicide*Row spacing	1	0.51	0.48	1	0.33	0.57	1	6.24	0.02	0.86	0.36
Planting date*Postemergence herbicide*Row spacing				1	2.37	0.13	1	0.35	0.56	0.12	0.73
Preemergence herbicide*Postemergence herbicide*Row spacing				1	2.17	0.15	1	0.03	0.86	0.61	0.44
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.20	0.66	1	0.00	0.99	1.46	0.23

Table 2-4. Palmer amaranth control at four weeks after application of pre (4WAPR) and postemergence herbicides (4WAP0) when soybeans were planted at different dates and different preemergence herbicides applied and pooled across row spacings and postemergence herbicides in Manhattan, Kansas in 2022 and 2023

Planting date	Preemergence herbicide	MHK 2022		MHK 2023
		4 WAPR	4WAP0	4WAPR
Early	sulfentrazone + metribuzin	84 b	97 ab	96 a
Early	flumioxazin + metribuzin	93 ab	98 a	99 a
Normal	sulfentrazone + metribuzin	62 c	94 b	79 b
Normal	flumioxazin + metribuzin	95 a	99 a	99 a
^h SE		3.11	0.96	1.2

Abbreviation: SE: standard error

Table 2-5. Visual estimation of percent Plamer amaranth control at four weeks after postemergence herbicide application (4WAP0)and yield when pooled across planting date, pre- and postemergence herbicides in Manhattan, Kansas in 2022

Row spacing (cm)	4WAP0
38	98 a
76	96 b
^h SE	0.96
Planting date	Yield (kg ha ⁻¹)
Early	1115.94 b
Normal	2889.18 a
^h SE	118.47

Table 2-6. Analysis of variance of fixed effects and all treatment interactions for Palmer amaranth control at four weeks after emergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAP0), and palmer amaranth biomass at R7 stage of soybean in Manhattan, Kansas in 2023

Fixed effects	4WAPR			4WAP0			Biomass (gram m ⁻²)		
	df	F-value	P-value	df	F-value	P-value	df	F-value	P-value
Planting date	1	8.14	0.01	1	0.31	0.58	1	1.73	0.19
Preemergence herbicide	1	14.45	0.00	1	0.62	0.44	1	0.28	0.60
Post emergence herbicide				1	1.02	0.32	1	0.28	0.60
Row spacing	1	0.18	0.68	1	1.02	0.32	1	0.28	0.60
Planting date*Preemergence herbicide	1	8.14	0.01	1	1.52	0.22	1	0.28	0.60
Planting date*Postemergence herbicide				1	1.02	0.32	1	0.28	0.60
Preemergence herbicide*Postemergence herbicide				1	1.52	0.22	1	1.73	0.19
Planting date*Row spacing	1	0.03	0.87	1	1.02	0.32	1	0.28	0.60
Preemergence herbicide*Row spacing	1	0.21	0.65	1	0.62	0.44	1	1.73	0.19
Post emergence herbicide*Row spacing				1	1.02	0.32	1	1.73	0.19
Planting date*Preemergence herbicide*Postemergence herbicide				1	0.62	0.44	1	1.73	0.19
Planting date*Preemergence herbicide*Row spacing	1	0.08	0.77	1	1.52	0.22	1	1.73	0.19
Planting date*Postemergence herbicide*Row spacing				1	1.02	0.32	1	1.73	0.19
Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.62	0.44	1	0.28	0.60
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				1	1.52	0.22	1	0.28	0.60

Table 2-7. Analysis of variance of fixed effects and all treatment interactions for at and four weeks after preemergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAPO), waterhemp biomass at R7 stage of soybean and soybean yield in Ottawa, Kansas in 2022

	4WAPR			4WAPO		Biomass (gram m ⁻²)			Yield (kg ha ⁻¹)		
	df	F-value	P-value	F-value	P-value	d	F-value	P-value	df	F-value	P-value
Fixed effects											
Planting date	1	1	0.32	1	0.32	1	0.33	0.57	1	144.81	0.00
Preemergence herbicide	1	1	0.32	1	0.32	1	0.70	0.41	1	0.12	0.73
Postemergence herbicide				1	0.32	1	1.94	0.17	1	0.06	0.81
Row spacing	1	1	0.32	1	0.32	1	1.94	0.17	1	2.01	0.16
Planting date*Preemergence herbicide	1	1	0.32	1	0.32	1	0.01	0.93	1	0.05	0.83
Planting date*Postemergence herbicide				1	0.32	1	0.42	0.52	1	1.11	0.30
Preemergence herbicide*Postemergence herbicide				1	0.32	1	0.83	0.37	1	0.02	0.89
Planting date*Row spacing	1	1	0.32	1	0.32	1	0.42	0.52	1	0.81	0.37
Preemergence herbicide*Row spacing	1	1	0.32	1	0.32	1	0.83	0.37	1	1.26	0.27
Postemergence herbicide*Row spacing				1	0.32	1	4.89	0.03	1	1.62	0.21
Planting date*Preemergence herbicide*Post emergence herbicide				1	0.32	1	0.53	0.47	1	6.13	0.02
Planting date*Preemergence herbicide*Row spacing	1	1	0.32	1	0.32	1	0.53	0.47	1	0.03	0.87
Planting date*Postemergence herbicide*Row spacing				1	0.32	1	0.33	0.57	1	0.19	0.66
Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.32	1	0.70	0.41	1	0.50	0.48
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.32	1	0.0086	0.92	1	0.60	0.44

Table 2-8. Visual estimation of percent waterhemp control at four weeks after postemergence herbicide (4WAP0) at different row spacings pooled across planting dates in Ottawa, Kansas, 2023

Planting date	Row spacings (cm)	4WAP0	
Early	38	98	a
Early	76	94	b
Normal	38	99	a
Normal	76	98	a
^h SE		0.95	

Abbreviations: ^hStandard Error

Table 2-9. Analysis of variance of fixed effects and all treatment interactions for waterhemp at and four weeks after preemergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAPO), waterhemp at R7 stage of soybean and soybean yield in Ottawa, Kansas in 2023

Fixed effects	4WAPR			4WAPO		R7			Yield		
	df	F-value	P-value	F-value	P-value	df	F-value	P-value	df	F-value	P-value
Planting date	1	1.67	0.20	6.20	0.02	1	0.45	0.51	1	6.14	0.02
Preemergence herbicide	1	0.35	0.56	1.02	0.32	1	1.63	0.21	1	0.12	0.73
Postemergence herbicide				6.88	0.01	1	0.90	0.35	1	0.65	0.42
Row spacing	1	1.55	0.22	3.55	0.07	1	1.56	0.22	1	0.83	0.37
Planting date*Preemergence herbicide	1	0.44	0.51	0.02	0.89	1	0.62	0.43	1	0.15	0.70
Planting date*Postemergence herbicide				4.07	0.05	1	0.87	0.36	1	0.19	0.67
Preemergence herbicide*Postemergence herbicide				0.45	0.50	1	0.60	0.44	1	1.78	0.19
Planting date*Row spacing	1	0.03	0.86	0.55	0.46	1	0.40	0.53	1	0.08	0.78
Preemergence herbicide*Row spacing	1	0.11	0.75	0.55	0.46	1	1.16	0.29	1	0.15	0.70
Postemergence herbicide*Row spacing				3.30	0.08	1	1.32	0.26	1	0.32	0.58
Planting date*Preemergence herbicide*Post emergence herbicide				0.00	0.95	1	1.11	0.30	1	0.34	0.56
Planting date*Preemergence herbicide*Row spacing	1	1.93	0.17	0.16	0.69	1	0.57	0.45	1	1.56	0.22
Planting date*Postemergence herbicide*Row spacing				1.47	0.23	1	0.94	0.34	1	0.46	0.50
Preemergence herbicide*Postemergence herbicide*Row spacing				1.16	0.29	1	0.95	0.33	1	0.00	0.98
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				0.22	0.64	1	1.19	0.28	1	1.46	0.23

Table 2-10. Analysis of variance of fixed effects and all treatment interactions for cocklebur control at four weeks after preemergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAP0), cocklebur biomass at R7 stage of soybean and soybean yield in Parsons, Kansas in 2023

	4WAPR			4WAP0			Biomass (gram m ⁻²)			Yield		
	d f	F- value	P-value	d f	F-value	P-value	df	F-value	P-value	d f	F-value	P-value
Fixed effects												
Planting date	1	0.07	0.79	1	0.63	0.43	1	1.34	0.25	1	0.05	0.83
Preemergence herbicide	1	0.09	0.77	1	0.84	0.36	1	0.04	0.84	1	0.02	0.88
Postemergence herbicide				1	1.16	0.29	1	0.27	0.61	1	1.55	0.22
Row spacing	1	0.20	0.66	1	0.84	0.36	1	0.04	0.83	1	0.53	0.47
Planting date*Preemergence herbicide	1	1.70	0.20	1	1.16	0.29	1	0.00	0.95	1	0.65	0.43
Planting date*Postemergence herbicide				1	0.84	0.36	1	0.02	0.88	1	1.05	0.31
Preemergence herbicide*Postemergence herbicide				1	0.99	0.32	1	0.23	0.63	1	0.33	0.57
Planting date*Row spacing	1	2.95	0.09	1	1.16	0.29	1	0.16	0.69	1	1.59	0.21
Preemergence herbicide*Row spacing	1	0.48	0.49	1	1.25	0.27	1	2.48	0.12	1	0.00	0.96
Postemergence herbicide*Row spacing				1	1.07	0.31	1	1.13	0.29	1	0.00	0.98
Planting date*Preemergence herbicide*Post emergence herbicide				1	0.99	0.32	1	1.90	0.17	1	0.11	0.74
Planting date*Preemergence herbicide*Row spacing	1	0.09	0.77	1	0.77	0.39	1	1.74	0.19	1	0.24	0.62
Planting date*Postemergence herbicide*Row spacing				1	0.91	0.34	1	1.70	0.20	1	0.00	0.94
Preemergence herbicide*Postemergence herbicide*Row spacing				1	1.07	0.31	1	0.38	0.54	1	0.00	0.92
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.91	0.34	1	0.00	0.95	1	0.00	0.98

Table 2-11. Analysis of variance of fixed effect and all treatment interactions for foxtail control at and four weeks after preemergence herbicide application (4WAPR) and four weeks after postemergence herbicide application (4WAPO), foxtail biomass at R7 stage of soybean and soybean yield in Scandia, Kansas in 2023

Fixed effects	4WAPR			4WAPO			Biomass (gram m ⁻²)			Yield		
	df	F-value	P-value	df	F-value	P-value	df	F-value	P-value	df	F-value	P-value
Planting date	1	0.00	0.99	1	0.73	0.40	1	0.05	0.83	1	3.29	0.08
Preemergence herbicide	1	1.76	0.19	1	0.73	0.40	1	2.29	0.14	1	5.57	0.02
Postemergence herbicide				1	0.43	0.52	1	0.05	0.83	1	1.10	0.30
Row spacing	1	13.44	0.00	1	2.14	0.15	1	2.29	0.14	1	31.75	0.00
Planting date*Preemergence herbicide	1	0.16	0.69	1	0.43	0.52	1	0.05	0.83	1	4.63	0.04
Planting date*Postemergence herbicide				1	0.73	0.40	1	2.29	0.14	1	0.58	0.45
Preemergence herbicide*Postemergence herbicide				1	0.73	0.40	1	0.05	0.83	1	0.24	0.63
Planting date*Row spacing	1	0.25	0.62	1	0.73	0.40	1	0.05	0.83	1	0.00	0.98
Preemergence herbicide*Row spacing	1	3.77	0.06	1	0.73	0.40	1	2.29	0.14	1	2.07	0.16
Postemergence herbicide*Row spacing				1	0.43	0.52	1	0.05	0.83	1	0.32	0.57
Planting date*Preemergence herbicide*Post emergence herbicide				1	2.14	0.15	1	2.29	0.14	1	0.10	0.76
Planting date*Preemergence herbicide*Row spacing	1	0.80	0.38	1	0.43	0.52	1	0.05	0.83	1	1.73	0.19
Planting date*Postemergence herbicide*Row spacing				1	0.73	0.40	1	2.29	0.14	1	1.98	0.17
Preemergence herbicide*Postemergence herbicide*Row spacing				1	0.73	0.40	1	0.05	0.83	1	0.72	0.40
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing				1	2.14	0.15	1	2.29	0.14	1	1.65	0.21

Table 2-12. Percentage foxtail control at four weeks after application of preemergent herbicide (4WAPR) in Scandia, Kansas in 2023

Row spacings (cm)	4WAPR	Yield (Kg ha ⁻¹)	
38	98	4448.46	a
76	82	3459.44	b
^h SE	4.25	324.172	

Abbreviations: ^hStandard Error

Table 2-13. Palmer amaranth biomass pooled across postemergence herbicide in Manhattan, Kansas in 2022

Planting date	Row spacings (cm)	Preemergence herbicide	Biomass (g m ⁻²)	
Early	38	sulfentrazone + metribuzin	0.20	b
Early	38	flumioxazin + metribuzin	0.00	b
Early	76	sulfentrazone + metribuzin	1.50	b
Early	76	flumioxazin + metribuzin	0.00	b
Normal	38	sulfentrazone + metribuzin	3.26	b
Normal	38	flumioxazin + metribuzin	3.10	b
Normal	76	sulfentrazone + metribuzin	27.13	a
Normal	76	flumioxazin + metribuzin	0.11	b
^h SE				3.6

Abbreviations: ^hStandard Error

Table 2-14. Waterhemp biomass at R7 stage of Soybean when combination of different postemergence herbicides application was pooled across row spacings in Ottawa, Kansas, 2022

Row spacings (cm)	Postemergence herbicide	Biomass (gram m ⁻²)
76	2,4-D choline + glyphosate	0 b
76	2,4-D choline + glyphosate + S-metolachlor	0.61 a
38	2,4-D choline + glyphosate	0.14 ab
38	2,4-D choline + glyphosate + S-metolachlor	0 b
^h SE		0.16

Abbreviations: ^hStandard Error

Table 2-15. Soybean yield when combination of row spacing and preemergence herbicide application were pooled across planting dates in Ottawa, Kansas, 2022

Planting date	Row spacings (cm)	Preemergence herbicide	Yield (Kg ha ⁻¹)	
Early	38	sulfentrazone + metribuzin	2662.63	a
Early	38	flumioxazin + metribuzin	2498.66	a
Early	76	sulfentrazone + metribuzin	2371.57	a
Early	76	flumioxazin + metribuzin	2640.12	a
Normal	38	sulfentrazone + metribuzin	1244.79	b
Normal	38	flumioxazin + metribuzin	1497.80	b
Normal	76	sulfentrazone + metribuzin	1605.99	b
Normal	76	flumioxazin + metribuzin	1376.42	b
^h SE			141.23	

Abbreviations: ^hStandard Error

Table 2-16. Soybean yield at planting dates in Ottawa, Kansas, 2023.

Planting dates	Yield (Kg ha ⁻¹)	
Early	2150.75	b
Normal	2510.06	a
^h SE	110.67	

Abbreviations: ^hStandard Error

Table 2-17. Analysis of variance of fixed effects and all treatment interactions for soybean yield in Scandia, Kansas in 2022

Fixed effects	Yield		
	df	F-value	P-value
Planting date	1	1.28	0.26
Preemergence herbicide	1	0.05	0.82
Postemergence herbicide	1	0.14	0.71
Row spacing	1	17.75	0.00
Planting date*Preemergence herbicide	1	1.25	0.27
Planting date*Postemergence herbicide	1	0.00	0.97
Preemergence herbicide*Postemergence herbicide	1	0.14	0.71
Planting date*Row spacing	1	0.35	0.56
Preemergence herbicide*Row spacing	1	0.02	0.88
Postemergence herbicide*Row spacing	1	2.69	0.11
Planting date*Preemergence herbicide*Post emergence herbicide	1	0.15	0.70
Planting date*Preemergence herbicide*Row spacing	1	0.03	0.87
Planting date*Postemergence herbicide*Row spacing	1	1.53	0.22
Preemergence herbicide*Postemergence herbicide*Row spacing	1	1.45	0.24
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing	1	2.15	0.15

Table 2-18. Soybean yield at planting dates in Scandia, Kansas, 2022

Row spacings (cm)	Yield (Kg ha ⁻¹)	
38	4394.88	a
76	3612.63	b
^h SE	67.52	

Abbreviations: ^hStandard Error

Table 2-19. Soybean yield when different preemergence herbicides were applied pooled across different planting dates in Scandia, Kansas in 2023

Planting date	Preemergence herbicide	Yield (Kg ha ⁻¹)	
Early	sulfentrazone + metribuzin	4509.202	a
Early	flumioxazin + metribuzin	3717.176	b
Normal	sulfentrazone + metribuzin	3812.972	b
Normal	flumioxazin + metribuzin	3776.454	b
^h SE		345.23	

Abbreviations: ^hStandard Error

Table 2-20. Partial budget comparing the return over selected cost (R) at different planting date, row spacing, preemergence herbicide and postemergence herbicides to the non-treated control and weed-free plots at Manhattan in 2022 (MHK22) and Ottawa in 2022 (OTT22) and 2023 (OTT23)

Fixed effects	df	R (US \$/ha)					
		MHK22		OTT22		OTT23	
		F-value	P-value	F-value	P-value	F-value	P-value
Planting date	1	79.87	<0.01	144.81	<0.01	6.38	0.01
Preemergence herbicide	1	1.51	0.23	1.44	0.24	0.09	0.77
Postemergence herbicide	1	1.52	0.22	0.43	0.51	0.71	0.40
Row spacing	1	0.49	0.49	0.59	0.45	0.24	0.63
Planting date*Preemergence herbicide	1	0.03	0.85	0.05	0.83	0.04	0.85
Planting date*Postemergence herbicide	1	0.40	0.53	0.81	0.37	0.19	0.66
Preemergence herbicide*Postemergence herbicide	1	1.07	0.31	1.26	0.27	0.64	0.43
Planting date*Row spacing	1	4.02	0.05	1.11	0.30	0.05	0.83
Preemergence herbicide*Row spacing	1	2.68	0.11	0.02	0.89	0.23	0.63
Postemergence herbicide*Row spacing	1	0.21	0.65	1.62	0.21	0.08	0.78
Planting date*Preemergence herbicide*Post emergence herbicide	1	0.16	0.69	0.03	0.87	0.16	0.69
Planting date*Preemergence herbicide*Row spacing	1	0.86	0.36	6.13	0.02	0.52	0.48
Planting date*Postemergence herbicide*Row spacing	1	0.12	0.73	0.19	0.66	0.15	0.70
Preemergence herbicide*Postemergence herbicide*Row spacing	1	0.61	0.44	0.50	0.48	0.14	0.71
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing	1	1.46	0.23	0.60	0.44	1.53	0.22

Table 2-21. Partial budget comparing the return over selected cost (R) at different planting date in Manhattan in 2022 and OTT23

Planting dates	R (US \$/ha)			
	MHK22		OTT23	
Early	369.57	b	1012.48	b
Normal	1280.67	a	1227.53	a
^h SE	97.26		100.19	

Abbreviations: ^hStandard Error

Table 2-22 Partial budget comparing the return over selected cost (R) of row spacing and preemergence herbicide application were pooled across planting dates in Ottawa, Kansas, 2022

Planting date	Row spacings (cm)	Preemergence herbicide	R (US \$/ha)	
Early	38	sulfentrazone + metribuzin	1131.61	a
Early	38	flumioxazin + metribuzin	1087.87	a
Early	76	sulfentrazone + metribuzin	1006.87	a
Early	76	flumioxazin + metribuzin	1185.36	a
Normal	38	sulfentrazone + metribuzin	613.52	b
Normal	38	flumioxazin + metribuzin	403.13	b
Normal	76	sulfentrazone + metribuzin	573.63	b
Normal	76	flumioxazin + metribuzin	536.07	b
^h SE			71.75	

Abbreviations: ^hStandard Error

Table 2-23. Partial budget comparing the return over selected cost (R) at different planting date, row spacing, preemergence herbicide and postemergence herbicides to the non-treated control and weed-free plots at Scandia in 2022 (SC22) and 2023 (SC23)

	df	R (US \$/ha)					
		SC22		SC23		PAR23	
		F-value	P-value	F-value	P-value	F-value	P-value
Fixed effects							
Planting date	1	1.28	0.26	3.29	0.08	0.85	0.36
Preemergence herbicide	1	0.43	0.52	3.58	0.06	0.45	0.64
Postemergence herbicide	1	0.57	0.45	2.15	0.15	0.96	0.33
Row spacing	1	15.62	0.00	28.90	0.00	1.78	0.19
Planting date*Preemergence herbicide	1	1.25	0.27	4.63	0.04	0.42	0.66
Planting date*Postemergence herbicide	1	0.00	0.97	0.58	0.45	1.00	0.32
Preemergence herbicide*Postemergence herbicide	1	0.14	0.71	0.24	0.63	1.61	0.21
Planting date*Row spacing	1	0.35	0.56	0.00	0.98	0.80	0.38
Preemergence herbicide*Row spacing	1	0.02	0.88	2.07	0.16	0.03	0.97
Postemergence herbicide*Row spacing	1	2.69	0.11	0.32	0.57	0.14	0.71
Planting date*Preemergence herbicide*Post emergence herbicide	1	0.15	0.70	0.10	0.76	0.30	0.59
Planting date*Preemergence herbicide*Row spacing	1	0.03	0.87	1.73	0.19	0.80	0.45
Planting date*Postemergence herbicide*Row spacing	1	1.53	0.22	1.98	0.17	0.12	0.73
Preemergence herbicide*Postemergence herbicide*Row spacing	1	1.45	0.24	0.72	0.40	0.57	0.45
Planting date*Preemergence herbicide*Postemergence herbicide*Row spacing	1	2.15	0.15	1.65	0.21	0.05	0.83

Table 2-24. Partial budget comparing the return over selected cost (R) when soybeans are planted at different row spacings at Scandia 2022 (SC22) and 2023 (SC23)

Row spacings (cm)	R (US \$/ha)			
	SC22		SC23	
38	2041.89	a	2206.07	a
76	1664.78	b	1689.75	b
^h SE	67.52		177.26	

Abbreviations: ^hStandard Error

Chapter 3 - A survey of Integrated Weed Management Practices used by Kansas Soybean Farmers

Abstract

With changing environmental conditions, increasing herbicide resistance, and adoption of new agricultural practices such as earlier planting, Kansas soybean farmers face significant weed management challenges. Although research provides many recommendations, validation of whether experimental results are implemented on farms remains limited. This raises the question: Are Kansas soybean farmers using integrated weed management (IWM) strategies, and if so, how closely do their practices align with research findings across different planting dates? To address this, a questionnaire-based survey was developed in Qualtrics in 2024 and distributed through Kansas State University's social media, extension agents, and printed handouts containing a brief description and QR code. The questionnaire focused on planting trends, problematic weeds, herbicide selection, and farmers' perspectives. By March 2025, 60 responses were collected, including 24 fully completed and 15 partially completed surveys. Data were analyzed using Qualtrics features (Stats IQ, Crosstab IQ, and Reports tab), categorizing planting dates as early (April), mid (May), or late (June) to identify patterns. Survey responses represented 9,780.45 hectares across 37 counties covering all agricultural statistics districts in Kansas (approximately two million hectares statewide). When respondents (n=30) reported soybean planting dates, 35 responses indicated early planting (April), 19 mid-season planting (May), and 6 late planting (June). A follow-up question about intentions to continue early planting received 24 responses, of which 21 (88%) indicated plans to continue this practice. Regarding weed challenges, Palmer amaranth was ranked most problematic by 28 of 29 respondents. When asked about weed management practices, 25 of 28 respondents reported

using IWM strategies. Within this group, 24 (86%) reported herbicide use, 18 (64%) manipulated row spacing, and 17 (61%) adopted cover crops. Among preemergence residual herbicides, pyroxasulfone was the most preferred, selected by 14 of 27 farmers (52%). S-metolachlor was the top choice among postemergence residual herbicides, selected by 16 of 25 respondents (64%). Additionally, narrow row spacing (25.4 cm or 38 cm) was used by 22 of 38 respondents (58%). When asked about satisfaction with current weed management practices, 19 of 24 respondents (79%) expressed satisfaction, whereas 5 respondents (21%) indicated interest in adjustments, such as adding more active ingredients, incorporating cover crops, or modifying burndown timing. Terminology gaps were also identified: some farmers referred to the same herbicides using different names or incorrect terminology, suggesting a need for improved technical communication. Overall, results suggest Kansas soybean farmers are adopting IWM practices and paying close attention to research updates, adapting strategies accordingly. By directly gathering insights from growers, this survey clarifies the extent to which research recommendations are applied on-farm. In the context of rising herbicide resistance, increasing input costs, and sustainability concerns, these findings provide valuable guidance for future research, extension efforts, and practical decision-making in Kansas agriculture.

Introduction

Soybean is one of the most important oilseed crops in Kansas. After World War II, soybean farming underwent an industrial revolution in Kansas and continued to evolve (Ewasiuk, 1953). Currently, soybeans are widely used in various food products such as soy milk, tofu, cooking oils, salad dressings, vegetable shortening, curry, and margarine. Additionally, it serves as raw material for other industrial applications including resins, paints, and biofuels (Thakur & Dhiman, 2016). Due to its diverse use, soybean is an important protein source for both human consumption and animal feed (Hartman et al., 2011) resulting in continuously growing demand (Wilson, 2008). This steadily increasing demand has been linked to long-term stability in the U.S. soybean market, positively contributing to the national GDP (Masuda & Goldsmith, 2009). With this continuously increasing demand, both farmers and researchers are focusing on finding ways to improve yield while tackling major production challenges, like weed management.

Weeds are one of the major problems in soybean cultivation, causing an estimated 37% yield loss globally, which is significantly more than losses from animal pests (11%), pathogens (11%), or viruses (Oerke, 2006). While field experiments provide valuable insights into weed control and yield, on farm results are often influenced by environmental conditions, making it difficult to draw universal conclusions (Soltani et al., 2017). Considering the importance of soybean production in Kansas and across the Midwest region (USDA, 2023), understanding planting trends is essential in improving long-term farming strategies. This is because bridging field research and on-farm practices requires analyzing both historical and current advances in soybean production.

Tracing back the history, soybean farming practices have changed significantly over time, particularly in weed management strategies. Researchers have explored multiple approaches, including narrow row spacing, new herbicides, herbicide-resistant cultivars, postemergence herbicide applications, and no-till farming (Lammers, 2025, Oerke, 2006; Singh et al., 2023; Vencill et al., 2012). Recently, early soybean planting has gained popularity in Kansas, with reports showing a gradual shift toward earlier planting dates by approximately one-third of a day per year (Ciampitti et al., 2017). This shift is believed to be influenced by farmers' efforts to optimize crop rotation, however it is hard to pinpoint the actual reason for this shift. While many reports suggests that early planting of soybean reduces the fecundity of weeds, improves the efficacy of weed management practices (Arsenijevic et al., 2022; Oliveira et al., 2022), and increases competitive ability of soybean (Chen & Wiatrak, 2010; Heatherly, 2005; Heneghan & Johnson, 2017; Schwartz et al., 2016), some reports also suggests that early planting might not be beneficial in soybean cultivation (Andales et.al., 2000; Kane et al.,1997; Steele & Grabau, 1997). In field experiments conducted in Kansas in 2022 and 2023, similar mixed results were observed (Chapter 2). These mixed findings highlight the need to understand the pros and cons of different planting dates for soybeans in Kansas farms. It is also important to assess whether farmers are likely to adjust their weed management practices in response. This is because understanding the practical application of weed management strategies in real-life situations (i.e., farmers' fields) and the farmer's perspective helps ensure that future research is relevant to farmers. Participatory processes, such as farmer surveys, help narrow the gap between research organizations' and farmers' realities and assure farmer involvement in formulating research questions (Hellin et al., 2006). Similarly, farmer feedback helps understand the

economic viability of these practices and provides insight into the sustainability of these change/trends (Prus, 2018).

The primary objective of this study was to understand current weed management and planting practices among soybean farmers in Kansas. Specifically, this survey aimed to analyze farmers' perceptions about early soybean planting, identify the most challenging weed species faced by farmers, evaluate their choice and effectiveness of herbicides, and gain insight into their decision-making processes for weed control. Through exploring farmers' real-world practices, the goal was to bridge existing gaps between field research recommendations and actual farm practices, enhancing the practical relevance and effectiveness of future research (Hellin et al., 2006; Prus, 2018).

Material and Methods

Survey design

Qualitative research was conducted using an online questionnaire (Appendix 3.1) to assess agronomic practices and to identify emerging trends in weed management across Kansas soybean fields. The questionnaire was designed in 2024 using the Kansas State Qualtrics Survey Platform (Qualtrics XM; Qualtrics LLC, Provo, UT). It included 26 questions (combination of multiple-choice, ranking, and open-ended questions), designed using a funnel approach. The first section focused on demographics and general farm characteristics; covering topics like counties where soybeans are grown, total acreage for full-season and double-crop soybeans, soybean maturity groups, row spacing, planting dates and factors influencing planting decisions and plans to continue or modify current planting strategies were covered in this section. The second section was more focused on weed management strategies used by farmers. This section included questions about type of weeds present in the field, weed management practices used to control

them (e.g., herbicide application, tillage, row spacing), residual and postemergence herbicide choices before and after planting, farmers' assessment of herbicide prices and effectiveness on weed control, and frequency of postemergence herbicide applications. The survey ended with questions intended to inform future research, like plans to continue or change weed management practices, suggestions for possible modifications and additional insights.

Questionnaire Validation and Distribution

After preparing the questionnaire, it was validated with K-State Research and Extension Crop Production agents in soybean-producing regions. A sample version was evaluated by the Extension agents and their feedback was used to improve the survey's logic and user friendliness. Approval was received from Kansas State University Institutional Review Board (IRB-12285). The survey was distributed through multiple channels. A brief survey description, QR code, and access link were created for social media posts and other extension-related outreach. The survey was shared through the social media platforms by KSRE and Kansas Soybean accounts and was published on platforms such as Kansas State University's Agronomy eUpdate to reach a wider audience. Additionally, paper copies containing brief information for survey and a QR code were distributed during Extension presentations. All the questions in the survey were self-instructed, meaning participants could skip any questions they would not like to answer. Along with that, to maintain the confidentiality of the participants, identifiable information was not asked in the questionnaire. Additionally, participation was entirely voluntary, and no compensation was provided. As a result, there were no anticipated risks or benefits associated with taking the survey (Pires et al., 2024).

Data collection and Analysis

Survey responses were exported from Qualtrics and initially analyzed with the inbuilt “Results” tab. Data were then reanalyzed using Stat IQ software (an integrated tool within Qualtrics). The “describe” feature was used to autogenerate descriptive statistics, whenever it was appropriate, providing additional insights into the data. Subsequently, the “Results” tab was also used to visualize ranking and ratings for multiple-choice questions. Summary statistics were exported to Excel to create box and whisker plots. Then management practices were ranked by their box plot positioning, with lower boxes indicating greater preference for farmers.

Qualtrics analyzed recorded responses for each question, without imputing missing data. From September 19, 2024, to March 16, 2025, a total of 60 responses were collected. Of these, 24 were fully completed, 15 were partially completed, and 21 were entirely blank. As a result, the number of responses varied across questions. To enable deeper analysis, four workspaces were created to extract information in “Stats IQ,” each with specific filters. These filters helped to categorize the data, making it easier to analyze and interpret trends across different groups. One included all responses, while the other three filtered data based on the planting dates selected by respondents. Planting date categories included Early (April 1–30), Mid (May 1–30), and Late (June 1–30). This classification helped examine differences in farmers’ cultivation practices, preferences, and weed management strategies across different planting dates. Furthermore, the “Crosstab IQ” function was used to understand the relationship between two questions, especially those about demography and planting dates. This tool generated matrices that revealed patterns based on the distribution of responses across categories.

Result and Discussion

Counties and area (Demography)

This survey included farmers from 37 counties across Kansas (54 responses) (Figure 3-1), covering all six agricultural statistics reporting districts in the state (13 responses from Central, 22 from Northeast, 6 from Northwest, 4 from Southwest, 9 from Southwest) (Table 3.1). In Kansas, there are 55,500 farms that cultivates soybeans in 1,812,993 ha (USDA-NASS 2023) area i.e., the average area of soybean cultivated by Kansas farmer is 327 ha. In our research, this area was 352 ha farmer⁻¹ (28 participants reported the acreage), and the average area cultivated with double crop soybean was 54.21 ha farmer⁻¹.

Variety of full-season soybean

A total of 40 responses were collected from 30 participants on the full-season soybean maturity groups used by Kansas farmers. Of these, one response suggested planting from maturity group 1, 20 farmers planted soybean from group 2 to 3, 18 grew varieties in group 3 to 4 and remaining one response grew soybeans IV to V (Table 3.2). Similar to our findings, researchers from Kansas State University have recommended maturity groups 2, 3, 4, and 5 for 2024 (Ciampitti et al., 2022). These results suggest that farmers are selecting soybean maturity groups in line with current recommendations.

Row spacing

Farmers were also asked to report the row spacing they used for soybeans (open ended question). Out of 38 responses, 16 responses reported using 38 cm spacing, 15 used 76 cm spacing and 6 used 24 cm spacing (Table 3.2). This suggests that more than half of the respondents prefer narrower row spacing for soybeans (Table 3.3), possibly to improve yield and weed control. Several studies have reported that narrow row spacing helps suppress weeds and

increases yield by accelerating canopy closure and limiting light availability to weeds (Datta et al., 2017; Heneghan & Johnson, 2017; Lammers, 2025; Oliveira et al., 2022) (Harder et al., 2007).

The preference for narrower rows observed in the survey aligns with findings from our field research and previous literature. In our field research, narrow row spacing provided better weed control and, in some cases, led to higher yield and profitability. This was especially true for two site-years in Scandia. The results from Scandia are also consistent with studies conducted in Michigan, possibly because Scandia is closest to Michigan during the research years in terms of latitudes (Scandia; 39.7989° N, Michigan; 41° N to 49° N) rainfall and temperatures (around 28.5–29°C). In that study, Harder et al. (2007) reported that 38 cm row spacing resulted in both higher yield and greater gross margins compared to wider rows. Overall, both the survey responses and field data suggest that narrow row spacing is a commonly adopted and potentially beneficial practice for soybean production in Kansas.

Planting dates

According to the report from Ciampitti, et al., (2022), the recommended soybean planting window was similar for all Kansas agricultural statistics districts (between May 10 to June 25). Therefore, responses from all regions were categorized using this same date range.

A multiple-choice question was asked about farmer's planting practice and a total of 60 responses were received from 30 participants. Among them, 23 responses indicated early planting in April (14 out of 40 responses from Northeast Kansas indicated early planting), 31 planted in mid-season in May (this response was from all over Kansas), and remaining 6 planted late i.e., in June (1 respondent who replied to this question was Central, 2 were from Southwest and 3 were from Northeast Kansas). Results show that 90% of respondents (44 out of 49)

completed planting by May 30 (Table 3.3), with only 10% planting later. Although respondents could select multiple planting dates, most did not choose dates beyond May. Similarly, USDA Crop Progress Reports indicate that 75% of soybeans in Kansas were planted by May 30 in 2022, and 67% in 2023. This suggests that our sample is representative of the broader planting trends in the state (USDA-NASS, 2022, 2023).

This questionnaire also investigated farmers' intentions regarding early soybean planting. Of the 24 respondents who answered this question, 21 stated that they already plant early and intend to continue the practice. These responses came from 20 out of 21 farmers who planted early-season in April, 17 out of 23 in mid-season (May), and 3 out of 4 in late-season (June) (Table 3.4). This indicates that most farmers avoid planting late in the season and even the ones planting later in the season prefer planting soybeans earlier.

One plausible reason for this shift is that in the Midwest region of the U.S.A., soybean yield tends to decrease rapidly when planting is delayed beyond a critical date, and this date can vary across site-years, which is similar to what we observed in our field results (Egli & Cornelius, 2009). Another reason could be that planting earlier gives soybeans a longer growing period and allows the crop to accumulate more growing degree days, which can lead to higher yield potential (Miranda et al., 2021). When crops are planted earlier, they establish their canopy faster, which shades the soil surface and reduces light availability for weeds. This limits weed germination, growth, and dry matter accumulation, and ultimately reduces their seed production (Oliveira et al., 2022). Our field research in 2022 and 2023 also supports this, along with other studies that show early planting improves weed control across locations and years (Arsenijevic et al., 2022). Similar findings were reported in a Kansas State University Agronomy eUpdate by Ciampitti et al. (2022), which noted that many Kansas farmers are already planting soybeans

earlier than the traditionally recommended window. This further confirms the ongoing shift toward early planting across the region.

Factors affecting planting dates

Farmers were also asked to rate different planting dates—early, mid, and late—on a scale from excellent to poor in terms of weed control, disease impact, yield, and logistics (Table 3.5). Early planting was most often rated excellent for weed control (9 of 18), reducing disease (7 of 18), and increasing yield (11 of 18). It was rated good for logistics (10 of 22). Mid planting was generally rated good for weed control (10 of 17), disease (12 of 17), and yield (11 of 17), and excellent for logistics (11 of 23). Late planting received mostly fair ratings for weed control and yield (7 of 16 each), good for disease control (9 of 16), and good for logistics (10 of 20) (Table 3. 5). These responses suggest that farmers may be adapting their planting schedules based on the perceived agronomic and operational performance of each window.

When asked what factors affected planting date decisions, 16 farmers reported that they considered the weather and temperature conditions and 16 cited moisture and soil conditions as crucial factors. Crop rotation timing and irrigation schedule also played a significant role (6 mentions), with some aligning soybean planting after corn planting or according to irrigation schedules.

A smaller number (4 mentions) considered agronomic research, suggesting that early planting increases the length of reproductive period and yield. Two respondents also mentioned weed and pest management and maturity group selection as influencing factors. Farmers' focus on extending the reproductive period and choosing suitable varieties may reflect their understanding of soybeans' photoperiod sensitivity, as soybeans are short-day plants. The developmental rate of soybeans is maximized when grown under photoperiods shorter than a

critical threshold, which varies by maturity group (Thomas & Raper Jr, 1983). Early-maturing soybean cultivars are typically bred to be less sensitive to longer daylight periods. Research also indicates that longer photoperiod delays flowering across all soybean varieties, a scenario typically associated with late planting. Nevertheless, planting early-maturing soybean varieties early in the season allows the crop to benefit from shorter photoperiods, thereby extending the reproductive period. However, excessive delays in maturity can expose soybeans to fall frost, ultimately reducing seed yield and quality (Ort et al., 2022).

These responses indicate that Kansas farmers (particularly the survey respondents) are proactive in staying informed and adapting their practices to enhance sustainability and productivity. Overall, these results suggest that Kansas farmers make informed planting decisions by balancing environmental factors, logistics, and research-based insights to optimize yield and reduce production risks.

Weeds

The survey asked farmers to rank the most problematic weeds in Kansas through a closed-ended question that included nine specific weeds and one 'other' category. The weeds were selected based on personal experience (Appendix 3.1). Responses were analyzed in the 'Results' tab of Qualtrics, and each weed was assigned a rank based on its mean score (lower scores indicated higher severity). Palmer amaranth was identified as the most problematic weed with 28 out of 29 respondents ranking it first, followed by ragweed species (common and giant), horseweed/marestail, morningglory species, common cocklebur, kochia, velvetleaf, common lambsquarters, and American black nightshade (Table 3.6). Twenty-three out of 29 respondents ranked "other" weeds as the least problematic weed. However, seven respondents gave them a

higher ranking (two respondents ranked them 4th, and the remaining five gave them isolated rankings of 3rd, 5th, 6th, and 8th).

When weed rankings were examined by planting date, early (April) and mid (May) plantings were similar to overall results. However, rankings for late-planted soybeans (June) varied. While Palmer amaranth (1st), ragweed species (2nd), nightshade (9th), and "other" weeds (10th) remained in consistent positions, kochia ranked third in June plantings, followed by velvetleaf, morningglory, common cocklebur, and horseweed. These findings reflect seasonal weed shifts similar to emergence patterns reported in Iowa (Rodrigo, 2014).

Overall, these findings indicate that weed species composition shifts with soybean planting date (Rodrigo, 2014). Nonetheless, pigweeds (*Amaranthus species*) remain as the most persistent challenge for Kansas soybean farmers. This is likely due to the evolution of herbicide resistance in them.

Farmers also identified other problematic weeds, including johnsongrass (3 mentions), shattercane (2), fall panicum (2), hophornbeam copperleaf (1), henbit (1), volunteer corn (1), field bindweed (1), and waterhemp species (1). Later-emerging grasses and shattercane were specifically noted as rising concerns in soybean fields. A similar trend of late-season grass emergence has been reported in previous research from Iowa (Rodrigo, 2014).

Integrated weed management practices (IWM)

To manage weeds, 25 out of 28 farmers reported using IWM practices. In response to a multiple-choice question about specific weed management strategies, 25 farmers detailed the approaches they use. Of these, 24 reported using herbicides, 18 manipulated row spacing, 17 used cover crops, 6 practiced tillage, and 3 adopted other management methods. Details on the selection of each weed management practice by geographic location are presented in Table 3.1.

The multiple responses provided by farmers suggest that IWM strategies are increasingly viewed as effective tools to manage herbicide-resistant weeds. Past research also supports this view, indicating that IWM helps suppress weeds in the field by reducing overdependence on herbicides, ultimately contributing to more resilient and cost-effective weed control systems (Knezevic, 2014; Oerke, 2006). The high number of responses citing herbicide use in this survey shows that while farmers are exploring alternative practices, they still primarily rely on herbicides. This may be due to their proven effectiveness and ease of access (Gianessi, 2013). Additionally, many farmers expressed an interest in adjusting row spacing, indicating a willingness to modify their production practices to improve weed management. Although farmers are adopting a variety of practices such as manipulating row spacings, cover crops, and mechanical methods, research has shown that weeds often adapt and escape these strategies (McLalchlan et. al., 1993). This underscores the importance of including herbicides in an integrated management plan.

An open-ended follow-up question was included to gather additional information about 'other' weed management practices used by farmers. Results showed that farmers used crop rotation (2 mentions; respondents planted soybeans in Thomas, Logan and Brown County). Similarly, other practices included no-till (1 mention), scouting and adaptive management (1), and hand rogueing (1), all reported from Brown County.

While a few farmers reported using hand rogueing and scouting, these methods are highly labor- and time-intensive. Given the current labor shortage in agriculture, such approaches are not easily adopted on a wider scale. Compared to herbicide application, adjusting row spacing, or using cover crops and tillage, these manual methods are less practical. These results support earlier research, which noted that farmers are increasingly moving away from labor-intensive

practices in favor of herbicides due to their affordability, availability, and ease of use (Gianessi, 2013). In fact, another report estimated that replacing herbicides with tillage and hand weeding would lead to a 20% reduction in soybean yield. Moreover, it would require around 70 million workers to manually prevent yield losses without herbicide use (Gianessi & Reigner, 2007). This helps explain why only a small number of respondents mentioned using tillage or hand weeding as part of their weed management strategy.

Farmer's perception on herbicides

Herbicides that were presented were the active ingredients listed in K-State Chemical Weed Control Guide (Lancaster et al., 2024).

Preplant/emergent residual herbicides. Farmers were asked to identify which residual herbicide active ingredients they used in preplant applications (multiple-choice question). Twenty-seven respondents answered the question. The data show that 14 farmers (52%) preferred using pyroxasulfone. Metribuzin, sulfentrazone, and S-metolachlor/metolachlor were also frequently used, each receiving more than 10 selections (Table 3.7). This preference may be due to the proven efficacy of these herbicides in weed control. According to research from Canada, pyroxasulfone provided more consistent weed control than sulfentrazone. The same study also reported that tank mixes of pyroxasulfone or sulfentrazone with imazethapyr and metribuzin controlled more than 90% of common lambsquarters and velvetleaf two weeks after treatment. However, they also noted that the effectiveness of these combinations could vary depending on the weed population and species present (Yamaji, Honda, Kobayashi, Hanai, & Inoue, 2014). Similarly, field trials from 1995 and 1996 showed that S-metolachlor was effective in controlling grass weeds (O'Connell, et.al., 1998). These findings suggest that farmers in this

survey tended to prefer herbicides that are widely documented to be effective across different weed types and conditions.

When asked about additional herbicides, three farmers mentioned dicamba (which is currently not labeled for postemergence applications in soybean, however, it can be used as a preplant herbicide for residual weed control), and one mentioned Authority Supreme, a combination of sulfentrazone and pyroxasulfone (these active ingredients were already present in the list). Overall, all herbicides included in the survey received at least five selections, indicating their widespread use among farmers. This suggests farmers are routinely using wide range of available herbicides indicating an awareness of herbicide resistance management recommendation among farmers.

When analyzed by planting date (separate tabs were created for planting dates), it was observed that at early- and mid-planting, most of the farmers preferred using pyroxasulfone and for late-planting, they preferred acetochlor (Table 3.7). This suggests that when farmers change their planting dates, they are likely to adjust their herbicide programs accordingly. One possible reason is that environmental conditions such as temperature and rainfall also change with planting date, comparable situation was observed in our field research. Similarly, a review paper noted that environmental factors like CO₂ levels, light, temperature, relative humidity, and soil moisture can all affect herbicide uptake, translocation, and overall activity (Varanasi et.al., 2016). Additionally, a field trial conducted in Ontario reported that environmental conditions, especially precipitation, influence herbicide efficacy, and therefore, growers need to consider weather conditions when planning herbicide applications (Stewart et.al., 2012). Overall, this shows that farmers are making herbicide decisions not just based on weed infestation, but also in response to changing environmental conditions across planting dates.

Additionally, the survey asked whether farmers include multiple active ingredients in their herbicide applications. This question helped in understanding whether farmers are aware about using herbicides with multiple mode of action in controlling weeds. A total of 26 responses were gained among which most of the farmers were mixing two herbicides (14 mentions) followed by three herbicide mixture (10 mentions). Only two responses indicated they use a single active ingredient. These findings align with research emphasizing the importance of using multiple modes of action to reduce herbicide resistance (Arbuckle & Lasley, 2013; Sarangi & Jhala, 2018). Overall, these data suggest that Kansas farmers are incorporating these recommendations into their weed management programs.

Postemergence residual herbicide application. Similar to the preplant herbicide section, farmers were shown a list of residual postemergence herbicides and were asked to select those they used in their fields. A total of 25 responses were collected. These responses were turned into ranking based on the summary statistics derived from “results” tab of Qualtrics. Based on selection frequency, the herbicides were ranked as follows: S-metolachlor (16 selections), pyroxasulfone (10), acetochlor (7), dimethenamid (5), and pendimethalin (1). An additional 7 responses were categorized as ‘other’ (Table 3.8). Responses were then separated based on planting date. In both early and mid-planting windows, most farmers preferred S-metolachlor or metolachlor; however, for late-planted soybeans, pyroxasulfone was the herbicide of choice.

Perceived economic value provided by the preplant residual herbicides. Farmers were requested to rate nine residual herbicides based on their effectiveness in controlling pigweeds (*Amaranthus* species; Figure 3-2), large-seeded broadleaf weeds (Figure 3-3), grass weeds (Figure 3-4), and their perceived cost (Figure 3-5).

Data from Table 3.9 were visualized using the ‘Reports’ tab in Qualtrics to generate summary statistics. These results were then used to create box-and-whisker plots in Excel, as shown in Figures 6, 7, 8, and 9. Herbicides were ranked in each category based on their mean scores, with lower values indicating better perceived performance. Results indicated that pyroxasulfone was rated as the most effective residual herbicide for controlling both pigweeds and grass weeds. However, it was also perceived as the most expensive option. In contrast, imazethapyr was rated the least effective herbicide in controlling pigweeds and grass weeds (Table 3.9), and the second most expensive herbicide. Nonetheless, it ranked fourth in controlling large-seeded broadleaf weeds. These findings suggest that imazethapyr may not be a preferred herbicide among Kansas soybean farmers.

Other postemergence herbicides. The survey asked farmers to list the other herbicides that they used in the field. The data suggest that the majority of respondents (24 mentions) listed herbicides that had already appeared in the previous question. Additionally, two respondents listed the same active ingredients under different trade names. Of the herbicides mentioned, 30 were residual and 43 were non-residual (Table 3.9). While data suggest that many farmers include residual herbicides in their postemergence applications, which is a good sign, the repeated listing of the same herbicides under different trade names is concerning. This reflects a gap in terminology among farmers, researchers, Extension agents, and the agricultural industry. Among the ‘other’ postemergence herbicides listed, glufosinate (13 mentions) and glyphosate (11 mentions) were the most commonly used, out of a total of 73 responses. When analyzed by planting date, glyphosate was mentioned 9 times in early planting and 10 times in mid planting. Glufosinate was mentioned 10 times in both early and mid-planting windows. For late-planted soybeans, pyroxasulfone was mentioned most frequently (2 out of 9 mentions) (Table 3.10).

Number of postemergence herbicide applications. Twenty-five farmers responded to the question about the number of postemergence herbicide applications used in their soybean fields. Of these, 11 farmers applied postemergence herbicide only once, 5 applied it twice, and 9 made applications based on scouting observations. These responses suggest that even though scouting-based applications are less common, many farmers evaluate the economic benefit of applying herbicides based on field conditions.

Perceived economic value provided by postemergence herbicides. Similar to residual preplant herbicides section, farmers were asked to rate eight postemergence herbicides (post to crop emergence) based on their effectiveness in controlling pigweeds (*Amaranthus* species; Figure 3-2), large-seeded broadleaf weeds (Figure 3-3), grass weeds (Figure 3-4), and their perceived cost (Figure 3-5).

Based on these responses, dicamba was rated as the most effective herbicide in controlling both pigweeds, large-seeded broadleaf weeds, receiving the highest number of first-place rankings. In contrast, glyphosate was rated as the most effective for grass weed control and was also perceived as the most affordable option.

These results are supported by previous research from Canada, which found that tank mixes of dicamba and glyphosate improved control of redroot pigweed, common ragweed, common lambsquarters, and lady's thumb by 14%, 3%, 7%, and 5%, respectively, up to eight weeks after emergence (Underwood et al., 2017). The same study also reported that dicamba alone or tank-mixed with glyphosate could provide broadleaf weed control for up to six weeks after application. However, both glyphosate and dicamba were found to be less effective when used alone for grass weed control.

Overall, this suggests that farmers are choosing postemergence herbicides based on how well they target specific weed types and their cost which highlights the importance of matching herbicide selection with field-level weed infestation.

Future plans. When asked whether they intended to continue their current weed management practices, 24 farmers responded. Of these, 19 were satisfied with their current approach, while 5 indicated a desire to make changes. Among the five who wanted to make changes, two planned to add new active ingredients to their herbicide mixtures, one mentioned the need for more research, one considered adding a cover crop, and one intended to apply an earlier burndown. These results indicate that while a few farmers are interested in changing and improving their weed management practices, the majority are satisfied with their current strategies.

Farmers' suggestions

At last, the survey concluded with an open-ended question inviting farmers to share any additional comments. 4 people responded to this question by requesting customized herbicide recommendation and tank mixes for their farm, 1 mentioned that late flush of grass is a problem in their field and one mentioned that pigweed is the only challenge in north-central Kansas.

Conclusion:

Kansas soybean farmers demonstrated a clear preference for early planting and integrated weed management strategies, aligning well with recent agronomic recommendations.

Amaranthus species (pigweed) remains the leading weed challenge across different planting schedules, highlighting an urgent need for focused research and effective management solutions. Farmers expressed high satisfaction with current herbicide practices but showed willingness to adapt if provided with targeted research insights.

While most practices aligned with research, a few gaps were still noticeable, mainly in terminology use, access to site-specific recommendations, and practical translation of research at the farm level. These areas could benefit from better coordination among farmers, researchers, and industry.

Overall, these survey findings underscore the value of engaging directly with farmers to ensure research remains practical, relevant, and actionable, ultimately helping bridge the gap between scientific findings and real-world soybean production.

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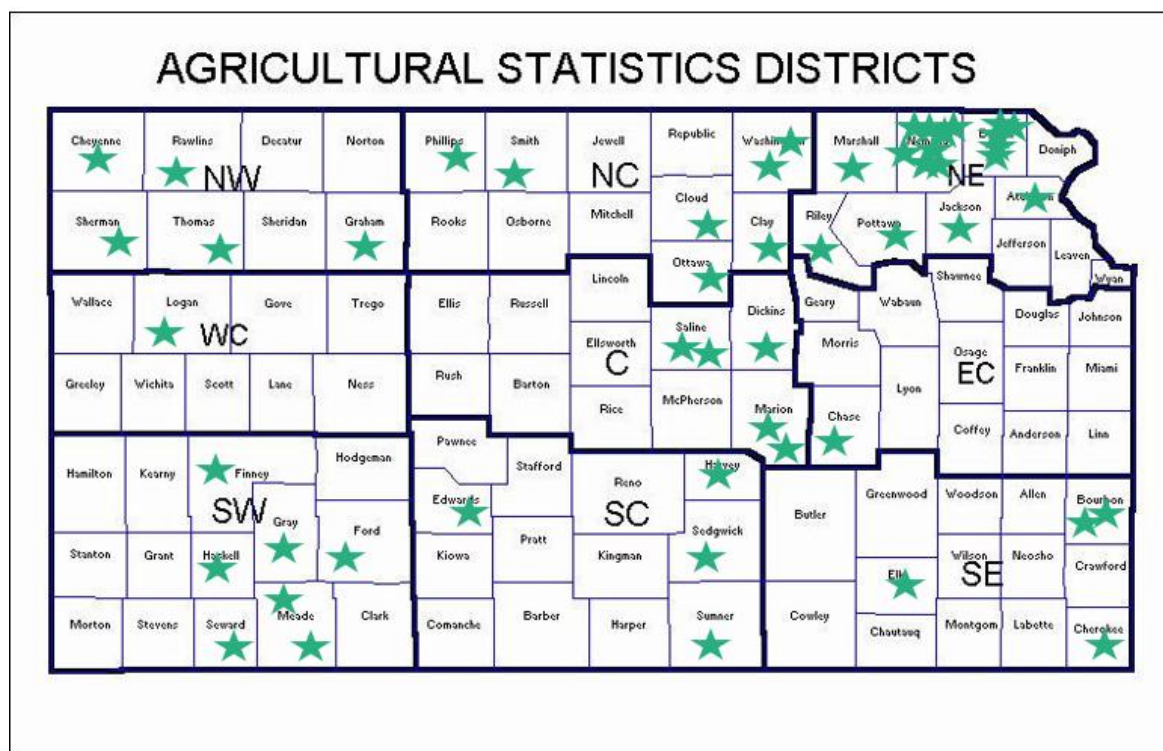


Figure 3-1. Responses acquired from each agricultural statistics districts

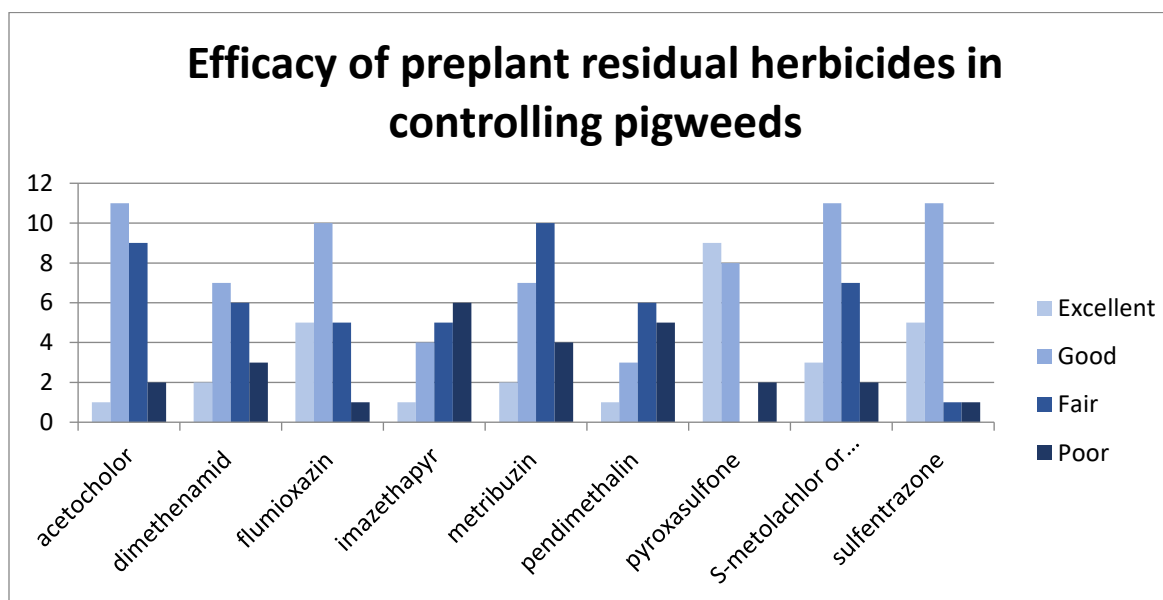


Figure 3-2. Respondents impression of residual herbicides in controlling pigweed

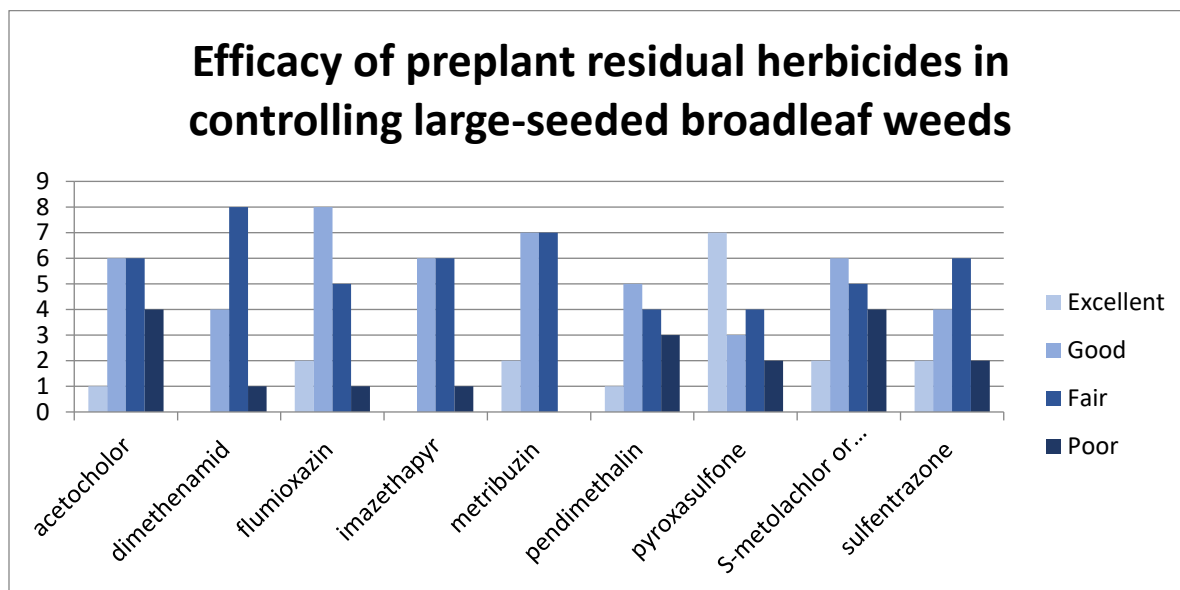


Figure 3-3 Respondents impression of residual herbicides in controlling large-seeded broadleaf weed

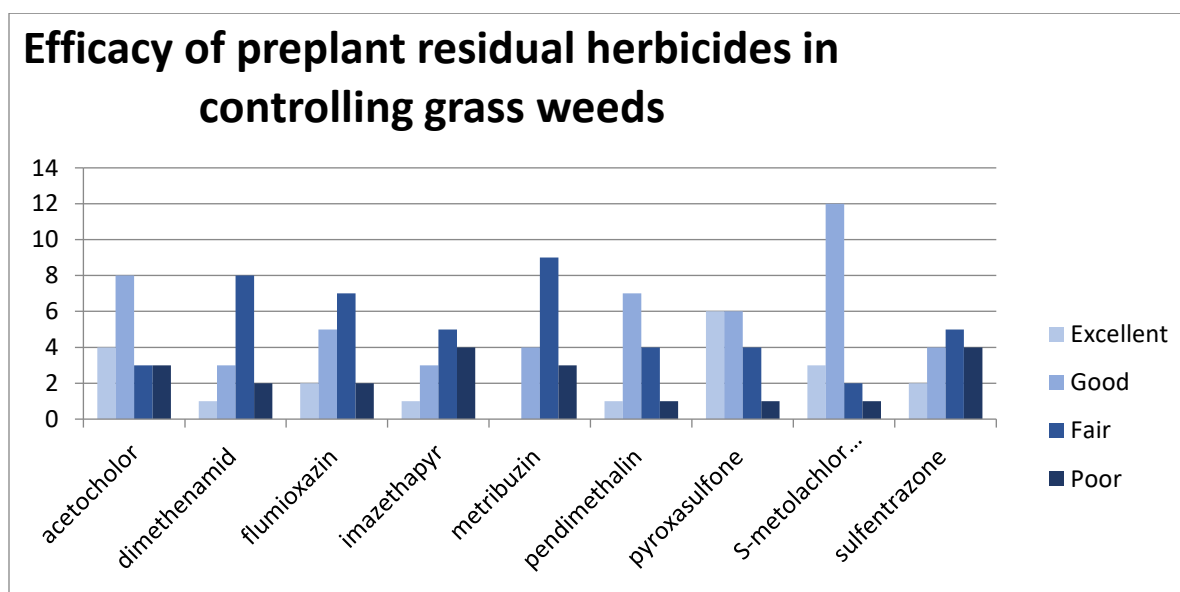


Figure 3-4 Respondents impression of residual herbicides in controlling grass weeds

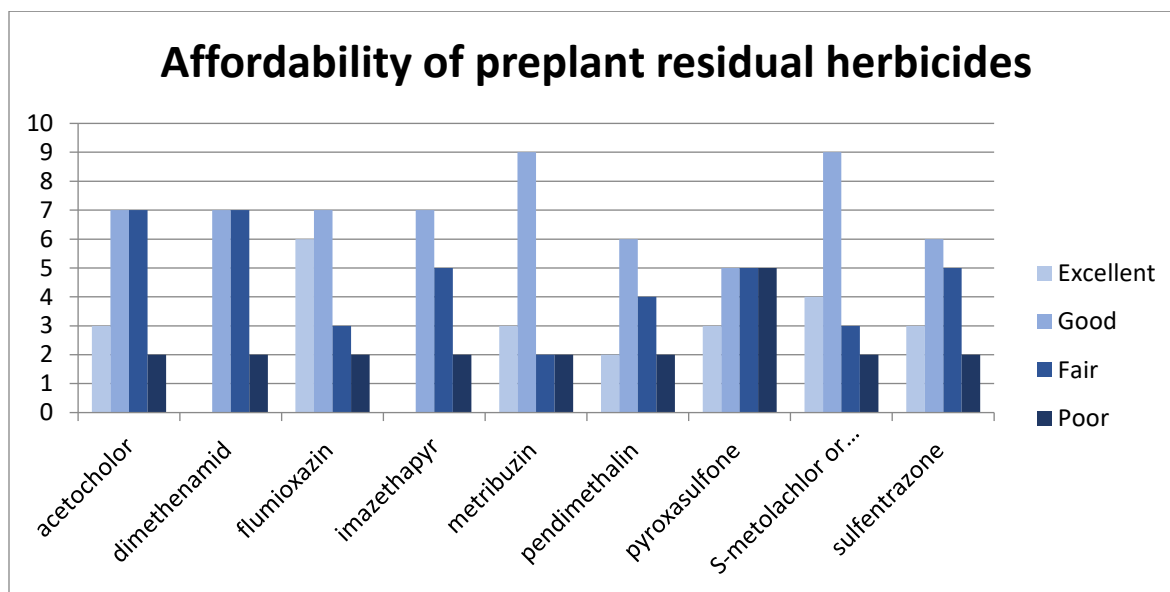


Figure 3-5 Respondents impression of the prices of residual herbicides.

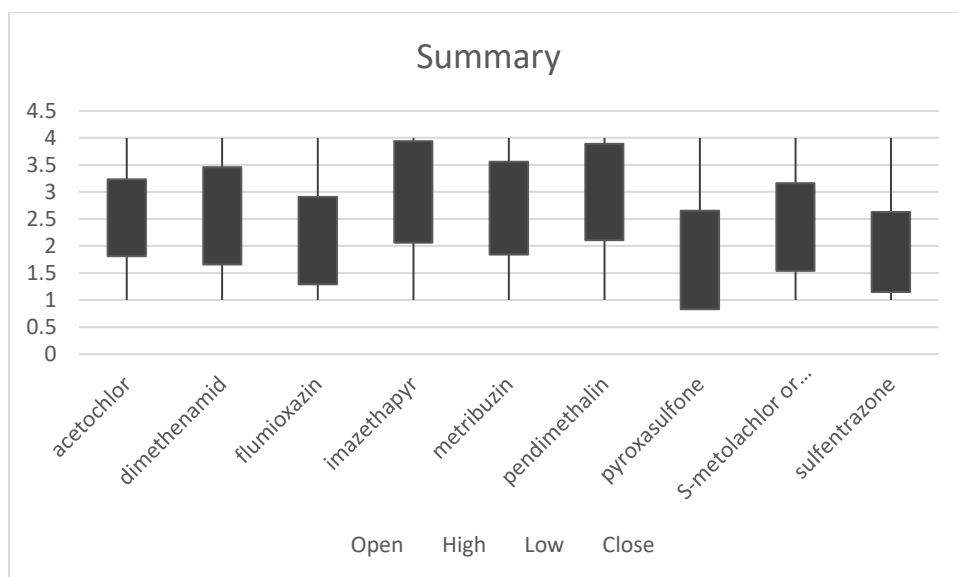


Figure 3-6 Summary of preplant residual herbicide ratings based on survey responses for pigweed control

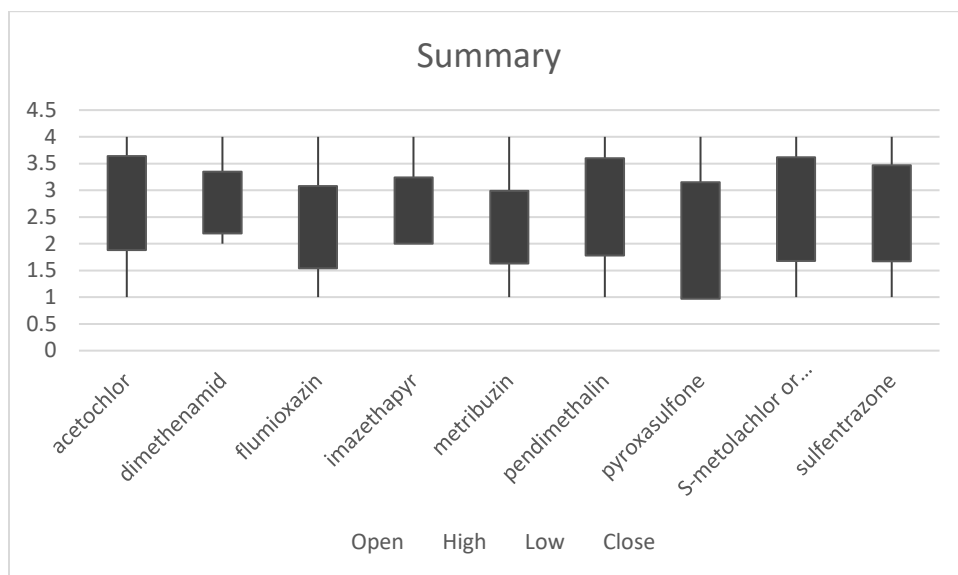


Figure 3-7 Summary of preplant residual herbicide ratings based on survey responses for large-seeded broadleaf weed control

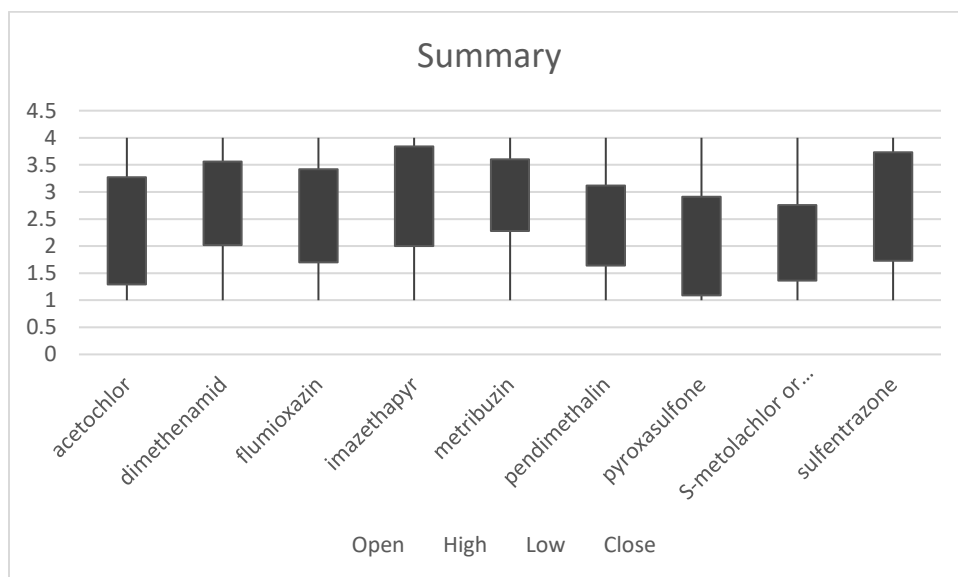


Figure 3-8 Summary of preplant residual herbicide ratings based on survey responses for grass weed control

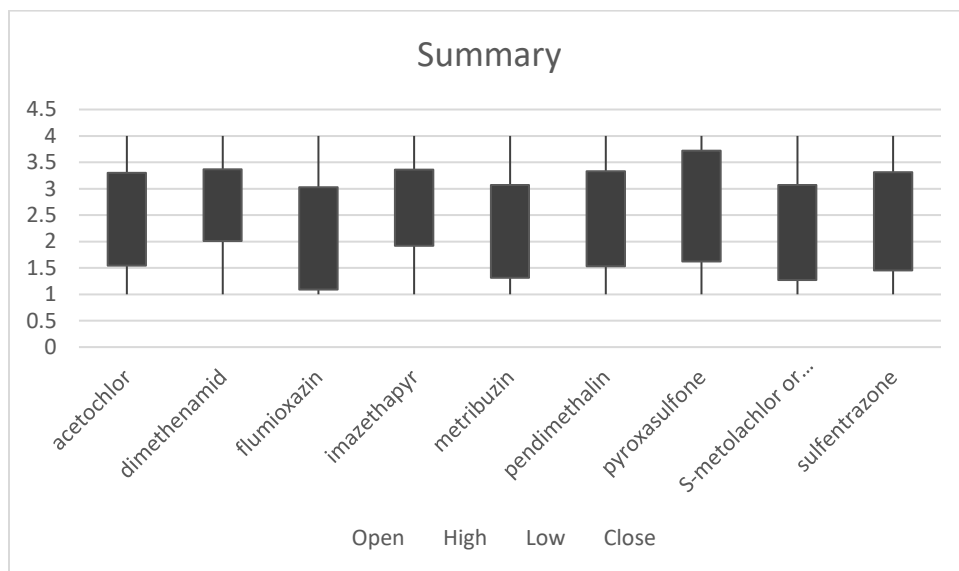


Figure 3-9 Summary of preplant residual herbicide ratings based on survey responses for affordability of preemergence residual herbicide

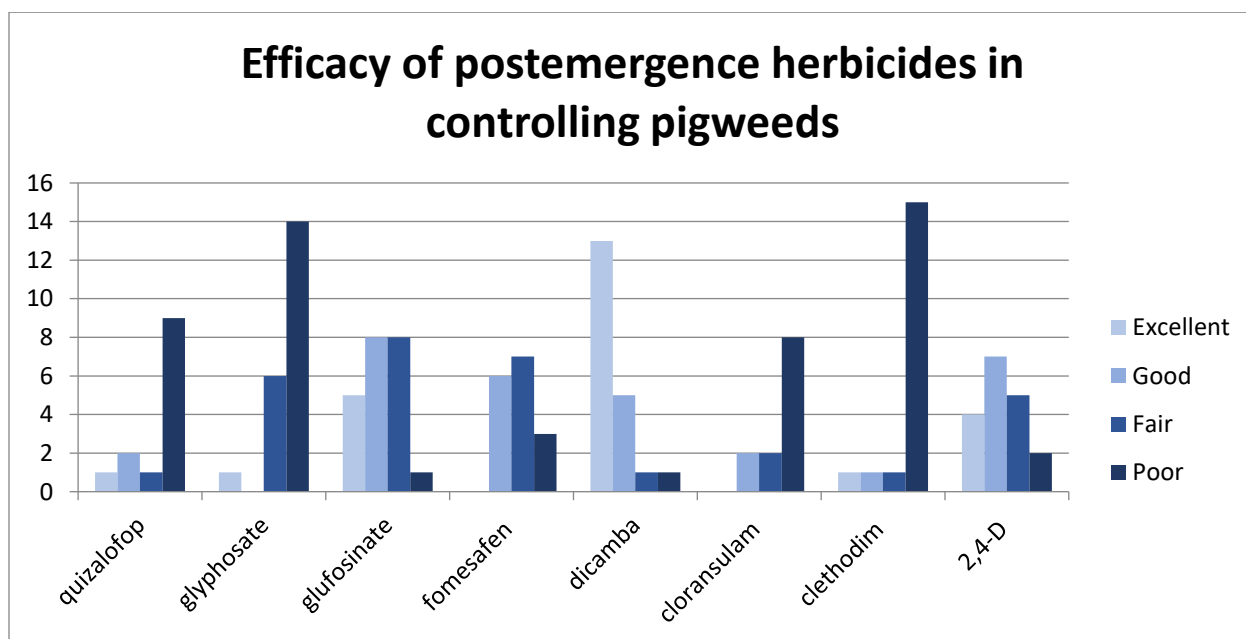


Figure 3-10 Respondents impression of postemergence herbicides in controlling pigweeds

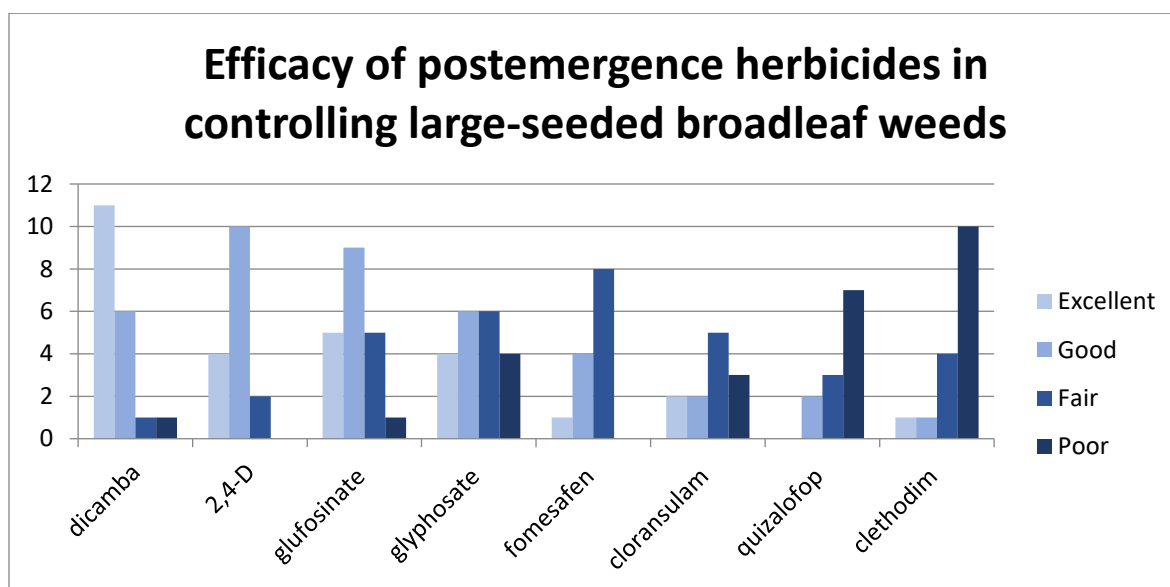


Figure 3-11 Respondents impression of postemergence herbicides in controlling large-seeded broadleaves.

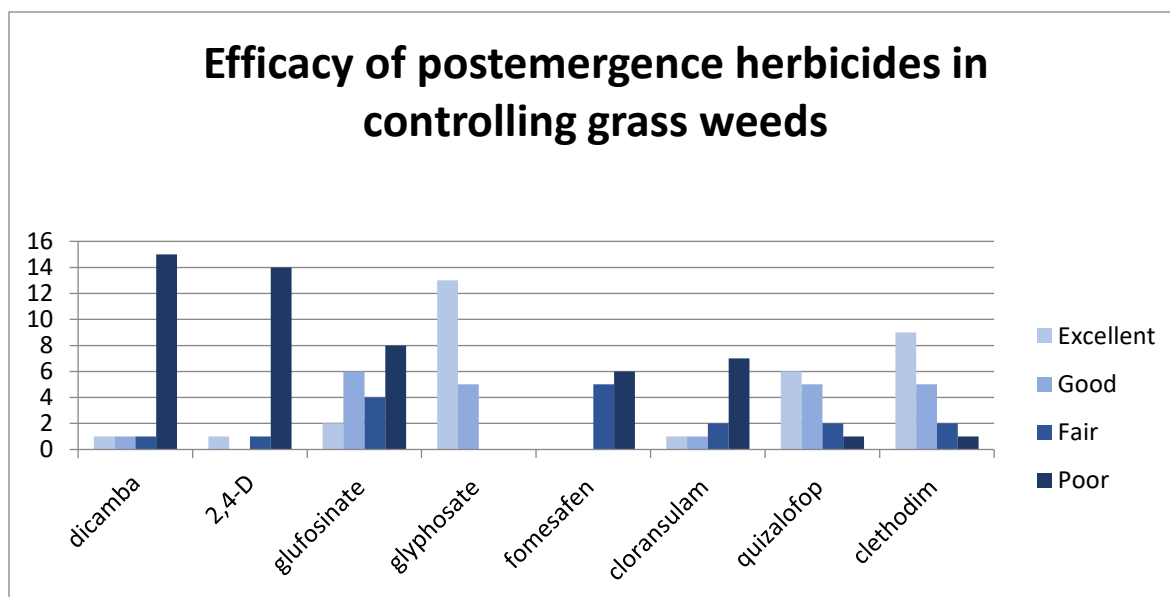


Figure 3-12 Respondents impression of postemergence herbicides in controlling grass weeds

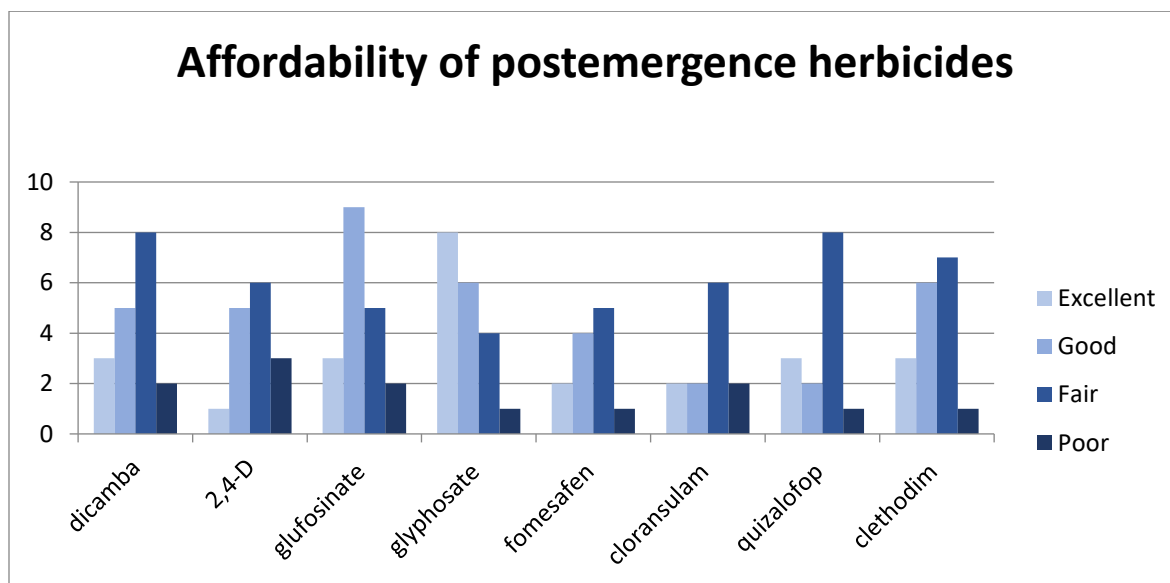


Figure 3-13 Respondents impression of the prices of postemergence herbicides

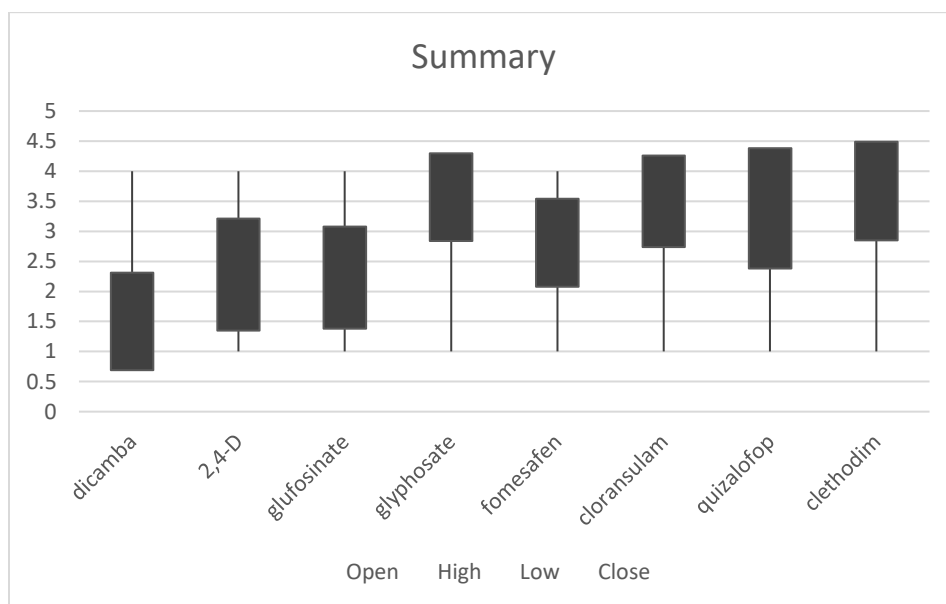


Figure 3-14 Summary of postemergence herbicide ratings based on survey responses for pigweeds control

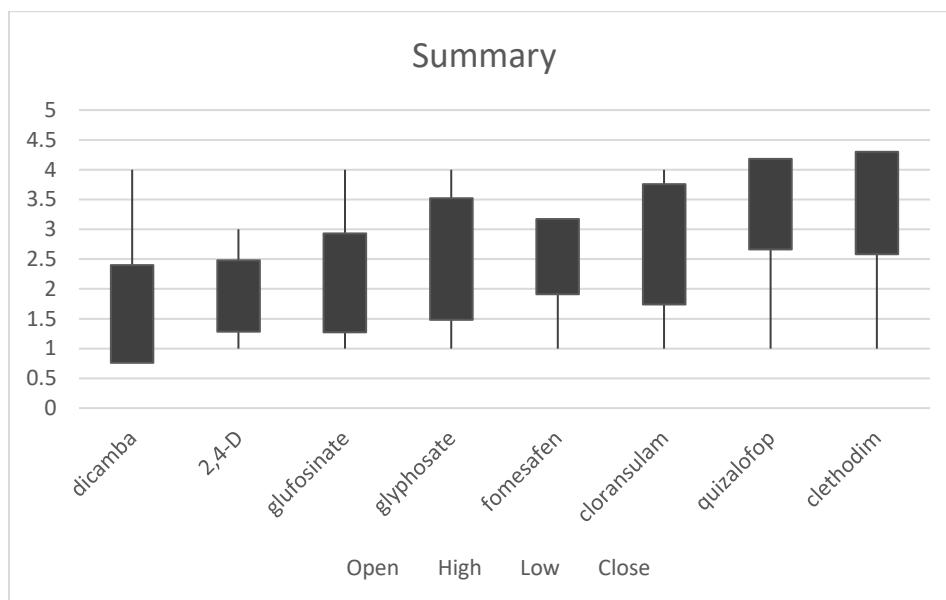


Figure 3-15 Summary of postemergence herbicide ratings based on survey responses for large-seeded broadleaf weed control

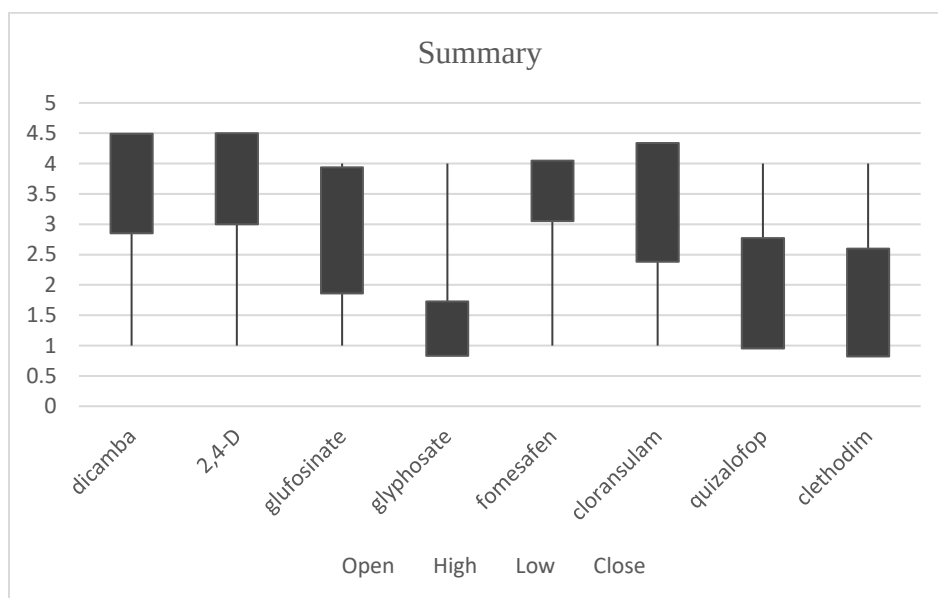


Figure 3-16 Summary of postemergence herbicide ratings based on survey responses for grass weed control

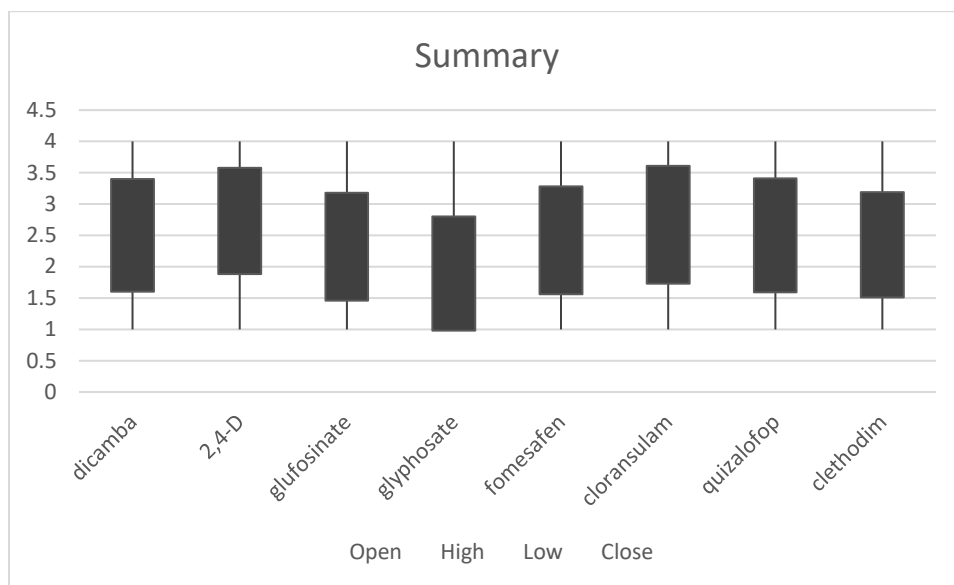


Figure 3-17 Summary of postemergence herbicide ratings based on survey responses for affordability of preemergence residual herbicide

Table 3-1. Selected counties and the agricultural statistics districts of soybean cultivation, number of responses per county and the weed management practices selected by respondents from each county in Kansas State.

Name of counties	Count of response	Agricultural Statistics		Weed management practices			
		District	Herbicide	Tillage	Row spacing	Cover crop	Other
Sedgwick	1	Central	1	1	1	0	0
Harvey	1	Central	0	0	0	0	0
Sumner	1	Central	0	0	0	0	0
Chase	1	Central	0	0	0	0	0
Saline	2	Central	1	0	1	0	0
Phillips	1	Central	1	0	1	0	0
Marion	2	Central	1	0	0	0	0
Riley	1	Central	1	0	0	0	0
Ottawa	1	Central	0	0	0	0	0
Smith	1	Central	1	0	0	1	0
Cloud	1	Central	0	0	0	0	0
Total	13		6	1	3	1	0
Dickinson	1	Northeast	1	0	0	0	0
Clay	1	Northeast	0	0	0	0	0
Pottawatomie	1	Northeast	0	0	0	0	0
Nemaha	9	Northeast	5	0	4	4	0
Marshall	1	Northeast	1	0	0	1	0
Jackson	1	Northeast	1	0	1	1	0
Brown	5	Northeast	5	1	5	5	2
Washington	2	Northeast	1	0	0	0	1
Atchison	1	Northeast	1	0	1	1	0
Total	22		15	1	11	12	3
Cheyenne	1	Northwest	0	0	0	0	0
Thomas	1	Northwest	1	0	1	1	0
Logan	1	Northwest	1	0	1	1	0

Name of counties	Count of response	Agricultural Statistics District	Weed management practices				
			Herbicide	Tillage	Row	Cover	Other
					spacing	crop	
Rawlins	1	Northwest	0	0	0	0	0
Sherman	1	Northwest	0	0	0	0	0
Graham	1	Northwest	0	0	0	0	0
Total	6		2	0	2	2	0
Bourbon	2	Southeast	0	0	0	0	0
Elk	1	Southeast	1	1	0	0	0
Cherokee	1	Southeast	1	0	0	1	0
Total	4		2	1	0	1	0
Haskell	2	Southwest	2	1	2	1	0
Meade	2	Southwest	2	2	2	2	0
Seward	1	Southwest	1	1	1	1	0
Finney	1	Southwest	1	1	1	1	0
Ford	1	Southwest	1	1	1	1	0
Gray	1	Southwest	1	1	1	1	0
Edwards	1	Southwest	1	1	1	1	0
Total	9		9	8	9	8	0

Table 3-2. Survey responses on soybean maturity groups and row spacings.

Soybean maturity groups	Number of responses	Row spacings (cm)	Number of responses
1	1	25	6
2 to 2.9	20	38	16
3 to 3.9	18	51	1
4 to 5	1	76	15
Total	40		38

Open ended question; N=30, Abbreviation: Sample size; N

Table 3-3. Ranges of soybean planting dates, frequency of selection of each range, options for planting dates in questionnaire, dates and frequency of selection of each option

Ranges for planting date	Number of responses	Planting dates in questionnaire	Number of responses
		April 1 to 15	6
Early-planting	23	April 16 to 30	17
		May 1 to 15	18
Mid-planting	31	May 16 to 31	13
		June 1 to 15	4
Late-planting	6	June 16 to 30	2

Multiple choice question; N=49, Abbreviation: Sample size; N

Table 3-4. Responses on continuing early soybean planting according to full-season soybean planting periods

Time at which full-season soybeans were planted	Groups for planting date	Groups in questionnaire	Plan to continue early-planting		
			Total response	Yes	No
	Early-planting	April 1 to 15	5.0	5.0	0.0
	planting	April 16 to 30	16.0	15.0	1.0
	Mid-planting	May 1 to 15	15.0	13.0	2.0
	planting	May 16 to 31	8.0	5.0	3.0
	Late-planting	June 1 to 15	3.0	2.0	1.0
	planting	June 16 to 30	1.0	1.0	0.0

Multiple choice question; N=25, Abbreviation: Sample size;N

Table 3-5. Impression of soybean planting dates on weed control, diseases, yield and logistics

Rating	Weed Control			Diseases		
	Early planting	Mid planting	Late planting	Early planting	Mid planting	Late planting
Excellent	9	5	2	7	4	5
Good	6	10	3	7	12	9
Fair	2	1	7	4	0	1
Poor	1	1	4	0	1	1
Rating	Yield			Logistics		
	Early planting	Mid planting	Late planting	Early planting	Mid planting	Late planting
Excellent	11	4	1	4	11	4
Good	6	11	6	11	6	11
Fair	0	1	7	1	0	1
Poor	1	1	2	1	1	1
Excellent	11	4	1	4	11	4

Single rating for each category at each planting date, N for weed control=26, disease=24, logistic=23 and yield=24,
Abbreviation: Sample size;N

Table 3-6. Ranking of troublesome weeds in Kansas, with 1 being the most troublesome and 10 being the least

Weeds	Min	Max	Mean	Rank	Standard		Responses	Sum
					Deviation	Variance		
Pigweed (Palmer amaranth or waterhemp)	1.00	4.00	1.10	1	0.55	0.30	29.00	32.00
Ragweed species	2.00	9.00	4.07	2	1.80	3.24	29.00	118.00
Horseweed/marestail	1.00	10.00	4.48	3	2.37	5.63	29.00	130.00
Morningglory species	2.00	10.00	4.72	4	1.95	3.79	29.00	137.00
Cocklebur	2.00	9.00	4.90	5	1.69	2.85	29.00	142.00
Kochia	2.00	10.00	5.52	6	2.75	7.56	29.00	160.00
Velvetleaf	2.00	10.00	5.86	7	2.58	6.67	29.00	170.00
Lambsquarters	5.00	9.00	7.45	8	1.07	1.14	29.00	216.00
Nightshade	6.00	10.00	7.93	9	1.20	1.44	29.00	230.00
Other	3.00	10.00	8.97	10	2.16	4.65	29.00	260.00

N=29, Abbreviation: Sample size; N

Table 3-7. Frequency of selection of preplant residual herbicides as a whole and based on planting dates

Residual herbicides	Number of responses			
	Overall (N=27)	Early planting (April) (N=17)	Mid planting (May) (N=18)	Late planting (June) (N=4)
acetocholor	9	7	6	1
flumioxazin	7	4	6	2
metribuzin	10	6	7	0
pyroxasulfone	14	10	9	1
sulfentrazone	10	6	8	1
dimethenamid	5	3	3	2
imazethapyr	0	0	0	0
pendimethalin	2	1	1	1
S-metolachlor or metolachor	10	8	7	1
Other	4	1	4	0

Abbreviation: Sample size; N

Table 3-8. Postemergence residual herbicides and their overall frequency of selection

	Frequency of selection			
	Overall (N=25)	Early planting (April) (N=17)	Mid planting (May) (N=18)	Late planting (June) (N=4)
Preemergence herbicides				
S-metolachlor or metolachor	16	11	9	3
pyroxasulfone	10	7	4	4
acetochlor	7	6	7	1
Others	7	3	5	0
dimethanamid	5	4	2	2
pendimethalin	5	1	0	1

Abbreviation: Sample size; N

Table 3-9. Impression of residual herbicides in pigweed, large-seeded broadleaf weed, and grass weed control and price of preemergence residual herbicides

Residual herbicides	Pigweed control N=23				Large-seeded broadleaf weed control N=17				Grass control N=18				Price N=18			
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
acetocholor	1	11	9	2	1	6	6	4	4	8	3	3	3	7	7	2
dimethenamid	2	7	6	3	0	4	8	1	1	3	8	2	0	7	7	2
flumioxazin	5	10	5	1	2	8	5	1	2	5	7	2	6	7	3	2
imazethapyr	1	4	5	6	0	6	6	1	1	3	5	4	0	7	5	2
metribuzin	2	7	10	4	2	7	7	0	0	4	9	3	3	9	2	2
pendimethalin	1	3	6	5	1	5	4	3	1	7	4	1	2	6	4	2
pyroxasulfone	9	8	0	2	7	3	4	2	6	6	4	1	3	5	5	5
S-metolachlor or metolachlor	3	11	7	2	2	6	5	4	3	12	2	1	4	9	3	2
sulfentrazone	5	11	1	1	2	4	6	2	2	4	5	4	3	6	5	2

Abbreviation: Sample size; N

Table 3-10. Other postemergence herbicides, their frequency of selection

Herbicide named by farmers	Active ingredient	Residual herbicides (Yes if it is and no if it is not)	Overall (N=71)	Early planting	Mid planting	Late planting
				(April) (N=45)	(May) (N=46)	(June) (N=9)
Enlist One	2,4-D	No	3	4	5	1
Glyphosate	glyphosate	No	11	9	10	1
Liberty	glufosinate	No	13	10	10	1
Fomesafen	fomesafen	No	3	2	3	0
dicamba/ Enginea	dicamba	No	6	4	4	1
Select/Clethodim	clethodim	No	6	2	4	0
Outlook	dimethanamid	Yes	3	2	0	1
Metribuzin	metribuzin	Yes	1	1	0	0
Zidua/Anthem Max	pyroxasulfone	Yes	4	2	2	2
Warrant Ultra	acetaclor+fomesafen		3	2	2	1
Dual II	S-metolachlor	Yes	2	2	2	1
Acetachlor	acetachlor	Yes	1	1	1	0
Prefix	acetaclor+fomesafen	Yes	4	3	2	0
Tavium	S-metolachlor	Yes	1	0	1	0
S-metolachlor	S-metolachlor	Yes	1	1	0	0

Abbreviation: Sample size; N

Table 3-11. Impression of postemergence residual herbicides in pigweed, large-seeded broadleaf weed, and grass weed control and price of postemergence herbicides

Postemergence herbicide	Pigweed control (N=21)				Large-seeded broadleaf weed control (N=20)				Grass weed control (N=18)				Price (N=19)			
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
quizalofop	1	2	1	9	11	6	1	1	1	1	1	15	3	5	8	2
glyphosate	1	0	6	14	4	10	2	0	1	0	1	14	1	5	6	3
glufosinate	5	8	8	1	5	9	5	1	2	6	4	8	3	9	5	2
fomesafen	0	6	7	3	4	6	6	4	13	5	0	0	8	6	4	1
dicamba	13	5	1	1	1	4	8	0	0	0	5	6	2	4	5	1
cloransulam	0	2	2	8	2	2	5	3	1	1	2	7	2	2	5	2
clethodim	1	1	1	15	0	2	3	7	6	5	2	1	3	2	6	1
2,4-D	4	7	5	2	1	1	4	10	9	5	2	1	3	6	7	1

Abbreviation: Sample size; N

Chapter 4 - Conclusion

Soybean is an important crop in Kansas, and herbicide-resistant weeds are the major challenge in soybean cultivation. To manage weeds, farmers have adopted various integrated weed management practices, of which many have proven to be effective in research fields. However, with farmers' inclination towards earlier planting of soybeans, the efficacy of different weed control strategies might change, mainly due to changes in environmental conditions during cropping period. This study aimed to understand how planting dates interact with other practices such as row spacing, pre- and postemergence herbicides, and layered residual herbicide applications.

In this thesis, complex interactions among planting dates, row spacing, and herbicide programs were explored in Kansas soybean fields through both field experiments and a farmer survey. The dual approach allowed for a consolidated evaluation of IWM practices with respect to evolving challenges such as herbicide-resistant weeds, shifting planting trends, and variable environmental conditions.

Field research demonstrated that early planting generally improved weed control, particularly when combined with narrow row spacing (38 cm) and the application of preemergence herbicides flumioxazin + metribuzin. However, the effect of planting date on soybean yield was inconsistent and highly dependent on site-specific environmental conditions, such as rainfall and temperature. Planting soybeans in narrow row spacing often supported better yield and profitability, likely due to faster canopy development and enhanced crop competitiveness. Moreover, herbicide treatments involving a two-pass program, i.e., combining preemergence and postemergence herbicides were effective in maintaining season-long weed control across all research locations.

The survey revealed that many Kansas soybean farmers are already adopting IWM strategies supported by a higher yield result data of research findings. Additionally, data showed that early planting, herbicide rotation, narrow row spacing, and use of cover crops were common IWM approaches used by farmers. Farmers also demonstrated a strong understanding of residual herbicide use and expressed general satisfaction with their current weed control programs. However, some

Furthermore, the survey confirms that *Amaranthus species*, especially Palmer amaranth, is viewed as the most troublesome species in Kansas. However, some gaps in terminology and herbicide classification were noted, which highlights the need for improved extension materials and targeted outreach.

Implications for Farmer Practices

Based on the findings of this thesis, Kansas soybean farmers could consider the following approaches to enhance weed management and sustainability, however the results in farmer's field can be influenced by other environmental factors:

Early planting. Adopt early planting where conditions permit, particularly in regions with lower weed pressure and moderate spring temperatures. Early planting can improve early-season weed control through faster canopy closure.

Use narrow row spacing (38 cm). Planting soybean in narrow row spacing may increase crop competitiveness and suppress weed growth.

Include preemergence herbicides. Using flumioxazin + metribuzin as preemergence herbicide program can improve early-season weed control.

Implement a two-pass herbicide program. Layer preemergence with postemergence applications to ensure season-long control, particularly in fields with persistent weed infestation.

Adopt a zero-tolerance approach. In fields with suspected herbicide resistant population, use multiple management practice to control them (e.g., Palmer amaranth and waterhemp) because even minimal biomass at R7 can replenish the seedbank and increase herbicide resistance.

Recommendations for Future Research and Extension

Future researchers can explore site-specific IWM guidelines based on Kansas's environmental diversity (especially weed diversity) for farmers. This includes tailoring recommendations for different soil types, rainfall regimes, and weed communities. Additionally, including herbicide literacy in extension programs ensuring that farmers can confidently identify active ingredients and understand herbicide groupings, especially with increasing reliance on residuals and conducting a follow up survey to test knowledge retained by farmers can be another approach. Similarly, researchers can conduct more studies on the economic implications of different IWM strategies across varying environmental conditions to evaluate farmers' input decisions. This is especially relevant for early planting, where yield and economic returns were highly variable.

Furthermore, research on late-season weed escapes of *Amaranthus* species can be explored to strengthen farmer's IWM practices, which remain a significant challenge in our research despite using a two-pass herbicide application.

Overall, this thesis strengthens the value of integrating agronomic experiments with farmer-centered research. By combining field trials with on-the-ground survey data, we gain a clearer understanding of not only which weed management strategies are effective, but also which are practical and acceptable to farmers, which is essential for improving soybean production in Kansas and promoting sustainable and resilient weed management systems.

Appendix A - Supplemental information for Chapter 2

Appendix Table A-1. Percent visible weed control of Plamer amaranth four weeks after application of postemergence herbicide application (WAPO) as influenced by planting date and preemergence herbicide Manhattan KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	4WAPO	Biomass (gram m ⁻²)
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	97	<0.01

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-2. Visual ratings of weed control for waterhemp at four weeks after preemergence herbicide application (4WAPR) in Ottawa KS in 2022

Planting date	Row spacing (cm)	Preemergence herbicide	4 WAPR
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	99
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	99
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	99
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	99
Normal	38	sulfentrazone + metribuzin	99
Normal	76	flumioxazin + metribuzin	99
Normal	38	sulfentrazone + metribuzin	99
Normal	76	flumioxazin + metribuzin	99
Normal	38	sulfentrazone + metribuzin	99
Normal	76	flumioxazin + metribuzin	99
Normal	38	sulfentrazone + metribuzin	99
Normal	76	flumioxazin + metribuzin	99

Appendix Table A-3. Visual ratings of weed control for waterhemp four weeks after application of postemergence herbicide (WAPO) in Ottawa KS in 2022

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	4WAPO
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	98
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-4. Visual ratings of weed control for waterhemp at four weeks after preemergence herbicide (4WAPR) in Ottawa KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	4 WAPR
Early	38	sulfentrazone + metribuzin	97
Early	76	flumioxazin + metribuzin	87
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	96
Early	38	sulfentrazone + metribuzin	97
Early	76	flumioxazin + metribuzin	99
Early	38	sulfentrazone + metribuzin	99
Early	76	flumioxazin + metribuzin	97
Normal	38	sulfentrazone + metribuzin	92
Normal	76	flumioxazin + metribuzin	95
Normal	38	sulfentrazone + metribuzin	97
Normal	76	flumioxazin + metribuzin	88
Normal	38	sulfentrazone + metribuzin	86
Normal	76	flumioxazin + metribuzin	91
Normal	38	sulfentrazone + metribuzin	98
Normal	76	flumioxazin + metribuzin	96

Appendix Table A-5. Waterhemp biomass at R7 in Ottawa, KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	Biomass (gram m ⁻²)
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	<0.01
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	<0.01

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-6. Visual ratings of weed control for waterhemp at four weeks after preemergence herbicide application (4WAPR) in Parsons KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	4 WAPR
Early	38	sulfentrazone + metribuzin	83
Early	76	flumioxazin + metribuzin	91
Early	38	sulfentrazone + metribuzin	95
Early	76	flumioxazin + metribuzin	90
Early	38	sulfentrazone + metribuzin	72
Early	76	flumioxazin + metribuzin	77
Early	38	sulfentrazone + metribuzin	97
Early	76	flumioxazin + metribuzin	76
Normal	38	sulfentrazone + metribuzin	88
Normal	76	flumioxazin + metribuzin	77
Normal	38	sulfentrazone + metribuzin	94
Normal	76	flumioxazin + metribuzin	76
Normal	38	sulfentrazone + metribuzin	92
Normal	76	flumioxazin + metribuzin	88
Normal	38	sulfentrazone + metribuzin	97
Normal	76	flumioxazin + metribuzin	81

Appendix Table A-7. Visual ratings of weed control for waterhemp at four weeks after application of postemergence herbicide (4 WAP0), and waterhemp biomass at R7 in Parsons, KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	4WAP0	Biomass (gram m ⁻²)	Yield (Kg ha ⁻¹)
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	97	<0.01	809.70
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	87	<0.01	1037.35
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01	821.98
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	96	<0.01	1020.53
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	97	<0.01	796.08
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01	924.87
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01	763.13
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	97	<0.01	879.48
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	92	<0.01	858.29
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	95	<0.01	772.21
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	97	<0.01	970.10
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	88	<0.01	890.40
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	86	<0.01	804.32
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	91	<0.01	782.80
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	98	<0.01	1059.20
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	96	<0.01	1064.92

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-8. Partial Budget comparing the return over selected cost (R) as influenced by planting date and preemergence herbicide Parsons KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	R (US \$/ha)
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	235.91
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	466.34
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	249.43
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	377.64
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	261.04
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	382.50
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	272.67
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	299.31
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	334.83
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	332.52
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	407.25
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	276.78
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	219.59
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	299.21
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	421.29
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	482.59

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-9. Visual ratings of weed control for waterhemp at four weeks after application of postemergence herbicide (4 WAPO), and weed biomass in Scandia, KS in 2023

Planting date	Row spacing (cm)	Preemergence herbicide	Postemergence herbicide	4WAPO	Biomass (gram m ⁻²)
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	98	<0.01
Early	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Early	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Early	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	94	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	38	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	76	^a Sulf + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	99	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly	98	<0.01
Normal	38	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01
Normal	76	^c Flumi + ^b Met	^e 2,4-D + ^f Gly + ^g S-met	99	<0.01

Abbreviations: ^asulfentrazone, ^bmetribuzin, ^cflumioxazin, ^e2,4-D choline, ^fglyphosate, ^gS-metolachlor

Appendix Table A-10. Maximum and minimum temperature and total precipitation throughout the season in Soybean production

Location	Maximum temperature (C)	Minimum temperature (C)	Total precipitation (cm)
MHK22	28.7	15.3	63.65
MHK23	29.7	15.2	34.77
OTT22	30.3	5.9	41.05
OTT23	30.1	15.5	39.17
PAR23	28.9	15.8	59.92
SC22	28.5	13.7	31.85
SC23	28.9	14.3	45.03

Appendix B - Supplemental information for Chapter 3

Appendix Questionnaire B-1



Integrated Weed Management Practices used by Kansas Soybean Farmers Introduction: This survey aims to collect information about your soybean production practices. The data gathered will inform Extension and research at K-State to develop programming and information. Your participation is voluntary and anonymous. We will not use your name, the name of your farm, or information that would allow others to know the precise location of your farm, and your information will not be distributed for others' research. The survey will take approximately 10 minutes to complete and poses no risks to you. You may skip any questions you do not want to answer. By submitting your survey, you consent to the use of your data for research purposes. If you do not agree to this, please refrain from completing the survey.

If you have questions or concerns about this study please contact Sarah Lancaster, study director at slancaster@ksu.edu; Lisa Rubin, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224; Brad Woods, Associate Vice President for Research Compliance, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.



In which Kansas counties do you grow soybeans? Please type in your answer.



Approximately how many acres of full-season soybeans do you plant? Please type in your answer.





Approximately how many acres of double-crop soybeans do you plant each year? Please type in your answer.



What soybean maturity groups do you use for full-season soybeans? Please type in your answer.



What row-spacing do you use to plant soybeans? Please type in your answer.



When do you plant full-season soybeans? You may choose more than one date.

☐ April 1 to 15

☐ May 16 to 31

☐ April 16 to 30

☐ June 1 to 15

☐ May 1 to 15

☐ June 16 to 30



What factors do you consider when choosing a soybean planting date? Please type in your answer.



If you plant soybeans early, do you plan to continue this practice?

☐ Yes

☐ No



Please indicate your impression of weed control, disease occurrence, soybean yield, and logistics for your farm based on planting date .

	Weed control				Diseases				Yield				Logistics			
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
Early-planted	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mid-planting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Late-planted	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



Please rank the following weeds in order from most troublesome to least troublesome. Drag the options to rank them.

Pigweed (Palmer amaranth or waterhemp)
Morningglory species
Ragweed species
Cocklebur
Horseweed/marestail
Kochia
Lambsquarters
Nightshade
Velvetleaf
Other



If you have other troublesome weeds in your fields, please list the species.



Do you use integrated weed management practices?

☐ Yes

☐ No



Which of the following weed management practices do you use in your field? You may choose more than one option.

☐ Herbicide application

☐ Cover crops

☐ Tillage

☐ Other

☐ Row spacing



Which of the following residual herbicide active ingredients did you use at or before soybean planting? You may choose more than one option.

☐ Acetochlor (Warrant, Fultime, others)	☐ Flumioxazin (Valor, others)	☐ Metribuzin (Sencor, Dimetric, others)	☐ Pyroxasulfone (Zidua, Anthem, others)	☐ Sulfentrazone
☐ Dimethenamid (Outlook, others)	☐ Imazethapyr (Pursuit, others)	☐ Pendimethalin (Prowl, others)	☐ S- metolachlor or metolachlor (Dual, others)	☐ Other

How many residual herbicide active ingredients do you use in one application? Please type in your answer.



Which of the following residual herbicide active ingredients do you use after soybean planting? You may choose more than one option.

☐ Acetochlor (Warrant, Fultime, others)

☐ Pyroxasulfone (Zidua, Anthem, others)

☐ Dimethenamid (Outlook, others)

☐ S-metolachlor or metolachlor (Dual, others)

☐ Pendimethalin (Prowl, others)

☐ Other



Please indicate your impression of the following residual herbicides.

	Pigweed control				Large-seeded broadleaf weed control				Grass control				Price			
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
Acetochlor (Warrant, Fultime, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dimethenamid (Outlook, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flumioxazin (Valor, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Imazethapyr (Pursuit, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Metribuzin (Sencor, Dimetric, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pendimethalin (Prowl, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pyroxasulfone (Zidua, Anthem, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
S-metolachlor or metolachlor (Dual, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sulfentrazone (Authority products, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



What post-emergence herbicides do you apply in soybeans?
Please type in your answer.



How many post-emergence herbicide applications do you plan
to make?

☐ 1

☐ 2

☐ 3

☐ Depends on scouting





Please indicate your impression of the following post-emergence herbicides.

	Pigweed control				Large-seeded broadleaf weed control				Grass control				Price			
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
Dicamba (XtendiMax, Engenia)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2,4-D (Enlist One)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Glufosinate (Liberty, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Glyphosate (Roundup, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fomesafen (Reflex, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cloransulam (FirstRate, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quizalofop (Assure II, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Clethodim (Select Max, others)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐





Do you plan to continue with the weed management practice that you have been conducting?

☐ Yes

☐ No, I will change some practices



Is there any other information you would like to provide? Please type in your answer.





Thank you for completing this survey!

Your feedback will help guide extension weed science programs to benefit Kansans.

Please understand that your answers will be anonymous and may be shared as a group to help other Extension programs. By submitting your survey, you agree that your data may be used in this way.

Appendix Table B-1. Ranking preemergence residual herbicides based on farmers' impression of controlling pigweed, large-seeded broadleaf weed, and grass weed control and price

Residual Herbicides	Ranking of herbicides based on the mean average score			
	Pigweed control (Figure 3-2)	Large-seeded broadleaf weed control (Figure 3-3)	Grass control (Figure 3-4)	Price (Figure 3-5)
acetocholor	5	7	3	5
dimethenamid	6	8	7	9
flumioxazin	3	2	5	1
imazethapyr	8	4	8	7
metribuzin	7	2	9	3
pendimethalin	8	6	4	6
pyroxasulfone	1	1	1	8
S-metolachlor or metolachor	4	5	2	2
sulfentrazone	2	3	6	4

Appendix Table B-2. Ranking postemergence herbicides based on impression on farmers in controlling in pigweed, large-seeded broadleaf weed, and grass weed control and price

Residual Herbicides	Ranking of herbicides based on the mean average score			
	Pigweed control (Figure 3-6)	Large-seeded broadleaf weed control (Figure 3-7)	Grass control (Figure 3-8)	Price (Figure 3-9)
quizalofop	5	8	3	5
glyphosate	7	4	1	1
glufosinate	2	3	4	2
fomesafen	4	5	6	4
dicamba	1	1	7	5
cloransulam	6	6	5	8
clethodim	8	7	2	6
2,4-D	2	2	8	3

N=, Abbreviation: Sample size; N