Cover crop management strategies for driver weeds in Kansas

by

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Abstract

Research was conducted in Kansas and other states in the north central region to understand how cover crops influence weed suppression and seedbanks. As cover crops increase on farm production hectares, management strategies must be evaluated to discover which ones result in optimum weed control. The effects of cereal rye cover crop on Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp (*Amaranthus tuberculatus* (Moq.) J. D. Sauer) seedbanks were evaluated. Seeds were collected in Kansas, Indiana, Missouri, North Dakota, and Wisconsin. Treatments included burial in cereal rye cover crop and in no cover crop in October of 2021. Seeds were removed in May and October of 2022 and sent to Kansas for viability testing. Seven months after burial, cover crop had no effect on seedbank viability. Twelve months after burial, when analyzing each population individually, Missouri and Indiana waterhemp exhibited greater viability in cover crop than in no cover crop treatments. Kansas Palmer amaranth and waterhemp dormancy was also greater in cover crop compared to no cover crop treatments at all locations. These findings are contrary to our hypothesis that cover crop treatments would increase seedbank decay. In a second study, the effects of grazing on weed suppression were evaluated on three on-farm locations near Castleton, Topeka, and Wabaunsee, Kansas. These three and two other locations including Clay Center and Ellsworth, Kansas were sampled to evaluate forage quality. Weed and cover crop biomass, stocking rate, cattle type, and grazing period varied by location. Near Wabaunsee, where giant foxtail (*Setaria faberi* Herrm.) and Palmer amaranth were present prior to planting soybean, grazing negatively influenced weed suppression. A reduction in weed suppression was observed when grazing at 1.95 AU ha^{-1} occurred later in the season. Near Topeka and Castleton, where winter annual weed species such as horseweed (*Erigeron canadensis* L.), common chickweed (*Stellaria media* (L.) Vill.), and

henbit (*Lamium amplexicaule* L.) were dominant prior to spring planting, grazing at 1.83 and 3.5 AU ha^{-1} respectively did not influence weed suppression. These results indicate that farmers should be cautious when allowing cattle to graze cover crops prior to spring planting when summer annual weeds are of concern. These data will provide a basis for further research involving seedbank decay in presence of cover crops as well as grazing cover crops.

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Dedication

This degree will be in the name of Lily Anne Woitaszewski, but many different people deserve the credit. Theisen Ziehmer's support ranged from winter field research to out-of-pocket jokes. My grandfather Lavern H. Woitaszewski only received an 8th grade education, but alongside my grandma (Karen Woitaszewski), built a life where all their grandchildren could achieve college degrees. My father and brother, Larry and Lance Woitaszewski, let me learn alongside them on the farm and have been an important piece of my success. My sister (Lacey Woody) and mother (Anne Woitaszewski) deserve thanks as well.

Chapter 1 - Literature Review

Introduction

Throughout Kansas, cover crops have gained popularity by contributing positively to soil health characteristics and allowing farmers to diversify crop rotations. As farmers continue to seed, grow, and manage cover crops, it is the obligation of Extension research to identify effects and best management strategies of cover crops. Noncash crops grown in agricultural fields to increase soil health parameters, inhibit pests, and reduce soil erosion, can be classified as a cover crop. Cover crop acres in the United States and Kansas have increased in the recent years. From 2012 to 2017 there was a 33% increase in acres "planted to a cover crop (excluding CRP)" in the United States (USDA NASS 2019). Kansas has increased cover crop acres by 30% within that 5-year span. This number is low compared to neighboring states such as Nebraska and Missouri with 56 and 36 % increases, respectively. Ultimately, the Census of Agriculture report concludes that Kansas farmers only utilize cover crops on roughly 1.9 % of cropland in the state. This slow adoption rate could be attributed to different factors, including rainfall; however, it is anticipated that maximizing profitability will further increase cover crop adoption in areas of Kansas that receive adequate annual precipitation. There is an expansive range of soil health benefits that result from the use of cover crops. As found in studies by Sainju and Singh (2001), pairing legume cover crops such as hairy vetch with tillage can significantly increase nitrogen in the soil. Grass cover crops are known to increase and support beneficial microbial populations in soybean production (Wagner et al. 1995). With the growth of all crops, there is the addition of plant residues. Crop residues on the soil surface can increase infiltration, protect soil structure, protect aggregate stability, reduce soil crusting, increase porosity, improve water retention, and reduce erosion (Ruan et al. 2001; Blanco-Canqui, Lal 2009). The advantages of cover crop residues are different for every field and are situation dependent. It is important to understand how factors such as cover crop species, soil type, and tillage characteristics can create unique outcomes in a cover cropping system.

Popular monocot cover crops in Kansas include cereal rye (*Secale cereale* L.), winter wheat (*Triticum* spp.) and triticale (*Triticosecale* Wittmack). Triticale is a cross between cereal rye and winter wheat that provides the durability of cereal rye and the forage value of winter wheat (Dennet et al. 2013; Ayalew et al. 2018). According to the United States Department of Agriculture Economic Research Service, small grains are utilized on 94% of the acres that contain cover crop (Wallander et al. 2021). The prominence of small grains as a cover crop may stem from the opportunity to be grazed by livestock. Cereal rye is the hardiest of cereals and can be seeded later in the fall than most cover crops and still produce a large amount of biomass. It has an extensive root system that holds soil in place and prevents erosion. On poor soils, cereal rye produces greater biomass compared to other cover crops and is inexpensive. Additionally, cereal rye retains moisture in the soil over the winter season (SARE 2021). Cereal rye's ability to retain soil moisture can prove beneficial in areas of Kansas that lose moisture to evaporation in fallow seasons.

Cover Crop Adoption

There are many factors that contribute to a cash crop farmers' adoption of cover crops. It is conceptualized that larger farms are more likely to adopt cover cropping systems since the farmers can take advantage of economies of scale (Lee, McCann 2019). Smaller operations may not have the capital to invest in cover cropping equipment or manage enough acres to increase revenues enough to incentivize the implementation of cover crops. It has been noted by Lee and

McCann (2019), that it is expected that younger farmers with a cow/calf operation will adopt the practice of cover cropping at a greater rate than an older farmer without a cattle production system. Cow/calf operators are generally more likely to adopt cover crops, with the incentive of grazing livestock on those hectares. In areas of the north central region, cover crop biomass is generally available for grazing when pastureland and other grazing sources are not.

The majority of cover crop adoption is attributed to farmers trying to prevent soil erosion, nutrient loss, and other soil health properties (Clay et al. 2020). With such a low adoption rate of cover crops in the north central region, farmers are still not capturing potential benefits of small grain cover crops. It is important that research is continually evaluated to provide cover crop management practices for farmers with economics, cash crop yield, and other agronomic benefits in consideration.

Cover Crop Benefits

Cultural weed suppression via cover crops can serve as a management strategy alongside herbicides and mechanical control. Cover crops reduce weed densities by directly competing for water, sunlight, and nutrients (Gfeller et al. 2018). However, residual herbicides or a combination of residual herbicides and cover crops are more effective at reducing weed densities than cover crops alone (Reddy et al. 2003; Cornelius, Bradley 2017). Reduced emergence and growth of weeds is observed when cover crops are alive at planting than when terminated before planting (Teasdale et al. 2007). In some cases, farmers use cereal rye to suppress winter annual weeds and reduce or eliminate pre-plant and burn down herbicide applications in soybean production (Reddy et al. 2003). Over previous years in the United States, cereal rye has proven to be ineffective at completely controlling weeds. Two to four times the natural amount of cover crop produced was needed to completely control a wide range of weed species (Mohler and Teasdale 1993). This cultivates the premise of utilizing herbicides, grazing, and other practices in cooperation with cereal rye as a cover crop to increase weed suppression. Overall, it is widely accepted that cover crops such as cereal rye can suppress winter annual weeds and early emerging summer annuals to some extent.

Weeds continue to evolve; therefore, it is crucial to implement integrated weed management (IWM) practices to combat herbicide resistance. As discussed in the prior paragraph, eliminating herbicide applications when cover crops are used may not be a viable option for row crop farmers in Kansas. However, winter annual grass cover crops can be utilized for weed suppression in partnership with pre-emergence herbicides to target winter annual and early emerging summer annual weeds. Research by Knezevic et al. (2019) supports that if weeds have been effectively controlled in the early growth stages (VC to R1), soybeans gain a competitive advantage over competing weeds. Row crop fields need constant scouting to determine timely weed control practices for cover crops and pre- and post-emergence herbicide applications (Reddy et al. 2003).

Grazing Livestock on Cover Crops

Grazing provides an opportunity to offset costs of cover crop seed and other inputs (Tobin et al. 2020). Integrated crop-livestock systems (ICLS), promote soil and cover crops to increase carbon sequestration, enhance soil fertility, and benefit other soil health qualities (Russelle et al. 2007). Grazing cover crops leads to increased soil microbial activity, bulk density, and little to no effect on crop yield. However, one specific study showed that soil aggregate stability was reduced when grazing cover crops with cattle (Poffenbarger 2010). Other studies have refuted this outcome (Simon et al. 2021). Therefore, aggregate stability effects may not be a similar occurrence in all grazing scenarios.

Cattle grazing could pair with grass cover crops to reduce early emerging weed populations in corn and soybean production and to ensure profitability. As cow/calf producers are more likely to adopt the practice of cover crops, it is essential to understand grazing practices that lead to weed suppression. This includes evaluating effects of cover crop grazing period and biomass removal. The decision of when to remove cattle from grazing cover crops can have a financial effect on farmers. Integrating cover crop grazing on cover crop production hectares can mitigate grazing pressure on native grass prairies in the state of Kansas and the north central region of the United States.

Crop rotations and increased cropping intensity have been shown to increase microbial activity. Today, it is not uncommon to find monocropping systems or dual crop rotation systems. Grazing and diversified cropping systems build soil microbial activity (Tiemann et al. 2015). Soil microbial activity is important for crops because it decomposes organic materials, increases carbon cycle turnover, and helps convert nutrients to plant available forms (SARE 2021).

In Oklahoma, grass cover crops such as cereal rye had more weed suppression and produced more forage in both dry and wet conditions. Not only can cereal rye boost grazing opportunities for farmers, but it can also provide greater weed suppression than broadleaf cover crops (Horn et al. 2020). It is possible that grazing cover crops may reduce biomass and allow a greater number of weeds to emerge. However, a study determined that in some cases areas grazed by cattle had a lower amount of weed biomass accumulation than areas excluded from grazing. These findings were not consistent across all measures of the experiment. So, it was concluded that grazing cattle on cover crops had no effect on weed suppression (Tracy and Davis

2009). Constant grazing of young palatable parts of weeds also prevents the production of weed seed heads and can indirectly prevent additions to the weed seedbank (Bunchek et al. 2019). When that occurs, farmers will have less weeds to control the subsequent year.

Weeds of Interest

Aggressive winter annual weeds in Kansas include horseweed (*Erigeron canadensis* L.), henbit (*Lamium amplexicaule* L.), and chickweed (*Stellaria media (L.) Vill.*). Horseweed has been ranked as very troublesome in soybean growing states across the north central (Van Wychen 2019). Summer annuals are of even more concern to farmers including Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp (*Amaranthus tuberculatus* (Moq.) J. D. Sauer) amongst the top. These species are growing in numbers in farmers' fields and can cause economic damage to row crops. Palmer amaranth and waterhemp are abundant in the state of Kansas and have been the focus of integrated weed management studies. Palmer amaranth has become one of the most widespread and economically damaging weeds in the United States of America (Beckie 2011). This species has become resistant to multiple herbicide modes of action commonly used in Kansas and the north central region. These herbicides include EPSP synthase inhibitors, HPPD inhibitors, and ALS inhibitors (Ward et al. 2013). Cereal rye as a cover crop, has been proven to partially suppress these winter annuals and early emerging summer annuals (Cornelius and Bradley 2017).

As studies have shown, increased weed density and biomass can have economic and environmental consequences. If Palmer amaranth is unmanaged, it can interfere with soybean growth. The rapid vertical growth of Palmer amaranth enhances its competitiveness for light with soybeans. Interference of Palmer amaranth had significant effects on soybean canopy which is crucial for row-crop farmers. Palmer amaranth has a high potential to decrease yield in soybeans (Klingaman et al. 1994). In Kansas yield loss has been shown to reach 79% (Bensch et al. 2003). The persistence of the Palmer amaranth and waterhemp seedbank is dependent on burial depth and time spent in the soil (Korres et al. 2018). These factors generally have more of an influence than geographical location of burial.

Herbicide Resistance Driving Integrated Weed Management Practices

Over recent years, weed resistance to herbicides has increased at such a high rate that row crop farmers can no longer ignore it. The north central region has consistently ranked Palmer amaranth and waterhemp as some of the top troublesome weeds in row crops (Van Wychen 2019). In the world, 154 individual cases of herbicide resistance in dicot weed species have been reported (Heap 2022). Palmer amaranth in Kansas has been found to be resistant to five different herbicide sites of action (Kumar et al. 2019). According to worst case scenario models of glyphosate resistance, up to 60% of Palmer amaranth populations in row crop fields could become glyphosate resistant in 10 years (Neve et al. 2011). The economic cost of herbicide resistance varies greatly by species and resistance type. In Kansas, the first direct cost of herbicide resistance is mainly attributed to a second (rescue) herbicide application, after the first herbicide application fails due to resistance (Peterson 1999). Other costs can involve mechanical and cultural control practices that farmers are not equipped to execute on their operations.

Since synthetic herbicide applications are used regularly in crop production, herbicide resistance is becoming common. Resistance is more likely to occur in cost-effective herbicide programs (Shaner 2014). This is due to the widespread usage associated with the economic advantage that cost-effective programs offer. Cost-effective programs sometimes use a single mode of action, which increases the selection pressure for genetic mutations and therefore resistance. Looking at the long-term economics of herbicide resistant weed populations, the main costs are attributed to herbicide effectiveness as well as population shifts (Shaner 2014). In the first few stages of herbicide resistance, the weed seedbank increases exceptionally due to lack of current weed control and more plants reaching senescence (Peterson 1999). This will continue to leave farmers searching for economical means of controlling weeds. Integrated weed management is the use of multiple practices to control weeds to provide a crop advantage over weeds. Integrated weed management must be implemented on a wide scale to reduce herbicide resistance. Farmers are presented with knowledge and educational materials from Extension and research personnel on integrated weed management. However, there still seems to be a lack of IWM adoption. This can be attributed to the lack of financial gain or short-term benefits from IWM. In other words, it is perceived that the risk is not worth the reward for many farmers (Wilson et al. 2009).

Small Grain Cover Crops and the Weed Seedbank

The weed seedbank is a compilation of viable seeds throughout the soil and on the soil surface. Row crop soils can contain thousands of viable seeds per square foot (Lehnhoff et al. 2013). Cereal rye as a cover crop, has been shown to reduce weed populations of both winter annuals and early emerging summer annuals through biomass production and competition (Reddy et al. 2003). However, what effects can cereal rye have on weeds, other than suppressing emergence with biomass production? Weed seedbanks are of great interest when considering the future of weed populations. The persistence and density of weed species all rely on the weed seedbank (Schwartz-Lazaro et al. 2019). Both agronomists and weed scientists have shown interest in the ideology that to reduce herbicide resistance, weed seedbanks must be understood and additions be minimalized (Norsworthy et al. 2012). Management practices to control weed seedbanks include weed free fields at planting, timely herbicide applications, and mechanical weed control. There has not been a single tactic to effectively control a weed seedbank on its own. However, a multitude of management practices must be assembled to adequately reduce a weed seedbank. The use of cover crops can be another piece of the weed seedbank management puzzle.

The relationship between emerged weeds and the weed seedbank may not always be linear. Some weed species may not frequently emerge but have a large presence in the seedbank. Timely and efficacious herbicide applications reduce the number of weeds producing and dispersing seeds to the seedbank. This can provide control to the same extent as a fall tillage pass (Tørresen et al. 2003). When looking at the broad picture, there are multiple types of seedbanks. A transient seedbank consists of viable seeds that will germinate within a short period of time such as a couple years. Some species rely on the transient seedbank and it must be replenished almost annually for the species to persist (Hossain and Begum 2016). There are some species that rely on a more persistent seedbank and seeds that can remain viable for decades. There are many different factors that contribute to longevity of a seed. Weed seed viability can be compromised in the seedbank due to predation, soil microbial activity, and germination (Korres et al. 2018). Weed seed predators consist of larger species such as birds and rodents as well as small insects.

It has been noted that grass cover crops can increase and support microbial populations in soybean production (Wagner et al. 1995). This suggests that the increase in microbial activity including fungi and pathogens, could result in a decrease of weed seedbank seeds by decay.

Crop rotations and management practices have direct and indirect effects on the weed seedbank. It is apparent that it may take years of crop rotations to have quantifiable effects on the weed seedbank (Buhler et al. 2000). However, grass cover crops in a crop rotation can be an effective tool to help manage the weed seedbank (Hossain and Begum 2016).

Effects of a Poorly Managed Weed Seedbank

When a weed seedbank goes unmanaged, significant weed populations will follow. Increased weed populations are both a cause and an effect of a dense weed seedbank. Proactive management can lead to a reduction in the weed seedbank. In some managed weed populations, the weed seedbank decreased at a significant percentage and eventually stabilized at a low percentage of the initial seed numbers (Buhler 1999). Harvest weed seed control is one way to help manage the weed seedbank (Walsh et al. 2018).

If a weed seedbank is poorly controlled, the longevity and persistence of new seeds can last for many years depending on the weed species. In other words, if the weed seedbank is not controlled, weed populations may not only cause economic damage for the current growing season, but also upcoming years of cropping systems (Kumar et al. 2019).

Decisions to control weeds during the growing season may be based on economic thresholds. The basis of economic thresholds is to ensure that the cost to control a weed population is either equal to or less than the financial gain from the application (yield increase of the crop) (Cousens 1987). However, the effect of controlling above-ground weed populations on the weed seedbank is not usually taken into consideration when determining the economic threshold of a weed pest. This is partly because economic thresholds are dependent on financial gains of the current growing season, rather than future cropping systems. Overall, farmers should consider thresholds and both short- and long-term effects of the weed seedbank when determining management strategies.

Conclusions

There have been many changes to the way that modern farms operate compared to those in the early 20th century. Farmers look for nutrient inputs in other places than crop rotation and natural biologicals. There are environmental and agronomic benefits that farmers will not realize until single cropping systems are converted to rotations. Crop rotation and integrated crop-livestock diversification allow farmers to improve soil health properties and mitigate financial risk across multiple commodities. The weed seedbank is a dynamic component of farming and is influenced by weed species and environment. It is an important consideration when farmers are making management decisions. Cover crops alter the environment, and it is important to understand how they subsequently alter the seedbank. The addition of grass cover crops on farmlands in the Kansas would diversify operations and allow for additional grazing opportunities for ranchers as well as add an additional source of income for farmers. Exploring when to remove cattle from grazing cover crops to maximize weed suppression, is a crucial step to discovering management methods that optimize grazing practices. Analyzing and introducing this information to farmers will boost adoption of grazing cereal rye and fine tune current work towards perfecting grazing practices for weed control.

References

Angela DL, Cooper KV, Trenthowan RM (2013) The Genotypic Interaction of Wheat and Rye Storage Proteins in Primary Triticale. Euphytica 194, no. 2: 235-42

Beckie HJ (2011) Herbicide-resistant weed management: focus on glyphosate. Pest Management Science 67:1037–1048

Bensch CN, Horak MJ, Peterson D. Interference of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*) in soybean (2003) Weed Science 51(1):37-43

Blanco-Canqui H, Lal R (2009) Crop Residue Removal Impacts on Soil Productivity and Environmental Quality, Critical Reviews in Plant Sciences, 28:3, 139-163

Brainard DC, Bellinder RR, Kumar V (2011) Grass–Legume Mixtures and Soil Fertility Affect Cover Crop Performance and Weed Seed Production Weed Technology 25(3) 473-479

Bruff SA, Shaw D (1992) Early Season Herbicide Applications for Weed Control in Stale Seedbed Soybean (*Glycine max*). Weed Technology, 6(1), 36-44

Buhler DD (1999) Weed Population Responses to Weed Control Practices: Seedbank, Weed Populations, and Crop Yields. Weed Science 47, no. 4: 416–22.

Buhler DD, Kohler KA, Thompson RL (2001) Weed Seed Bank Dynamics during a Five-Year Crop Rotation. Weed Technology 15, no. 1: 170-76

Bunchek J, Mirsky S, Curran W, Ackroyd V (2019) Chapter 12: Cover Crops for Weed Suppression. Essay. In A Practical Guide for Integrated Weed Management in Mid-Atlantic Grain Crops, 85–95. National Institute of Food and Agriculture

Cornelius CD, Bradley KW (2017) Influence of various cover crop species on winter and Summer annual Weed emergence in soybean. Weed Technology, 31(4), 503-513

Cousens R (1987) Theory and Reality of Weed Control Thresholds. Plant Protection Quarterly 2(1) (1987)

Dimitri C, Effland A, Conklin NC (2005) The 20th Century Transformation of the U.S. Agriculture and Farm Policy. USDA. https://doi.org/10.22004/ag.econ.59390

Fabian M, Schonbeck M (2013) Manage the Weed Seed Bank-Minimize ‘Deposits’ and Maximize Withdrawals. eOrganic https://eorganic.org/node/2806.

Gfeller A, Herrera JM, Tschuy F, Wirth J (2018) Explanations for *Amaranthus retroflexus* suppression by cover crops. Crop protection 104:11-20

Habtamu A, Kumssa TT, Butler T, Ma X (2018) Triticale Improvement for Forage and Cover Crop Uses in the Southern Great Plains of the United States. Frontiers in Plant Science 9 https://doi.org/10.3389/fpls.2018.01130

Harker KN, O'Donovan JT (2013) Recent Weed Control, Weed Management, and Integrated Weed Management. Weed Technology 27(1), 1-11

Heap I (2022) The international Herbicide Resistant Weed Database. Online

Horn KM, Rocateli AC, Warren JG, Turner KE, Antonangelo JA (2020) Introducing Grazable Cover Crops to the Winter Wheat Systems in Oklahoma. Agronomy Jouranal 112, no 5. 3677-94

Hossain MM, Begum M (2016) Soil Weed Seedbank: Importance and Management for Sustainable Crop Production-A Review. Journal of the Bangladesh Agricultural University 13, no.2: 221-28

Klingaman TE, Lawrence OR (1994) Palmer Amaranth (*Amaranthus Palmeri*) Interference in Soybeans (*Glycine Max*). Weed Science 42, no. 4: 523–27.

Knezevic SZ, Pavlovic P, Osipitan OA, Barnes ER, Beiermann C, Oliveira MC, Jhala A (2019) Critical time for weed removal in glyphosate-resistant soybean as influenced by preemergence herbicides. Weed Technology 33(3), 393-399.

Korres NE, Norsworthy JK, Young BG, Reynolds DB, Johnson WG, Conley SP, Smeda RJ, et al. (2018) Seedbank persistence of Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus*) across diverse geographical regions in the United States. Weed Science 66:446-456 doi:10.1017/wsc.2018.27

Kumar A, Choudhary T, Das S, Meena SK (2019) Weed Seed Bank: Impacts and Management for Future Crop Production. Agronomic Crops. Springer, Singapore. https://doi.org/10.1007/978-981-32-9783-8_12

Kumar V, Liu R, Boyer G, Stahlman PW (2019) Confirmation of 2,4-D resistance and identification of multiple resistance in a Kansas Palmer amaranth (*Amaranthus palmeri*) population. Pest Management Science 75: 2925-2933

Lee S, McCann L (2019) Adoption of cover crops by U.S. soybean producers. Journal of Agricultural and Applied Economics 51(04), 527-544

Lehnhoff EA, Keith BK, Dyer WE, Peterson RK, Menalled F (2013) Multiple herbicide resistance in wild oat and impacts on physiology, germinability, and seed production. Agronomy Journal 105(3):854-62

Lucas C, Perkins K, Motallebi M, Plastina A. Farmaha BS (2020) The Perceived Benefits, Challenges, and Environmental Effects of Cover Crop Implementation in South Carolina Agriculture 10 no. 9: 372

Magdoff, Van ES (2021) Soil Microorganisms. SARE. SARE, https://www.sare.org/publications/building-soils-for-better-crops/the-living-soil/soil-microorganisms/.

Mohler CL, Teasdale JR (1993) Response of weed emergence to rate of Vicia villosa Roth and *Secale cereale* L. residue. Weed Research 33: 487-499

Neve P, Norsworthy, JK, Smith KL, Zelaya IA (2011) Modelling evolution and management of glyphosate resistance in *Amaranthus palmeri*. Weed Research 51: 99-112

Nord EA, Curran WS, Mortensen DA, Mirsky SB, Jones BP (2011) Integrating Multiple Tactics for Managing Weeds in High Residue No-Till Soybean. Agronomy Journal 103: 1542-1551

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, et al. (2012) Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations. Weed Science 60 (SP1). Cambridge University Press: 31–62.

Peterson DE. (1999) The Impact of Herbicide-Resistant Weeds on Kansas Agriculture.Weed Technology 13, no. 3: 632-35

Petrosino JS, Dille JA, Holman JD, Roozeboom KL (2015) Kochia suppression with cover crops in Southwestern Kansas. Crop, Forage & Turfgrass Management, 1(1), 1-8

Poffenbarger H (2010) Ruminant Grazing of Cover Crops: Effects on Soil Properties and Agricultural Production. Journal of Natural Resources and Life Sciences Education, 39: 49-39.

Reddy K, Zablotowicz R, Locke M, Koger C (2003) Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield. Weed Science, 51(6), 987-994

Ruan H, Ahuja LR, Green TR, Benjamin JG (2001) Residue Cover and Surface-Sealing Effects on Infiltration. Soil Science Society American Journal 65: 853-861

Russelle MP, Entz MH, Franzluebbers AJ (2007) Reconsidering Integrated Crop–Livestock Systems in North America. Agronomy Journal 99: 325-334

Sainju UM, Singh BP (2001), Tillage, Cover Crop, and Kill-Planting Date Effects on Corn Yield and Soil Nitrogen. Agronomy Journal 93: 878 886

SARE Outreach (2021) Cereal rye. https://www.sare.org/publications/managing-cover-crops-profitably/nonlegume-cover-crops/cereal-rye/

Schwartz-Lazaro LM, Copes JT (2019) A Review of the Soil Seedbank from a Weed Scientists Perspective. Agronomy 9, no. 7: 369 https://doi.org/10.3390/agronomy9070369

Tørresen KS, Skuterud R, Tandsæther HJ, Hagemo MB, Long-term experiments with reduced tillage in spring cereals and effects on weed flora, weed seedbank and grain yield, Crop Protection, Volume 22, Issue 1, 2003, Pages 185-200, ISSN 0261-2194, https://doi.org/10.1016/S0261-2194(02)00145-X.

Shaner DL. Lessons learned from the history of herbicide resistance (2014) Weed Science 62(2):427-31.

Singer J, Nusser S, Alf C (2007) Are cover crops being used in the US corn belt? Journal of soil and water conservation 62, 353.

Teasdale JR, Brandsater LO, Calegari A, Neto S (2007) Cover Crops and Weed Management. In Non-chemical weed management: Principles, concepts and technology (pp. 49-63). Wallingford, UK: CABI.

Tiemann LK, Grandy AS, Atkinson EE, Marin-Spiotta E, McDaniel MD. "Crop Rotational Diversity Enhances Belowground Communities and Functions in an Agroecosystem." Ecology Letters 18, no. 8 (2015): 761–71 https://doi.org/10.1111/ele.12453.

Tobin C, Singh S, Kumar S, Wang T, Sexton P (2020) Demonstrating Short-Term Impacts of Grazing and Cover Crops on Soil Health and Economic Benefits in an Integrated Crop-Livestock System in South Dakota. Open Journal of Soil Science 10, 109-136

Tracy BF, Davis AS. (2009) Weed Biomass and Species Composition as Affected by an Integrated Crop-Livestock System. Crop Science 49, no. 4:1523–30

U.S. Department of Agriculture's National Agricultural Statistics Service (2019) 2017 Census of Agriculture. USDA. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/

Van Wychen L (2019) 2019 Survey of the most common and troublesome weeds in broadleaf crops, fruits & vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. https://wssa.net/wp-content/uploads/2019-Weed-Survey_broadleaf-crops.xlsx

Wagner SC, Zablotowicz RM, Locke MA, Smeda RJ, Bryson CT (1995) Influence of Herbicide-Desiccated Cover Crops on Biological Soil Quality in the Mississippi Delta. https://www.researchgate.net/profile/Stephen-Wagner/publication/255575433_Influence_of_Herbicide-Desiccated_Cover_Crops_on_Biological_Soil_Quality_in_the_Mississippi_Delta/links/563b7cba08ae45b5d2868c62/Influence-of-Herbicide-Desiccated-Cover-Crops-on-Biological-Soil-Quality-in-the-Mississippi-Delta.pdf

Wallander S, Claassen R, Bowman M, Smith D (2021) Cover Crop Trends, Programs, and Practices in the United States. Department of Agriculture, Economic Research Service, EIB 222. www.ers.usda.gov

Walsh MJ, Broster JC, Schwartz-Lazaro LM, Norsworthy JK, Davis AS, Tidemann BD, Bagavathiannan MV (2018) Opportunities and challenges for harvest weed seed control in global cropping systems. Pest management science, 74(10) 2235-2245

Webster TM, Scully BT, Grey TL, Culpepper AS (2013) Winter cover Crops influence *Amaranthus Palmeri* establishment. Crop Protection, 52, 130-135

Wilson RS, Hooker N, Tucker M, LeJeune J, Doohan D (2009) Targeting the farmer decision making process: A pathway to increased adoption of integrated weed management, Crop Protection, Volume 28, Issue 9, Pages 756-764, ISSN 0261-2194

Chapter 2 - Effect of Cereal Rye Cover Crop on Seed Viability of *Amaranthus* spp.

Abstract

Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp (*Amaranthus tuberculatus* (Moq.) J. D. Sauer) are aggressive summer annual species that are ranked as some of the most difficult to control weeds in soybean fields. Using cereal rye as a cover crop (CC) is popular in the north central region and has been found to boost soil microbial activity. Soil microbial activity, in turn, can increase weed seedbank decay; however, this is dependent on what weed species are present. A study was conducted to determine if a cereal rye CC can enhance seedbank decay of Palmer amaranth and waterhemp in soybean production systems. Waterhemp seeds were collected in Kansas, Indiana, Missouri, North Dakota, and Wisconsin, and Palmer amaranth seeds were collected from Kansas and North Dakota. Overall, seven populations were collected. Seeds were counted and placed into wire mesh packets and sent back to respective locations. Seeds were buried around the time of cereal rye planting in October 2021 in four replications. Treatments included burial in cereal rye CC and in no CC. Kansas populations were buried alongside locally-collected seeds at six sites – one each in Indiana, Missouri, and North Dakota, and two sites in Kansas and Wisconsin. All populations were buried at one site in Kansas. Seeds were removed in May and October of 2022 and sent to Kansas for viability testing. Seven months after burial, CC had no effect on the seedbank viability of all amaranth populations across five states. Twelve months after burial, when analyzing populations individually, Missouri and Indiana waterhemp exhibited greater viability in CC than in no CC. These findings are contrary to our hypothesis, that CC would result in greater weed seed decay.

These data will provide a basis for further research involving weed seedbank decay in presence of CC.

Introduction

Soybean production is important across the north central region of the United States. In 2017, Kansas, Indiana, North Dakota, Missouri, and Wisconsin soybean sales were greater than $10 billion. All these states, except Wisconsin, ranked within the top ten soybean producing states (NASS 2019). Weed species such as Palmer amaranth (*Amaranthus palmeri* S. Watson) and waterhemp (*A.tuberculatus* (Moq.) J. D. Sauer) pose a critical economic threat to these production systems (Korres et al. 2020).

Control of Palmer amaranth and waterhemp is becoming increasingly difficult with existing herbicides since multiple site of action resistance has been recorded in both species (Shaym et al. 2021; Bell et al. 2013). Yield reduction is highly correlated to Palmer amaranth biomass and waterhemp interference (Klingaman et al. 1994; Cordes et al. 2004). Alternative methods of weed control are being explored to contribute to integrated weed management. Cover crop (CC) species are an alternative strategy that can be successful when incorporated with other management options. Cover crops suppress weeds through different mechanisms both physically and chemically (Creamer et al. 1996). Cover crops have been shown to reduce weed seedbank densities in conventional tillage systems (Moonen and Barberi 2004; Nichols et al. 2020). The decline is likely due to CC changing the environment with additional biomass, microbial activity, and increased predation. Some argue the true mechanism of how CC reduces the weed seedbank needs to be explored further (Nichols et al. 2020).

Cereal rye (*Secale cereale* L.) is a common CC across the north central region due to its cold hardiness and ability to withstand low moisture conditions. Cereal rye increases microbial levels within the soil as plant biomass decomposes (Nevins et al. 2018). Increased microbial levels in the soil have been known to increase weed seedbank decay; however, these findings were dependent on what weed species were present in the seedbank. For example, velvetleaf (*Abutilon theophrasti* Medik.) and Pennsylvania smartweed (*Persicaria pensylvanica* (L.) M. Gomez) were much more susceptible to microbial decay than other species like shattercane [*Sorghum bicolor (*L.) Moench ssp. verticilliflorum (Steud.) de Wet ex Wiersema & J. Dahlb.] and wild oat (*Avena fatua* L.) (Chee-Sanford et al. 2006).

Cereal rye alters the soil environment. It increases organic matter and microbial activity, reduces temperature fluctuation, and creates habitat for weed seed predators (Sias et al. 2021). If *Amaranthus* spp. are susceptible to seedbank decay through increased microbial activity, cereal rye has the potential to increase rate of decay. We hypothesize that within CC there will be a decrease in seed viability. The objective of this research was to determine if cereal rye CC affects Palmer amaranth and waterhemp seed viability over time compared to no CC across several locations in the north central region.

Materials and Methods

Seed Collection, Cleaning, and Distribution

Seven *A.* spp. populations were collected from agricultural sites in five states in fall 2021 (Table 2.1). Female plants were identified, and inflorescences were removed and mailed to Kansas State University. Inflorescences were stored at room temperature until fruits were thrashed by hand to separate seed from other flower components. Seeds were cleaned by sifting threshed components through wire mesh to accommodate different seed sizes. An air column seed separator was used to further separate chaff from seed.

Once seeds were cleaned, groups of 50 were counted and placed in 120-mm wire mesh packets capable of retaining the seed but also allowing for a transient barrier (Figure 2.1). Packets were distributed to all locations (Table 2.2). Then were buried at five cm depth in the soil to mimic *A.* spp. weed seedbank conditions (Table 2.3). Each location received packets of populations collected from the state of collection and two Kansas populations (one of Palmer amaranth and one of waterhemp). Twenty-four packets of each population were sent to respective locations to accommodate two treatments (CC and no CC), three removal times, and four replications. Each burial site received enough packets to evaluate viability changes over one and a half years. The data provided here summarize the first two removal timings: May 2022 at soybean planting and October 2022 at soybean harvest.

Site Description

Five states in the north central region were selected and included Kansas, Missouri, Wisconsin, North Dakota, and Indiana. All sites were in a pre-existing experiment and chosen due to consistency of CC and cooperator willingness to implement the experiment. Geographic coordinates are listed in Table 2.3. At these locations, organic matter, clay content, and pH were sampled from 0 to 20 cm and recorded. Each location had cereal rye and soybean planted the previous year, while Rossville, KS was the exception with no previous cover crop. In Fall 2021, all locations were seeded with a cover crop of 67 kg ha^{-1} cereal rye except for Manhattan, KS where the cover crop consisted of 56 kg ha^{-1} cereal rye and 34 kg ha^{-1} crimson clover. Rainfall and temperature were recorded at the nearest weather station (Figure 2.2 and 2.3). Rossville, KS was an irrigated location, while all other locations were dryland.

Strip-plots were utilized within a randomized complete block design with four replications. This experiment was placed in a larger no-tillage experiment evaluating CC termination, residual herbicides, and planting date (Nunes et al. 2022). The experiment was 36.6 m long by 36.6 m wide with plots 3 m wide by 9 m long. Two treatments were CC and no CC. Three seed packets of each population were buried in each plot to allow removal at soybean planting in May 2022, soybean harvest in October 2022, and soybean planting in May 2023. The number of packets buried at each location depended on the number of populations provided by each state. For example, Rossville, KS had 21 packets (seven populations) in each plot for a total of 168 (four replications in CC and no CC treatments). Janesville and Brooklyn, WI, Columbia, MO, and Lafayette, IN each received 72 seed packets, while Fargo, ND received 96 seed packets, and Manhattan, KS received 48 seed packets.

All plots were treated with glyphosate (N-(phosphonomethyl) glycine), ammonium sulfate, and glufosinate-ammonium at or just before soybean planting in the spring of 2022. No pre-emergence residual herbicide was applied within treatments. Post-emergent weed control was implemented when 10-20% of Palmer amaranth plants reached 20 cm with an application of 656 g ha^{-1} glufosinate-ammonium, 408 kg ha^{-1} glyphosate N-(phosphonomethyl) glycine, and 1424 g ha^{-1} ammonium sulfate.

Viability Testing

At the designated removal times, one of each population's seed packets were removed from burial locations at all sites. Seed packets were sent to Kansas State University to undergo a two-step viability test.

The first step was a germination test. Soil was removed from the exterior of the packets by hand, then packets were placed into a rinse solution of 0.5% sodium hypochlorite and distilled water (Boydston 1989; Guo and Al-Khatib 2003). Packets were agitated to ensure the solution penetrated the packet, then packets rested in solution for five minutes before being rinsed with distilled water. Packets were opened and seeds placed into a petri dish on moist filter paper and transferred to a growth chamber set at 30/20 °C and 14/10-hour day/night conditions (Guo and Al-Khatib 2003). Petri dishes were monitored for germination, which was recorded when a radicle emerged from the seed coat. Germinated seeds were removed from petri dishes until no more germination occurred for three days. The seeds that germinated at this stage were considered non-dormant and viable. The second step was a crush test for seeds that did not germinate in the growth chamber. The purpose of this test was to observe the endosperm and determine if it was viable or nonviable. Petri dishes with seeds were removed from the growth chamber and dried before the crush test was performed. Each seed was crushed using forceps which opened the seed coat to expose the interior including the endosperm. A seed was considered nonviable when the interior of the seed was brown, black, and/or powdery (Figure 2.4). A seed was considered viable if the interior of the seed was white, oily, and fleshy (Figure 2.5). If the seed coat had no interior contents, it was considered a "loss" from the seedbank and therefore assumed to have germinated in the field or decayed over time (Figure 2.6).

Based on viability testing, seeds were categorized into the following classes: growth chamber germinated (GCG), dormant (D), empty (E), viable (V), and nonviable (N). GCG were hard seed that germinated during optimum growing conditions within the growth chamber. D seeds were those that did not germinate during optimum growth chamber conditions but still had a viable endosperm within the seed coat. E seed coats were considered to have germinated within the field and had no interior seed to examine; they were categorized as N. Additionally, seeds that were examined during the crush test and had a black, brown and/or powdery interior were also considered N. Overall, V seeds included both D and GCG classes. For each class, the percentage of total seeds that were returned in each packet was determined as follows:

1. Total seeds = (GCG+D+N)
2. GCG % = (GCG/ Total seeds) x 100
3. D % = (D/ Total seeds) x 100
4. V % = ((D+GCG/ Total seeds) x 100
5. N % = (N+E/ Total seeds) x 100

Statistical Analysis

If fewer than ten seeds were counted from a seed packet during viability tests, the data were removed prior to analysis. All data were analyzed using the software "R" (R Core Team 2021). All assumptions of normality were evaluated with box plots, residuals, and quantile-quantile plots using R package ggplot2 and ggthemes (Wickham 2016; Arnold 2021). Data were subjected to an analysis of variance in R using a linear mixed model using package lme4 and lmerTest ($\alpha = 0.05$) (Kuznetsova, Brockhoff, Christensen 2017). Fixed effects included location, population, species, removal timing, and treatment. Replication was considered a random effect. Means were separated using Tukey's HSD Test ($\alpha = 0.05$) with R package emmeans, multcomp, and multcompView (Hothorn, Bretz, and Westfall 2008; Graves, Piepho, and Selzer 2019; Lenth 2022).

Results and Discussion

Over one year, seeds buried in cereal rye CC treatments exhibited higher viability compared to no CC treatments in two different populations. Dormancy of Kansas populations in cover crop treatments also increased at all locations evaluated. The mechanisms for these changes have not been identified in this experiment but CC alterations to the environment are likely the cause. Organic matter, clay content, and pH were variable across locations but were consistent with production conditions in respective states (Table 2.2). Rainfall was less at WI-2 and ND than all other locations (Figure 2.2). At KS-2 rainfall was supplemented with 190.5 millimeters of irrigation water that was applied between June 21 and Sept 7, 2022. It is imperative to note temperature conditions at each location and the influence of temperature on dormancy. Air temperature fluctuated throughout the experiment (Figure 2.3)

Kansas Palmer Amaranth and Waterhemp at All Locations

There was no effect of CC treatment on viability of Kansas waterhemp (KSWH) and Kansas Palmer amaranth (KSPA) across locations after seven and twelve months of burial (Table 2.4). Location, species, and removal time influenced the level of viability observed. KSPA and KSWH populations had less viability after twelve months compared to after seven months of burial at KS-1 and at ND (Figure 2.7). KS-1, ND, WI-1, WI-2 had greater viability after seven months than KS-2 or IN (Figure 2.7). No major differences existed for precipitation, temperature, or soil conditions such as organic matter, pH or clay content within KS-2 and IN that would explain these differences (Figure 2.2 and Table 2.2.). Previous studies have found that viability of *A.* spp. seeds generally decrease over time within the seedbank (Jha et al. 2014; Korres et al. 2018).

Kansas Palmer amaranth had less viability at WI-2 when removed after seven months compared to later at twelve months (Figure 2.7). This difference is unique and may be due to many empty seeds within packets upon receipt. There is a likelihood of rapid germination of seed in the packets between time of removal from the seedbank and receipt of seed packets in KS.

The only difference observed between KSPA and KSWH at individual locations at the same removal time was at KS-2. KSWH had greater viability than KSPA at the seven-month removal timing (Figure 2.7). Farmers in the eastern side of the United States deal primarily with waterhemp because of different environmental conditions and spread of populations. However, because we didn't observe a difference between KSPA and KSWH in states to the east, it leads us to believe that seedbank conditions are just as conducive to Palmer amaranth as waterhemp. Kansas population characteristics could be a larger, more important factor to eastern spread than species difference due to preferred emergence conditions in Kansas.

Levels of dormancy of KSPA and KSWH were influenced by CC treatment, species, location, and removal time, and the interaction of location and removal time (Table 2.5). At IN and WI-1 there was less dormancy at twelve months than seven months within the weed seedbank (Figure 2.8). However, dormancy was greater at twelve months compared to seven months at KS-1, KS-2, ND, and WI-2 locations (Figure 2.8). Indiana and WI-1 both had the highest amount of rainfall at any location, but this was true for both removal times (Figure 2.2).

These data show that an increased amount of precipitation could result in higher levels of dormancy.

Kansas Palmer amaranth had reduced dormancy (27%) compared to KSWH (35%), but this was expected, as these are different species with unique genetic and population factors that may have influenced initial dormancy levels. The presence of CC increased dormancy of KSPA and KSWH (34%) compared to no CC (28%) at all locations. This was a consistent response and thus the most important of the study. Increased dormancy for both species across all locations indicates that CC's are changing the seedbank environment, but not as expected.

Cover crops can result in reduced light exposure to the weed seedbank. A reduction in light exposure has been shown to create partial dormancy, but not complete dormancy for weed seeds (Batlla and Benech-Arnold 2014). Teasdale and Mohler's (1998) research indicated that less light transmittance was a good prediction of weed suppression through reduced germination. Reduced light exposure makes sense to reduce germination and dormancy of pigweed species because they are phytochrome regulated (Leon and Owen 2003).

All *A*. spp. Populations at Rossville, Kansas

Cover crop presence did not influence seedbank viability of any species or population at either removal time at KS-2. An interaction was observed between population and removal time, and this was expected as all populations would start with unique viability and dormancy levels. Therefore, comparisons will not be made amongst populations, but rather by differences at removal time.

North Dakota waterhemp was the only population at KS-2 that showed less viability at twelve months compared to removal at seven months. All other populations exhibited no difference in viability by removal time (Figure 2.9). This could be attributed to genetic population factors. No difference in KSWH, KSPA, WIWH, NDPA, NDWH, MOWH, INWH seed dormancy was observed by CC treatment or removal time (Table 2.6). This was contrary to KSPA and KSWH seeds placed at KS-1, KS-2, WI-1, WI-2, ND, and IN where CC treatment did increase dormancy.

Population Response as influenced by Location

Palmer amaranth and/or waterhemp populations from each state were buried at the native location and at KS-2. Missouri waterhemp was studied at only one location (KS-2) because packet population identification was lost at MO location. Cover crop treatment resulted in greater viability of MOWH (71%) when buried at KS-2 compared to no CC (42%) (Table 2.7). For farmers, this means that there may be a greater number of emerged weed seedlings to control within the subsequent cropping year. Similar to MOWH, an interaction was observed with the viability of INWH, removal time, and treatment (Table 2.7). Cover crop treatment resulted in greater viability of INWH (49%) at the 12-mo removal timing compared to no CC (17%) (Figure 2.10). Our findings contradict previous research and assumptions, which exhibited a reduction of seed viability with CC in place (Teasdale et al. 2007). Missouri waterhemp dormancy was not influenced by CC treatment, location, or removal time (Table 2.8).

Viability of WIWH was influenced by an interaction of removal time and location (Table 2.7). At WI-2 there was less viability at seven months than twelve months, however, as previously stated there were many empty seed coats in the packets removed at seven months when returned to Manhattan, KS, resulting in fewer seed to evaluate. At ND, removal time had an effect of NDWH viability (Table 2.7). Viability of NDPA was affected by an interaction between location and removal timing (Table 2.7). At ND only, there was greater viability at seven months (80%) than twelve months (27%), but this was not the case at KS-2 where viability was not different between removal times.

Dormancy of INWH was influenced by location (Table 2.8). In IN, INWH had a greater level of dormancy (42%) than when placed at KS-2 (3%). When looking at WIWH dormancy, an interaction between location and removal time occurred (Table 2.8). At WI-1 a decrease in dormancy from seven months (79%) to twelve months (53%) occurred. There was no difference in dormancy levels at KS-1. However, there was an increase in dormancy at WI-2 but that is likely due to high germination within the seed packet before testing. Dormancy was influenced by location where NDWH had greater dormancy at ND (34%) than when buried within the weed seedbank in KS (13%). This coincides with trends observed with INWH.

Influence of Location on Viability

Kansas Palmer amaranth and KSWH were buried at KS-1. At KS-1, neither CC nor species influenced weed seed viability. Kansas Palmer amaranth and KSWH had lower viability at twelve months (33%) than seven months (90%) after burial. In Kansas, farmers should generally expect KSPA and KSWH seedbank persistence to decline with time. Kansas Palmer amaranth, KSWH, and WIWH were buried at WI-1. There was no effect of CC or population at this location, but removal time was similar to KS-1, where viability was lower at twelve months (56%) than seven months (84%). Kansas and North Dakota Palmer amaranth and waterhemp were buried at ND. Neither cover crop treatment nor population affected viability at this location. Removal time revealed lower viability at twelve months (34%) than seven months (85%). These results are similar to observations at KS-1 and WI-1. Kansas Palmer amaranth, KSWH, and

INWH were buried at IN. There was no effect of CC at this location. Removal time and population did have an interaction effect, but after adjustment, there appears to be no difference. Kansas Palmer amaranth, KSWH, and WIWH were buried at WI-2. There was no effect of CC nor population at this location. After twelve months (56%) there was greater viability than seven months (14%). However, the validity of this can be questioned due to a great number of empty seed coats sent back that could be explained by germination between field removal and viability testing. Kansas Palmer amaranth, KSWH, and MOWH were buried at MO. At this location, population data was lost and was unable to be recorded. Therefore, population was not analyzed at this location. Instead, all populations were combined together as amaranth species. There was no effect of CC at this location. At twelve months (63%) there was lower viability than seven months (87%) as observed at other previous locations discussed. Overall, CC is changing the weed seedbank by increasing dormancy and interacting with populations to increase viability compared to no CC treatments. These results depict the short-term CC effects (one year of CC) on the weed seedbank and may allude to differences that occur in long-term CC systems.

Conclusions

Cover crops are changing the weed seedbank in terms of Palmer amaranth and waterhemp viability, dormancy, and losses. Viability and dormancy were quantified by location, population, species, cover crop treatment, and removal timing to illustrate effects of CC on the weed seedbank. Two of the seven populations evaluated exhibited greater viability within CC treatments than no CC. Across the other five populations, there was no influence of CC on *A.* spp. seed viability. Regarding dormancy, location influenced the percentage of dormant seeds, however, no consistent pattern was observed among rainfall, soil characteristics, temperature, longitude, or latitude. Generally, populations and locations had reduced viability over time, which is consistent with previous literature.

Farmers need to be cognizant of seedbank changes as CC's continue to be implemented on new hectares. With increased dormancy, seeds will be less likely to germinate early in the crop growing season or during the first growing season after cover crop termination. An increase in viability of two populations in CC means that CC environments are more suitable for specific characteristics of different populations. Farmers may be looking at a prolonged weed germination period and therefore a greater number of emerging weeds to control in the subsequent crop. Further research needs to be conducted to understand genetic and environmental factors that contribute to dormancy and viability differences among populations and burial locations.

References

Arnold JB (2021) ggthemes. Extra Themes, Scales and Geoms for 'ggplot2'. R package version 4.2.4. https://CRAN.R-project.org/package=ggthemes

Batlla D, Benech-Arnold RL (2014) Weed seed germination and the light environment: Implications for weed management: Light control of weed seed germination. Weed. Bio. Manage 14:77-87

Bell MS, Hager AG, Tranel PJ (2013) Multiple resistance to herbicides from four site-of-action groups in waterhemp (*Amaranthus tuberculatus*). Weed Science 61(3):460–468

Boydston RA (1989) Germination and emergence of longspine sandbur (*Cenchrus longispinus*). Weed Science 37(1):63-67

Chee-Sanford JC, Williams MM, Davis, AS, Sims, GK (2006) Do microorganisms influence seed-bank dynamics? Weed Science 54(3):575–587

Cordes JC, Johnson WG, Scharf P, Smeda RJ (2004) Late-emerging common waterhemp (*Amaranthus rudis*) interference in conventional tillage corn. Weed Technology 18(4) 999-1005

Creamer NG, Bennett MA, Stinner BR, Cardina J, Regnier EE (1996) Mechanisms of weed suppression in cover crop-based production systems, HortScience, 31(3):410-413

Graves S, Piepho HP, Selzer L with help from Dorai-Raj S (2019). multcompView: Visualizations of Paired Comparisons. R package version 0.1-8. https://CRAN.R-project.org/package=multcompView

Guo P, Al-Khatib K (2003) Temperature effects on germination and growth of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*). Weed Science 51(6):869-875

Hothorn T, Bretz F, Westfall P (2008) Simultaneous Inference in General Parametric Models. Biometrical Journal 50(3), 346--363

Jha P, Norsworthy, JK, Riley M, Bridges W (2010). Annual changes in temperature and light requirements for germination of Palmer amaranth (*Amaranthus palmeri*) seeds retrieved from soil. Weed Science 58(4): 426-432

Jha P, Norsworthy, JK, Garcia J (2014) Depletion of an Artificial Seed Bank of Palmer Amaranth (*Amaranthus palmeri*) over four years of burial. American Journal of Plant Sciences, 5: 1599-1606

Korres NE, Norsworthy JK, Mauromoustakos A, Williams MM II (2020) Soybean density and Palmer amaranth (*Amaranthus palmeri*) establishment time: effects on weed biology, crop yield, and economic returns. Weed Science 68: 467–475

Klingaman TE, Oliver LR (1994) Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). Weed science 42(4) 523-527

Kuznetsova A, Brockhoff PB, Christensen RHB (2017) "lmerTest Package: Tests in Linear Mixed Effects Models." Journal of Statistical Software 82 (13), 1-26. doi:10.18637/jss.v082.i13

Lenth RV (2022) emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.7.5. https://CRAN.R-project.org/package=emmeans

Leon RG, Owen MD (2003) Regulation of weed seed dormancy through light and temperature interactions. Weed Science 51(5) 752-758

Mohler CL, Taylor AG, DiTommaso A, Hahn RR, Bellinder RR (2018) Effects of incorporated rye and hairy vetch cover crop residue on the persistence of weed seeds in the soil. Weed Science 66: 379–385 Moonen AC, Barberi P (2004) Size and composition of the weed seedbank after 7 years of different Cover-crop-maize management systems. Weed Research 44(3): 163-177

Nevins CJ, Nakatsu CL, Armstrong SH (2018) Characterization of microbial community response to cover crop residue decomposition. Soil Biology and Biochemistry 127:39-49

Nichols V, English L, Carlson S, Gailans S, Liebman M (2020) Effects of long-term cover cropping on weed seedbanks. Frontiers in Agronomy 2, 591091

Nunes JJ, Arneson NJ, Johnson B, Young BJ, Ikley JT, Wallace JM, Gage KM, Jha P, Lancaster S, Legleiter T, Kumar V, Werle R (2022) Planting Soybean Green: Agronomic and Weed Management Benefits and Challenges. Oral. Proceedings of North Central Weed Science Society Vol. 77:103

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, https://www.R-project.org/.

Shyam C, Borgato EA, Peterson DE, Dille JA, Jugulam M (2021) Predominance of metabolic resistance in a six-way-resistant Palmer amaranth (*Amaranthus palmeri*) population. Frontiers in Plant Science 11:614618. doi: 10.3389/fpls.2020.614618

Sias C, Wolters BR, Reiter MS, Flessner ML (2021). Cover crops as a weed seed bank management tool: A soil down review. Italian Journal of Agronomy, 16(4). https://doi.org/10.4081/ija.2021.1852

Teasdale JR, Brandsaeter LO, Calegari A, Neto FS, Upadhyaya MK, Blackshaw RE (2007) Cover crops and weed management. Non chemical weed management principles. Concepts and Technology, CABI 49-64

Teasdale JR, Hatfield JL, Buhler DD, Stewart BA (1998) "Cover crops, smother plants, and weed management." Integrated weed and soil management 247:270

U.S. Department of Agriculture's National Agricultural Statistics Service (2019) 2017 Census of Agriculture. USDA.

Wickham H (2016) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Figure 2.1. Palmer amaranth and waterhemp seed packets made of 120 mm fine wire mesh. Liquid paint pens were used to mark packets to identify populations. This location is Manhattan, Kansas with both Kansas Palmer amaranth and waterhemp populations.

Figure 2.2. Cumulative precipitation since burial measured at each experiment site. Seed removal times were seven and twelve months after burial. Indiana (IN), Manhattan, Kansas (KS-1), Rossville, Kansas (KS-2), Missouri (MO), North Dakota (ND), Brooklyn, Wisconsin (WI-1), and Janesville, WI (WI-2).

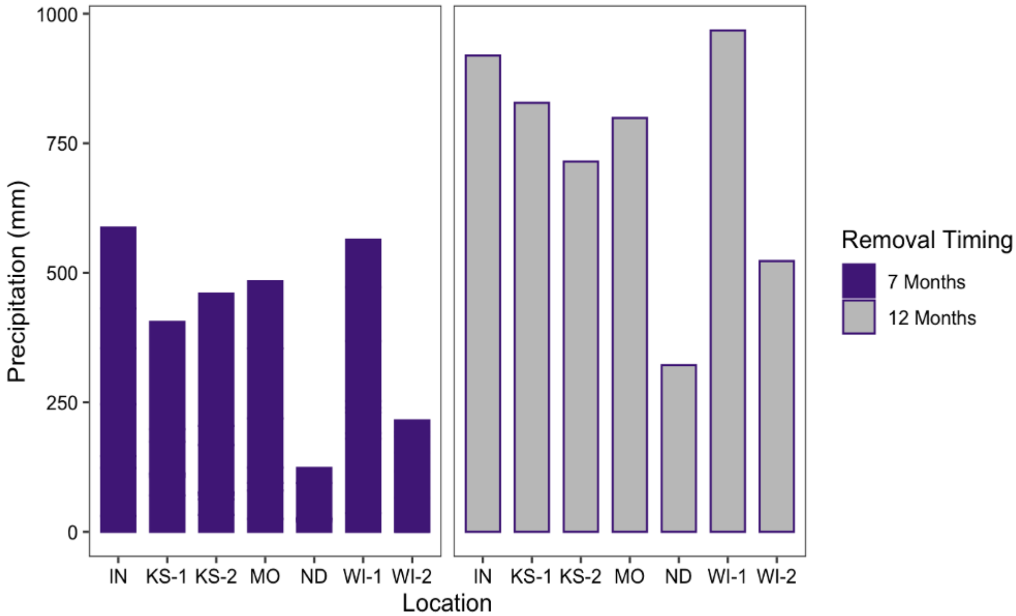


Figure 2.3. Temperature (°C) measured near each experiment site. Locations include Indiana (IN), Manhattan, Kansas (KS-1), Rossville, Kansas (KS-2), Missouri (MO), North Dakota (ND), Brooklyn, Wisconsin (WI-1), and Janesville, Wisconsin (WI-2).

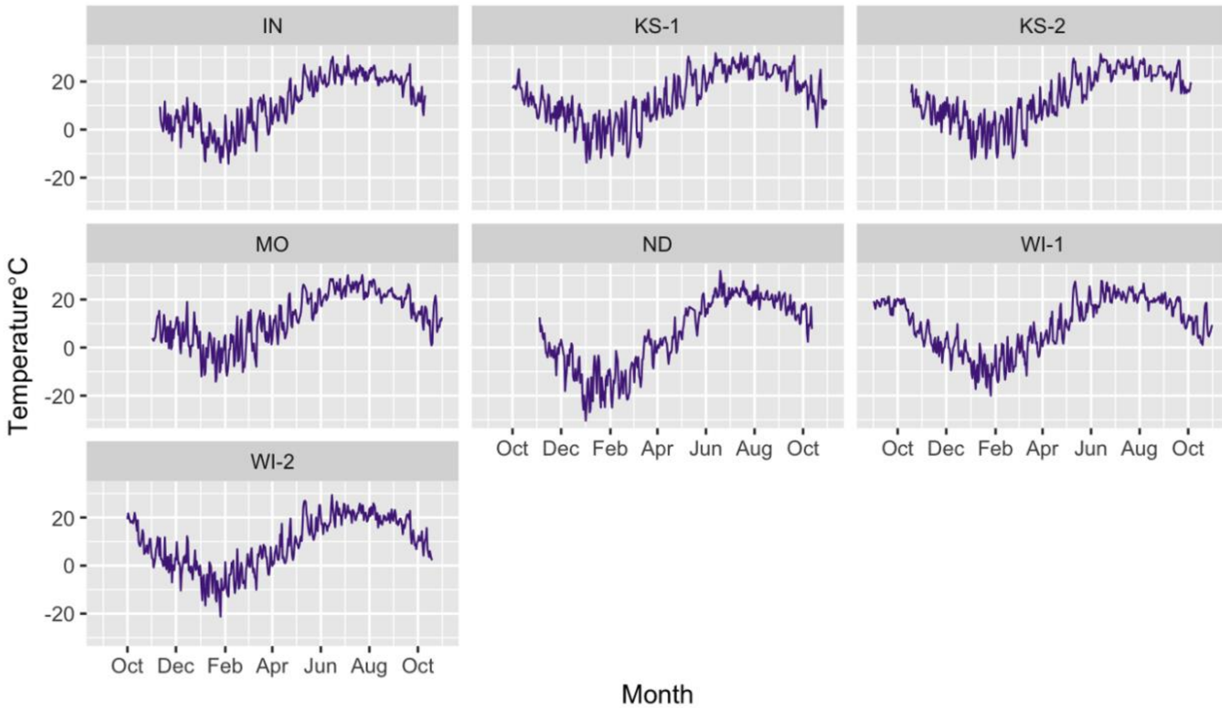


Figure 2.4. This image is of a nonviable seed that has the consistency of black, brown, or powdery interior. Previous research has considered this to be nonviable during a crush test to determine viability.

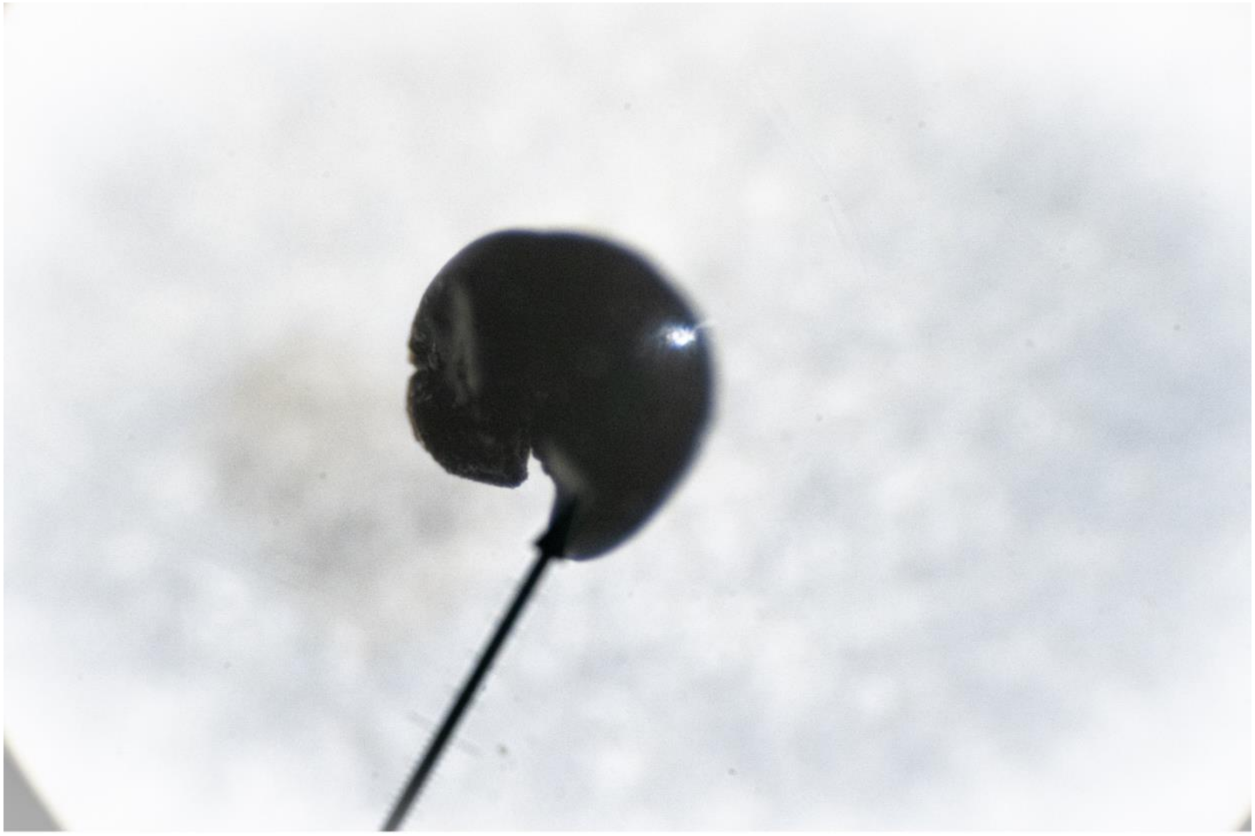


Figure 2.5. This image is of a viable seed that has the consistency of a white, oily, and fleshy interior. Previous research has considered this to be viable during a crush test to determine viability.

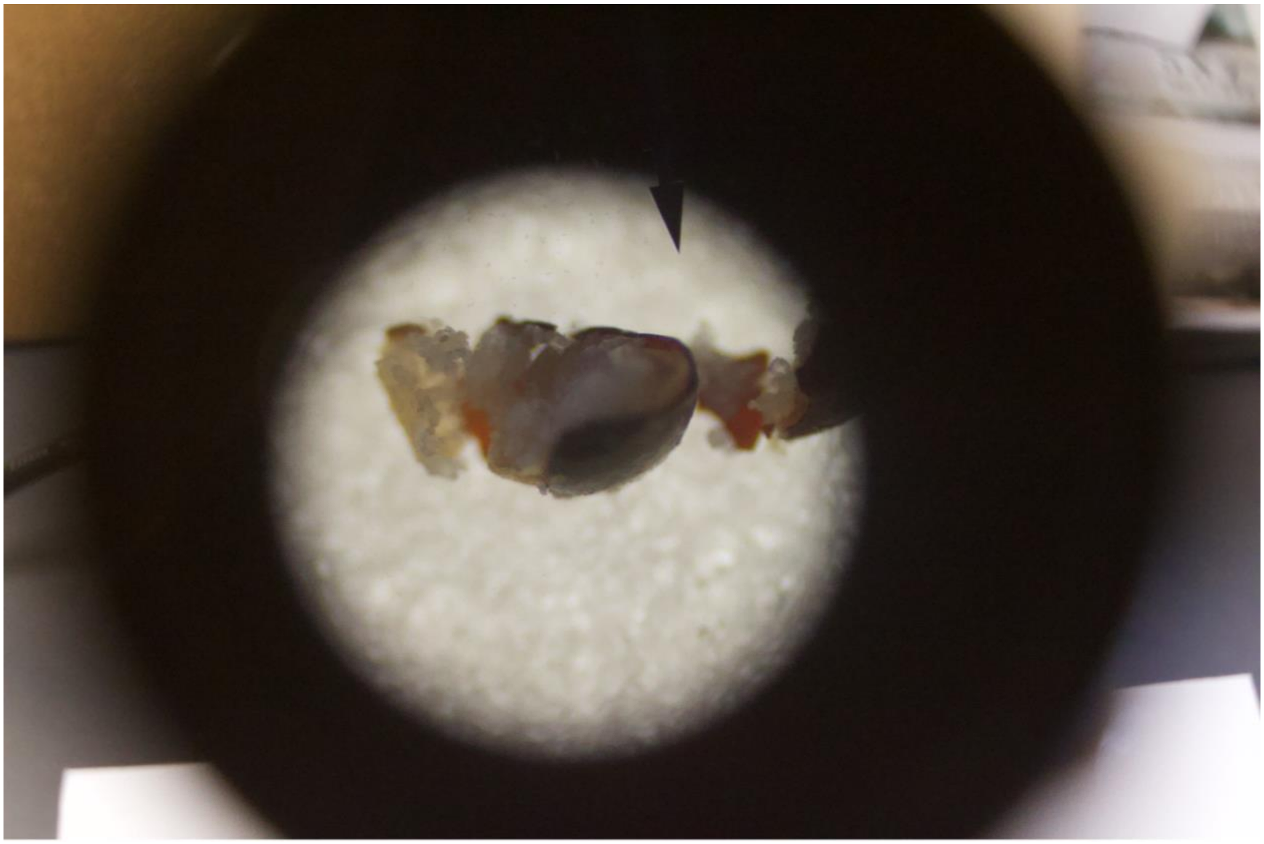


Figure 2.6. This image is of a nonviable seed that has the consistency of an empty interior to the seed coat. Previous research has considered this to be nonviable during a crush test to determine viability.

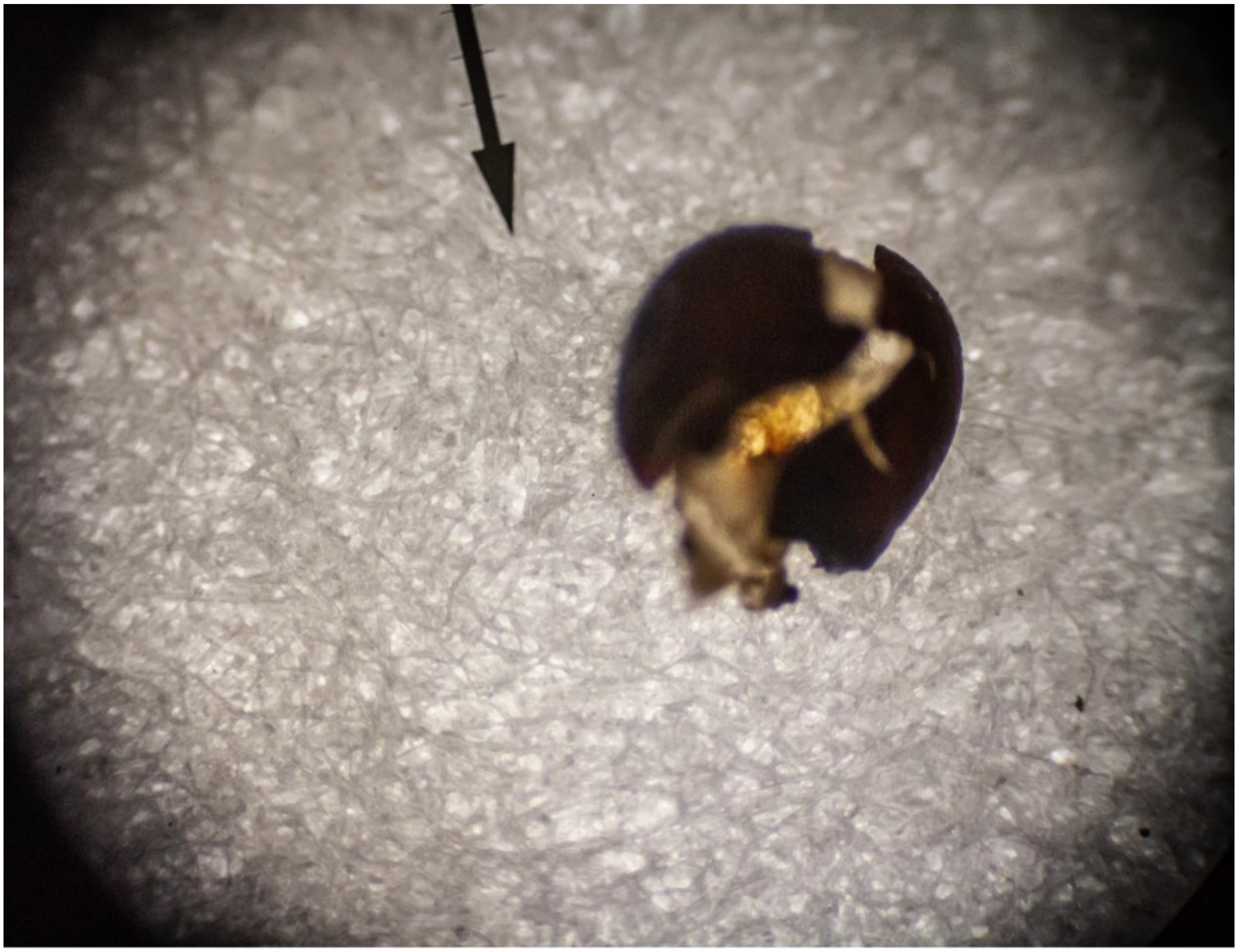


Figure 2.7. Kansas Palmer amaranth (PA) and KS waterhemp (WH) viability expressed as a percent of received seeds at all locations including Indiana (IN), Manhattan, Kansas (KS-1), Rossville, KS (KS-2), Missouri (MO), North Dakota, (ND), Brooklyn, Wisconsin (WI-1), and Janesville, Wisconsin (WI-2).

Removal time consisted of seven and twelve months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

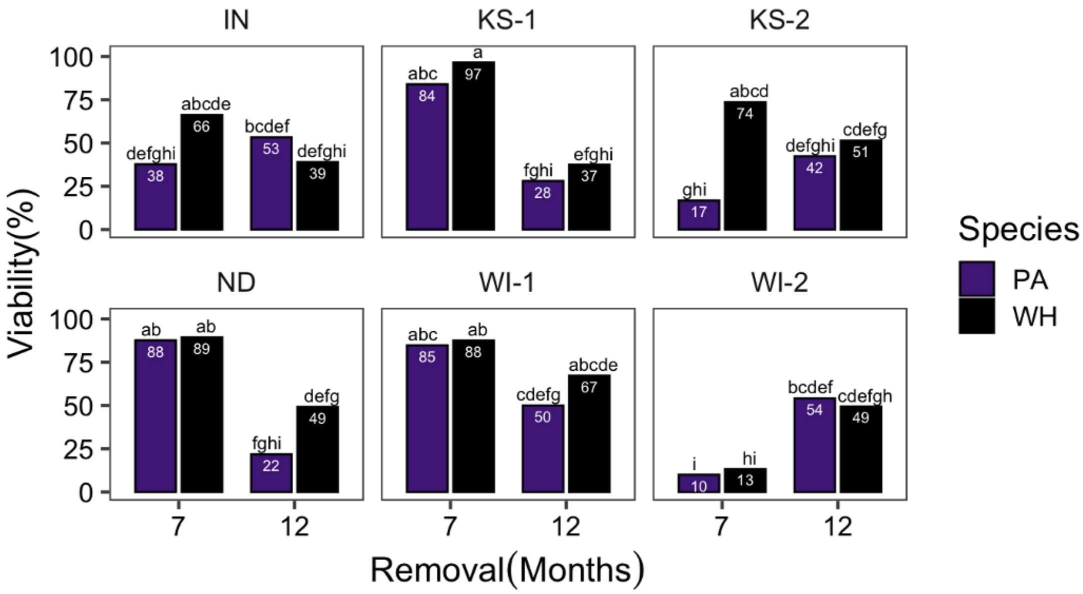


Figure 2.8. Kansas Palmer amaranth and KSWH dormancy expressed as a percent of received seeds at all locations including Indiana (IN), Manhattan, Kansas (KS-1), Rossville, Kansas (KS-2), Columbia, MO (MO), Fargo, North Dakota (ND), Brooklyn, WI (WI-1), Janesville, WI (WI-2).

Removal time consisted of seven and twelve months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

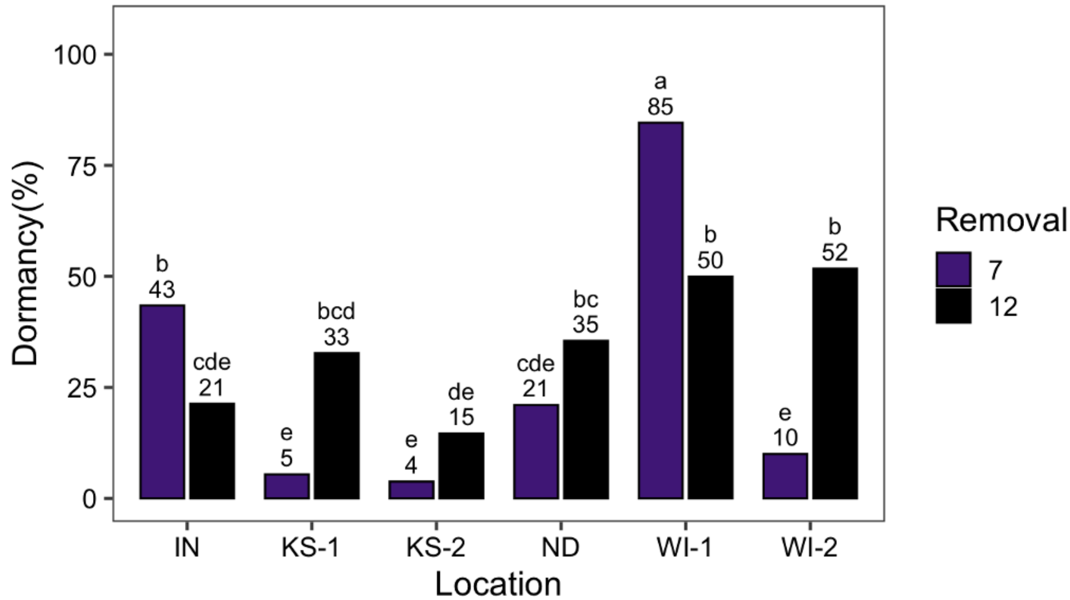


Figure 2.9. Viability of Indiana waterhemp (INWH), Kansas Palmer amaranth (KSPA), Kansas waterhemp (KSWH), Missouri waterhemp (MOWH), North Dakota Palmer amaranth (NDPA), North Dakota waterhemp (NDWH), and Wisconsin waterhemp (WIWH) seed populations at KS-2 were calculated as a percent of received seed.

Removal time consisted of seven and twelve months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different ($\alpha \leq 0.05$).

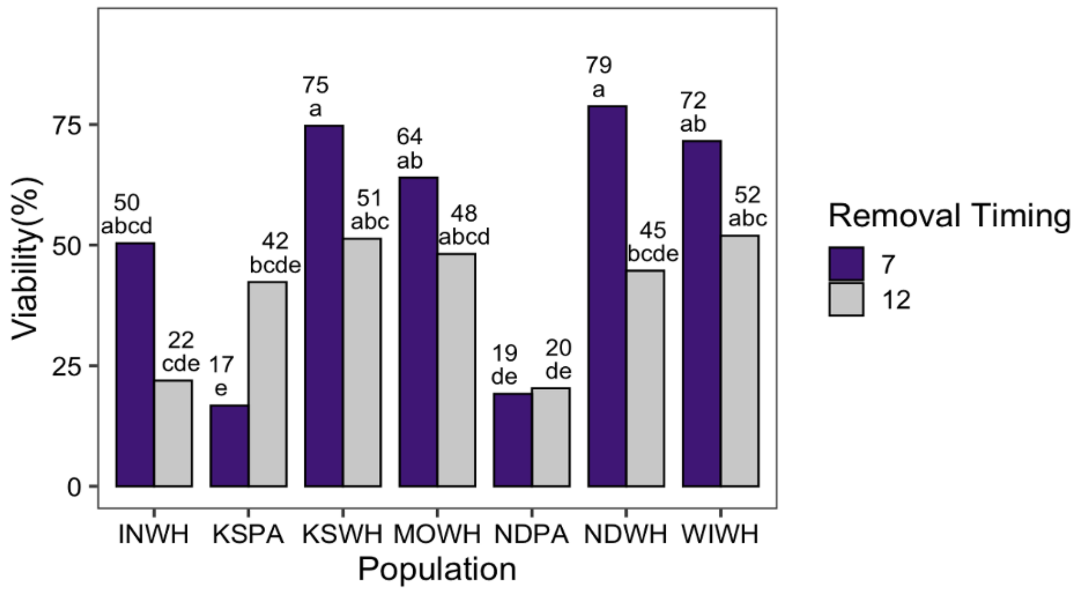


Figure 2.10. Indiana waterhemp viability comparison among treatments and removal time in cover crop (cc) and no cover crop (ncc) averaged over two locations including IN and KS-2.

Removal timing consisted of months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

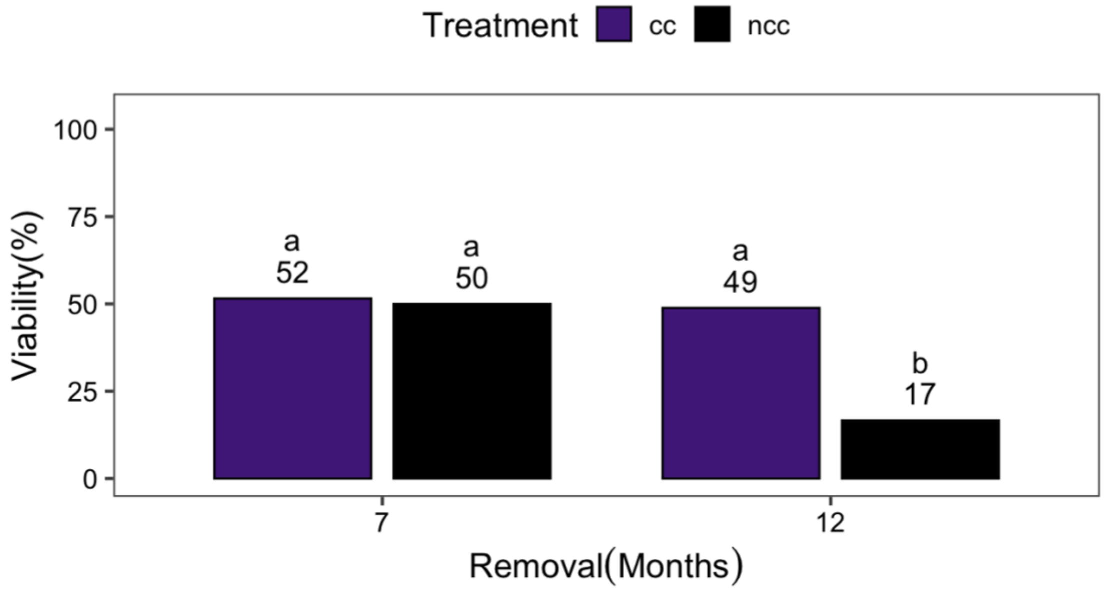


Table 2.1. Each collaborator selected a population from their state and the respective species are listed.

State	Species
Kansas	*Amaranthus palmeri*
Kansas	*Amaranthus tuberculatus*
North Dakota	*Amaranthus palmeri*
North Dakota	*Amaranthus tuberculatus*
Wisconsin	*Amaranthus tuberculatus*
Missouri	*Amaranthus tuberculatus*
Indiana	*Amaranthus tuberculatus*

Table 2.2. Description of locations used in study of *Amaranthus* seed viability, including soil series, cover crop (CC) or no cover crop (NCC), organic matter (OM%), clay content (clay(%)), and pH

Location	Soil Series	Treatment	OM (%)	Clay (%)	pH
Rossville, Kansas (KS-2)	Eudora Silt Loam	CC	1.7	10	5.8
		NCC	1.7	10	5.5
Manhattan, Kansas (KS-1)	Reading Silty Clay Loam	CC	2.9	24	6.2
		NCC	2.9	27	6.8
Columbia, Missouri (MO)	Mexico Silt Loam	CC	3.2	19	6.7
		NCC	3.1	20	6.6
Brooklyn, Wisconsin (WI-1)	Kegonsa Silt Loam	CC	2.1	14	7.4
		NCC	1.9	12	7.5
Fargo, North Dakota (ND)	Fargo-Ryan, Thick Solum Silty Clays	CC	7.4	51	7.9
		NCC	7.3	49	7.7
Lafayette, Indiana (IN)	Toronto-Millbrook Complex	CC	3.0	15	6.4
		NCC	3.1	19	6.3
Janesville, Wisconsin (WI-2)	Plano Silt Loam	CC	4.4	19	5.9
		NCC	3.9	21	6.4

Table 2.3. Listed are geographic coordinates, date seed packets were buried and removed, and locations used in study of *Amaranthus* seed viability.

Location	Coordinates	Burial	Removal
Rossville, Kansas (KS-2)	39°07'12.7"N 95°55'23.2"W	10/25/2021	5/20/2022 10/4/2022 5/2023
Manhattan, Kansas (KS-1)	39°03’05.8”N 96°44’06.8”W	11/30/2021	5/9/2022 10/16/2022 5/2023
Columbia, Missouri (MO)	38°53’53.3”N 92°13’09.8”W	11/12/2021	5/31/2022 10/20/22 5/2023
Brooklyn, Wisconsin (WI-1)	42°52’15.6”N 89°23’57.0”W	10/26/21	5/27/2022 10/17/2022 5/2023
Fargo, North Dakota (ND)	46°55’49.4”N 96°51’06.5”W	10/21/2021	6/16/2022 10/5/2022 5/2023
Lafayette, Indiana (IN)	40°16’09.7”N 86°52’58.3”W	11/10/21	5/26/2022 10/28/2022 5/2023
Janesville, Wisconsin (WI-2)	42°43’33.9”N 89°01’26.0”W	10/26/21	6/1/2022 10/17/2022 5/2023

Table 2.4. An analysis of variance was applied to Kansas Palmer amaranth and waterhemp seeds placed at all sites.

Fixed Effects	F value	Pr(>F)
Location	17.09	6.62E-13
Species	19.28	2.3E-05
Removal Time	35.91	1.99E-08
Treatment	1.56	0.21
Location X Species	2.78	0.02
Location X Removal Time	29.2	1.2E-19
Species X Removal Time	3.27	0.07
Location X Treatment	1.84	0.11
Species X Treatment	1.25	0.27
Removal Time X Treatment	0.004	0.95
Location X Species X Removal Time	**4.64**	**0.0006**
Location X Species X Treatment	0.28	0.92
Location X Removal Time X Treatment	1.23	0.30
Species X Removal Time X Treatment	0.83	0.36
Location X Species X Removal Time X Treatment	0.57	0.72

Table 2.5. An analysis of variance applied to Kansas Palmer Amaranth and waterhemp dormancy placed in the experiment at all sites and values are listed.

Fixed Effects	F value	Pr(>F)
Species	12.40	0.0006
Location	45.80	7.34E-27
Treatment	7.24	0.008
Removal Time	6.94	0.01
Species X Location	1.73	0.13
Species X Treatment	0.57	0.45
Location X Treatment	1.32	0.26
Species X Removal Time	2.21	0.14
Location X Removal Time	**23.91**	**6.78E-17**
Treatment X Removal Time	1.37	0.24
Species X Location X Treatment	0.50	0.78
Species X Location X Removal Time	0.67	0.64
Species X Treatment X Removal Time	0.28	0.60
Location X Treatment X Removal Time	1.49	0.20
Species X Location X Treatment X Removal Time	0.63	0.67

Table 2.6. An analysis of variance was applied to the viability of seeds placed in the experiment at Rossville, Kansas and values are listed.

Fixed Effects	F value	Pr(>F)
Treatment	0.24	0.63
Population	9.12	0000014
Removal Time	16.37	0.0001
Treatment X Population	0.34	0.91
Treatment X Removal Time	0.2	0.66
Population X Removal Time	**5.45**	**0.00009**
Treatment X Population X Removal Time	0.53	0.78

Table 2.7. An analysis of variance applied to each population's viability placed in the experiment and values are listed.

Population	Fixed Effect	F value	Pr(>F)
Missouri waterhemp	Treatment	16.9	0.002
	Removal Time	**5.04**	**0.05**
	Treatment X Removal Time	1.58	0.24
North Dakota waterhemp	Treatment	0.85	0.37
	Removal Time	**27.25**	**0.00004**
	Location	0.08	0.78
	Treatment X Removal Time	0.45	0.51
	Treatment X Location	0.67	0.42
	Removal Time X Location	0.30	0.59
	Treatment X Removal Time X Location	1.80	0.19
North Dakota Palmer amaranth	Treatment	0.63	0.44
	Removal Time	24.89	0.00006
	Location	42.75	0.0002
	Treatment X Removal Time	0.37	0.55
	Treatment X Location	1.33	0.26
	Removal Time X Location	**27.16**	**0.0004**
	Treatment X Removal Time X Location	0.07	0.8

Population	Fixed Effect	F value	Pr(>F)
Indiana waterhemp	Location	2.83	0.11
	Treatment	6.42	0.02
	Removal Time	7.32	0.01
	Location X Treatment	0.87	0.36
	Location X Removal Time	2.47	0.13
	Treatment X Removal Time	**5.29**	**0.03**
	Location X Treatment X Removal Time	1.26	0.28
Wisconsin waterhemp	**Location**	**42.23**	**00002**
	Treatment	0.80	0.38
	Removal Time	0.78	0.39
	Location X Treatment	1.06	0.31
	Location X Removal Time	0.54	0.47
	Treatment X Removal Time	1.34	0.26
	Location X Treatment X Removal Time	0.54	0.47

Table 2.8. An analysis of variance applied to each population's dormancy placed in the experiment and values are listed.

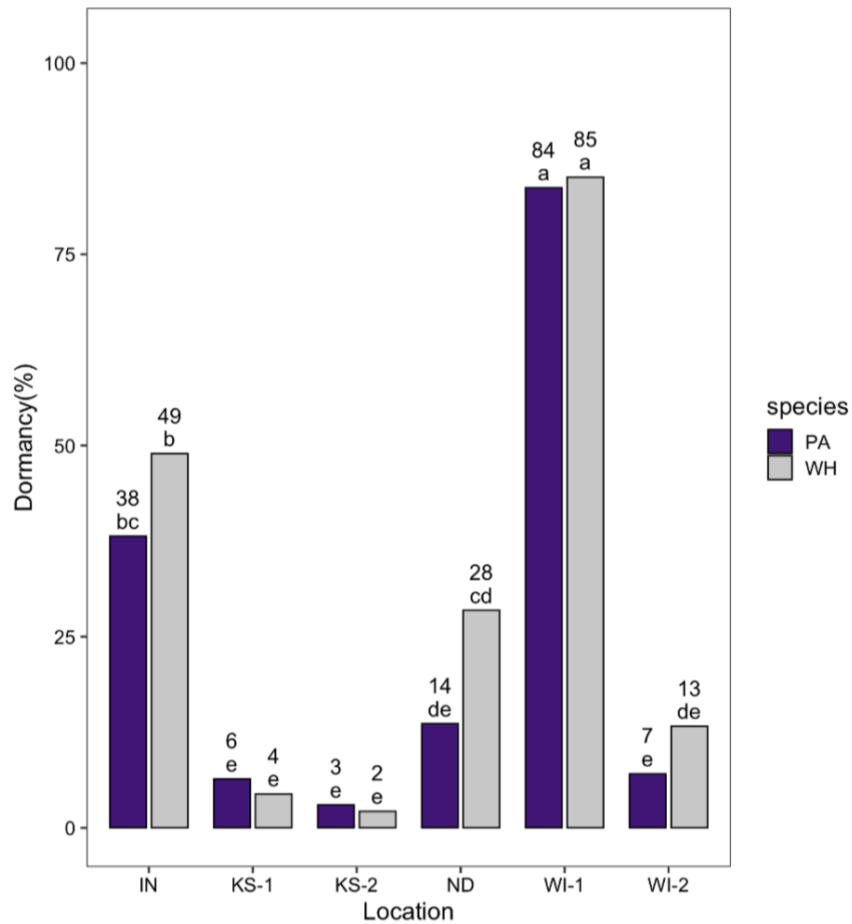
Population	Fixed Effect	Value	Pr(>F)
Missouri waterhemp	Treatment	0.94	0.36
	Removal	0.95	0.35
	Treatment X Removal Time	0.80	0.39
North Dakota Palmer amaranth	Treatment	2.86	0.10
	Removal Time	3.27	0.09
	Location	28.63	0.00003
	Treatment X Removal Time	1.67	0.21
	Treatment X Location	0.001	0.98
	Removal Time X Location	**12.00**	**0.002**
	Treatment X Removal Time X Location	4.40	0.05

Population	**Fixed Effect**	**Value**	**Pr(>F)**
North Dakota waterhemp	Treatment	0.01	0.92
	Removal	3.40	0.08
	Location	**8.88**	**0.01**
	Treatment X Removal Time	1.13	0.30
	Treatment X Location	0.03	0.86
	Removal Time X Location	0.23	0.64
	Treatment X Removal Time X Location	1.16	0.29
Indiana waterhemp	**Location**	**42.23**	**0.000002**
	Treatment	0.80	0.38
	Removal Time	0.78	0.39
	Location X Treatment	1.06	0.32
	Location X Removal Time	0.54	0.47
	Treatment X Removal Time	1.34	0.26
	Location X Treatment X Removal Time	0.54	0.47

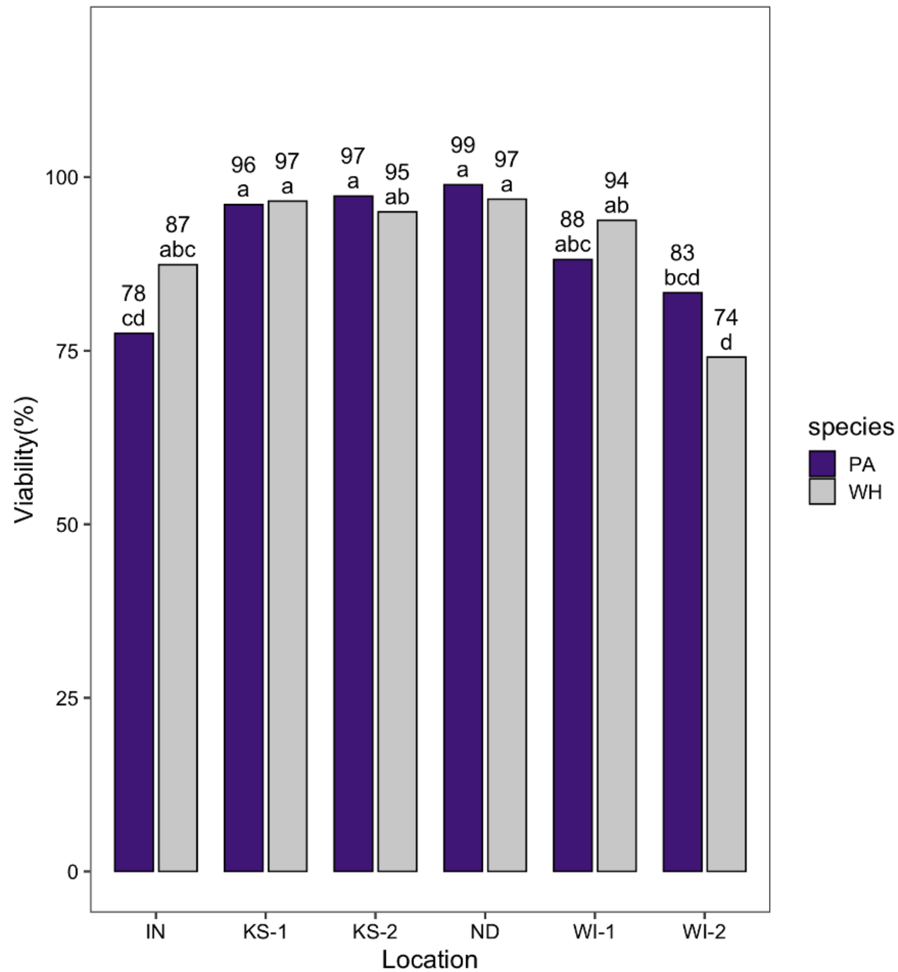
Population	Fixed Effect	Value	Pr(>F)
	Treatment	3.22	0.08
	Removal Time	0.02	0.89
	Location	8.13	0.001
Wisconsin waterhemp	Treatment X Removal Time	0.15	0.70
	Treatment X Location	2.43	0.10
	Removal Time X Location	**17.63**	**0.000008**
	Treatment X Removal Time X Location	0.44	0.65

Appendix A - Effect of Cereal Rye Cover Crop on Seed Viability of *Amaranthus* spp.

Appendix A Figure A.1. Kansas Palmer amaranth (PA) and waterhemp (WH) dormancy after seven months of burial. Removal timing consisted of months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).



Appendix A Figure A.2. Kansas Palmer amaranth (PA) and waterhemp (WH) viability after seven months of burial. Removal timing consisted of months after seed packet burial. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).



Appendix A Table A.1. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Manhattan, Kansas average of four replications.

Location	Population	Treatment	Removal Timing (months)	V (%)	D (%)	GCG (%)	N (%)	Total Seeds (number per packet)
Manhattan, KS	Kansas WH	CC	7	96.20	2.6	93.6	3.8	42.8
			12	48.61	48.6	0.0	51.4	33.5
		NCC	7	96.89	6.3	90.6	3.1	48.3
			12	26.19	26.1	0.0	73.8	32.3
	Kansas PA	CC	7	15.76	10.3	85.3	4.4	47.8
			12	44.46	38.1	0.0	61.9	25.8
		NCC	7	17.74	2.5	94.0	3.5	49.5
			12	40.23	18.0	0.0	82.0	35.3

Appendix A Table A.2. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Columbia, Missouri average of four replications.

Location	Population	Treatment	Removal (Months)	V (%)	D (%)	GCG %	N (%)	Total Seeds (number per packet)
Columbia, MO	All populations	CC	7	89.2	10.6	78.6	10.8	44.9
			12	66.8	8.5	58.2	33.2	39.0
		NCC	7	84.7	21.9	62.8	15.3	43.6
			12	59.7	23.2	36.5	40.3	44.0

Appendix A Table A.3. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Janesville, Wisconsin average of four replications.

Location	Population	Treatment	Removal (Months)	V (%)	D (%)	GCG %	N (%)	Total Seeds (number per packet)
Janesville, WI	Kansas WH	CC	7	5.3	5.3	0.0	94.7	37.0
			12	61.3	61.3	0.0	38.7	44.8
		NCC	7	21.3	21.3	0.0	78.7	34.0
			12	37.8	37.8	0.0	62.2	30.3
	Kansas PA	CC	7	16.2	11.0	5.1	83.9	33.3
			12	64.3	64.3	0.0	35.8	45.8
		NCC	7	5	2.3	1.9	95.0	38.7
			12	43.7	49.5	0.0	56.3	32.3
	Wisconsin WH	CC	7	29.6	6.3	23.3	70.4	26.0
			12	74.1	74.1	0.0	25.9	46.0
		NCC	7	11	8.8	2.2	89.0	34.0
			12	52.2	52.2	0.0	47.8	39.3

Appendix A Table A.4. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Fargo, North Dakota average of four replications.

Location	Population	Treatment	Removal (Months)	V (%)	D (%)	GCG %	N (%)	Total Seeds (number per packet)
Fargo, ND	Kansas WH	CC	7	90.6	41.8	48.9	9.4	44.3
			12	52	86.5	13.5	48.0	30.0
		NCC	7	88.1	15.1	72.9	11.9	37.8
			12	46.4	78.6	21.4	53.6	27.5
	Kansas PA	CC	7	89.3	17.6	71.6	10.8	40.8
			12	27.5	91.4	8.6	72.5	24.8
		NCC	7	86.1	9.6	76.5	13.9	46.0
			12	16.1	92.7	7.3	83.9	16.8
	North Dakota WH	CC	7	73.7	22.0	51.7	26.3	36.5
			12	46.3	94.0	6.0	53.7	20.3
		NCC	7	87.7	36.3	51.4	12.3	39.8
			12	30.9	93.2	6.8	69.1	29.5
	North Dakota PA	CC	7	83.1	9.7	73.5	16.9	48.0
			12	34.6	82.5	17.5	65.4	19.0
		NCC	7	77.5	14.5	63.0	22.5	45.5
			12	19.9	86.5	13.5	80.1	15.3

Appendix A Table A.5. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Lafayette, Indiana average of four replications.

Location	Population	Treatment	Removal (Months)	V (%)	D (%)	GCG (%)	N (%)	Total Seeds (number per packet)
Lafayette, IN	Kansas PA	CC	7	46.0	46.0	0.0	53.9	46.5
			12	49.6	21.8	27.7	50.4	44.0
		NCC	7	30.3	30.3	0.0	69.7	46.5
			12	58.1	7.5	50.6	41.9	43.8
	Kansas WH	CC	7	64.2	51.0	13.4	35.9	42.0
			12	31.9	26.4	5.5	68.0	41.5
		NCC	7	69.1	46.8	22.3	30.9	54.3
			12	46.1	30.2	15.9	53.9	38.0
	Indiana WH	CC	7	46.7	46.7	0.0	53.3	44.0
			12	60.3	48.3	12.0	39.6	37.5
		NCC	7	57.2	46.5	10.7	42.8	46.5
			12	26.8	25.4	1.4	73.2	37.3

Appendix A Table A.6. All observations of viable (V), dormant (D), nonviable (N), and growth chamber germinated (GCG) waterhemp (WH) and Palmer amaranth (PA) seeds placed in cover crop (CC) and no cover crop (NCC) at Brooklyn, Wisconsin average of four replications.

Location	Population	Treatment	Removal (Months)	V (%)	D (%)	GCG (%)	N (%)	Total Seeds (number per packet)
Brooklyn, WI	Kansas WH	CC	7	83.8	80.1	3.6	16.2	41.3
			12	58.5	58.5	0.0	41.5	44.0
		NCC	7	90.1	90.1	0.0	9.9	27.5
			12	76	56.3	19.7	24.0	40.3
	Kansas PA	CC	7	84.1	82.0	2.2	15.9	23.0
			12	38.6	38.6	0.0	61.4	36.7
		NCC	7	85.4	85.4	0.0	14.6	27.3
			12	60.2	45.6	14.7	39.8	43.3
	Wisconsin WH	CC	7	81.3	81.3	0.0	18.7	26.5
			12	44.1	44.1	0.0	55.9	29.0
		NCC	7	78.2	78.2	0.0	21.8	26.3
			12	60.8	53.1	7.7	39.2	43.6

Chapter 3 - Grazing Winter Cover Crops: Does it Affect Weed Suppression in Kansas?

Abstract

Cover crop hectares across Kansas have increased in recent years to further develop soil health parameters, reduce erosion, and suppress weeds. Farmers are attempting to offset costs of cover crop implementation through forage use. The objective of this research was to evaluate the influence of grazing grass-dominated cover crop mixes on weed suppression. The effects of grazing on weed suppression were evaluated on three on-farm locations near Castleton, Topeka, and Wabaunsee, KS. Two additional locations with forage cover crops, Clay Center and Ellsworth, KS were sampled to evaluate forage quality. Weed and cover crop biomass, stocking rate, cattle type, and grazing period varied by location. Four replications of exclusion cages were placed in the field prior to grazing as a nontreated check, then exclusion cages were placed every two weeks to simulate the removal of grazing. Cover crop and weed biomass were harvested at the time of exclusion cage placement and in the spring prior to cover crop termination. Similar influence of grazing was observed at locations that contained weed species of similar lifecycles. Near Wabaunsee, where summer annuals of giant foxtail (*Setaria faberi* Herrm.) and Palmer amaranth (*Amaranthus palmeri* S. Watson) were present, grazing at 1.95 AU ha^{-1} negatively influenced weed suppression. Cover crop biomass sampled over the grazing season ranged from 135 to 2500 kg ha^{-1}. Near Topeka and Castleton, where winter annual weed species such as horseweed (*Erigeron canadensis* L.), common chickweed (*Stellaria media* (L.) Vill.), and henbit (*Lamium amplexicaule* L.) were dominant, grazing did not influence weed suppression. Cover crop biomass at Topeka ranged from 77 to 828 kg ha^{-1} over the grazing season with 1.83 AU ha^{-1}, while at Castleton, cover crop biomass ranged from 102 to 703 kg ha^{-1} with 3.5 AU ha^{-1}.

Grazing under a wide range of stocking rates had no influence on weed suppression when winter annual weeds were present. However, grazing later in the cover crop growing season negatively influenced weed suppression when troublesome summer annuals were emerging. Farmers should be aware that grazing cover crops can reduce summer annual weed control and can increase the need for an efficacious herbicide program.

Introduction

The United States Department of Agriculture refers to cover crops as "any crop grown to cover the soil and may be incorporated into the soil later for enrichment" (USDA n.d.). Generally, in Kansas, these crops are grown in the off season between cash crops such as corn, soybean, wheat, and sorghum. Research has proven that cover crops provide several benefits to soil health parameters, under certain environmental conditions in Kansas (Blanco-Canqui et al. 2011; Blanco-Canqui et al. 2020; Star et al. 2019). Cover crops also suppress troublesome weeds but will not achieve complete control (Reddy et al. 2003; Teasdale et al. 2007; Mohler and Teasdale 1993). Nonetheless, advantages of cover crops have led farmers to adopt the practice on an increased number of production hectares in the last decade (USDA NASS 2019).

Cover crops require input costs for seed, planting, and termination but offer little financial return in the short term. Because of the lack of economic return on cover crops and the need for feed during the winter season, Kansas farmers often employ grazing of cover crops with livestock to add value. Some of the common grass cover crops in Kansas that are used for both grazing and weed suppression are triticale, winter wheat, and cereal rye. Farmers will mix other brassica and legume species with a dominant grass cover crop to improve certain soil health and fertility parameters including nitrogen production and compaction mitigation. These grass cover crop species can provide nutritious feed for cattle, which is important during the winter months as a substitute for hay when rangeland is not productive enough for extensive grazing (Watson et al. 1993). Nutritive values such as crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD) are important metrics to determine the quality of livestock forage. All these values play a role in forage consumption, digestibility, and overall weight gain of livestock. These values also determine the monetary value that farmers pay for forage and hay (USDA AMS Livestock, Poultry, and Grain Market News 2022).

It is also important to ensure that grazing cover crops does not minimize the positive influence that cover crops can have on cropping systems. The influence of grazing cover crops on weed suppression has yet to be explored in the state of Kansas. Grazing cattle can reduce cover crop biomass, cover crop stands, and have other lasting impacts that could influence the success of weed species. Research locations were established across Kansas to quantify weed and cover crop biomass over the grazing period and prior to cash crop planting to determine if there was an effect of grazing cover crops on weed suppression.

Materials and Methods

Site Description

Five research locations were selected in eastern and central areas of Kansas (Figure 3.1). These were on-farm locations planted to cover crops between August and September of 2021 and were to be grazed by cattle. Each location had unique management parameters including cover crop species mix, cattle type, stocking rate, field size, and grazing period length. The common parameter was that each cover crop mix had a dominant grass cover crop species such as cereal rye or triticale. Cropping and management history of each field likely affected weed species and biomass recorded.

Wabaunsee, Kansas

The field in Wabaunsee, KS was a no-tillage field in the north-eastern area of the state. This field was in a corn-soybean rotation, and just prior to this research silage corn was harvested. Soil tests registered organic matter at 3% with a pH of 5.4. The cover crop mix of cereal rye, spring barley, radish, and spring pea was drilled after silage harvest on September 11, 2021. No irrigation was utilized at this location, and the field was considered dryland crop production. Predominant weed species as noted by the farmer were giant foxtail (*Setaria faberi* Herrm.) and Palmer amaranth (*Amaranthus palmeri S*. Watson). Cattle at this location consisted of 80 Angus heifers that weighed an estimated 454 kg and had access to 41 ha of pasture to graze (1.95 AU ha^{-1}). Grazing occurred for 92 non-consecutive days between December 5, 2021 and April 16, 2022. Cattle were provided hay when available cover crop biomass was low due to grazing or snow cover.

Castleton, Kansas

The field in Castleton, KS was a no-tillage field in the south-central area of the state. This field was in an annual forage rotation, and prior to this research was an annual summer forage and recurring crabgrass which was grazed in the late summer-fall. The cover crop mix of triticale, winter pea, and turnip was drilled on October 1, 2021. No irrigation was utilized at this location, and the field was considered dryland crop production. Predominant weed species at this location were horseweed (*Erigeron canadensis* L.), common chickweed (*Stellaria media* (L.) Vill.), henbit (*Lamium amplexicaule* L.), green flower pepperweed (*Lepidium densiflorum* Schrad.), prickly lettuce (*Lactuca serriola* L.), Carolina geranium (*Geranium carolinianum* L.), evening primrose (*Oenothera biennis* L.), yarrow (*Achillea millefolium* L.), pinnate tansy mustard (*Descurainia pinnata* (Walter) Britton) and flixweed (*Descurainia sophia* (L.) Webb ex Prantl). Cattle consisted of 546 red Angus calves that weighed an estimated 227 kg and had access to 78 ha of pasture to graze (3.5 AU ha^{-1}). Grazing occurred for 32 consecutive days between January 3 and February 1, 2022. Cattle were provided hay when available biomass was low due to grazing or snow cover.

Ellsworth, Kansas

The field in Ellsworth, KS was a no-tillage field in the south-central area of the state. Prior to this research grain sorghum was grown in 2021. The cover crop mix of cereal rye, radish, and turnip was interseeded into the grain sorghum crop on September 7, 2021. The field has a center pivot, but the cover crop did not receive any irrigation. Predominant weed species at this location were henbit and common chickweed. Cattle type consisted of 118 commercial crossbreed calves that weighed an estimated 305 kg and had access to 116 ha of pasture to graze (0.68 AU ha^{-1}). Grazing occurred for 68 consecutive days between November 11, 2021 and January 18, 2022. Cattle were provided hay when available biomass was low due to grazing or snow cover.

Clay Center, Kansas

The field in Clay Center, KS was a no-tillage field in the north-central area of the state. Prior to this research corn was grown in 2021. The cover crop mix of cereal rye, radish, forage collars, and turnip were interseeded into the corn crop on August 26, 2021. The field has a center pivot but the cover crop did not receive any irrigation. Predominant weed species at this location were chickweed and henbit. Cattle consisted of 75 commercial cows that weighed an estimated 545 kg and had access to 135 ha of pasture to graze (0.67 AU ha^{-1}). Grazing occurred for 62 consecutive days between January 29 and April 1, 2022. Cattle were supplemented feedstuff when available biomass was low due to grazing or snow cover.

Topeka, Kansas

The field in Topeka, KS was a no-tillage field in the north-eastern area of Kansas. Prior to this research corn was grown in 2021. The cover crop mix of cereal rye, radish, and crimson clover was drilled after corn harvest on September 29, 2021. The field has a center pivot, but the cover crop did not receive any irrigation. Predominant weed species at this location were chickweed, henbit, and horseweed. Cattle consisted of 139 commercial calves that weighed an estimated 227 kg and had access to 38 ha of pasture to graze (1.83 AU ha^{-1}). Grazing occurred for 106 consecutive days between December 19, 2021 and April 4, 2022. Cattle were supplemented feedstuff when available biomass was low due to grazing or snow cover.

Experimental Design

A randomized complete block design with four replications was used at each experimental location. Each site was unique to the number of treatments it received and what each of those treatments was. At each location, treatment was grazing days and was unique based on weather conditions and farm management at respective sites. Measurements were taken of both weeds and cover crop biomass present. During the grazing period, exclusion cages were placed in the field to restrict the grazing of cattle from 0.75 m^2 area. This area simulated the removal of grazing from the entire field. Four replications were placed at each simulated removal timing to ensure variability was captured across the field. These four replications were placed with geographic regard to the water source (Figure 3.2). Grazing is inevitably higher near the water source, so replications were placed to ensure that variability was accounted for at each site.

Data Collection:

At all locations before grazing, during grazing, and prior to cover crop termination (or planting) cover crop biomass, cover crop height, weed biomass, forage quality, and weed height were measured. These values were measured to understand the relationship between stocking rate, cover crop biomass, cover crop height, and weed biomass.

Cover crop and weed heights were assessed by measuring three representative plants with a ruler and reporting the mean. Cover crop and weed biomass were measured by clipping and removing all biomass above ground level within 0.1 m^2 and recording wet weights. Wet biomass was then placed in a dryer until constant dry weight was recorded.

Forage quality was assessed by hand plucking samples outside of cages in the field to resemble biomass removal habits of cattle (enough to fill a 1 liter plastic bag). These samples were dried at 48°C until constant dry weight and then sent to Ward Laboratories Inc. in Kearney, NE for near infrared spectroscopy analysis. Values analyzed were CP, ADF, NDF, NDFD, IVDMD, RFV, and RFQ. These values were determined to estimate the economic value of cover crop as feed inKansas. These feed values all play an important role in cattle nutrition and production (Lalman 2017; Lemus 2020).

Statistical Analysis:

All data were analyzed using the software “R” (R Core Team 2021). All assumptions of normality were evaluated with box plots, residuals, and quantile-quantile plots using R package ggplot2 and ggthemes (Wickham 2016; Arnold 2021). Data were subjected to an analysis of variance in R using a linear mixed model using package lme4 and lmerTest ($\alpha = 0.05$) (Kuznetsova, Brockhoff, Christensen 2017). Replication was considered a random effect. Means were separated using Tukeys HSD Test ($\alpha = 0.05$) with R package emmeans, multcomp, and multcompView (Hothorn, Bretz, and Westfall 2008; Graves, Piepho, and Selzer 2019; Lenth 2022).

Results

Across all locations, three locations provided adequate data to analyze and report results. One location, Clay Center, had high wind and lack of moisture which resulted in corn residue filling paneled areas. Despite attempts to remove residue, weed emergence was affected and none was observed within treatment areas. At another location, Ellsworth, an extremely low stocking rate, under 0.68 AU/ha^{-1}, and treatment locations were not placed in primary grazing locations. This resulted in lack of consistent grazing and data was not presumed reliable.

At Castleton, Topeka, and Wabaunsee, results varied by weed species type and life cycle. Both Castleton and Topeka were predominantly winter annuals with no summer annual species observed. On the other hand, Wabaunsee was predominantly summer annuals with little to no winter annual weed emergence observed. Each location will be analyzed based on weed species present, while conclusions will be based on weed species' life cycle.

Summer Annual Weeds and Grazing

In Wabaunsee, KS, treatments consisted of 0, 16, 37, 49, 65, and 92 days of grazing between December 5, 2021 and April 16, 2022. During the grazing season, cover crop biomass ranged from 133 to 2498 kg ha^{-1} and declined over time as days of grazing increased (Figure 3.3). This decline in biomass is consistent with other studies involving cover crop grazing during the fall, winter, and springtime (Anderson et al. 2022; Schomberg et al. 2014). Cover crop height and biomass recorded during the grazing season did not reduce weed control, but regrowth height and biomass (CC measured in the spring) did reduce weed control. As cover crop height and biomass in the spring increased, weed biomass also increased (Figure 3.4 and 3.5). Overall, reduced cover crop biomass negatively influenced summer annual weed biomass (Tables 3.2 and 3.3). Treatments with less CC biomass generally resulted in more weed biomass during the spring planting season (Figures 3.3 and 3.6). These data were collected on May 16, 2022, before cover crop termination and planting took place. Arguably, that is one of the most influential times when farmers are concerned with weed competition with the emerging crop. When grazing treatment reached around 65 days of grazing, a decline in weed control was observed before planting (Figures 3.3 and 3.6). As little to no research in the semi-arid Great Plains region of the United States has been conducted to discover the influence of cover crops on summer annual weed biomass, these data stand-alone (Kumar et al. 2020).

Winter Annual Weeds and Grazing

The two locations with winter annual weed species present were Castleton and Topeka, KS. At Castleton and Topeka, CC biomass ranged from 102 to 703 kg ha^{-1} and 77 to 828 kg ha^{-1}, respectively, over the grazing season with a general decline over the grazing period, similar to biomass at Wabaunsee (Figures 3.7 and 3.8). During the grazing season and prior to cover crop termination at Castleton and Topeka, there was no influence of grazing cover crops on winter annual weed control (Figures 3.9 and 3.10). This was consistent with findings out of Missouri where, in some cases, grazing cover crops influenced chickweed and henbit control, but in other cases, it did not (Dhakal et al. 2022). Previous research and these data suggest that control may be more dependent on grazing interactions with other environmental conditions or winter annual weed densities.

Forage Quality

Forage quality was assessed at all locations in Kansas including Castleton, Wabaunsee, Topeka, Clay Center, and Ellsworth (Tables 3.4 3.5, 3.6, 3.7, and 3.8 respectively). Previous research indicated a positive linear relationship observed between NDF and forage maturity (Nordheim-Viken, Volden 2009). The NDF value indicated the total cell wall constituents and a higher value in turn results in more energy necessary to break down the forage (Ball et al. 2001). The highest NDF values were observed with cereal rye at Ellsworth over the grazing season from November to January ranging from 44.4 to 56.3. This was consistently high compared to other values observed at Clay Center (29.3) and Topeka (33.5). These values were significantly lower compared to other on-farm research that recorded cereal rye NDF values at boot stage in Ontario, Canada (Landry et al. 2019). However, in Kansas, many farmers utilize cereal rye for cattle grazing long before boot stage and therefore take advantage of lower NDF values, which resulted in better forage for livestock.

Relative feed value is “an index for ranking cool-season grass and legume forages based on combining digestibility and intake potential. Calculated from ADF and NDF. The higher the RFV, the better the quality. It is used to compare varieties, match hay/silage inventories to animals, and to market hay” (Ball et al. 2001). As RFV increases, the economic value of the forage follows. Overall, RFV should not be used to compare different species of forages, rather to rank feeds of the same species (Dunham 1998). The lowest RFV values were observed in Ellsworth ranging from 100 to 144 while the highest values were in Clay Center ranging from 156 to 255 (Figures 3.7 3.8).

Relative forage quality is also an index of forages and is determined from both dry matter intake (DMI) and TDN. Every class of livestock has different RFQ value requirements (Hancock et al. 2014). For example, young heifers and stocker cattle need around 120 to 140 RFQ values while lactating beef cattle need around 115 to 130. Relative forage quality is typically greater for younger forage. In our study, RFQ was generally higher earlier in the grazing season at all locations excluding Ellsworth. This might have stemmed from the previous crop of sorghum. The highest RFQ values were observed at Clay Center, Topeka, and Wabaunsee with values at 221 (0 days of grazing), 212 (0 days of grazing), and 234 (37 days of grazing), respectively (Tables 3.5, 3.6, and 3.7).

Crude protein values are based on nitrogen content and can be influenced by the amount of rainfall on the forage (Ball et al. 2001). Crude protein values at all locations were variable. At Clay Center, Topeka, and Wabaunsee, the lowest values were observed at the beginning of the season and the highest values towards the end of the grazing season (Tables 3.5, 3.6, and 3.7, respectively). The highest values were observed at Clay Center with recordings at 22.9 to 23.9 (Table 3.7). This is high for cereal rye, but values were sampled when plants were young and naturally have high CP. Other research has also found similarly high CP values in young cereal rye plants (Kantar et al. 2011).

Acid detergent fiber is used to calculate digestibility and TDN and is critical to hay value and forage quality since it “contains cellulose, lignin, and silica, but not hemicellulose” (Ball et al. 2001). As ADF increases, the value of forage decreases. ADF was variable, but highest values were observed in the central areas of the state where rainfall is lesser than in the eastern portion which had lower ADF.

At all locations grazing occurred in January 2022. The January 7, 2022 Kansas Direct Hay Market Report contains alfalfa forage quality and prices that are displayed alongside forage values from this experiment in Table 3.9. Crude protein values of cereal rye and triticale compared to fair alfalfa crude protein values in most cases. This is the main report in Kansas that gives accurate and current hay prices based on quality. These values are presented to provide background information for what capital farmers may be gaining from grazing cover crops instead of purchasing hay.

Cereal rye and triticale cover crops at all five Kansas locations provided adequate CP, ADF, and NDF values to support feeder calves and cow/calf pairs during the fall, winter, and spring months. Cover crop biomass can affect grazing availability, but in years with adequate rainfall, cover crops can take the place of hay. Farmers should take advantage of quality cover crop forage when grazing cattle at low stocking rates at early cover crop growth stages.

Conclusions

Grazing cover crops in Kansas can negatively influence weed suppression depending on weed life cycle. Summer annual weed species such as Palmer amaranth and giant foxtail were more dominant in longer grazed cover crop treatments. However, these same effects were not observed with winter annual weed species, likely due to the similar life cycle of cereal rye and triticale. Farmers and ranchers should be cautious when grazing cover crops if the main use of cover crops is for suppression of aggressive summer annual weed species. If farmers plan to graze cover crops, they should look to early seeding in the fall to produce larger amounts of biomass early in the growing season which would allow for earlier grazing. Cattle, in turn, could be removed from grazing earlier in the growing season to allow cover crops to recover and compete with summer annual species in the springtime. Alternatively, a reduced stocking rate to ensure adequate ground cover and plant recovery time could be a viable option for cattle grazing in the late winter or early spring.

Cover crops provide a forage source for livestock during the winter months when pastureland is not readily available for grazing due to dormancy. Although grass-based cover crop mixtures do not contain the nutritive value that high quality alfalfa does, it is still providing adequate feed for cattle at a time when costs may be high for hay. Farmers and ranchers should utilize these data to align with their strategies for grazing, cattle production, crop management, and weed control.

References

Anderson L, Blanco-Canqui H, Drewnoski ME, MacDonald JC, Carlson Z, Hansen BH, Brinton MM, Ulmer KM, Calus KJ (2022) Cover crop grazing impacts on soil properties and crop yields under irrigated no-till corn–soybean management. Soil Science Society of America Journal 86(1), 118–133

Ball DM, Collins D, Lacefield GD, Martin NP, Mertens DA, Olson KE, Putnam DH, Undersander DJ, Wolf MW (2001) Understanding forage quality. American Farm Bureau Federation Publication 1, no. 01: 1-15.

Blanco-Canqui H, Mikha MM, Presley DR, Claassen MM (2011) Addition ofcover crops enhances no-till potential for improving soil physical properties. Soil Science Society of America Journal 75: 1471-1482

Blanco-Canqui H, Ruis SJ (2020) Cover crop impacts on soil physical properties: A review. Soil Science Society of America Journal 84: 1527– 1576

Dunham JR (1998) Relative feed value measures forage quality. Forage Facts 41, no. 3

Lalman D (2017) Nutritive Value of Feeds for Beef Cattle | Oklahoma State University. https://extension.okstate.edu/fact-sheets/nutritive-value-of-feeds-for-beef-cattle.html

Lemus R (2020) Forage nutritive value on livestock production: Why CP and TDN matter? Mississippi State University Extension Service. http://extension.msstate.edu/newsletters/forage-news/2020/forage-nutritive-value-livestock-production-why-cp-and-tdn-matter

Dhakal D, Erwin ZL, Nelson KA (2022) Grazing cover crops in a no-till corn and soybean rotation. Agronomy Journal 114: 1255–1268

Hancock DW, Saha U, Stewart RL, Bernard JK, Smith RC, and Johnson JM (2014) Understanding and improving forage quality UGA Extension Bulletin 1425: 16.

Kantar M, Sheaffer C, Porter P, Krueger E, and Ochsner TE (2011) Growth stage influences forage yield and quality of winter rye. Forage and Grazinglands doi: 10.1094/FG-2011-0126-01-RS.

Kumar V, Obour A, Jha P, Liu R, Manuchehri MR, Dille JA, Holman J, Stahlman PW (2020) Integrating cover crops for weed management in the semiarid US Great Plains: opportunities and challenges. Weed Science 68: 311-323.

Landry E, Janovicek K, Lee EA, Deen W (2019) Winter cereal cover crops for spring forage in temperate climates. Agronomy Journal 111: 217-223.

Maas J (1987) Relationship between nutrition and reproduction in beef cattle. Veterinary clinics of North America: food animal practice 3, no. 3: 633-646

Nordheim-Vikenn H, Volden H (2008) Effect of maturity stage, nitrogen fertilization and seasonal variation on ruminal degradation characteristics of neutral detergent fibre in timothy (*Phleum pratense* L.). Animal Feed Science and Technology 149: 30–59.

Schomberg H, Fisher DS, Reeves DW, Endale DM, Raper RL, Jayaratne KSU, Gamble GR, Jenkins, MB (2014) Grazing Winter Rye Cover Crop in a Cotton No-Till System: Yield and Economics. Agronomy Journal 106: 1041-1050

Starr LM, Tomlinson PJ, Nelson NO, Roozeboom KL (2019) Effects of Cover Crops and Phosphorus Fertilizer Management on Soil Health Parameters in a No-Till Corn-Soybean Cropping System in Riley County, Kansas. Kansas Agricultural Experiment Station Research Reports, 198.

Watson S (1998) Small Grain Cereals for Forage, Kansas State University Research and Extension

Thompson NM, Armstrong SD, Roth RT, Ruffatti MD, Reeling CJ (2020) Short-run net returns to a cereal rye cover crop mix in a midwest corn–soybean rotation. Agronomy Journal 112: 1068– 1083

U.S. Department of Agriculture's National Agricultural Statistics Service (2019) 2017 Census of Agriculture. USDA. from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/

USDA (n.d.). Cover crops and crop rotation. USDA.from https://www.usda.gov/peoples-garden/soil-health/cover-crops-crop-rotation#:~:text=Cover%20crops%20are%20traditionally%20planted,the%20soil%20later%20for%20enrichment.

USDA AMS Livestock, Poultry Grain Market News (2022), www.ams.usda.gov/lpgmn

Figure 3.1. All Kansas experiment sites including Topeka, Castleton, Clay Center, Wabaunsee, and Ellsworth.

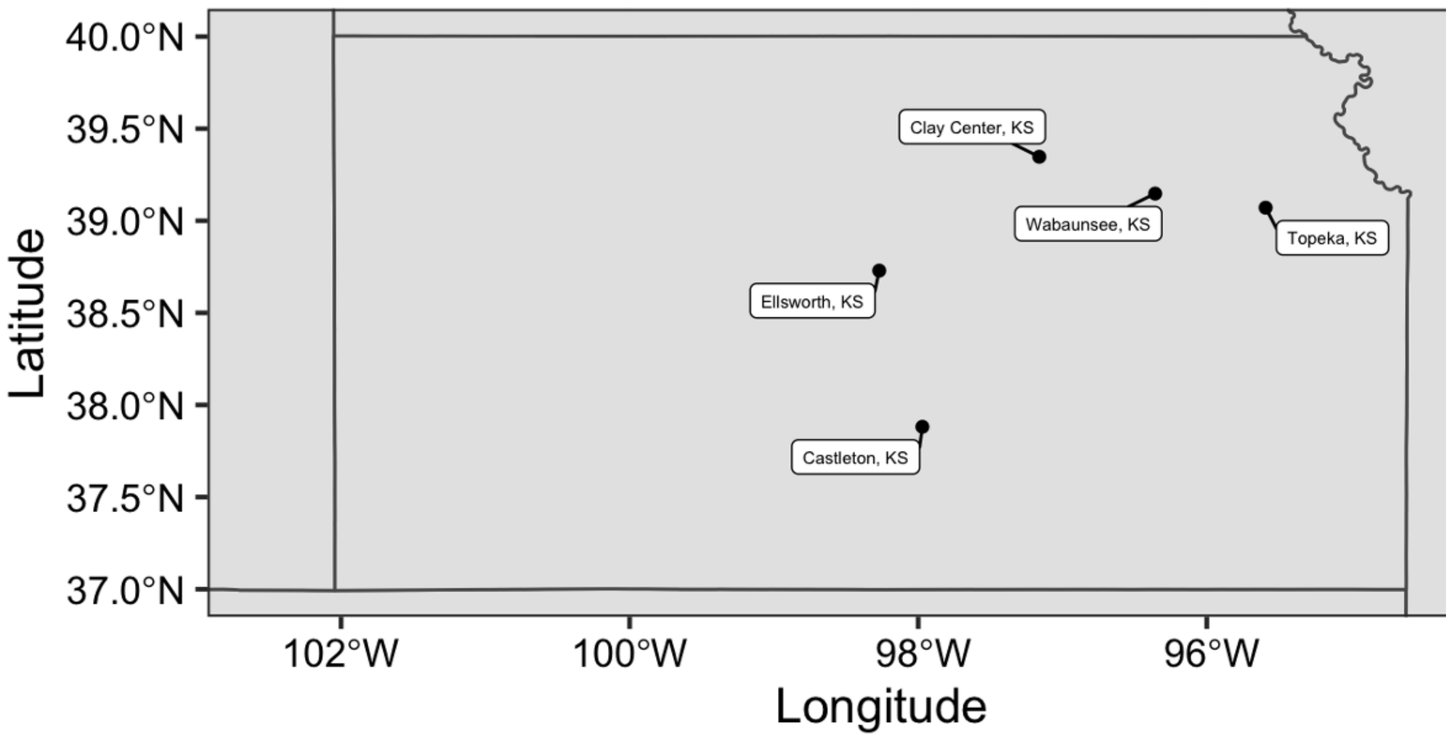


Figure 3.2. All of the exclosures placed in Topeka, Kansas with geographical regard to the water source (water droplet). Each color of dot represents a replication and one of each replication was placed out during treatment initiation. This was also conducted at all other experiment sites.

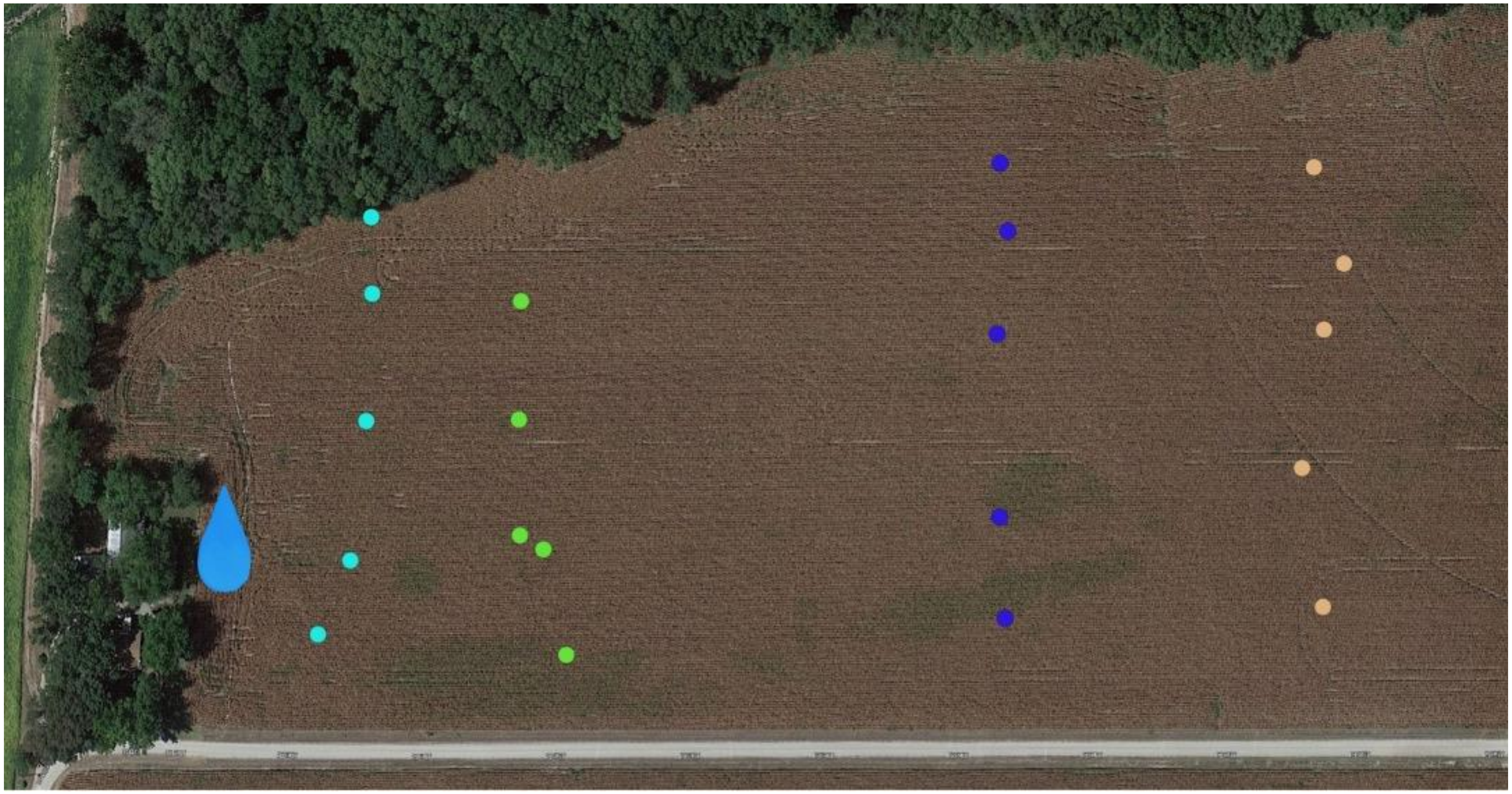


Figure 3.3. Cover crop biomass during the grazing season when treatments were initiated Wabaunsee, Kansas. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

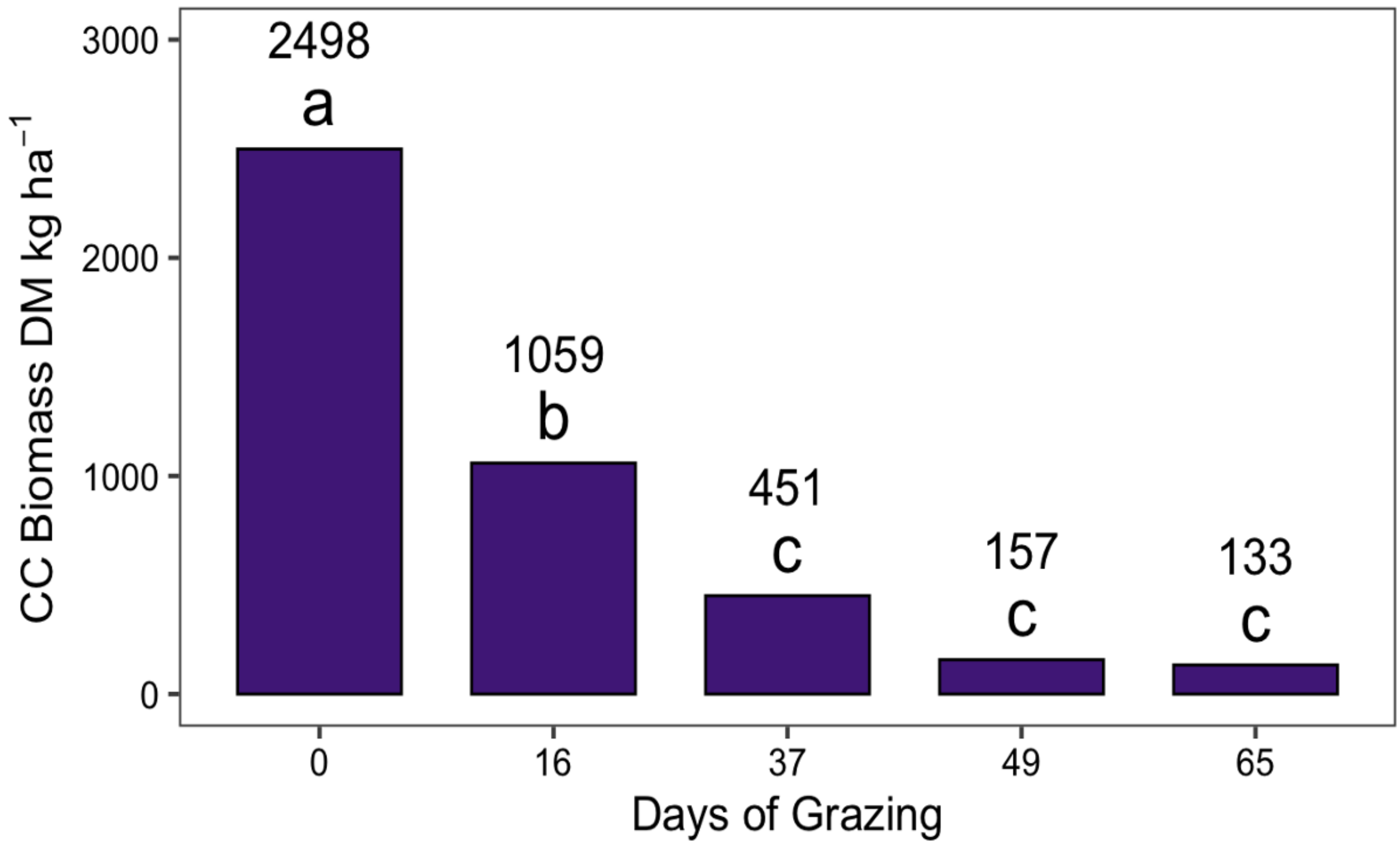


Figure 3.4. Cover crop and weed biomass regression line for late spring sample timing on May 16 2022 in Wabaunsee, KS. P-value = 0.00979 with an adjusted R squared value of 0.23 and equation of Y= -0.0019x+10.55 that indicates there was an effect of grazing cover crops on weed suppression.

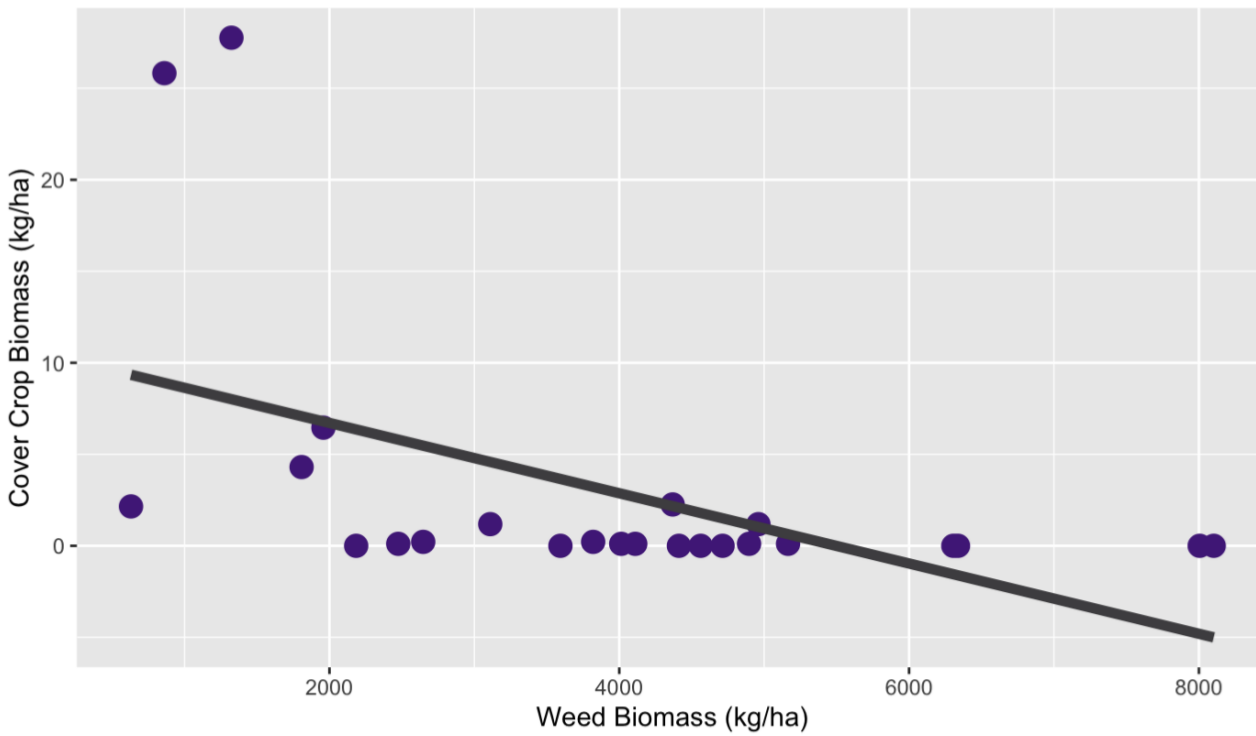


Figure 3.5. Cover crop height over the grazing season and weed biomass on May 16, 2022 regression for late spring sample timing in Wabaunsee, KS. A p-value of 0.00772 was reported, an adjusted R squared of 0.25, and an equation of Y= - 0.2876x + 31.14368 that indicates a negative influence of grazing cover crops on weed suppression.

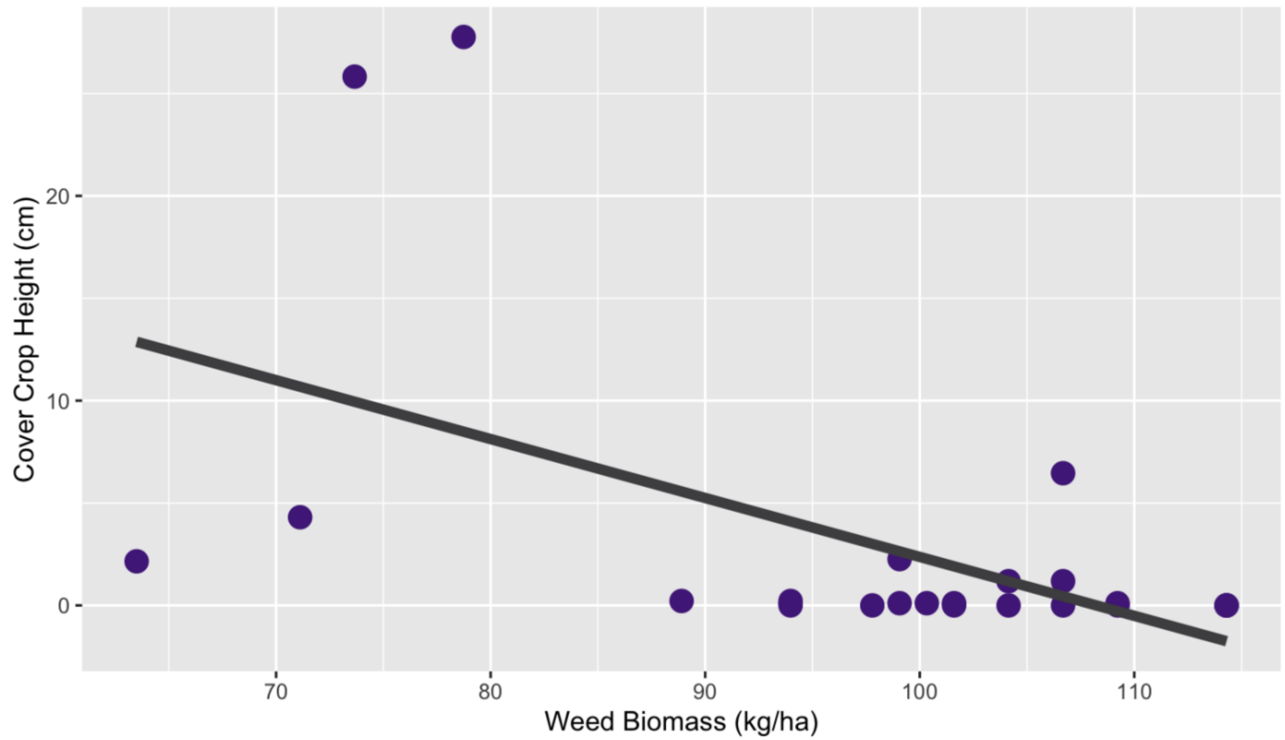


Figure 3.6. Weed biomass dry matter (DM) sampled on May 16, 2022in Wabaunsee, KS. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

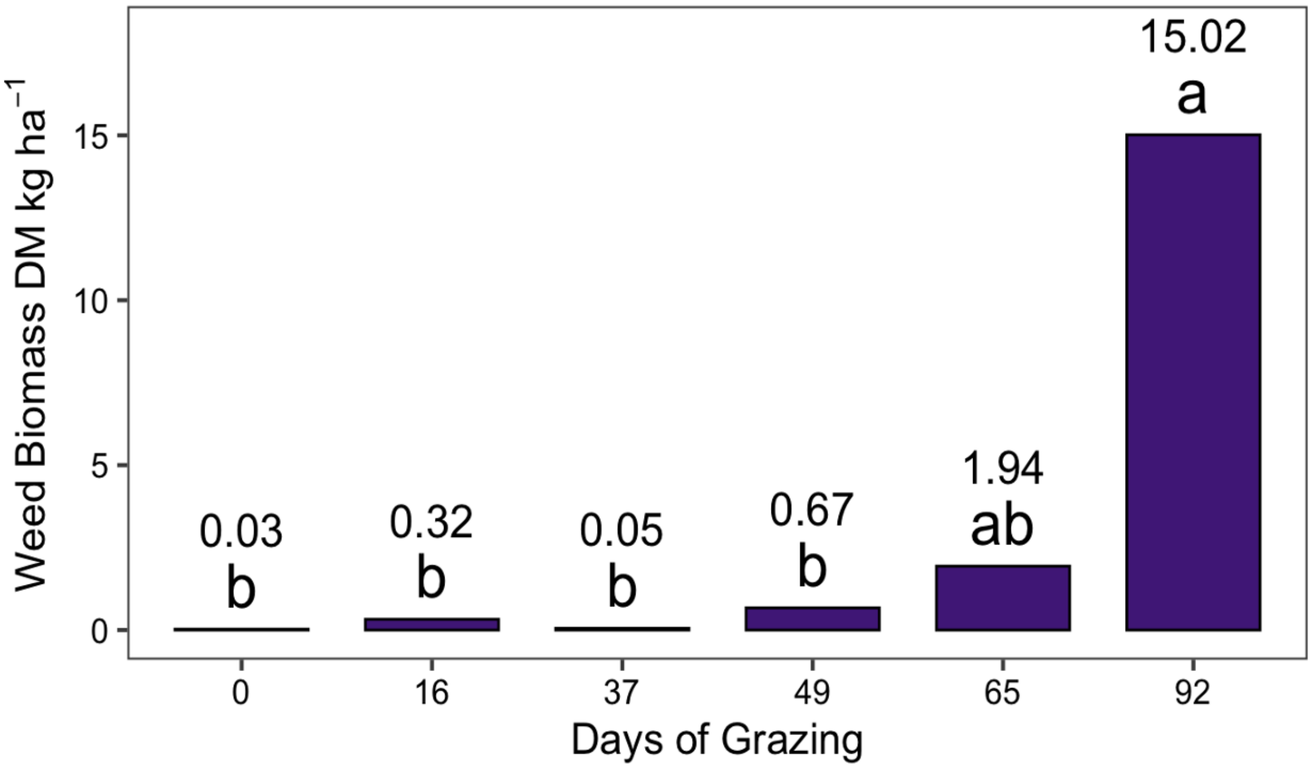


Figure 3.7. Cover crop biomass dry matter (DM) during the grazing season when treatments were placed at Topeka, KSfrom Dec. 19, 2021 to Apr. 4, 2022. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

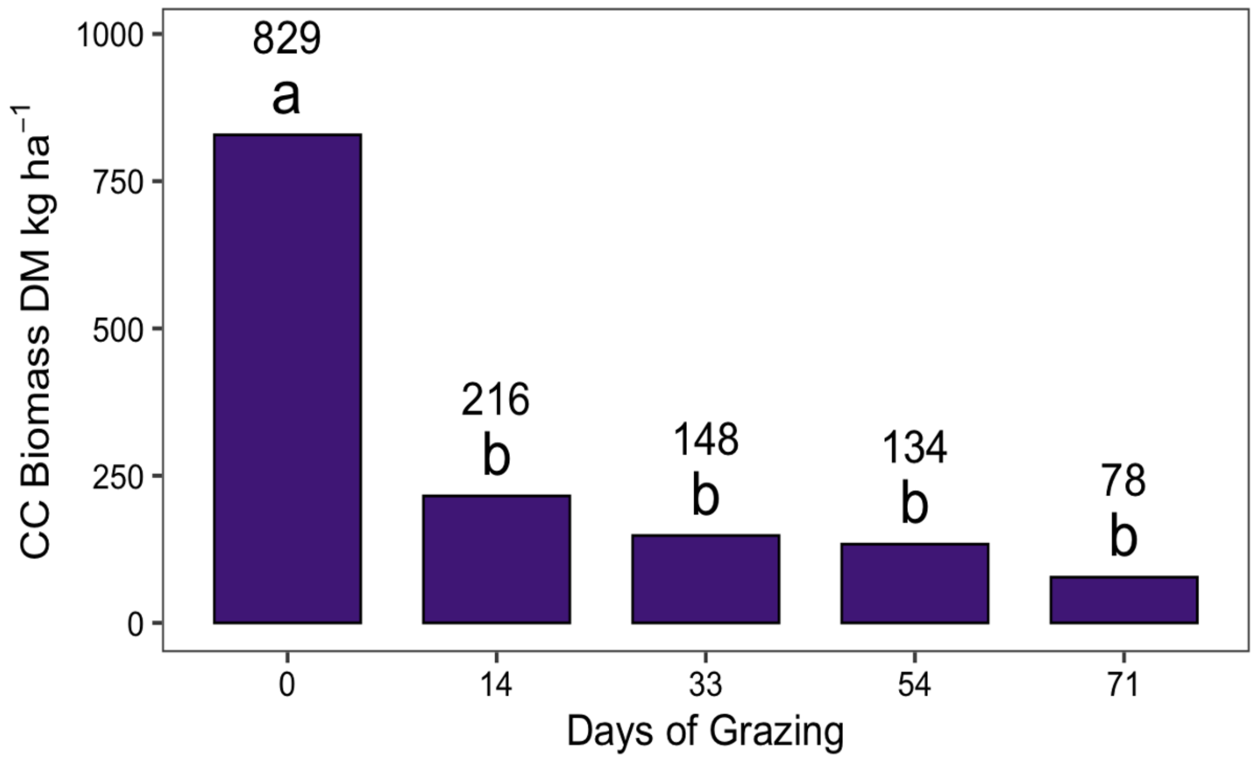


Figure 3.8. Cover crop biomass dry matter (DM) sampled during the grazing season when treatments were initiated at Castleton, KSfrom January 3 to February 1, 2022. Means were separated with Tukey's HSD Test and similar letters are not different (α ≤ 0.05).

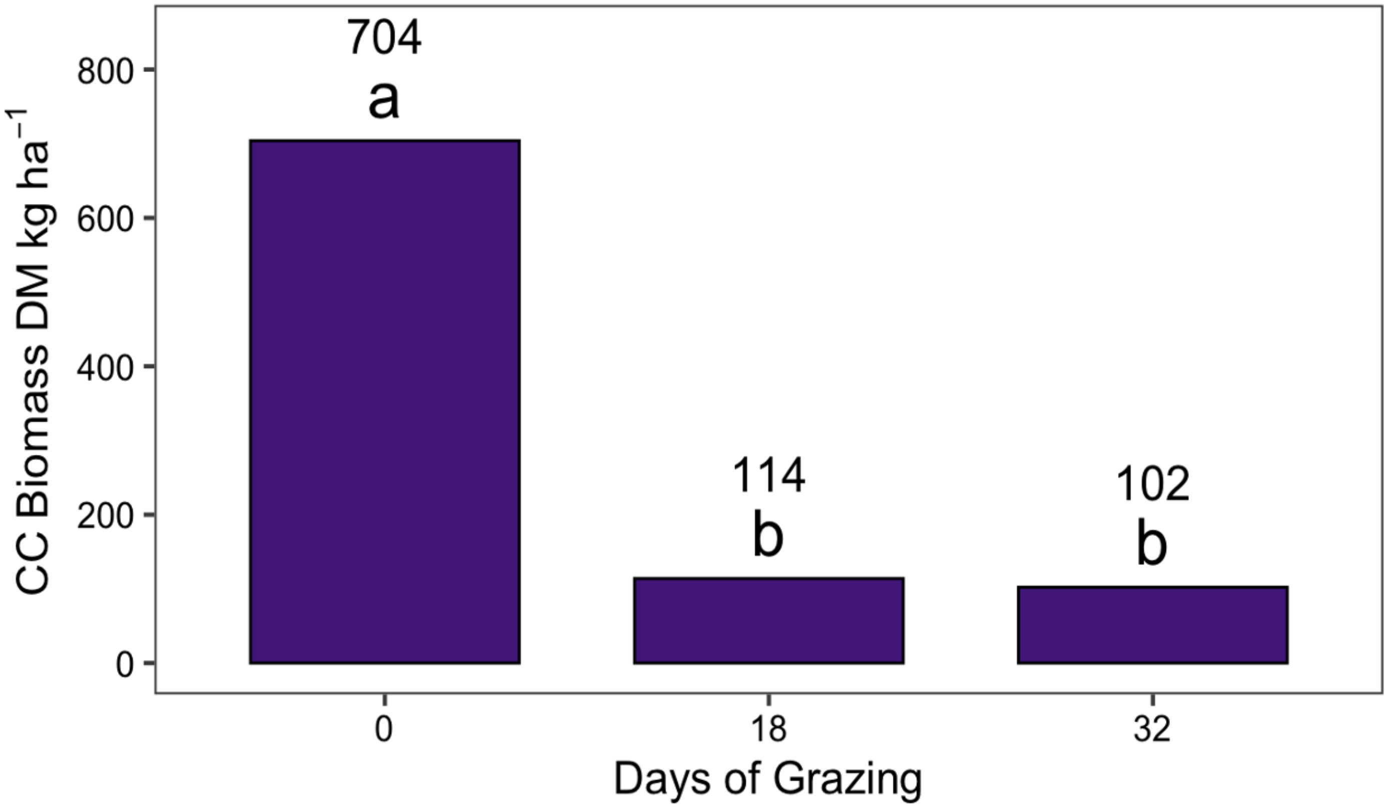


Figure 3.9. Weed biomass dry matter (DM) sampled on April 25, 2022in Topeka, KS. Means were separated with Tukey's HSD Test and similar letters are not different ($\alpha \leq 0.05$).

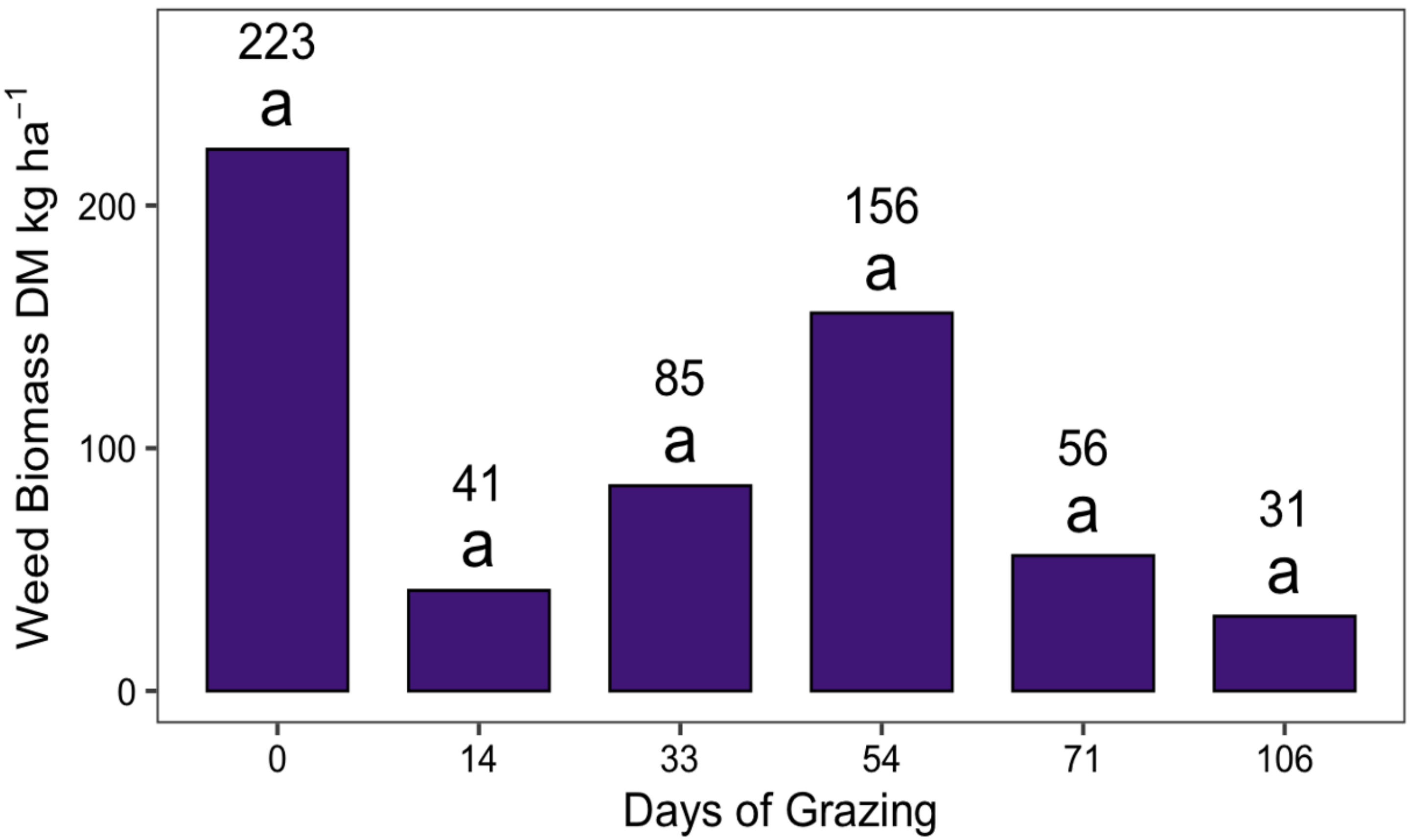


Figure 3.10. Weed biomass dry matter (DM) sampled on May 16, 2022 in Castleton, KS. Means were separated with Tukey's HSD Test and similar letters are not different ($\alpha \leq 0.05$).

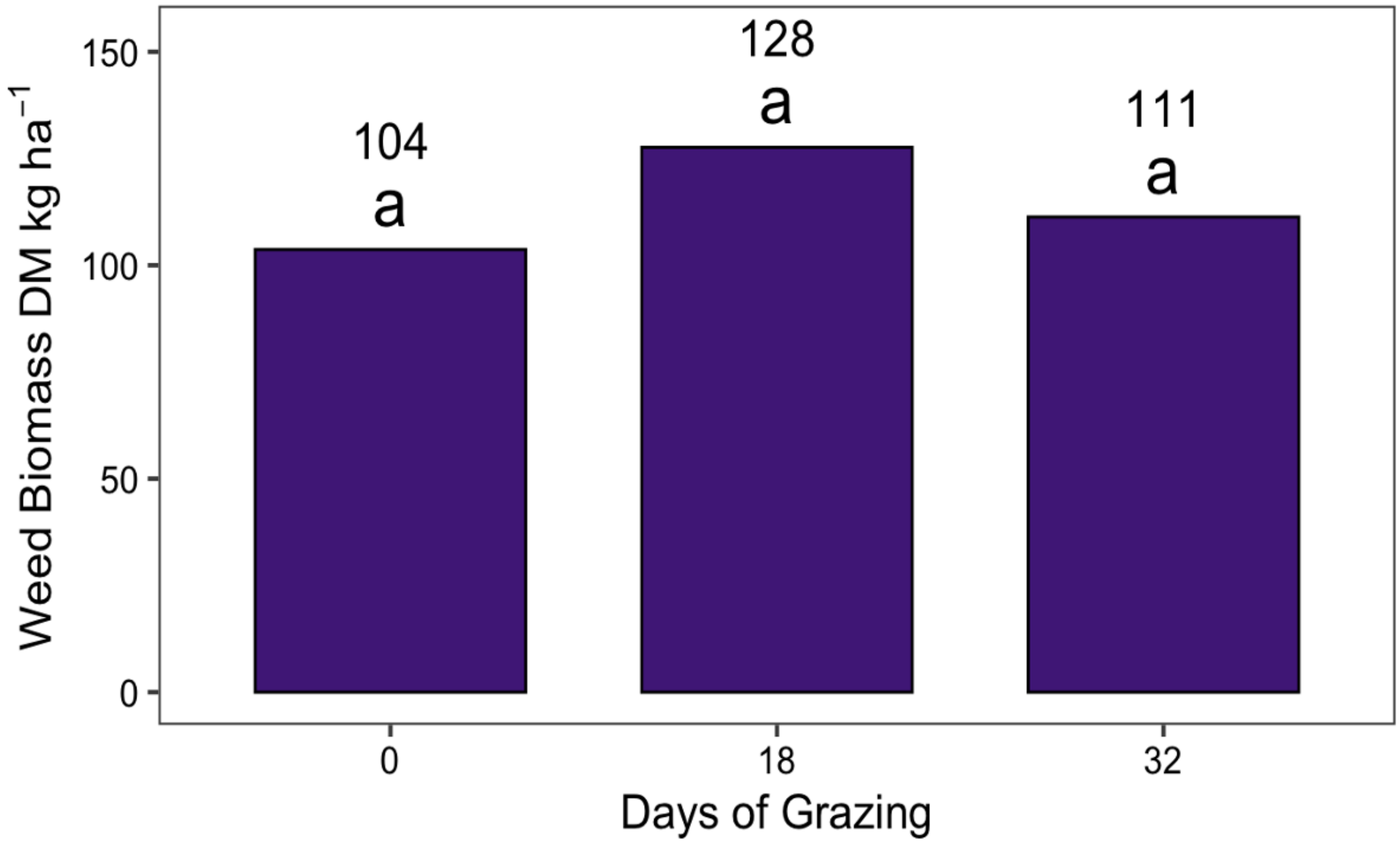


Table 3.1. Descriptions of locations utilized to study effects of grazing on weed suppression by cover crops.

Location	Coordinates (Latitude, Longitude)	AU ha^{-1}	Cover crop species and seeding rate (kg ha^{-1})	Dates Grazed	Days Grazed
Wabaunsee, KS	39.147527, -96.357732	0.3	cereal rye (50), spring barely (28), radish (1), spring pea (6)	Dec. 5, 2021 to Apr. 16, 2022	92
Castleton, KS	37.881564, -97.970899	0.6	triticale (79) winter pea (11), turnip (0.5)	Jan. 3 2022 to Feb. 1 2022	32
Ellsworth, KS	38.729398, -98.270043	0.1	cereal rye (90), radish (2), turnip (1)	Nov. 11, 2021 to Jan. 18, 2022	68
Clay Center, KS	39.347329, -97.160787	0.3	cereal rye (59), radish (3), turnip (3), forage collars (3)	Jan. 29, 2022 to Apr. 1, 2022	62
Topeka, KS	39.071080, -95.592086	0.3	cereal rye (95), crimson clover (5), radish (1)	Dec. 19, 2021 to Apr. 4, 2022	106

Table 3.2. Cover crop and weed dry matter biomass over the grazing season by location and treatment (days of grazing) alongside standard error of the mean (SEM) over the grazing season. Grazing began on (dates) at (locations), respectively. Values that were not recorded are represented by NR.

Location	Treatment (Days of Grazing)	CC (kg ha –1)	SEM	Weed (kg ha –1)	SEM
Castleton, KS	0	703	200	13	11
	18	114	23	4	3
	32	102	20	2	1
Wabaunsee, KS	0	2497	173	0	0
	16	1058	158	0	0
	37	450	45	0	0
	52	157	38	0	0
	68	133	21	0	0
	89	NR	NR	NR	NR
Topeka, KS	0	828	64	57	41
	14	215	45	22	14
	33	148	30	86	53
	54	133	21	43	16
	71	77	21	42	23
	106	NR	NR	NR	NR

Table 3.3. Cover crop and weed dry matter biomass by location and treatment (days of grazing) alongside standard error of the mean (SEM) before planting or cover crop termination in the spring.

Location	Collection Date	Treatment (Days of Grazing)	CC (kg ha –1)	SEM	Weed (kg ha –1)	SEM
Castleton, KS	May 17, 2022	0	2646	453	103.65	54.4
		18	2757	345	127.59	97
		32	341	196	111.26	55.61
Wabaunsee, KS	May 16, 2022	0	5283	656	0.03	0.03
		16	4180	684	0.32	0.29
		37	5673	1415	0.05	0.03
		52	3849	431	0.67	0.53
		68	3448	595	1.94	1.53
		89	1156	261	15.01	6.83
Topeka, KS	April 25, 2022	0	2599	637	223.03	90.95
		14	2069	256	41.37	25.58
		33	1523	476	84.50	17.92
		54	2188	342	155.62	99.14
		71	1391	161	55.74	37.39
		106	561	59	30.77	17.62

Table 3.4. Cover crop forage values at Castleton, Kansas. Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD). All testing was conducted by Ward Laboratories in Kearney, Nebraska. Values that were not recorded or lost are represented by NR. Values represent from January 3, 2022 to February 1, 2022.

	Castleton, KS
Treatment (days of grazing)	0
Cover Crop (kg ha^{-1})	705
CP (%)	13
ADF (%)	29.4
NDF (%)	49.8
NDFD (% of NDF)	71
IVTDMD (%)	86
RFV	123
RFQ	168

Table 3.5. Cover crop forage values at Wabaunsee, Kansas. All testing was conducted by Ward Laboratories in Kearney, Nebraska. Values that were not recorded or lost are represented by NR.

Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD). Values represented are from December 5, 2021 to April 16, 2022.

	Wabaunsee, KS					
Treatment (days of grazing)	0	16	37	52	65	89
Cover Crop (kg ha^{-1})	2497	1058	450	158	133	NR
CP (%)	14.4	12.1	15.3	13.5	24.7	20.9
ADF (%)	20	19.8	19	21.2	21.2	21.2
NDF (%)	33.6	34.7	33.7	34.8	41.9	39.2
NDFD % of NDF	101	90	93	91	81	81
IVTDMD (%)	99.5	94.9	97.4	95.3	94.3	90.5
RFV	203	197	204	193	161	172
RFQ	234	204	206	197	142	179

Table 3.6. Cover crop forage values at Topeka, Kansas. All testing was conducted by Ward Laboratories in Kearney, Nebraska. Values that were not recorded or lost are represented by NR.

Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD). Values represent from December 19, 2021 to April 4, 2022.

	Topeka, KS					
Treatment (Days of grazing)	0	14	33	54	71	106
Cover Crop (kg ha^{-1})	828	215	148	133	77	NR
CP (%)	14.1	20.5	17.6	NR	15.8	NR
ADF (%)	18.8	17.1	28.8	NR	22.2	NR
NDF (%)	33.5	36.9	43.2	NR	40.3	NR
NDFD % of NDF	92	94	80	NR	82	NR
IVTDMD (%)	95.8	97.9	90.9	NR	92.6	NR
RFV	206	190	143	NR	165	NR
RFQ	212	203	137	NR	182	NR

Table 3.7. Cover crop forage values at Clay Center, Kansas. All testing was conducted by Ward Laboratories in Kearney, Nebraska. Values that were not recorded or lost are represented by NR.

Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD). Values represent from January 24, 2022 to April 1, 2022.

	Clay Center, KS			
Treatment (days of grazing)	0	17	35	49
Cover Crop (kg ha^{-1})	396	175	71	35
CP (%)	22.9	NR	23.9	NR
ADF (%)	10.7	NR	21.2	NR
NDF (%)	29.3	NR	43.2	NR
NDFD % of NDF	108	NR	81	NR
IVTDMD (%)	98.8	NR	90.1	NR
RFV	255	NR	156	NR
RFQ	221	NR	144	NR

Table 3.8. Cover crop forage values at Ellsworth, Kansas. All testing was conducted by Ward Laboratories in Kearney, Nebraska. Values that were not recorded or lost are represented by NR.

Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD). Values represent from November 11, 2021 to January 18, 2022.

	Ellsworth, KS				
Treatment (days of grazing)	0	14	27	41	55
Cover Crop (kg ha^{-1})	90	58	109	129	99
CP (%)	11.7	9.6	12.3	10.9	11.6
ADF (%)	30.5	36.7	26.1	26.1	33.1
NDF (%)	54.3	56.3	44.4	45.3	53.9
NDFD % of NDF	69	69	80	80	64
IVTDMD (%)	78.3	75.1	85.3	84.2	75.8
RFV	112	100	144	141	109
RFQ	158	126	190	188	142

Table 3.9. All forage values were derived from forage analysis at Ward Laboratories in Kearney Nebraska. *Values reported from the Kansas Direct Hay Market Report on January 7th, 2022.

Values recorded are crude protein (CP), relative feed value (RFV), relative forage quality (RFQ), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and in vitro dry matter digestibility (IVDMD)

	ADF	RFV/RFQ	CP	$/Per Ton
Supreme*	<27	>185	>22	200
Premium*	27-29	170-185	20-22	200
Good*	29-32	150-170	18-20	160
Fair*	32-35	130-150	16-18	167-175
Utility*	>35	<130	<16	NR
Wabaunsee	19	204	15.3	NR
Ellsworth	33.1	109	11.6	NR
Topeka	17.1	190	20.5	NR
Clay Center	10.7	255	22.8	NR
Castleton	29.4	123	13	NR