

GRAZING WARM-SEASON GRASSLANDS SUPPORTS BENEFICIAL INSECT
DIVERSITY WHILE MAINTAINING PRODUCTIVITY.

BY:

Colin Cooksey

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1. **Abstract**

Insect biodiversity loss is a global concern driven in part by the widespread adoption of agricultural annual monoculture systems and chemical pesticides, much of which is grown for cattle feed. Grazing perennial grasslands has been suggested as an alternative to mitigate the negative impacts of annual cropping systems which are highly dependent on synthetic pest management inputs while supporting the production of cattle. However, particularly in the North Central United States, pastures rarely incorporate the native plant species most beneficial to insects. This study seeks to investigate the impact of incorporating warm season grasslands (WSG) on insect abundance, familial richness, functional diversity, and Shannon diversity indices. Furthermore, we seek to investigate the forage quality and quantity produced from the use of WSG in grazing systems to understand the potential impacts on cattle growth. Cattle were grazed on three treatments, one conventional cool-season pasture, one warm-season switchgrass monoculture and one-warm season native prairie. Insect biodiversity was measured via sticky traps in each experimental plot, and forage quality was monitored via biomass sampling. We found no difference in cumulative insect abundance, familial richness, or Shannon index by treatment. WSG's showed greater seasonal insect abundance in mid-summer than pasture and supported higher numbers of beneficial insects such as parasitoids. WSG showed higher forage availability, and similar consumption amounts to pasture. Forage from cool-season pasture was significantly higher in crude protein but was not different from other treatments in other forage metrics. These data support the use of WSG to support insect biodiversity while supporting the dietary needs of cattle raised as beef or dairy cows.

2. Introduction

Insect biodiversity loss is an issue of heightened concern (Jactel et al. 2020, Millard et al. 2021), due to the critical role insects play in global food webs (Wood et al. 2016, Potapov et al. 2017, Génier et al. 2025, Birkhofer et al. 2026), and pollination in agricultural systems (Khalifa et al. 2021, Buxton et al. 2022, Omuse et al. 2024). This trend is primarily driven by global habitat loss (DEFRA 2019, Hemberger et al. 2021, McHugh et al. 2023), increased use of pesticides (Renzi et al. 2016, Stanley et al. 2016, Evans et al. 2018, Venu et al. 2024) and climate change (Eigenbrode et al. 2022, Hemming et al. 2022).

Industrial agriculture systems, particularly those based on chemically-intensive, annual monocultures, have been linked to declines in overall insect numbers as well as diversity (Raven and Wagner 2021, Shanahan 2022, Iuliano 2024, Quandahor et al. 2024). Much of the crops produced in these intensive systems are fed to livestock, primarily dairy and beef cattle (Bond 2025 Apr 17, Rotz et al. 2026). Grass-based livestock systems provide an alternative to these intensive feed production systems that benefit farmer profitability (Parker et al. 1992, Hanrahan et al. 2018), while supporting diverse ecosystem services, including providing habitat for beneficial insects and pollinators (Shanahan 2022, Lightburn et al. 2026). While the grazing of cool-season perennial pasture is the most common grass-based agricultural system in the North Central US, its productivity can be impacted due to high temperatures and low rainfall during mid-summer (Heins 2014, Billman et al. 2022, Churchill et al. 2022). This results in a period of decreased biomass production, colloquially known as the “summer slump” (Heins 2014, Ritz et al. 2020, Cavadini and Paine 2023).

In contrast to cool-season pasture, the warm season grasslands (WSG) which historically dominated much of North America’s “corn belt” (i.e., IA, IL, IN, and to a lesser extent MN, and

WI) are characterized by an abundance of native warm-season grasses (Noble et al. 2025) such as switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vitman), and indiangrass (*Sorghastrum nutans* (L.) Nash) (Doll and Jackson 2009, Drobney et al. 2020, Noble et al. 2025). Warm season grasses are characterized by the C4- photosynthetic pathway (i.e., the Hatch–Slack pathway) as opposed to the C3- photosynthetic pathway that is characteristic of the cool-season species in typical Midwestern pastures (Ehleringer and Monson 1993). C4 photosynthesis is highly energy efficient and confers a notable metabolic advantage relative to C3 photosynthesis under conditions of excess heat or limited water, CO₂, or N (Gherbin et al. 2007, Rubio et al. 2010, Muir et al. 2011, Strömberg 2011, Gelley et al. 2016, Vendramini et al. 2023). Grazing WSG’s is a promising option for improving forage productivity (Heins 2014, Gelley et al. 2016, Ruh et al. 2018, Ritz et al. 2020, Kraus et al. 2022, McHugh et al. 2023), especially during periods of high heat stress that limit cool season production (e.g. the “summer slump”). In addition to forage production benefits, use of WSG in grazing systems may support critical habitat to enhance insect biodiversity (Moore et al. 2004, Gherbin et al. 2007, Drobney et al. 2020).

Much of the research related to the impact of WSG on insect biodiversity has been conducted in the context of prairie restorations solely for conservation purposes (Monroe et al. 2017, Drobney et al. 2020, Sexton and Emery 2020, Darst et al. 2024, Apfelbaum et al. 2025). Several studies have observed positive relationships between WSG restorations and insect biodiversity (Vulliamy et al. 2006, Silver and Vamosi 2012, Ravetto Enri et al. 2017, Bruninga-Socular et al. 2023). However, far fewer studies have evaluated the potentially multifunctional benefits of integrating WSG into working agricultural landscapes to both insects and forage production in the North Central region of the US. In order to address this gap in the literature,

this study evaluates the impact of incorporating WSG into rotational grazing operations on insect biodiversity metrics, as well as assesses both the quantity and quality of forage available in each system to support ruminant livestock. We hypothesized that 1) WSG will support higher insect biodiversity (e.g., abundance, richness, functional roles) than cool-season pasture due to improved habitat quality (e.g., plant diversity); and 2) WSG will provide an alternative feed source for cattle when cool-season pasture production is waning, producing forages of suitable quantity and quality for grazing livestock.

3. Materials and Methods

3.1 Study Site and Duration

To understand the impact of incorporating WSG into rotational grazing systems, we conducted a study at the Wisconsin Integrated Cropping Systems Trial (WICST), located at the UW Arlington Agricultural Research Station (43°18'17.7"N 89°19'50.4"W) in 2024 and 2025. WICST compares several cropping systems representative of agriculture in the upper Midwest, (including rotationally grazed cool-season pasture), with treatments arranged in a randomized complete block design. In addition to the core WICST systems established in 1999, a suite of WSG treatments have been integrated into the long-term experiment over the years, including switchgrass monocultures (est. 2007), as well as a low-diversity and a high-diversity prairie (both est. 1999). Further management details are presented in Appendix, table 13.

3.2 Experimental Design

This work was conducted in the four rotationally grazed grassland systems as WICST: 1) cool-season pasture, consisting of common Midwestern forages such as orchard grass (*Dactylis glomerata* L.), smooth brome grass (*Bromus inermis* Leyss.), meadow fescue (*Lolium pratense* Huds.), Kentucky blue grass (*Poa pratensis* L.), white clover (*Trifolium pratense* L.), and red

clover (*Trifolium pratense* L.), which serves as a control baseline. 2) a WSG switchgrass (*Panicum virgatum* L.) monoculture; 3) a WSG low diversity prairie (Appendix, Table 14), and 4) a WSG high diversity prairie (Appendix, Table 15). While each prairie was established as a unique treatment with different species (6 vs. 25), after 25 years, the two communities converged and are now largely identical; thus, these treatments were combined for analysis. We sampled three cool-season pasture plots and three WSG (switchgrass) plots, while six plots were sampled in the WSG (prairie) treatment (low- + high-diversity plots). Cool-season pasture plots, which were part of the core WICST experiment, are 18 m wide and 155 m long (0.3 ha). WSG plots, which are nested within the core WICST experiment, are 14 m wide and 75 m long (0.1 ha).

3.3 Grazing Management

In 2024 and 2025, a cohort of six Holstein heifers sourced from the UW-Madison Emmons Blaine Dairy Center, were brought to WICST to graze each treatment. Heifers began the grazing season around 230 kg. and ended the grazing season around 350 kg. New heifers were selected each year to maintain consistent weight and age. The full grazing season ran from May 1st through October 1st each year. Cool-season pasture plots provided forage from May 1st to mid-July, and late July through September, while WSG was grazed when warm season grasses reached “boot stage” (Large 1954), or Feekes 10.3 on the Feekes scale (Appendix, Fig. 15), which typically corresponds with the warmest and driest parts of the Midwestern summer (July 10th -August 6th in 2024, and July 8th -July 24th in 2025). The transition from cool-season pasture to WSG during the ‘summer slump’ provided longer mid-season rest periods, protecting pasture sward health (Donovan and Monaghan 2021); while maintaining daily dry matter needs of the herd.

For the cool-season pasture treatment, each experimental unit (plot) was surrounded with permanent high-tensile fencing, which was then subdivided into 18 m by 22 m paddocks using braided electric wire. Heifers were allowed to graze each paddock for 24 hours before being moved to a new paddock. After seven days, heifers were moved to a new experimental unit (plot) based on forage regrowth, and availability in the plot. This resulted in a roughly 28-day rotation for each paddock, with shorter rest periods in spring and fall, and longer periods in the mid-summer.

For WSG, each experimental unit (plot) was intensively grazed once during the season due to the slower growth of the plant species. Heifers had access to each experimental unit (plot) for 72 hours in 2024 and 48 hours in 2025. Further management details are shown in Table 1.

Table 1. Grazing dates for each treatment plot at WICST in 2024 and 2025. Cool-season pasture were grazed twice in early season and twice in the late season (May-July and August-October respectively). WSG (switchgrass) and WSG (prairie) were grazed a single time during the mid-season (July-August).

Year	Treatment	Grazing Dates	Total Grazing Days
2024	Cool-Season pasture	May 1 st -July 10 th , August 6 th - October 1 st	128
2024	WSG (switchgrass)	July 10 th - July 12 th , July 19 th - July 21 st , July 26 th - July 27 th , July 31 st - August 2 nd	8
2024	WSG (prairie)	July 13 th - July 18 th , July 22 nd -July 25 th , July 28 th -July 30 th , August 3 rd - August 5 th	12
2025	Cool-Season pasture	May 1 st – July 8 th , July 24 th – October 1 st	139
2025	WSG (switchgrass)	July 8 th - July 10 th , July 14 th – July 16 th , July 20 rd – July 22 nd	6
2025	WSG (prairie)	July 10 th -July 14 th , July 16 th - July 20 th , July 22 nd -July 24 th	10

3.4 Insect Monitoring

Insect monitoring was conducted using sticky cards placed in fields for 13 weeks in 2024 (6/18/24-8/19/2024) and 18 weeks in 2025 (6/2/2025-9/8/2025) (Wallace et al. 2023). Traps were replaced on a biweekly basis. A total of 36 traps were placed into 12 separate plots, with three traps placed in each plot at different spacings determined by the forage treatment plot area (Fig. 1, Fig. 2). Cool-season pasture plots had three traps placed with 39 m buffers between traps and 9 m buffers from the sides of the plot (Fig. 1). In WSG (switchgrass) and WSG (prairie) plots, the traps were placed with 19 m buffers between traps and 7 m buffers from the sides of the plot (Fig. 2). Sticky cards collected from traps were kept in storage below 0°C to reduce insect decomposition (Cojkic et al. 2025). Traps were removed from plots for the grazing duration to protect both the traps and the animals.

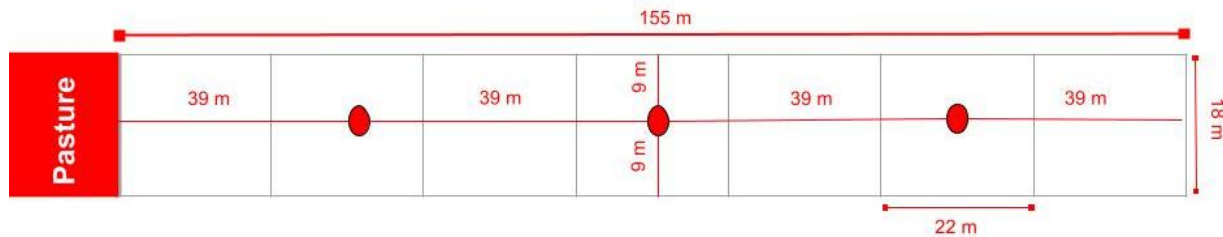


Fig. 1. Sticky card map for pasture treatment plots. Cool-season pasture plots were 155 m long and 18 m wide, with length subdivided into seven paddocks each 22 m long. Red circles indicate position of insect traps. Three sticky card traps were placed throughout the research plot, with 39 m buffers between traps and 9 m buffers from each side of the plot. Pasture label on the left side indicates treatment of plot.

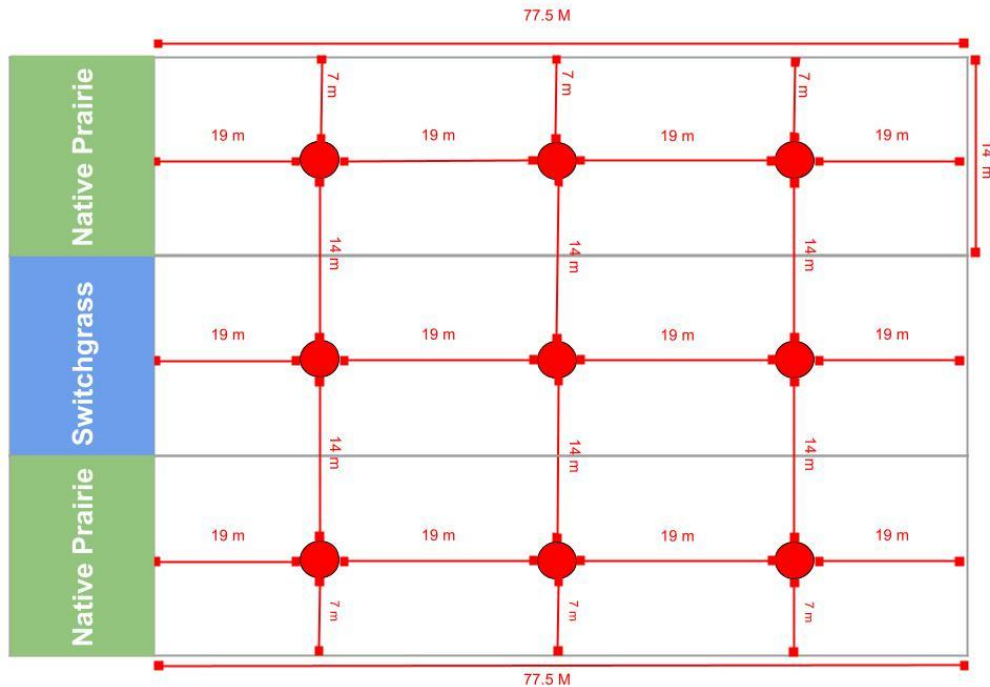


Fig. 2. Sticky card map for WSG (switchgrass) and WSG (prairie) plots. Plots were 77.5 m long, and 14 m wide. Red circles indicate position of insect traps. Three sticky card traps were placed throughout each research plot, with 19 m buffers between traps within the same plot, and 7 m buffers from each side of the plot. Internal side buffers compounded to create 14 m buffers between traps in neighboring plots. Colored label at left side of plot indicates treatment of plot. Plots were grown in continuous sections with touching borders to facilitate grazing rotation.

In 2024, automated trap sensors were provided by FMCTM Agriscience (FMC, 2024, *Arctm Farm Intelligence*, Physical trap). Traps consisted of a timed imaging camera placed over a standard white sticky card adhesive trap protected by a plastic triangular prism (Fig. 3). Collection involved removing the sticky card from the delta trap and placing a new sticky card under the camera.

In 2025, sticky cards were directly attached to crozier hooks via zip ties and left uncovered (Fig. 3). To reduce breakage, holes were punctured within the sticky cards at 1.27 cm depth from the edge. This was done to improve insect collection amounts following low efficacy of the traps used in 2024.

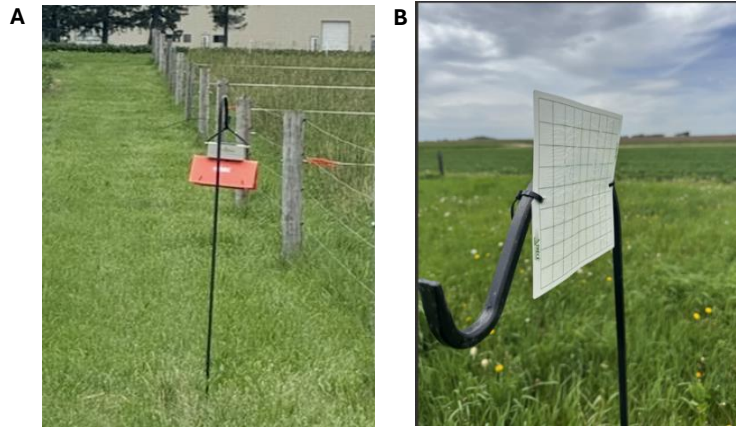


Fig. 3. Sticky card systems used at WICST. (A) FMCT™ brand smart traps protected by a delta trap and attached to crozier hooks, used in 2024. (B) Sticky cards attached directly to poles via zip ties, used in 2025.

3.5 Insect Identification

Analysis of insect populations was manually conducted via post sampling visual identification of each trap card sample. In 2024, identification of each insect specimen's functional group and family was recorded. However, in 2025, the large volume of insects collected limited the ability to accurately identify each specimen to family. Therefore, insects were instead identified to the functional group level only (biting pests, pests, predators, parasitoids, and pollinators).

3.6 Available Forage

To estimate available forage quantity and quality, biomass samples were collected from each paddock (cool-season pasture) or plot (WSG) before a grazing event. For cool-season

pasture, one quadrat was sampled randomly from each paddock for a total of seven samples per experimental unit. To provide consistency in sample density across treatments, six quadrats were taken from the WSG treatments. All samples were collected between 9:00AM and 11:00AM to reduce variability in metrics of forage quality.

In 2024, 1 m² quadrats (1 m x 1 m) were used for biomass collection (Fig. 4). To address excess defoliation and its impact on sward density and health, quadrat size was reduced to 0.25 m² (0.5 m x 0.5 m) (Fig. 4) in 2025. All biomass was cut and removed from the quadrat, leaving 4 cm of residual stubble. For analytical consistency, the biomass quadrats from 2025 were transformed when analyzed against the biomass collected in 2024 using equation 1 below.

$$\text{Equation 1. } Biomass_{adjusted} = Biomass_{collected} * 4$$



Fig. 4. Forage sampling quadrats for each year. (A) 1 m² quadrats in 2024 were measured using tape measures and indicated with the use of flags. (B) 0.25 m² quadrats in 2025 were measured using controlled length PVC pipe squares.

Once sampled, the collected forages were dried at 50° C for one week (~168 hours), or until weights had stabilized, before final weights were recorded. Following each grazing event,

one forage sample was randomly selected from the pre-grazing and post-grazing sample sets for forage quality testing. These samples were ground to a 5 mm particle size and submitted to Rock River Lab (Watertown, WI). Forage quality analysis was carried out using Near-Infrared Reflectance (NIR) spectroscopy to determine the amounts of amylase-treated neutral detergent fiber (aNDFom), crude protein (CP), total tract neutral detergent fiber digestibility (TTNDFD), and relative forage quality (RFQ).

3.7 Statistical Analysis

Data was analyzed using R statistical software (version 4.5.3) and RStudio (Posit Core Team 2026). To compare insect diversity metrics by treatment across seasonal time, generalized linear models were deployed, following the model of *diversity metric = treatment + date + (treatment * date)*. The package “*emmeans*” (Lenth et al. 2026) was used to calculate means from generalized linear models. Additionally, the packages “*Tidyverse*” (Wickham and RStudio 2023), “*dplyr*” (Wickham and RStudio 2023), “*ggsignif*” (Ahlmann-Eltze and Patel 2021) and “*ggplot*” (Wickham et al. 2026) were deployed for data manipulation and visualization. For all pairwise testing, Bonferroni correction was used to safeguard against inflation of significance. For insect diversity metrics years were tested separately to account for differences in collection methods.

To evaluate differences in insect biodiversity metrics, respective metrics were evaluated using generalized linear models and two-way ANOVA testing. Models consisted of a biodiversity metric (i.e., insect abundance, familial richness, and Shannon index) as the response variable, with treatment and date as independent variables. Pairwise comparisons were then employed to assess the nature of significant interactions.

To estimate abundance across treatments, each sticky card's insects were counted. Insect counts were aggregated per sticky card to provide multiple data points for treatment and date. To evaluate the impact of forage treatment on number of families (family richness), the total number of insect families per sticky card were aggregated by treatment. To evaluate the richness and evenness of species across treatments, we calculated Shannon diversity indices (Shannon 1948) for each sticky card. In 2024, we calculated Shannon indices using both family and functional group data. In 2025 we calculated Shannon indices using only functional group data.

To evaluate the relative abundance of functional groups in each treatment, we used a multivariate analysis of variance (MANOVA) test. The five functional groups were used as response variables, while treatment, date, and their interaction effect were used as factors. To determine abundance within each functional group, individual ANOVA tests were then conducted using individuals in the respective functional group as a response variable, with treatment, date, and their interaction effect as factors.

To evaluate the impact of grazing on the above metrics we used paired t-testing to evaluate the differences between samples immediately prior and post each grazing event. Abundance, number of families, and Shannon index calculated on familial and functional group data were used as the sample means respectively, with samples sorted by treatment. Multiple t-tests were performed for cool-season pasture to reflect being grazed in the early and late season, while WSG (switchgrass) and WSG (prairie) treatments' grazing period was treated as a single time block across the various plots.

General linear models and two-way ANOVA tests were also used to evaluate the impact of treatment and season on forage availability and quality metrics. With the full model being $Y = \text{treatment} + \text{season} + (\text{treatment} * \text{season})$, in which all factors were considered fixed effects. To

determine biomass consumption (delta-grazing), post-grazing biomass was subtracted from pre-grazing biomass.

4. Results

4.1 Insect Abundance

In 2024, a total of 2,181 insect specimens were collected (~545 specimens per monitoring date); in 2025, that number increased to 90,622 specimens (~11,328 specimens per monitoring date). This 41-fold increase was due to methodological changes in insect collection described above (Fig. 3). No significant differences were seen in cumulative insect abundance across each treatment 2024 ($F = 0.09$; $df = 2,9$; $P = .92$) or 2025 ($F = 0.45$; $df = 2,18$; $P = .64$), despite the significant difference ($F = 10.4$; $df = 2,18$; $P < .001$) between respective years (Table 2).

Table 2. Cumulative insect abundance for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments in 2024 and 2025 at WICST. Data was collected from sticky cards, and reported as the sum-total insect abundance for each trap in a given treatment type. Data is given as mean value $\pm$ the standard deviation. Letters indicate significant relationships ($P < .05$) across columns.

Year	Cool-Season pasture	WSG (switchgrass)	WSG (prairie)
2024	473b $\pm$ 168.9	546b $\pm$ 203.1	592b $\pm$ 215.3
2025	16315a $\pm$ 8175.3	21191a $\pm$ 12380.6	21720a $\pm$ 12377.8

WSG (switchgrass) showed the highest single incidence of familial richness (Table 3), but no statistical differences in mean familial richness across treatments were found (Table 3).

Table 3. Average number of insect families for each treatment by date in 2024. Data was collected from individual delta traps and aggregated over treatment type. Data is given as mean value $\pm$ the standard deviation. Letters indicate statistically significant ($P < .05$) relationships within rows.

Treatment	7/1/24	7/22/24	8/5/24	8/19/24
Cool-Season pasture	4.2a $\pm$ 0.3	4.3a $\pm$ 0.6	4.0ab $\pm$ 0.4	2.7b $\pm$ 0.8
WSG (switchgrass)	2.8b $\pm$ 0.4	4.9a $\pm$ 1.1	2.6b $\pm$ 0.8	4.1a $\pm$ 0.5
WSG (prairie)	3.4ab $\pm$ 0.3	3.3ab $\pm$ 0.6	2.7b $\pm$ 0.7	4.0a $\pm$ 0.6

4.2 Functional Groups

In 2024, parasitoids were the only functional group differing significantly across treatments ($T = 2.5$; $df = 8$; $P = .014$), with cool-season pasture having significantly higher numbers of parasitoids than WSG (prairie). (Table 4).

Table 4. Average individual count of five insect functional groups for cool-season pasture, WSG (switchgrass), and WSG (prairie), treatments in 2024. Data was collected by taking the number of individual insects representing each functional group over each trap and averaging by treatment. Data is given as mean value $\pm$ the standard deviation. Letters indicate significance groupings ($P < 0.05$) within a column.

Treatment	Biting pest	Pest	Predator	Parasitoid	Pollinator
Cool-Season pasture	0.8a $\pm$ 1.1	0.1a $\pm$ 0.1	4.2a $\pm$ 12.3	4.8a $\pm$ 3.0	0.05a $\pm$ 0.2
WSG (switchgrass)	2.0a $\pm$ 3.4	0.1a $\pm$ 0.3	1.6a $\pm$ 2.0	3.8ab $\pm$ 3.1	0.08a $\pm$ 0.3
WSG (prairie)	1.2a $\pm$ 2.9	0.4a $\pm$ 3.3	1.6a $\pm$ 1.8	3.3b $\pm$ 2.7	0.2a $\pm$ 0.3

Treatment differences for both predators and biting pests were significant in 2025 (Table 5). Cool-season pasture had the greatest number of predators overall ($F = 16.1$; $df = 2,189$; $P < .001$), while WSG (switchgrass) had significantly more biting pests than WSG (prairie) ($T = 2.67$; $df = 77.6$; $P .009$) (Table 5).

Table 5. Average individual count of five insect functional groups for cool-season pasture, WSG (switchgrass), and WSG (prairie), treatments in 2025. Data was collected by taking the number of individual insects representing each functional group over each trap and averaging by treatment. Data is given as mean value $\pm$ the standard deviation. Letters indicate significance groupings ($P < 0.05$) within a column.

Treatment	Biting pest	Pest	Predator	Parasitoid	Pollinator
Cool-Season pasture	25.1ab $\pm$ 18.5	218.5a $\pm$ 106.8	16.3a $\pm$ 14.9	38.5a $\pm$ 8.1	5.1a $\pm$ 4.7
WSG (switchgrass)	35.1a $\pm$ 30.1	234.9a $\pm$ 147.9	10.9b $\pm$ 8.1	50.5a $\pm$ 8.1	4.5a $\pm$ 4.8
WSG (prairie)	23.0b $\pm$ 19.5	194.7a $\pm$ 122.0	8.1b $\pm$ 6.84	43.4a $\pm$ 8.1	3.64a $\pm$ 4.9

Across both years, the most prevalent families in each category were: biting pests (*Culicidae*, *Simuliidae*, and *Ceratopogonidae*); pests (*Aeolothripidae*, and *Cicadellidae*); predator (*Chrysopidae*, *Dolichopodidae*, *Formicidae*, and *Staphylinidae*); parasitoids (*Trichogrammatidae*, *Tachinidae*, and *Diapriidae*); and pollinators (*Syrphidae*, *Apidae*, and *Cantharidae*).

4.3 Shannon Index

We used Shannon indices to evaluate evenness of familial richness across treatments in the first season. A high Shannon index (3.0 or above) (Shannon 1948, Ortiz-Burgos 2016), indicates a diverse ecosystem with an even distribution. A low Shannon index (2.0 or less) indicates an ecosystem with either few families, or a large proportion of a single family (Joern 2005). In 2024, familial richness was dominated by Muscidae (40% of total), resulting in Shannon indices at a near uniform 0.3 (Table 6), indicating extremely low evenness. We found no difference in Shannon index by treatment or date in 2024 ($F = 2.9$; $df = 2,113$; $P = .06$)

Table 6. Shannon index values for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments in 2024. Shannon indices were calculated using the Shannon indices equation (Shannon 1948), using total abundances of each family, and total abundance of each trap as population proportions and totals, respectively. Data is given as mean value $\pm$ the standard deviation. Indices were then averaged over trap to produce one value for each treatment. Letters indicate significant relationships ($P < .05$) within columns.

Date	Cool-Season pasture	WSG (switchgrass)	WSG (prairie)
7/1/24	0.3a $\pm$ 0.1	0.3a $\pm$ 0.1	0.3a $\pm$ 0.1
7/22/24	0.3a $\pm$ 0.1	0.3a $\pm$ 0.0	0.3a $\pm$ 0.0
8/5/24	0.3a $\pm$ 0.1	0.3a $\pm$ 0.1	0.3a $\pm$ 0.0
8/19/24	0.3a $\pm$ 0.0	0.2a $\pm$ 0.1	0.2a $\pm$ 0.0

Since family identification was not recorded for both seasons, Shannon index was also applied to the ‘functional group’ category. Given five functional groups, a high Shannon index would be 1.5, indicating presence of all functional groups and a high evenness between groups. An index of 0.8 or below would indicate a low level of evenness across functional groups (Ortiz-Burgos 2016).

As 2024 data was dominated by two functional groups (25% parasitoid and 15% predator respectively), the Shannon index calculated on functional group was uniformly 0.1, indicating extremely low evenness. The 2025 data showed higher Shannon indices (Table 7), indicating

more evenness across functional groups. However, no statistical differences were found in mean Shannon index by treatment ($F = 0.51$; $df = 2,200$; $P = .60$).

Table 7. Shannon index values calculated with functional groups for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments in 2025. Shannon indices were calculated using the Shannon indices equation (Shannon 1948), using total abundances of each functional group, and total abundance of each treatment as population proportions and totals, respectively. Data is given as mean value $\pm$ the standard deviation. Letters indicate significant relationships ($P < .05$) within columns.

Date	Cool-Season pasture	WSG (switchgrass)	WSG (prairie)
6/2/25	0.9 b $\pm$ 0.1	0.9 b $\pm$ 0.2	1.0 b $\pm$ 0.1
6/16/25	0.9 b $\pm$ 0.1	0.7 b $\pm$ 0.1	0.8 b $\pm$ 0.1
7/14/25	1.2 a $\pm$ 0.1	1.2 a $\pm$ 0.1	1.1 a $\pm$ 0.2
7/28/25	1.2 a $\pm$ 0.1	1.1 a $\pm$ 0.1	1.2 a $\pm$ 0.1
8/11/25	1.1 a $\pm$ 0.2	1.3 a $\pm$ 0.1	1.2 a $\pm$ 0.2
8/25/25	1.1 a $\pm$ 0.1	1.2 a $\pm$ 0.1	1.1 a $\pm$ 0.1
9/8/25	1.1 a $\pm$ 0.1	1.1 a $\pm$ 0.2	1.2 a $\pm$ 0.2

4.4 Seasonality of Abundance

Neither date ($F = 2.83$; $df = 3,6$; $P = .144$) nor treatment X date's interaction ($F = 0.71$; $df = 6,132$; $P = .64$) significantly effected insect abundance in 2024 (Table 8). In 2025, both date ($F = 27.64$; $df = 8,207$; $P < 0.001$) and treatment X date interaction ($F = 3.34$; $df = 12,207$; $P < 0.001$) significantly effected insect abundance. All treatments showed a decreasing trend as the season progressed (Table 9). Insect numbers in the cool-season pasture decreased consistently through the season. Conversely, insect numbers in WSG (switchgrass) and WSG (prairie) treatments showed slight plateaus and increases in insect abundance in the mid-summer (Fig. 5).

Table 8. Mean total insect abundance for each collection trap event for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments, in 2024. Data is shown as mean value $\pm$ the standard deviation. Letters indicate significant differences ($P < .05$) within rows.

Treatment	7/1/24	7/22/24	8/5/24	8/19/24
Cool-Season pasture	11.4ab $\pm$ 1.7	7.8b $\pm$ 0.9	20.2a $\pm$ 8.9	13.1ab $\pm$ 3.7
WSG (switchgrass)	8.1b $\pm$ 1.4	16.2a $\pm$ 5.5	6.1b $\pm$ 2.1	27.3a $\pm$ 5.1
WSG (prairie)	8.5b $\pm$ 0.6	15.7ab $\pm$ 8.3	12.4ab $\pm$ 5.3	23.8a $\pm$ 3.9

Table 9. Mean total insect abundance for each collection trap event for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments, in 2025. Data is shown as mean value $\pm$ the standard deviation. Letters indicate significant differences ($P < .05$) within rows.

Treatment	6/16/25	7/14/25	7/28/25	8/11/25	8/25/25	9/8/25
Cool-Season pasture	446.3a $\pm$ 46	447.3a $\pm$ 75	275.0b $\pm$ 12	250.9bc $\pm$ 16	287.7b $\pm$ 13	193.5bc $\pm$ 34
WSG (switchgrass)	597.8a $\pm$ 44	500.6ab $\pm$ 83	455.7ab $\pm$ 29	333.5bc $\pm$ 24	252.6cd $\pm$ 6	137.1d $\pm$ 10
WSG (prairie)	497.8ab $\pm$ 39	347.6bc $\pm$ 42	387.5abc $\pm$ 17	274.2bc $\pm$ 17	252.8cd $\pm$ 18	181.2d $\pm$ 22

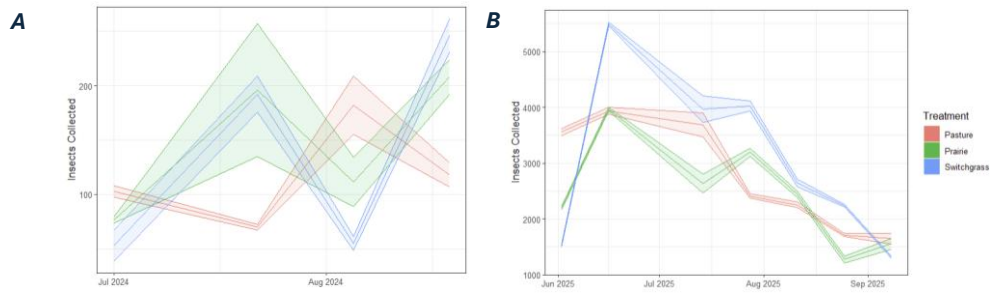


Fig. 5. Total number of insects collected at WICST in each treatment in (A) 2024, and (B) 2025. Lines show mean insect abundance averaged over traps in each treatment. Shaded areas around mean line show standard deviation from the mean. Data was collected by aggregating the total insect abundance of each sticky card by trap for a given date. Colors correspond to treatment types.

Seasonality had a significant effect on family richness within each treatment. Significant differences ($P < .05$) for number of insect families were found at each timepoint across

treatments. Specifically, insect family richness in the cool-season pasture treatment peaked in early summer. Insect family richness of WSG (switchgrass) showed more variability, with peaks in mid and late summer. WSG (prairie) showed lower but more consistent insect family richness in 2024.

Date had a significant effect on functional group abundance in 2024 ($F = 5.81$; $df = 3,129$; $P < .001$). Low levels of predators, biting pests, and pests were found across all treatments, with discrete peaks in cool-season pasture, WSG (switchgrass) and WSG (prairie) at specific points in time (Fig. 6). Cool-season pasture peaked in late summer, while WSG (switchgrass) and WSG (prairie) peaked in early summer. Parasitoids showed higher variability, with WSG (switchgrass) having the highest amount in early summer and cool-season pasture having the highest in late summer (Fig. 6).

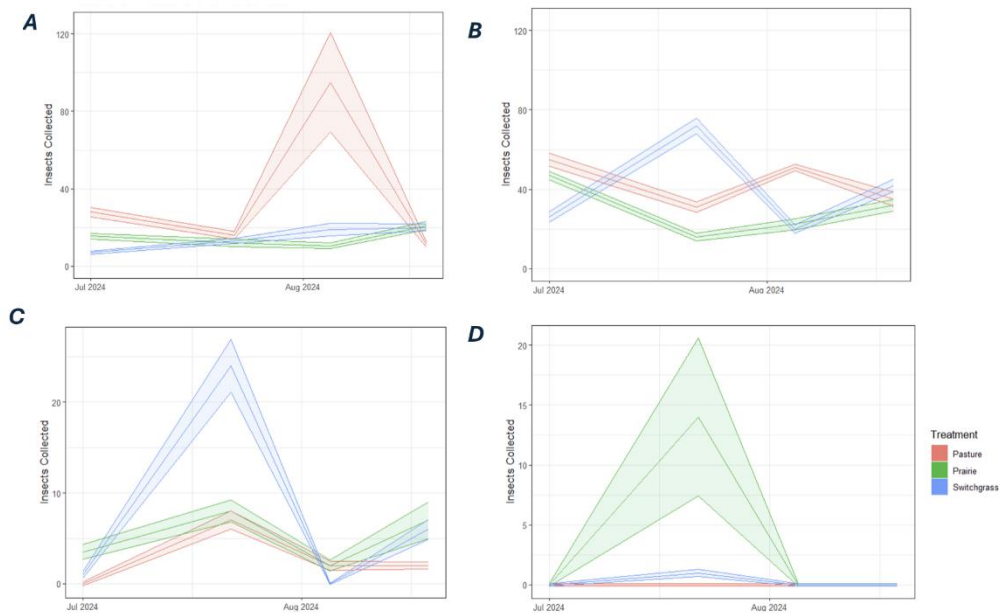


Fig. 6. Total number of individual insects per functional groups at WICST over time in 2024, sorted by grazing treatment. Graphs are sorted by functional group, as follows: (A) predators, (B) parasitoids, (C) biting pests and (D) pests. Lines show mean number of individuals collected in traps averaged over treatment groups. Shaded areas around lines show standard deviation from mean. Colors show treatment type.

Date and treatment X date had a significant effect on functional groups' abundance in 2025 ($F = 34.96$; $df = 6,188$; $P < .001$) ($F = 3.46$; $df = 12,188$; $P < .001$). Predator numbers peaked in both early and late summer, with numbers in cool-season pasture significantly higher ($F = 9.87$; $df = 2,29$; $P < .001$) in the early summer peak (Fig. 7). Parasitoid numbers also peaked in late summer, with WSG (switchgrass) and WSG (prairie) being significantly higher than cool-season pasture ($F = 8.52$; $df = 2,32$; $P = .001$), which decreased instead (Fig. 7). Biting pest numbers showed the greatest differences over treatment, with numbers in WSG (switchgrass) increasing till mid-summer and falling, while numbers in cool-season pasture and WSG (prairie) increased in late summer. Pest numbers peaked in early summer, with numbers in WSG (switchgrass) higher than other treatments ($F = 38.2$; $df = 2,15$; $P < .001$), and numbers decreasing in all treatments over the season (Fig. 7).

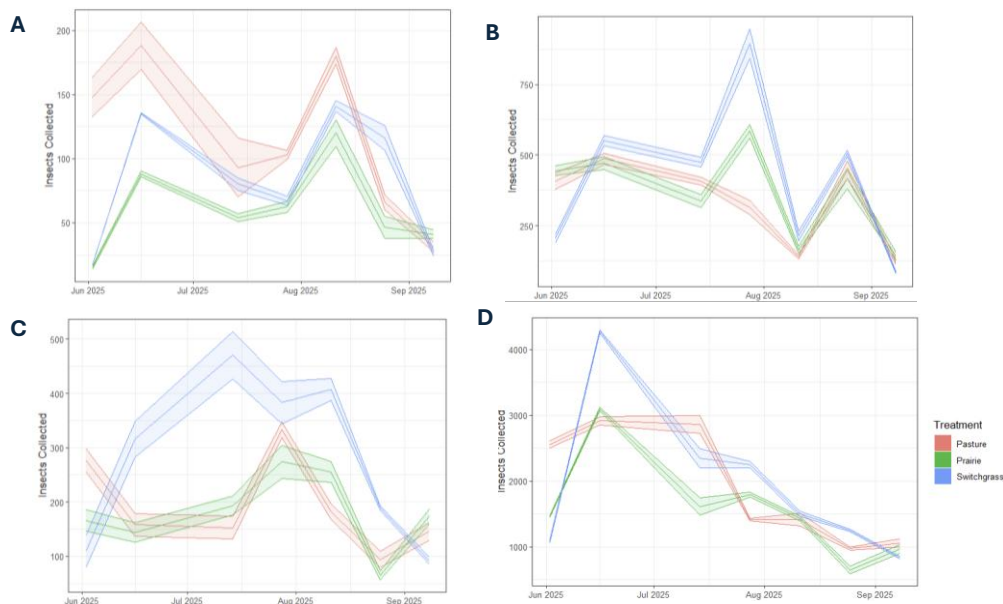


Fig. 7. Total number of individual insects per functional groups at WICST over time in 2025, sorted by grazing treatment. Graphs are sorted by functional group, as follows: (A) predators, (B) parasitoids, (C) biting pests and (D) pests. Lines show mean number of individuals collected in traps averaged over treatment groups. Shaded areas around lines show standard deviation from mean. Colors show treatment type.

We found no significant differences by date in Shannon index calculated by familial richness ($F = .01$; $df = 2,113$; $P = .06$) or functional groups ($F = .71$; $df = 2,111$; $P = .49$) in 2024. However, in 2025, we found a significant effect of date on Shannon indices calculated on functional groups, with a statistically significant increase in evenness ($F = 100$; $df = 2,200$; $P < .001$) across all treatments as the season progressed.

4.5 Grazing Impacts on Insect Diversity Metrics

In 2024, grazing events correlated with insect abundance trends for each treatment. While we found no significant difference in insect abundance over grazing events, each treatment showed decreases in abundance while being grazed. We found that insect abundance in WSG (switchgrass) increased significantly ($T = 3.87$; $df = 10$; $P = .003$) after its grazing event (Fig. 8).

Grazing

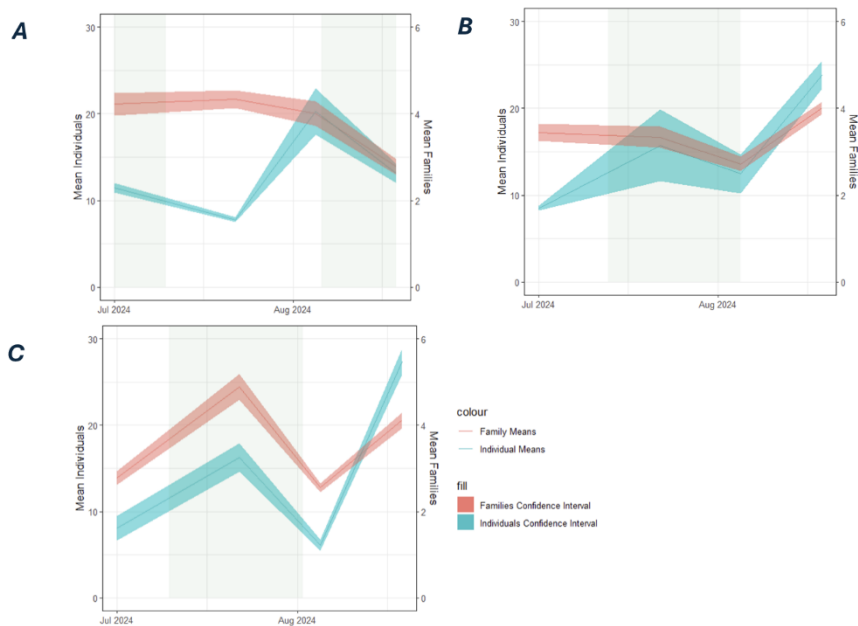


Fig. 8. Grazing's effect on abundance in 2024. Blue lines show mean number of individuals. Blue shading shows 95% confidence interval centered on mean individuals. Red lines show mean familial richness. Red shading show 95% confidence interval centered on mean familial richness. Sections shaded green represent durations the treatment was being grazed. Data was collected from aggregated sticky cards placed in WICST treatments. Graphs are sorted by treatment: (A) cool-season pasture, (B) WSG (prairie), and (C) WSG (switchgrass).

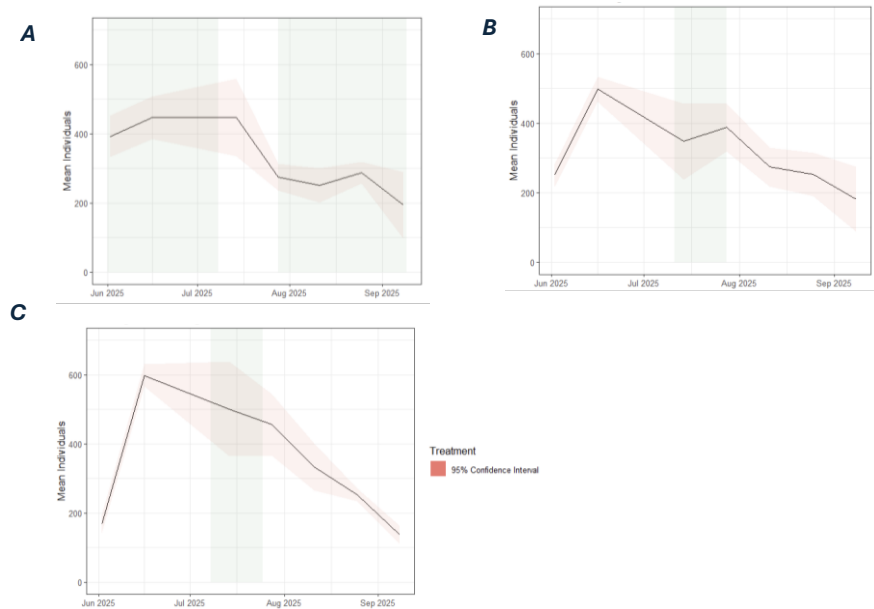


Fig. 9. Grazing's effect on abundance in 2025. Lines show mean number of individuals. Red shading show 95% confidence interval centered on mean individuals. Sections shaded green represent durations the treatment was being grazed. Data was collected from aggregated sticky cards placed in WICST treatments. Graphs are sorted by treatment: (A) cool-season pasture, (B) WSG (prairie), and (C) WSG (switchgrass).

No significant differences ($F = 1.25$; $df = 3,132$; $P = .30$) in mean familial richness during or after grazing periods across treatments were seen in 2024. WSG (switchgrass) and WSG (prairie) treatments showed a numerical decrease in family richness during their grazing periods, with increases following a post-grazing recovery period.

Grazing had a significant effect on functional group dynamics in 2024. Predators significantly increased in cool-season pasture ($T = 6.44$; $df = 8$; $P < .001$) between grazing periods. Parasitoid numbers significantly decreased in WSG (switchgrass) ($T = 2.09$; $df = 8$; $P = .035$) while being grazed, and significantly increased in cool-season pasture ($T = 2.2$; $df = 8$; $P = .044$) when not being grazed. Biting pests numbers significantly decreased in WSG (switchgrass) ($T = 2.78$; $df = 8$; $P = .024$) during grazing and increased in cool-season pasture (T

= 2.6; $df = 8$; $P = .034$) when not being grazed. Pests numbers significantly increased in WSG (prairie) ($T = 4.32$; $df = 26$; $P < .001$) when not being grazed.

In 2025, predator numbers significantly increased in cool-season pasture ($T = 4.16$; $df = 8$; $P < .001$) and decreased in WSG (switchgrass) ($T = 2.44$; $df = 8$; $P = .037$) during grazing. Parasitoid numbers significantly increased in WSG (switchgrass) ($T = 5.30$; $df = 8$; $P < .001$) and WSG (prairie) ($T = 8.87$; $df = 16$; $P < .001$) during grazing, and decreased in cool-season pasture ($T = 2.33$; $df = 8$; $P = .043$) when not being grazed. Biting pest numbers significantly decreased in WSG (switchgrass) ($T = 2.34$; $df = 8$; $P = .047$) during grazing, and significantly increased in cool-season pasture ($T = 2.45$; $df = 8$; $P = .027$) when not being grazed. Pest numbers significantly decreased in cool-season pasture ($T = 2.05$; $df = 8$; $P = .039$) when not being grazed. No effect of grazing on Shannon diversity indices across season or treatment was observed.

4.6 Available Forage

Significant differences in forage availability by treatment ($F = 58.5$; $df = 2,211$; $P < .001$) and treatment X year ($F = 4.64$; $df = 2,211$; $P = .01$) were observed. Biomass availability of cool-season pasture was significantly lower than both WSG (switchgrass) and WSG (prairie) in 2024 ($F = 40.91$; $df = 2,86$; $P < .001$) (Table 10), while both cool-season pasture and WSG (switchgrass) were lower than WSG (prairie) in 2025 ($F = 25.64$; $df = 2,125$; $P < .001$) (Table 11, Fig. 10). No significant differences in forage biomass consumption across either treatment or year were observed (2024: $F = 1.59$; $df = 2,86$; $P = .21$) (2025: $F = 1.12$; $df = 2,121$; $P = .33$).

Table 10. Forage availability and consumption for cool-season pasture, WSG (switchgrass), and WSG (prairie) treatments in 2024. Data is presented as mean forage availability $\pm$ standard deviation. Data was collected from biomass sampling before and after grazing at WICST. Letters indicate significant differences ($P < .05$) between values across rows.

Treatment	Cool-Season pasture		WSG (switchgrass)		WSG (prairie)	
	Mean	Proportion	Mean	Proportion	Mean	Proportion
Available (g/m ²)	471.4c ± 20.9	100%	759.1b ± 38.7	100%	904.1a ± 45.3	100%
Consumed (g/m ²).	66.1a ± 33.8	14.0%	225.5a ± 65.7	29.7%	90.6a ± 69.0	10.0%

Table 11. Forage availability and consumption for cool-season pasture, WSG (switchgrass), and WSG (prairie) treatments in 2025. Data is presented as mean forage availability $\pm$ standard deviation. Data was collected from biomass sampling before and after grazing at WICST. Letters indicate significant differences ($P < .05$) between values across rows.

Treatment	Cool-Season pasture		WSG (switchgrass)		WSG (prairie)	
	Mean	Proportion	Mean	Proportion	Mean	Proportion
Available (g/m ²)	550.8b ± 22.2	100%	565.7b ± 57.6	100%	898.7a ± 55.1	100%
Consumed (g/m ²).	68.1a ± 24.3	12.4%	137.0a ± 53.6	24.2%	16.4a ± 68.5	1.8%

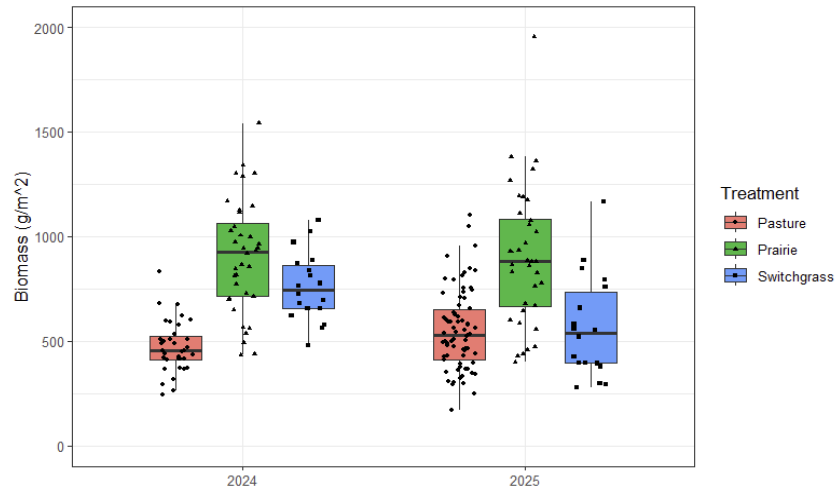


Fig. 10. Forage availability (g m^{-2}) across cool-season pasture, WSG (prairie), and WSG (switchgrass) treatments in 2024 and 2025. Data was derived from forage dry matter weight samples collected from WICST in each year. Boxplots show median, upper and lower quantiles, minimum and maximum values and jittered raw data. Whiskers show a 95% confidence interval centered on the median. Dots show individual data points.

4.7 Forage Fiber Content

No significant treatment X year effect was observed with respect to aNDFom ($F = 0.96$; $df = 2,42$; $P = 0.39$); thus, data from both years were aggregated to increase statistical power. No significant differences ($F = 2.273$; $df = 2,45$; $P = .115$) in aNDFom across treatments before grazing was observed (Table 12). Numerically, forage collected from cool-season pasture had the lowest mean aNDFom, and forage collected from WSG (switchgrass) had the highest aNDFom (Fig. 11). Forage collected from WSG (prairie) samples had greater variability ($F = 5.09$; $df = 2,45$; $P = .01$) as compared to the variation across cool-season pasture samples (Table 12).

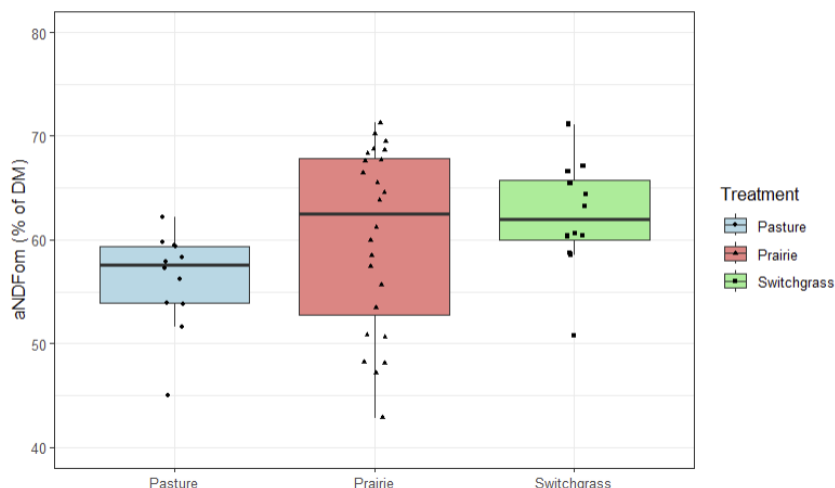


Fig. 11. Pre-grazing distribution of aNDFom values for cool-season pasture, WSG (prairie), and WSG (switchgrass) treatments, aggregated across forage quality samples. Boxplots show median, upper and lower quantiles, minimum and maximum values and jittered raw data. Whiskers show a 95% confidence interval centered on the median. Dots show individual data points.

Table 12. Forage quality analysis for cool-season pasture, WSG (switchgrass) and WSG (prairie) treatments, aggregated over both years. Data was collected through near infrared reflectance spectroscopy (NIRS) conducted on forage samples. Data is depicted as mean $\pm$ the standard deviation. Letters indicate significant differences ($P < .05$) between values down columns.

Treatment	RFQ	ANDFom (%DM)	TTNDFD (% aNDF)	Crude Protein (%DM)
Cool-Season pasture	117.1a $\pm$ 11.7b	56.2a $\pm$ 1.3c	46.2a $\pm$ 2.7b	13.2a $\pm$ 0.8c
WSG (switchgrass)	91.8a $\pm$ 4.7c	62.3a $\pm$ 1.5bc	45.9a $\pm$ 1.5b	8.2b $\pm$ 0.5cd
WSG (prairie)	108.6a $\pm$ 4.6c	60.3a $\pm$ 1.8b	49.0a $\pm$ 1.1b	8.7b $\pm$ 0.3d

4.8 Total Tract Neutral Detergent Fiber Digestibility

No significant treatment X year effect was observed for total tract neutral detergent fiber digestibility (TTNDFD) values ($F = 0.38$; $df = 2,45$; $P = .68$); thus, data from both years were aggregated to increase statistical power. No significant differences ($F = 1.23$; $df = 2,45$; $P = .303$) in TTNDFD between forage treatments were observed (Fig. 12). Additionally, no significant

differences ($F = 0.86$; $df = 2,45$; $P = .429$) in variability between treatments were observed. All TTNDFD values fell within the average-to-good range for forage quality (Combs 2013, 2014) (Table 12).

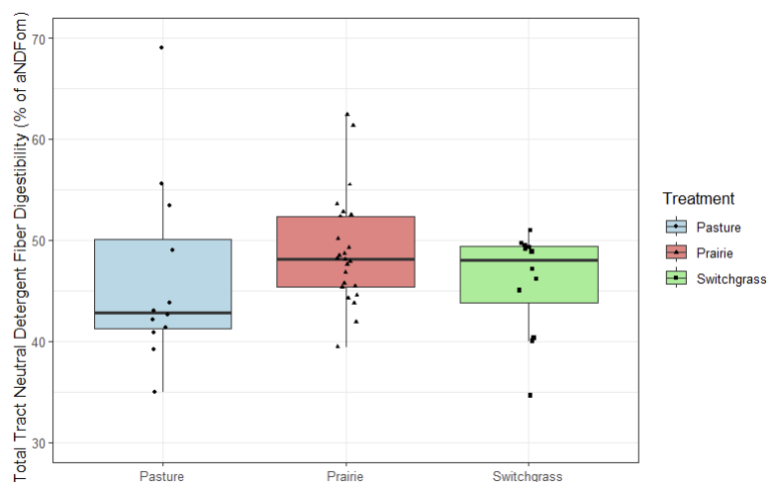


Fig. 12. Pre-grazing distribution of total tract neutral detergent fiber digestibility (TTNDFD) values for cool-season pasture, WSG (prairie) and WSG (switchgrass) treatments, aggregated across forage quality samples. TTNDFD is presented as percent of digestible fiber. Boxplots show median, upper and lower quartiles, minimum and maximum values and jittered raw data. Whiskers show a 95% confidence interval centered on the median. Dots show individual data points.

4.9 Crude Protein

No significant treatment X year effects were observed with respect to crude protein ($F = 1.15$; $df = 2,42$; $P = 0.33$); thus, data across the two years were aggregated to improve statistical power. Crude protein content of forage from cool-season pasture was significantly higher ($F = 27.59$; $df = 2,45$; $P < .001$) than forage collected from WSG (switchgrass) and WSG (prairie) treatments (Table 12). Neither WSG (switchgrass) nor WSG (prairie) treatments were significantly different from each other (Fig. 13). Crude protein from forage of cool-season pasture displayed significantly higher variance ($F = 4.38$; $df = 2,45$; $P = .018$) than forage from WSG (switchgrass) or WSG (prairie) treatments (Table 12).

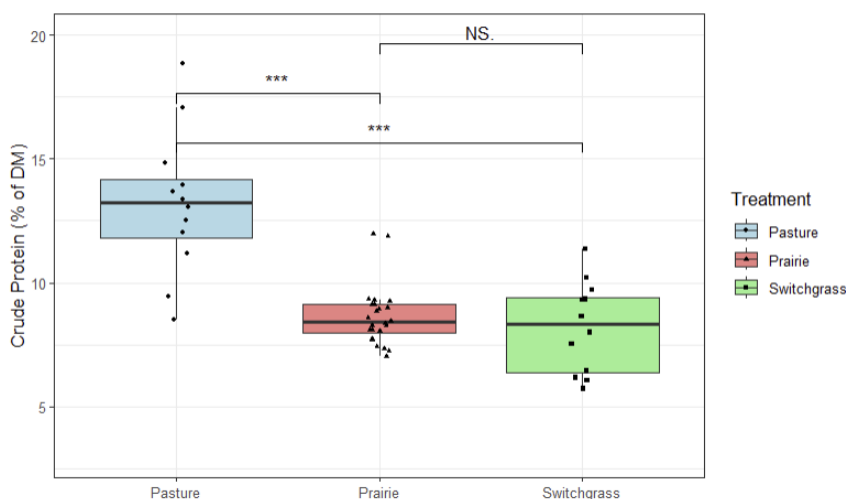


Fig. 13. Pre-grazing distribution of crude protein content of forage from cool-season pasture, WSG (prairie), and WSG (switchgrass) treatments, aggregated across forage quality samples. Boxplots show median, upper and lower quantiles, minimum and maximum values and jittered raw data. Crude protein given as percent of dry matter. Whiskers show a 95% confidence interval centered on the median. Dots show individual data points. P-values are indicated as follows: NS=no significance, *P = <.1, **P = <.05, ***P = <.001.

4.10 Relative Forage Quality

No significant treatment X year interaction was found for relative forage quality (RFQ) ($F = 0.39$; $df = 2,45$; $P = .68$); thus data was aggregated across years to increase statistical power. No significant differences ($F = 3.19$; $df = 2,45$; $P = .051$) in RFQ were observed between treatments (Table 12). Numerically, RFQ of forage from cool-season pasture had the highest mean value, and forage from WSG (switchgrass) had the lowest mean value (Fig. 14). Variability was not statistically different ($F = 3.04$; $df = 2,45$; $P = .059$) across treatments.

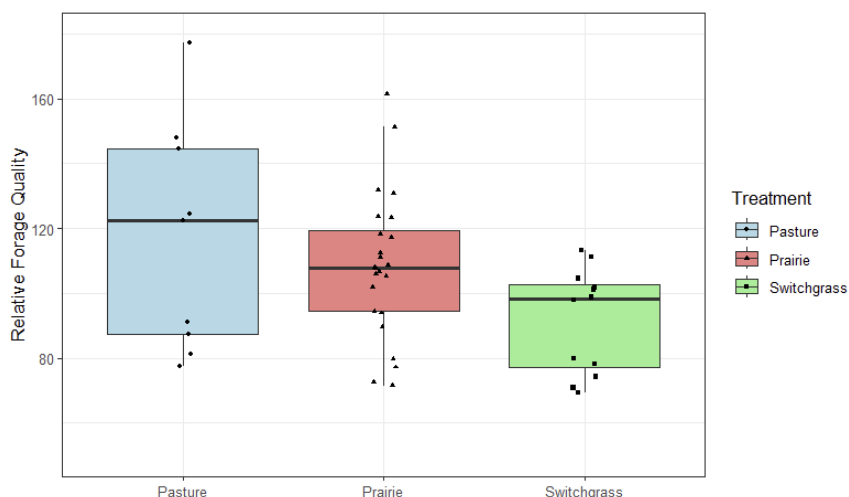


Fig. 14: Pre-grazing distribution of relative forage quality values for cool-season pasture, WSG (prairie), and WSG (switchgrass) treatments aggregated across forage quality samples. Boxplots show median, upper and lower quantiles, minimum and maximum values and jittered raw data. Whiskers show a 95% confidence interval centered on the median. Dots show individual data points.

5. Discussion

5.1 WSG Support Insect Biodiversity While Providing Critical Mid-Season Forage

This study finds that implementing WSG into a grazing plan can support improved insect numbers and biodiversity while maintaining forage quality and intake. Despite no observed differences in total insect abundance across treatments, insect abundance in cool-season pasture steadily declined through the season, while WSG (switchgrass) and WSG (prairie) treatments maintained moderate levels of insect numbers well into mid-summer. We found no differences in insect family richness or Shannon indices between treatments; however, seasonal differences in functional group diversity were observed. Cool-season pasture and WSG (switchgrass) have peaks of pests in early summer, while WSG (prairie) maintain low levels of pests and comparable levels of beneficials throughout the season. WSG also showed promise as a forage supplement, with similar or higher forage availability compared to cool-season pasture, and no

difference in consumption observed. Finally, both WSG (switchgrass) and WSG (prairie) are of high enough forage quality for use with heifers and dry cows, despite crude protein levels being too low for lactating cattle (Lemus 2020, Undersander et al.).

5.2 Incorporating WSG Improves Insect Abundance and Biodiversity

The insect abundance trends seen in this study are consistent with those seen in other similar studies. The high individual insect counts in early summer align with known insect seasonal dynamics (Powell and Logan 2005, Pires et al. 2014, Ueno et al. 2021, Van Dijk et al. 2024, Kaliang et al. 2025). Furthermore, the higher insect abundance in cool-season pasture and WSG (switchgrass), both of which contain less plant diversity, is consistent with observations from other studies that showed an inverse correlation between plant biodiversity and insect abundance (Haddad et al. 2001) due to a lack of generalist predators. The decline in insect abundance in cool-season pasture throughout the season also aligns with the results of previous studies that demonstrate that decreased plant structural diversity leads to decreased insect biodiversity (Mitchell et al. 2023, Wyckhuys et al. 2024). The sustained insect abundance seen in WSG (switchgrass) and WSG (prairie) treatments may be supported by the advantage C4 photosynthesis gives these grasses as the weather warms, supporting more consistent growth and persistence throughout the summer (Vendramini et al. 2023). More stable persistence protects the environmental niches insects rely on, producing an effect similar to that seen in Durak et al. 2025, where ecological niches remain in late summer and sustain insect populations.

The differences in functional groups between treatments are likely influenced by the same plant diversity that influenced seasonal insect abundance trends. As expected, less diverse plantings such as cool-season pasture and WSG (switchgrass), show higher numbers of pests (Haddad et al. 2001). WSG (prairie), however, have a higher degree of plant diversity and

therefore more niches available to support beneficial functional groups (Durak et al. 2025). The advantages of warm-season grasses in prairies support these niches remaining established as the season progresses, sustaining insect biodiversity and supporting beneficial insects (Drobney et al. 2020, Mitchell et al. 2023, Wyckhuys et al. 2024, Durak et al. 2025). These findings support other studies (Haddad et al. 2001, Durak et al. 2025) that demonstrate that increasing native plants may serve as integrated pest management. This offers a method to reduce the prevalence of plant pests during the grazing season, reducing the incidence of crop diseases (Stuart et al. 2011, Jones and Medina 2020) and supporting farm resilience in mixed-production systems.

Contrasting with studies focused on ungrazed prairie restorations (Rowe and Holland 2013), or those that found negative impacts from traditional management (Doxon et al. 2011), we found no differences in insect biodiversity metrics such as family richness or Shannon index across treatments. We did observe that evenness between functional groups increased as the season progressed and plant biomass developed, supporting similar findings relating to ground insect evenness improving as wheat develops (Hummel et al. 2012). This may be due to an increase in ecological niches as a grassland developed, allowing for more diverse insect populations to be supported.

5.3 Grazing Disruptions Increase Biodiversity

These results align with previous studies that indicate management intensive grazing can improve insect biodiversity outcomes (Morris et al. 2005, Vulliamy et al. 2006, Silver and Vamosi 2012, Ravetto Enri et al. 2017, Cruz-González et al. 2023). Limited evidence indicates grazing reduces insect abundance, similar to studies which show sheep grazing reduces the suitability of salt marshes to support moths (Rickert et al. 2018). However, strong evidence from this study indicates that functional diversity and beneficial insects (predators and parasitoids)

increase immediately following grazing. This may be due to grazing serving as a disruption to pest dominated systems (Doxon et al. 2011, Briske et al. 2026), with a more diverse plant communities in the regrowth period offering niches for beneficial insects to establish footholds (Vulliamy et al. 2006, Rickert et al. 2018). The numeric decrease in family richness after grazing further indicates grazing's role as a disruption of plant communities (Wang et al. 2025). This highlights the need to align grazing instances with periods of high biomass productivity in plant communities (Panassiti et al. 2025), when recovery can mitigate the negative impact of grazing and maximize the benefits to functional diversity.

5.4 WSG Provide Suitable Forage for Heifers and Dry Cows

The higher forage availability, and comparable palatability, of WSG followed trends established in previous studies (Rogers et al. 2014, Van Die and Entz 2022). This offers an opportunity for risk reduction for farmers, allowing them to graze WSG during peak summer heat and increase the recovery time of cool-season pasture. Forage samples from cool-season pasture demonstrated higher quality with respect to crude protein, which correlates with milk protein (Tarr et al. 2025), milk pay price (Popescu and Angel 2019), and later body weight gain (Shee et al. 2016). This difference will limit the ability to use WSG as extended feed for lactating cattle. However, using WSG as feed for heifers, or dry cows could be beneficial for farmers, as feeding non-productive cattle is a source of substantial overhead costs (Souza et al. 2006, Lowe et al. 2016, Boulton et al. 2017, Puerto et al. 2021). Using WSG as part of feed management strategies could have further benefits for heifers, as feeding calves early forage diets has been found to increase ruminal papillae concentrations (Toledo et al. 2024), correlating with higher feed efficiency later in life (Fregulia et al. 2021).

5.5 Implications of the Study

This study provides guidance for the recommendation of grazing strategies to optimize the support of insect biodiversity, while supporting the nutrition needs of certain cattle and reducing production risk for farmers. Grazing WSG has been promoted as an alternative feed for cattle (Moore et al. 2004, Lowe et al. 2016b, Ruh et al. 2018, Boyer et al. 2020, Ritz et al. 2020, Neto et al. 2024) and as a method to prevent overgrazing of cool-season pasture (Boyer et al. 2020, Rushing et al. 2020), which these results support. Our findings further indicate that farmers can contribute to the restoration of native habitats and support beneficial insect functional groups, while also utilizing this habitat as supplemental forage during periods of increased heat (Heins 2014, Boyer et al. 2020). This offers a “win-win” solution that will improve both the environmental sustainability of agricultural practices, as well as reduce the production risk of farms that implement those practices.

Our results also offer considerations for future research. The change in insect sampling methods from 2024 to 2025 limits our ability to compare results across years. With greater ease of execution and high quality data, sampling methods as performed in 2025 should be used for future experiments. The relatively small spatial distribution and plot sizes used in this experiment may have impacted insect richness and diversity metrics. This risk is particularly high related to flying insects with wide traveling ranges (Brühl et al. 2021, Birnbeck et al. 2025). We recommend further studies use spatially isolated treatments to reduce the chance of insect sampling “carry-over.” Finally, collecting forage samples on fixed timing across treatments would expand our understanding of biomass production and quality changes over the year, enabling a more in depth analysis of how these systems might meet cattle nutritional needs.

This study finds that incorporating WSG into a grazing operation can support increased insect biodiversity while reducing the need for supplemental forages. These findings support the conclusions drawn by previous studies (Anjichi et al. 2007, Doll and Jackson 2009, Adhikari et al. 2023, Briske et al. 2026). Interdisciplinary work of this nature is critical to guide the successful implementation of conservation practices, while meeting the practical needs of farmers.

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Appendix

Table 13. Management timeline for the WICST Native Systems Experiment, including the establishment of low-diversity WSG (prairie) and high-diversity WSG (prairie) in 1999. Bioenergy harvest treatments were initiated in 2008 (southern ~20 m of each plot), rotational grazing began in 2009 (northern ~77 m), and nitrogen fertilizer (56 kg N ha⁻¹) was added to select bioenergy plots in 2010. (Adapted from Richmond et al. 2025)

System	1989-1998	1999	2008	2009	2010
Low Diversity Prairie (LDP)	Cool-season grass waterway	LDP established	Biofuel treatments begin	Grazing treatments begin	Biofuel fertilizer begins
		6 species mixture - planted 1999-06-04 - plots ~14 x 155 m - burn every 1-2 years	- south end of “main” plot - plots ~14 x 20 m - fall harvest	- north end of “main” plot - plots ~14 x 77 m - grazing begins: 2009-06 - rotational grazing 1-2 grazing events per year	56 kg N/ha <i>sub plot</i>: 0 kg N/ha
High Diversity Prairie (HDP)	Cool-season grass waterway	HDP established	Biofuel treatments begin	Grazing treatments begin	Biofuel fertilizer begins
		25 species mixture - planted 1999-06-04 - plots ~14 x 155 m - burn every 1-2 years	- south end of “main” plot - plots ~14 x 20 m - fall harvest	- north end of “main” plot - plots ~14 x 77 m - grazing begins: 2009-06 - rotational grazing 1-2 grazing events per year	0 kg N/ha <i>sub plot</i>: 56 kg N/ha

Table 14. Species planted in WSG (low-diversity prairie) at Arlington Agricultural Research Station in 1999 (6 species) and observed in 2023 (30 species). Species were selected in 1999 based on regional prairie restoration guidelines. Seeding rates originally reported by Simonsen (2003) in lbs/acre and oz/acre were converted to kg PLS/ha. Palatability was determined based on grazing behavior and forage preferences of Holstein heifers at WICST as well as pre- and post-grazing forage sampling. (Adapted from Richmond et al. 2025)

Group	Species	Planting Rate (kg PLS/ha)	Planted (1999)	Observed (2023)	Palatability
Forb	<i>Ambrosia artemisiifolia</i> L.	N/A		X	Unpalatable
Forb	<i>Asclepias syriaca</i> L.	N/A		X	Unpalatable
Forb	<i>Daucus carota</i> L.	N/A		X	Unpalatable
Forb	<i>Erigeron annuus</i> L.	N/A		X	Unpalatable
Forb	<i>Galium boreale</i> L.	N/A		X	Palatable
Forb	<i>Helianthus grosseserratus</i> M.	N/A		X	Unpalatable
Forb	<i>Heliopsis helianthoides</i> (L.) Sweet.	N/A		X	Unpalatable
Forb	<i>Monarda fistulosa</i> L.	N/A		X	Unpalatable
Forb	<i>Ratibida pinnata</i> Vent.	0.035	X	X	Unpalatable
Forb	<i>Rudbeckia hirta</i> L.	0.035	X	X	Unpalatable
Forb	<i>Rumex crispus</i> L.	N/A		X	Unpalatable
Forb	<i>Silphium integrifolium</i> Michx.	N/A		X	Unpalatable
Forb	<i>Solidago canadensis</i> L.	N/A		X	Unpalatable
Forb	<i>Solidago rigida</i> L.	N/A		X	Unpalatable
Forb	<i>Sonchus arvensis</i> L.	N/A		X	Unpalatable
Forb	<i>Symphyotrichum novae-angliae</i> L.	N/A		X	Unpalatable
Forb	<i>Symphyotrichum pilosum</i> (Willd) G.L. Nesom.	N/A		X	Unpalatable

Group	Species	Planting Rate (kg PLS/ha)	Planted (1999)	Observed (2023)	Palatability
Forb	<i>Taraxacum officinale</i> L.	N/A		X	Palatable
Grass	<i>Andropogon gerardii</i> Vitman.	0.56	X	X	Palatable
Grass	<i>Bromus inermis</i> Leyss.	N/A		X	Palatable
Grass	<i>Dactylis glomerata</i> L.	N/A		X	Palatable
Grass	<i>Elymus canadensis</i> L.	N/A		X	Palatable
Grass	<i>Elymus repens</i> L.	N/A		X	Palatable
Grass	<i>Panicum virgatum</i> L.	N/A		X	Palatable
Grass	<i>Phleum pratense</i> L.	N/A		X	Palatable
Grass	<i>Poa Pratensis</i> L.	N/A		X	Palatable
Grass	<i>Sorghastrum nutans</i> L.	0.56	X	X	Palatable
Legume	<i>Desmodium canadense</i> (L.) DC.	0.018	X	X	Palatable
Legume	<i>Lespedeza capitata</i> Michx.	0.035	X		Palatable
Legume	<i>Vicia cracca</i> L.	N/A		X	Unpalatable
Other	<i>Vitis vinifera</i> L.	N/A		X	Unpalatable

Table 15: Species planted in WSG (high-diversity prairie) at Arlington Agricultural Research Station in 1999 (25 species) and observed in 2023 (32 species). Species were selected in 1999 based on regional prairie restoration guidelines. Seeding rates originally reported by Simonsen (2003) in lbs/acre and oz/acre were converted to kg PLS/ha. Palatability was determined based on grazing behavior and forage preferences of Holstein heifers at WICST as well as pre- and post-grazing forage sampling. (Adapted from Richmond et al. 2025)

Group	Species	Planting Rate (kg PLS/ha)	Planted (1999)	Observed (2023)	Palatability
Forb	<i>Allium cernuum</i> Roth.	0.035	X	X	Palatable
Forb	<i>Ambrosia artemisiifolia</i> L.	N/A		X	Unpalatable
Forb	<i>Asclepias syriaca</i> L.	N/A		X	Unpalatable
Forb	<i>Asclepias tuberosa</i> L.	0.035	X		Unpalatable
Forb	<i>Astragalus canadensis</i> L.	0.035	X		Unpalatable
Forb	<i>Coreopsis palmata</i> Nutt.	0.035	X		Unpalatable
Forb	<i>Daucus carota</i> L.	N/A		X	Unpalatable
Forb	<i>Drymocallis arguta</i> (Pursh) Rydberg.	0.004	X		Unpalatable
Forb	<i>Erigeron annuus</i> L.	N/A		X	Unpalatable
Forb	<i>Eryngium yuccifolium</i> Michx.	0.035	X		Unpalatable
Forb	<i>Galium boreale</i> L.	0.018	X	X	Unpalatable
Forb	<i>Geum triflorum</i> Pursh.	0.018	X		Unpalatable
Forb	<i>Helianthus grosseserratus</i> M. Martens.	0.018	X	X	Unpalatable
Forb	<i>Helianthus pauciflorus</i> Nutt.	N/A		X	Unpalatable
Forb	<i>Helianthus laetiflorus</i> Pers.	0.018	X		Unpalatable
Forb	<i>Heliopsis helianthoides</i> (L.) Sweet.	N/A		X	Unpalatable
Forb	<i>Monarda fistulosa</i> L.	0.018	X	X	Unpalatable

Group	Species	Planting Rate (kg PLS/ha)	Planted (1999)	Observed (2023)	Palatability
Forb	<i>Oenothera biennis</i> L.	N/A		X	Unpalatable
Forb	<i>Ratibida pinnata</i> Vent.	0.035	X	X	Unpalatable
Forb	<i>Rosa carolina</i> L.	0.070	X		Unpalatable
Forb	<i>Rudbeckia hirta</i> L.	0.018	X	X	Unpalatable
Forb	<i>Silphium integrifolium</i> Michx.	0.035	X	X	Unpalatable
Forb	<i>Solidago canadensis</i> L.	N/A		X	Unpalatable
Forb	<i>Solidago rigida</i> L.	0.035	X	X	Unpalatable
Forb	<i>Symphyotrichum novae-angliae</i> L.	0.018	X	X	Unpalatable
Forb	<i>Symphyotrichum pilosum</i> (Willd) G.L. Nesom.	N/A		X	Unpalatable
Forb	<i>Tradescantia ohioensis</i> Raf.	0.018	X		Palatable
Forb	<i>Viola pedatifida</i> Don.	0.035	X		Unpalatable
Grass	<i>Andropogon gerardii</i> Vitman	0.56	X	X	Palatable
Grass	<i>Bromus inermis</i> Leyss.	N/A		X	Palatable
Grass	<i>Dactylis glomerata</i> L.	N/A		X	Palatable
Grass	<i>Elymus canadensis</i> L.	2.24	X	X	Palatable
Grass	<i>Elymus repens</i> L.	N/A		X	Palatable
Grass	<i>Panicum virgatum</i> L.	N/A		X	Palatable
Grass	<i>Phleum pratense</i> L.	N/A		X	Palatable
Grass	<i>Poa Pratensis</i> L.	N/A		X	Palatable
Grass	<i>Sorghastrum nutans</i> L.	0.56	X	X	Palatable
Legume	<i>Baptisia leucantha</i> Torr. & A. Gray	0.035	X		Unpalatable

Group	Species	Planting Rate (kg PLS/ha)	Planted (1999)	Observed (2023)	Palatability
Legume	<i>Desmodium canadense</i> (L.) DC.	0.035	X	X	Palatable
Legume	<i>Lespedeza capitata</i> Michx.	0.035	X		Palatable
Legume	<i>Melilotus albus</i> Medik.	N/A		X	Palatable
Legume	<i>Trifolium pratense</i> L.	N/A		X	Palatable
Other	<i>Morus alba</i> L.	N/A		X	Unpalatable
Other	<i>Rosa carolina</i> L.	N/A		X	Unpalatable

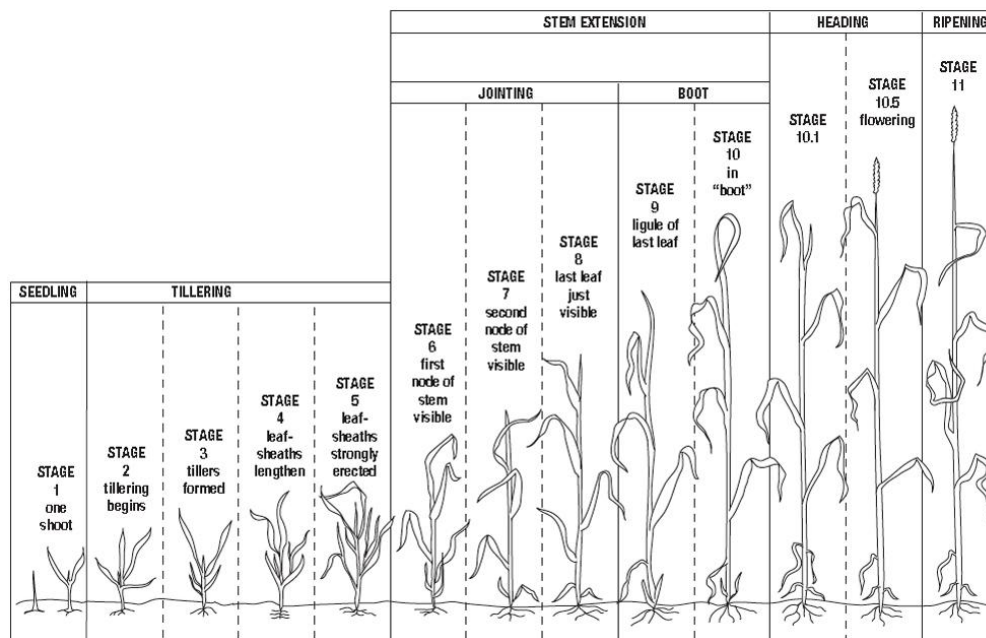


Figure 15: Feekes scale of grass development. Indicates stages of development used as reference points for grazing at WICST. Adapted from B. Curran and D. Lingenfelter, cords., The Penn State Agronomy Guide (University Park: Penn State College of Agricultural Sciences, 2013).