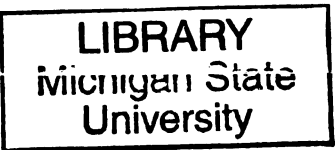


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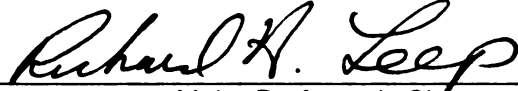
EVALUTATION OF SWITCHGRASS AND BIG BLUESTEM FOR
USE IN COOL-SEASON GRAZING SYSTEMS TO IMPROVE
SEASONAL FORAGE YIELD AND LIVESTOCK GAINS

presented by

Daniel John Hudson

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**EVALUTATION OF SWITCHGRASS AND BIG BLUESTEM FOR USE IN COOL-
SEASON GRAZING SYSTEMS TO IMPROVE SEASONAL FORAGE YIELD AND
LIVESTOCK GAINS**

By

Daniel John Hudson

A DISSERTATION

**Submitted to
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ABSTRACT

USING SWITCHGRASS AND BIG BLUESTEM IN COOL-SEASON GRAZING SYSTEMS TO IMPROVE SEASONAL FORAGE YIELD AND LIVESTOCK GAINS

By

Daniel John Hudson

Michigan livestock producers are faced with a choice that arises annually: to move their livestock from dormant summer pastures to locations where they are fed stored forage, or to allow their livestock to continue grazing, risking damage to the land. Keeping livestock on high-quality pasture is in the economic interest of the farmer, the physical interest of the animal, and the land itself. In this study we compared a typical Michigan grazing system with two other grazing systems, each of which integrate one native warm season grass species into the typical grazing system to provide quality mid-summer forage. The grazing experiment was conducted at the W.K. Kellogg Biological Station in Hickory Corners, MI. A completely randomized design with four replications was used. Treatments for this trial include: 1) traditional Michigan cool season grass/legume pasture; 2) a treatment two-thirds of which is the same as '1)' and one-third of which is composed of switchgrass (*Panicum virgatum*); 3) a treatment two-thirds of which the same as to '1)' and one-third which is composed of big bluestem (*Andropogon gerardii*). A variable stocking rate was be used and pastures were rotationally grazed. Grazing began in late-April and ended by October 15 of each year, depending upon conditions. Pasture performance is described in terms of forage dry matter offered throughout the grazing season, botanical composition, forage quality, number and

distribution of animal unit grazing days, average daily gain of animals on pasture, and total animal weight gain/hectare. The animals used in this study were Holstein steers, weighing approximately 240 kg at the beginning of the grazing season. Results reveal that although average daily gains do not differ among treatments, total animal weight gain per hectare is significantly different among treatments. Inclusion of big bluestem or switchgrass in a grazing system may reduce the risk of extreme declines in available pasture dry matter, but management constraints of these grasses reduce total grazable acreage in the spring and early fall. Economic comparisons that include variable costs show that integrating switchgrass or big bluestem into traditional cool-season grass and legume pastures in the proportions used in this experiment will result in an economic disadvantage for southwest Lower Michigan livestock producers. However, these differences in economic performance could be offset by moderate financial incentives from organizations that wish to encourage livestock producers to enhance wildlife habitat by including switchgrass and big bluestem in their grazing systems. There were no significant differences in the relative abundance of grassland birds among the treatments. The size and design of the grazing experiment was not suitable for rigorous research on the effect of native warm season grasses in grazing systems on grassland bird species.

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INTRODUCTION AND BACKGROUND INFORMATION

During the mid-summer months of most years, Michigan producers who keep livestock on pasture are faced with a choice: to remove their livestock from dormant summer pastures to locations where they are fed stored forage, or to allow their livestock to continue grazing. The choice to leave livestock on pasture during periods of inadequate pasture productivity can result in overgrazing. Overgrazing often reduces pasture productivity (Coleman, 2007) resulting in weed invasion (Hazell, 1967), and therefore may require renovation or replanting. In southwest Lower Michigan, spring and fall cool season grass-legume growth is excellent due to mild temperatures and adequate rainfall, but drought stress during the summer months often causes these grasses and legumes to become dormant (Laude, 1953). Several state universities in the North Central Region promote the use of native perennial warm season grasses, such as switchgrass and big bluestem as summer forage in some circumstances (Anderson, 2000; Barnhart, 1994; Bartholomew). These grasses have the potential to provide large volumes of high quality mid-summer forage when cool season grasses and legumes are less productive (Balasko, 2003). While both species are indigenous to Michigan, no grazing research has been conducted to determine if using these species in a pasture system is a viable option. Beyond their capacity to produce large quantities of biomass, switchgrass and big bluestem grow well in marginal soils and can provide excellent cover for nesting birds (George et al., 1979; Tober, 1992) and for other types of wildlife and can reduce the loss of sediment, nitrogen, and phosphorus in areas prone to erosion (Blanco-Canqui, 2004). Switchgrass (Ma, 2000) and other native tallgrass prairie species

are believed to sequester large amounts of carbon in the soil, and grasslands in general present great aesthetic appeal (Keeney, 2007), particularly in the summer and fall.

The Michigan Hay and Grazing Council has described alternative forage research as one of its top priorities (Lindquist, 2002). Both the Michigan Department of Natural Resources (Sargent, 1999) and the USDA Natural Resource Conservation Service (USDA-NRCS, 1996) have encouraged Michigan graziers to include native warm season grasses in their grazing systems. However, graziers may be reluctant to use these grasses without knowledge of their performance in Michigan. This project was designed to demonstrate how livestock perform when these grasses are integrated into the typical grazing systems in Southern Michigan.

Literature review

Switchgrass and big bluestem are both erect-growing native perennial warm season grasses. They have C₄ metabolism, so peak biomass production occurs at a leaf temperature of 37°C, in contrast to cool season grasses which peak between 20 and 25°C and dramatically decline at temperatures above 27°C (Nelson, 1995). This physiological characteristic makes warm season grasses most productive in mid-summer. Big bluestem, switchgrass, and indiangrass have been used extensively in U.S. government programs such as the Soil Bank and the Conservation Reserve Program since the 1930's, resulting in several million hectares being replanted with either mixtures or monocultures of these grasses (Moser, 1995). The extensive use of these grasses in the Conservation Reserve Program demonstrates their contribution to grassland ecosystems and their role in providing wildlife habitat (USDA-NRCS, 1999; USDA-NRCS, 2007). The ecological importance of these grasses is widely recognized (Harvey, 2000; Henning, 1993; USDA-

NRCS, 1999) and they can be planted along railroad right-of-ways and roadsides, near waterways, for wildlife cover (Moser, 1995), for erosion control (Blanco-Canqui, 2004; Rankins, 2001), and can function well as vegetative conservation buffers to prevent soil pesticide loss via surface water (Rankins, 2001). Both big bluestem and switchgrass tolerate a soil pH of 4.5 and 4.9, respectively (Duke, 1978) and thus can be planted in areas that are not typically used for crop production. Switchgrass and big bluestem both have extensive root systems that penetrate the soil to depths of more than two meters (Weaver, 1954) and show great potential for carbon sequestration. Beyond having vast potential for wildlife habitat, erosion control, and carbon sequestration, these grasses are recommended by many research and extension institutions for summer grazing. Mitchell (1996) suggests that summer grazing is more efficient if separate pastures of warm and cool season grasses are maintained; placing grazing animals in the warm season pastures during mid-summer, and then returning them to cool season pastures after cool season pasture recovery. Henning (1993) points out that a combination of cool season and warm season grass pastures can provide a more constant supply of high-quality feed through the summer than either cool or warm season grass pastures can provide alone. Barnhart (1994) indicates that pasture efficiency may be increased by converting one-fourth to one-third of the cool season grass pasture acreage to a warm season grass pasture to be grazed at different times during the grazing season. This allows the cool season grasses to be grazed in the spring and early summer, occasionally throughout the summer, and in the fall, while utilizing the warm season grass pasture more intensively during periods of low cool season grass productivity. Also, this strategy allows greater rest periods for cool

season pastures, which will increase their vigor and productivity for late summer through early fall grazing.

Recommendations for inclusion of warm season grasses in grazing systems are supported by numerous studies in many states. Kreuger and Curtis (1979) conducted a study in South Dakota comparing switchgrass, big bluestem, indiangrass (*Sorghastrum nutans* (L.) Nash), and sideoats grama (*Bouteloua curtipendula*) for mid-summer grazing and concluded that switchgrass and big bluestem are useful species for beef production in July and August. George (1996) demonstrated that grazing either big bluestem or switchgrass pastures in mid-summer can result in impressive steer weight gains (1.42 and 1.11 kg day⁻¹, respectively) and that rotational grazing management is superior to continuous grazing management for both switchgrass and big bluestem. In an Iowa study, (Moore et al., 2004) concluded that, in some circumstances, sequentially grazing cool- and warm-season grasses may be a desirable alternative to remaining on cool-season pastures throughout the summer. This management strategy is an option because warm-season grasses are highly productive during the mid-summer when cool-season grasses are typically less productive. Much of this improved seasonal productivity is due to the resource use-efficiency of warm season grasses for water (Ehleringer, 1993; Moser, 2004; Wedin, 2004) phosphorus (Morris, 1982), and nitrogen (Brown, 1985). Brown (1985) observed that the C₄ grasses in his experiment synthesized twice as much dry matter per unit of nitrogen taken up from a soil with low levels of N. While the productivity of warm-season grasses is high, the forage quality is low and tends to decline rapidly, which can result in depressed livestock performance (Moore et al., 2004).

Barnhart (1994) presents data that shows dry matter yield increasing with increasing nitrogen inputs, but the relationship is not linear; approximately 75 kg ha⁻¹ of nitrogen is optimal, considering biomass production and crude protein responses. Switchgrass matures earlier in the summer than big bluestem and the forage quality of big bluestem does not decline as rapidly as it does with switchgrass (Moser, 1995). Both switchgrass and big bluestem pastures must be managed differently than cool season grass pastures. Neither species tolerates close grazing and both require rest periods of 21 to 45 days between grazing events, depending on environmental conditions (Anderson, 2000; Henning, 1993; Mitchell, 1996).

Objectives and Hypotheses

- Objective 1: To compare the productivity of a traditional Michigan cool season grass-legume grazing system with the productivity of two model systems that include warm season grasses, in the first three years after planting the warm season grasses.
 - *Hypothesis 1a:* The grazing system models that are integrated with warm season grasses will result in higher livestock weight gains (kg/ha) than typical Michigan grazing system model which includes only cool season grasses and legumes.
 - *Hypothesis 1b:* An integrated grazing system that includes big bluestem will result in higher livestock weight gains (kg/ha) than an integrated grazing system that includes switchgrass.
- Objective 2: To compare the profitability of the above systems over three years of experimentation.

- *Hypothesis 2a*: When considering all inputs and outputs, the initial cost of establishing the warm season grass-integrated grazing systems will be offset by their higher productivity by the end of the third year.
- *Hypothesis 2b*: Big bluestem-integrated grazing systems will not be significantly more profitable than switchgrass-integrated grazing systems by the third year of experimentation.
- Objective 3: To describe songbird species diversity in the respective pasture systems, describing apparent relationships between species spatial distribution and type of pasture system.
 - *Hypothesis 3*: Pasture systems that include switchgrass and big bluestem will have a higher songbird species diversity, nesting success, and evidence greater use by raptors feeding on mice and other rodents

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Chapter 1

SEASONAL FORAGE DYNAMICS OF COOL-SEASON PASTURES INTEGRATED WITH SWITCHGRASS AND BIG BLUESTEM

ABSTRACT

High temperatures and lack of precipitation often cause the productivity and quality of cool-season pastures in Michigan to severely decline for an extended period during the summer. This study was conducted to determine whether integration of switchgrass or big bluestem into cool-season grazing systems would mitigate this period of low pasture productivity and quality. Cool-season grass and legume pastures (CS-Only) were compared to integrated big bluestem and cool-season grass and legume pastures (CS-BBS) and integrated switchgrass and cool-season grass and legume pastures (CS-SG). The seasonal dynamics of forage dry matter offered, crude protein, neutral detergent fiber, and acid detergent fiber were used to compare the dynamics of the pasture productivity and quality in each of three pasture systems. Dry matter offered in the CS-Only treatment was higher earlier in the grazing season and the peak in dry matter-offered occurred between 20 and 30 days earlier in the CS-Only treatment than in the other treatments. The seasonal trend for crude protein was generally higher and more constant for the CS-Only treatment than for the CS-BBS and CS-SG treatments, which were very similar to each other. The seasonal trend for acid detergent fiber and neutral detergent fiber (NDF) was generally lower and more constant for the CS-Only treatment than for the CS-BBS and CS-SG treatments, which were very similar to each other. These findings suggest that, compared to the CS-Only treatment, the CS-SG or the CS-BBS treatments probably will not improve livestock gain or improve the distribution of animal grazing days throughout the summer.

Introduction

Switchgrass and big bluestem have been promoted as forage for livestock (Anderson, 2000; Barnhart, 1994; Bartholomew, 1995) and are also known to provide valuable wildlife habitat (Delisle and Savidge, 1997; Sample and Mossman, 1997). Thus far, little research has been conducted in the Great Lakes region to describe livestock performance on grazing systems that include big bluestem or switchgrass. Because livestock performance is closely related to forage quality and abundance, it is important to measure these parameters in addition to the response of the grazing animal. In order to explain animal response, it is helpful to describe pasture system dynamics in terms of forage dry matter yield, and forage quality parameters including crude protein, acid detergent fiber, and neutral detergent fiber.

One of the primary objectives of the study was to compare the productivity of a traditional Michigan cool season grass-legume grazing system with the productivity of two model systems that include warm season grasses, in the first three years after planting the warm season grasses. The associated hypotheses were:

1. The grazing system models that are integrated with warm season grasses will result in higher livestock weight gains (kg ha^{-1}) than a typical Michigan grazing system model which includes only cool season grasses and legumes.
2. An integrated grazing system that includes big bluestem will result in higher livestock weight gains (kg ha^{-1}) than an integrated grazing system that includes switchgrass.

These hypotheses were evaluated in Chapter 3 of this dissertation. The subject of this chapter is pasture quality and the dynamics of forage dry matter offered to the grazing

animals, both of which will help to understand why the above hypotheses were or were not validated.

LITERATURE REVIEW

Measurement of pasture forage yield

While there are numerous parameters that can be measured in pasture research, the high cost of conducting these investigations dictates that only those most directly related to the objectives be measured. Burns (1989) recommends that herbage mass, green leaf mass, forage quality, herbage density, and botanical composition data be collected for all grazing experiments. Depending on the objectives of the experiment, measurements such as grazing time, bite size, and leaf area index may also be taken.

Accurate appraisal of the quantity of forage present is a difficult procedure because of the high degree of natural variation across most pastures. The most accurate means of estimating forage yield is direct sampling (i.e. clipping a quadrat of known area), but the number of samples required to obtain a reliable mean and the amount of labor required to perform this work is usually prohibitive, and indirect methods are necessary (Wilm, 1944).

There are several methods which can be used to estimate forage yield including capacitance meters, rising plate meters, visual estimates (O'Donovan, 2002), and grazing rulers (Sanderson et al., 2001). The electronic capacitance meter uses the difference of the dielectric constant between the air and the herbage to describe the quantity of herbage present (Sanderson et al., 2001). Although they can be fabricated in many ways, a basic type of rising plate meter can be made by taking a wood, metal, or plastic plate of known area and mass and cutting a hole in the middle; the hole should be large enough for a 2.5

cm dowel to easily pass through. The plate, which rests at the bottom of the dowel, is connected by the corners to the top of the dowel by string. The dowel is then marked along the axis, from the bottom upward, with length graduations. The rising plate meter is used by holding the top end of the dowel and setting the plate on the pasture forage surface (Scrivner et al., 1986). The forage supports the plate at a certain height above the ground, while the dowel passes through to the ground. The graduation closest to the intersection of the plate and the dowel is the height measurement recorded. This measurement describes the total standing crop (Scrivner et al., 1986) and is calibrated to actual pasture dry matter per unit area by means of double-sampling (Wilm, 1944). (Earle and McGowan, 1979) indicate that more readings are necessary to estimate herbage biomass in pastures where there is a high degree of yield variability. While the rising plate meter is commonly accepted as a way to determine pre-grazing herbage, Stockdale and Kelly (Stockdale and Kelly, 1984) suggest that it is not appropriate for estimating heavily trampled post-grazing residue.

When using the rising plate meter to determine total herbage dry matter weight, a wide range of dry matter values should be chosen for double-sampling in the pasture being evaluated (Lucas, 1990). Linear regressions are used to relate rising-plate meter readings to dry matter yield by either pooling all data from the grazing season (Michell, 1982; Scrivner et al., 1986) or by pooling data from different parts of the grazing season (Michell and Large, 1983). If conditions (e.g. lodged forage) indicate that the rising-plate meter method is not appropriate (Stockdale, 1984), then direct sampling is an appropriate means to estimate pasture dry matter yield (Stockdale and Kelly, 1984).

Opinions about the usefulness of these techniques for indirectly measuring forage dry matter in pastures vary widely. Scrivner et al. (1986) concluded that “the rising plate meter was a quick and effective way of assessing total forage growth and utilization.” (Gabriels, 1993) concluded that “at the present it is impossible to make an accurate prediction of the dry matter of a certain site on the basis of non-destructive measurements.” However, the reason that there is so much research on indirect pasture measurements is that most pasture researchers recognize that measurement of pasture productivity is necessary and that direct measurement is not practical or financially feasible.

Measurement of pasture forage botanical composition and forage quality

The purpose of planting a pasture with a diverse mixture of species is to increase productivity, improve the quality of the forage, and to provide more uniformity in forage availability throughout the grazing season (Henson, 1941). Thus, monitoring botanical composition is an important aspect of pasture studies. Changes in botanical composition can reflect the impact of management practices (VanKeuren, 1957) as well as animal preference and hence, should be monitored periodically through the grazing season. Weed dynamics in particular agricultural systems are influenced by the patterns of disturbance of plants and soil. Grazing systems range from continuous to intensive-rotational in nature and specific weed species can either be favored or selected against. For example, Canada thistle is favored by continuously grazing pastures, while high-intensity, low-frequency grazing reduces the density of Canada thistle (De Bruijn, 2006). Alternately, excessive grazing under particular conditions can cause other weed species to proliferate (Harker, 2000).

One method of determining botanical composition is hand-separation of the forage into the component species and calculating the relative contribution of each species to the dry matter weight. This method is labor intensive, expensive, and time consuming and there have been numerous attempts to develop indirect methods of determining botanical composition (VanKeuren, 1957). VanKeuren and Algren compared (1957) the inclined point quadrat method (Army, 1942; Mannetje, 1963) of estimating botanical composition with the vertical point quadrat method, visual estimation, and hand-separations. They concluded that the inclined point quadrat method had the highest correlation and the least variation of the indirect methods. This method uses quadrats with ten needles fixed within them. These quadrats are placed randomly multiple times in the area to be assessed. The species of plant through which each needle passes every time the quadrat is placed is recorded, and the botanical composition of the pasture is derived using the resulting data.

Mannetje (1963) describes another indirect method of estimating botanical composition called the dry-weight-rank method. This procedure is carried out by taking 50 to 80 visual ratings from within quadrats placed within the pasture that is being described. Visual estimation is used to rank which species is first (1), second (2), and third (3) in dry matter production within each quadrat. The total number of times that a species receives any of the rankings (1, 2, or 3) is calculated as well as the total number of times that species is given a specific rating of 1, 2, or 3. Relative proportions of '1', '2', and '3' ratings are calculated and multiplied by 70.2, 21.1, and 8.7, respectively. The sum of these three numbers represents the percent composition of that species in the

pasture at that time. Mannetje concluded that the dry-weight-rank method provides an accurate estimation of botanical composition by weight in a wide variety of pasture types.

Forage quality including crude protein (crude protein), neutral detergent fiber (neutral detergent fiber), and acid detergent fiber (acid detergent fiber) are frequently appear in forage quality reports (Collins, 2003) and are frequently used in studies where livestock performance is of concern (Karsli et al., 1999; Wen et al., 2002). There are standard wet-chemistry techniques that are used for each component, but they are often used in conjunction with near infra-red reflectance spectroscopy (NIRS) (Hart, 1989).

MATERIALS AND METHODS

This experiment was conducted at W. K. Kellogg Biological Station in Hickory Corners, MI, on Kalamazoo series (fine-loamy, mixed, mesic Typic Hapludalfs) soils. Four replications of three treatments were assigned to the experimental area using a completely randomized design. The experimental layout is described in Appendix I Figure 1.1.

The three treatments included:

1. A cool-season grass-legume pasture (CS-Only) representative of pastures found throughout the Lower Peninsula of Michigan. These pastures were comprised primarily of perennial ryegrass (*Lolium perenne*), quackgrass (*Agropyron repens*), alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*).
2. An integrated big bluestem and cool-season grass-legume pasture. One-third of the system is a monoculture of big bluestem that was planted in 2002, and two-

thirds is composed of the cool-season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).

3. An integrated switchgrass and cool-season grass-legume pasture. One-third of the system is a monoculture of switchgrass that was planted in 2002, and two-thirds is composed of the cool-season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).

All pastures had an area of 1.6 ha with the exception of two which, because of the shape of the experimental area and existing permanent fencing, were somewhat smaller or larger. The cool-season grass and legume (henceforth, 'cool-season') portions of all treatments predated this experiment. The major cool season species included: perennial ryegrass, Kentucky bluegrass, white clover, quackgrass, and alfalfa. In the planning stages of this experiment, differences in species abundance between replications were considered negligible and blocking was not considered. After the experiment began, it became apparent that the variability in 'alfalfa abundance' was significant and should be considered a blocking effect. All pastures which were planted with alfalfa in 1994 were considered were included in 'alfalfa abundant' block. The pasture layout with respect to experimental treatments and alfalfa abundance is described in Appendix I Figure A.2.

2002 Warm-season Pasture Pre-planting Preparation

On April 26 all areas which were to be planted with switchgrass or big bluestem were treated with glyphosate at a rate¹ of 1.12 kg ha⁻¹. At this time, existing cool-season grasses were approximately 20-25 cm tall. On May 22 and 23 we attempted to burn the

¹ All pesticide rates are described in terms of kg ha⁻¹ of active ingredient applied.

residue of the herbicide-killed pasture, but the low volume of biomass prevented a complete burn.

2002 Planting

The big bluestem and switchgrass monoculture portions of the CS-BBS and CS-SG treatments were planted between May 28 and May 30. The seeding equipment was a Truax rangeland drill with a 1.5 m planting width. Niagara big bluestem was planted with a target rate of 10 kg pure live seed (PLS) ha⁻¹. Forestburg switchgrass was planted in the CS-SG pastures at a rate of 10 kg PLS ha⁻¹.

2002 Weed and Insect Control

On June 7 the area that had been planted with switchgrass or big bluestem was sprayed with a herbicide combination that delivered 0.07 kg ha⁻¹ imazethapyr and 0.91 kg ha⁻¹ glyphosate. At the time of herbicide application, less than 5% of crop seedlings had emerged. On June 12, scouting revealed that many of the emerging switchgrass seedlings were being damaged by insects; some were being consumed to ground level while others were fenestrated. Further investigation suggested that the fenestration was caused by Stewart's bacterial wilt (Munkvold, 2002), which can be transmitted by corn flea beetles (*Chaetocnema pulicaria* M.) as well as other species of flea beetles (NCSU, no date). Other cutting and chewing damage was attributed to thrips (order *Thysanoptera*). On June 20, big bluestem and switchgrass pastures were sprayed with 1.12 kg ha⁻¹ of carbaryl. On August 3 clopyralid was sprayed on all big bluestem and switchgrass pastures at a rate of 0.28 kg ha⁻¹, in order to control broadleaf weeds.

2003 Switchgrass Pasture Reseeding and Subsequent Insect and Weed Control

The switchgrass pastures that had been planted in 2002 were assessed in the spring of 2003. At that time, it was evident that flea beetle and Stewart's bacterial wilt damage from summer of 2002 had damaged the switchgrass stand enough to cause stand failure and replanting was deemed necessary. Switchgrass pastures were replanted with Forestburg switchgrass on May 19, 2003 at a rate of 14.3 kg ha^{-1} . Because the ground was relatively free of debris and living plants, a conventional three meter drill was used for replanting. The big bluestem pastures planted in 2002 had not been damaged by Stewart's bacterial wilt and did not need re-planting.

On June 10, 2003, when the switchgrass seedlings in the re-seeded pastures had reached a height of approximately 2.5 cm, carbaryl insecticide was applied at a rate¹ of 1.68 kg ha^{-1} , in order to control the flea beetle and thrip populations. The switchgrass portion of the CS-SG treatment was not grazed in 2003.

On July 17, 2003, a combination of herbicide and insecticide mixture was used to control weeds and insects:

- Carbaryl (flea beetles/thrips): 1.68 kg ha^{-1}
- 2,4-D amine (broadleaf weeds): 1.06 kg ha^{-1}
- Imazethapyr (broadleaf and grass weeds): 0.07 kg ha^{-1}

2002-2003 Cool-season Pasture Improvement

Some of the pasture systems had been planted with alfalfa in 1994 while others had not. On April 18, 2003, white clover (Kopu II, Ampac Seed Company) was drilled into all cool-season pastures in order to make the legume composition more uniform among

treatments and replications. The John Deere 750 drill was set to plant 1.63 kg of pure live seed ha⁻¹ into the living sod of all cool season pastures of all treatments.

On August 22, 24, and 25 of 2003, orchardgrass, tall fescue, and white clover were planted into the dormant (but living) sod of all cool-season portions of all treatments. A John Deere 750 no-till drill was used for planting:

- Orchardgrass (Tekapo, Ampac Seed Company): 8.4 kg PLS ha⁻¹
- Endophyte free tall fescue (Bronson, Ampac Seed Company): 6.0 kg PLS ha⁻¹
- White clover (Kopu II, Ampac Seed Company): 3.9 kg PLS ha⁻¹

2004-2005 weed control in switchgrass and big bluestem pastures

2004: Broadleaf weeds were controlled in 2004 by spraying the switchgrass and big bluestem portions of the CS-SG and CS-BBS treatments on April 14-15 with a combination of:

- 0.84 kg ha⁻¹ of 2,4-D ester
- 0.73 kg ha⁻¹ of dicamba

2005: Due to competition from quackgrass (*Elytrigia repens* (L.)), the following herbicide combination was applied to all big bluestem and switchgrass pastures on April 6 in order to control broadleaf and grass weeds:

- 0.54 kg ha⁻¹ of dicamba
- 0.81 kg ha⁻¹ of 2,4-D ester
- 1.08 kg ha⁻¹ of glyphosate

At the time of application, the quackgrass was approximately 10 cm tall and very few big bluestem or switchgrass crown buds were showing. The inclusion of glyphosate in the herbicide mixture virtually eliminated the quackgrass while leaving big bluestem and switchgrass unharmed.

Control of pokeweed and bull thistle

Due to their noxious and aggressive characteristics, pokeweed (*Phytolacca americana* L.) and bull thistle (*Cirsium vulgare*) were controlled manually as part of daily pasture observation.

Pasture Fertility Management

The soils on which the experiment was conducted are Kalamazoo series (fine-loamy, mixed, mesic Typic Hapludalfs). Soil testing was conducted by taking 20 20-cm soil cores per pasture in 2003-2004. In the case of the CS-BBS and CS-SG treatments, twenty soil cores were collected from both cool season and warm-season grass (i.e. switchgrass and big bluestem) portions and tested separately by the MSU Soil and Plant Nutrient Laboratory. Soil tests from 2003 indicated that the soil pH of pastures ranged between 5.5 and 6.2, indicating a need for lime application. On April 7, 2003, lime was applied according to soil test recommendations.

Pasture nitrogen fertility was managed by applying urea twice per grazing season to the cool-season portions of the treatments and once to the switchgrass and big bluestem monocultures as described in Table 1.1.

Pastures were managed as uniformly as possible, but each was managed separately and optimally (Bransby, 1989). When grazing was initiated each spring, cattle on all treatments were given access to the entire cool-season portion of their respective

pastures, with the exception of the fourth replication of the CS-Only treatment, where a concurrent experiment was being carried out which required that livestock be excluded from a portion of the pasture at certain points of time. As the spring flush of cool-season pasture growth intensified, pastures were “staged” (Barker, 1999): cattle were limited to one half, and later, one quarter of the cool-season portion of their treatments at which point rotational grazing began and continued until the end of the season. During the final grazing event of the season, the cattle were again given access to the entire cool-season portion of their respective pastures. In 2003, the big bluestem portion of the CS-BBS treatments was split into three parts each of which was grazed in rotation (the switchgrass portion of the CS-SG treatment was not grazed in 2003). In 2003, residue of refused big bluestem forage was mowed after grazing as needed in order to make the pasture height more uniform at subsequent grazing events. However, it was noted that the small size of the subdivisions within the big bluestem pasture resulted in excessive trampling of forage which caused a high proportion of plants to re-grow from the crown rather than internodes, thereby increasing the amount of time required for regrowth. Further, the tractor tire tracks left from mowing caused the crushed plants to regrow from the crown; this regrowth was lush and tended to be grazed preferentially by the livestock. Thus, in 2004 and 2005 the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments were not subdivided or mowed and each portion was left undivided and grazed as one of the rotations.

Decisions about timing and duration of rotations were dictated by current and anticipated pasture forage availability rather than using strict dates or interval lengths. Variables such as soil moisture, physiological and re-growth stages of forage species,

typical seasonal weather patterns, and weather forecasts were used to make rotation decisions. After the spring flush, the grazing intervals were usually seven days for the CS-BBS and CS-SG treatments; CS-only treatments were usually rotated every ten days and consisted of four subdivisions.

Mid-season grazing pressure was adjusted using the put-and-take method² of pasture stocking (Mott, 1960). ‘Tester steers’ were left on the same replication of the same treatment for the entire grazing season. Put-and-take steers were added to or removed from a particular replication to increase or reduce the grazing pressure in order to:

- optimize utilization of pasture forage
- prevent the accumulation low-quality forage
- meet but not exceed the current or anticipated forage dry matter production

The protocol for this experiment required equivalent treatment for each replication to the extent possible, while managing each replication optimally, relative to grazing intensity, rotation frequency, and grazing initiation/termination dates. Decisions about timing and duration of rotations were not managed using strict dates or interval lengths but rather were dictated by current and anticipated pasture forage availability. Variables such as soil moisture, physiological and re-growth stages of forage species, typical seasonal weather patterns, and weather forecasts were considered in deciding when to rotate a group of steers from one pasture location to another and whether to reduce grazing intensity by removing put-and-take steers from particular pastures. Within an individual pasture, animals were rotated when one or more of the following

² See Technical Note 1 in Appendix III

was true: 1) paddocks forward in the rotations were about to become over-mature; 2) animals or pasture might be harmed by low forage levels in the current rotation; 3) rapid pasture growth indicated that shorter intervals were needed in the immediate future to prevent accumulation of low-quality forage which would likely be refused.

The anticipated date for termination of grazing was October 1, but pasture conditions including plant stress, drought, and forage dry matter availability were the primary considerations for termination of grazing for the season (Bransby, 1989; Leep, 2003). Dates of grazing and termination dates for each year are listed in Table 1.2.

All forage samples collected in this study were placed in paper bags and dried for a minimum of 48 hours at 43°C³, and then weighed. When grazing was initiated each year, dry matter availability was determined by harvesting plant tissue from within six 0.25 m² quadrats. Each time the rotation sequence brought steers to a cool-season portion of their respective treatment, plants within the quadrats were clipped at a height of approximately 5 cm. When steers were moved into the big bluestem or switchgrass portions of treatments, plants within quadrats were harvested at approximately 13 cm. When rotations began, dry matter availability was determined using a rising-plate meter (Gabriels, 1993; Harmony et al., 1997; Michell, 1982) unless conditions (lodging of forage, rain) were not appropriate, in which case quadrat clippings were used instead. When the rising-plate meter was used to measure forage availability, 100 rising-plate meter readings⁴ were taken from the paddock into which the animals were about to be moved. Three of the rising-plate meter measurements from each pasture were double-sampled at the time of rotation in order to calibrate the rising-plate meter (Harmony et

³ See Technical Note 2 in Appendix 3

⁴ See Technical Note 3 in Appendix 3

al., 1997). Double-sampling was performed by measuring the forage with the RPM and then overlaying the rising-plate meter with a 0.209 m^2 quadrat, removing the rising-plate meter, and harvesting the forage within the quadrat as described above. A range of quadrat rising-plate meter values were chosen for double-sampling at the time of rotation in order to represent the range of values present in the pastures being assessed (Lucas, 1990). Linear regression was used to relate rising-plate meter readings to dry matter yield (Michell, 1982; Scrivner et al., 1986; Stockdale and Kelly, 1984). When a rising-plate meter needed to be replaced and the replacement rising-plate meter had a different weight, a new regression was performed for the replacement rising-plate meter. Regressions for cool-season, big bluestem, and switchgrass pastures were performed separately. Following weighing, the sub-samples were combined and ground through a 1 mm screen in preparation for laboratory analysis.

For cool-season pastures, regressions for spring pasture production were based on rising-plate meter data collected between May 4 and June 23 of all years. Data collected from June 24 through September 10 of all years was used for the second regression. For big bluestem and switchgrass monocultures, regressions for spring pasture production were based on rising-plate meter data collected up to and including June 20 of 2003 and 2004. Data collected from June 21 onward was used for the second regression. Regression coefficients changed and correlation coefficients were improved when the separate regressions were performed for spring and summer pastures. In many cases, logarithmic transformation of rising-plate meter data was necessary (Gabriels, 1993).

If conditions in the CS-portion of treatments were not appropriate for using the rising-plate meter (Stockdale, 1984), then six 0.209 m^2 quadrats were clipped from each

paddock before rotation (Stockdale and Kelly, 1984). In 2003 and 2004, yield for the big bluestem and switchgrass monocultures yield was determined using the rising-plate meter when conditions (precipitation, wind) permitted; in 2005, quadrats were used exclusively. When quadrats were used to estimate forage yield, forage from within 0.209 m² quadrats was harvested at a height of approximately 13 cm to obtain an estimate of forage dry matter present. In 2003, four quadrats were used to determine yield and quality. In 2004 and 2005 dry matter yield in big bluestem and switchgrass monocultures was estimated for to each grazing event by taking the average weight of dried forage from six quadrat clippings.

Botanical Composition

Botanical composition was determined differently for the big bluestem monocultures than for the cool-season portions of the treatments. The botanical composition of the warm-season grass portions, was determined by clipping four quadrats to grazing height (approximately 13 cm) and manually separated into 'weed' and 'crop' components. Each component from each quadrat was placed into a separate bag, dried for 48 hours at 43°C, and weighed. Warm season grass botanical composition is described by the percentage of the total sample dry matter made up of the crop (i.e., big bluestem or SG) planted to that pasture. This data was collected from each paddock at the time of each rotation (Burns, 1989).

The botanical composition of the cool-season portions of the systems were assessed two times in 2003 and 2004 and three times in 2005 by using the dry-weight rank method (DWRM) (Mannetje, 1963). The DWRM was performed by making visual ratings of the forage contained in a 0.209 m² quadrat that was non-selectively placed on

the ground 80 or more times in each pasture while following a zig-zag (Z-shaped) pattern or making multiple linear transects. Workers visually estimated and ranked the forage species which contributed most to the total plant dry matter contained within the quadrat as '1'; the second most prevalent plant species was given a rank of '2'; and the third most prevalent as '3'. If only one or two plant species was contained by the quadrat, the plant species present did not receive more than one ranking each. If the worker was unable to distinguish which of two or three species was most prevalent, they were both given the same two or three numbers. For example, if perennial ryegrass was the most prevalent species, but the worker was unable to tell whether orchardgrass or white clover was the next most prevalent species, both the orchardgrass and the white clover would receive a ranking of '2 and 3'. The total number of times that a species receives any of the rankings (1, 2, or 3) was calculated as well as the total number of times that species was given a specific rating of 1, 2, or 3. Relative proportions of '1,' '2,' and '3' ratings were calculated for each species and then multiplied by 70.2, 21.1, and 8.7, respectively. The sum of these three numbers represents the percent composition of that species in the pasture (Mannetje, 1963).

In all years, botanical composition of big bluestem and switchgrass monocultures was based on hand-separations of the harvested forage from four quadrats. Forage quality of the harvested big bluestem and switchgrass subsamples was determined using the same procedures used to determine the forage quality of samples collected from the cool-season portions of the treatments. Because the rising-plate meter is not useful for determining post-grazing residue (Stockdale, 1984).

After drying, forage dry matter was ground first using a Wiley Mill with a 2 mm screen and then through a 1 mm screen with either a UDY Cyclone Mill (Udy Mill Corporation, Fort Collins, CO) or a Christy-Turner Lab Mill (Christy-Turner Ltd., Ipswich Suffolk, UK); subsamples from the same date, paddock, and rotation were combined for analysis. Forage quality parameters including crude protein, neutral detergent fiber, and acid detergent fiber were determined by using wet-chemistry techniques. In-house modifications⁵ of the Modified Van Soest method (Stern, 1991) were used to determine neutral detergent fiber and acid detergent fiber concentrations. The Hach modified Kjeldahl procedure (Hach, 1985; Watkins, 1987) was used to determine total N concentration in the forage.

Pasture and animal performance were also described in this experiment. The animals used in this study were Holstein steers that weighed approximately 240 kg at the beginning of the grazing season. The put-and-take method of pasture stocking (Mott, 1960) was used (modifications to the protocol are described in Appendix II). Data calculated from animal measurements includes: average daily gain, gain per hectare, animal unit grazing days per hectare (see Chapter 3 of this dissertation), and net income per hectare (see Chapter 4 of this dissertation).

Statistical Analysis

PROC MIXED of SAS (SAS Institute, 2000-2003) was used to conduct analysis of variance tests for forage quality and quantity parameters. Transformations necessary to normalize the distribution of studentized residuals are given in Table 1.3.

Because rotation decisions were made according to the current and anticipated forage dry-matter availability rather than by calendar date, the forage quality and quantity

⁵ See Technical Note 4 in Appendix 3

dynamics are modeled according to day of year (DOY) rather than particular date intervals. Dynamics of forage quality and quantity are modeled using all dry matter, crude protein, acid detergent fiber, and neutral detergent fiber data points from the experiment together with the significant fixed and blocking effects for each parameter to describe the behavior of those parameters at ten day intervals between DOY 117 (April 28) and DOY 257 (September 15).

The statistical model for dry matter offered includes treatment, year, day of year, and WSG (i.e. whether either big bluestem or switchgrass was included within the system) nested within treatment, as fixed effects; these effects were also tested for interactions. Date was used as a repeated measurement, and the SP(POW) covariance structure for unequally spaced measurements was used to model the covariance between measurements (e.g., DOY_A and DOY_B).

The full model for forage dry matter offered is:

$$y_{ijkl} = \mu + A_i + B_j + C_k + C_k^2 + D_l + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (CD)_{kl} + (BC^2)_{jk} + e_{ijkl}$$

where:

y_{ijkl} is the dry matter value observed in i^{th} treatment for the j^{th} year at the k^{th} day of year at on the l^{th} pasture type (WSG or non-WSG)

and:

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

B_j is a fixed effect, the j^{th} year (2003, 2004, 2005)

C_k	is a fixed effect, the k^{th} DOY
C_k^2	is the square of the k^{th} day of year
D_l	is a blocking effect, the l^{th} pasture type sampled (WSG or non-WSG)
$(AB)_{ij}$	is the interaction of treatment and year
$(AC)_{ik}$	is the interaction of treatment and DOY
$(BC)_{jk}$	is the interaction of year and DOY
$(CD)_{kl}$	is the interaction of DOY and WSG(trt)
$(BC^2)_{jk}$	is the interaction used to describe the quadratic relationship of DOY and year
e_{ijkl}	is the error term

The statistical model for the crude protein of forage offered includes treatment, alfalfa abundance, year, DOY, and WSG nested within treatment as fixed effects; these effects were also tested for interactions. Date was used as a repeated measurement, and the SP(POW) covariance structure for unequally spaced measurements was used to model the covariance between measurements (e.g., DOY_A and DOY_B).

The full model for the crude protein of the forage dry matter offered is:

$$y_{ijk} = \mu + A_i + B_j + C_k + C_k^2 + D_l + E_m + (AC)_{ik} + (BC)_{jk} + (CD)_{kl} + e_{ijkl}$$

where:

y_{ijkl} is the crude protein value observed in i^{th} treatment for the j^{th} year at the k^{th} day of year at on the l^{th} pasture type (warm-season grass or non-warm-season grass) at the m^{th} alfalfa abundance

and:

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

B_j is a fixed effect, the j^{th} year (2003, 2004, 2005)

C_k is a fixed effect, the k^{th} DOY

D_l is a blocking effect, the l^{th} pasture type (WSG or non-WSG)

E_m is a blocking effect, the l^{th} alfalfa abundance (abundant, not abundant)

$(AC)_{ik}$ is the interaction of treatment and DOY

$(BC)_{jk}$ is the interaction of year and DOY

$(CD)_{kl}$ is the interaction of DOY and WSG(trt)

e_{ijklm} is the error term

The statistical model for the acid detergent fiber of forage offered includes treatment, year, day of year, and WSG nested within treatment as fixed effects; these effects were also tested for interactions. Date was used as a repeated measurement, and the SP(POW) covariance structure for unequally spaced measurements was used to model the covariance between measurements (e.g., DOY_A and DOY_B).

The full model for the acid detergent fiber of the forage dry matter offered is:

$$y_{ijkl} = \mu + A_i + B_j + C_k + C_k^2 + D_l + (AC)_{ik} + (BC)_{jk} + (CD)_{kl} + (BC^2)_{jk} + e_{ijkl}$$

where:

y_{ijkl} is the acid detergent fiber value observed in i^{th} treatment for the j^{th} year at the k^{th} day of year at on the l^{th} pasture type (WSG or non-WSG)

and:

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

B_j is a fixed effect, the j^{th} year (2003, 2004, 2005)

C_k is a fixed effect, the k^{th} DOY

C_k^2 is the square of the k^{th} day of year

D_l is a blocking effect, the l^{th} pasture type sampled (WSG or non-WSG)

$(AC)_{ik}$ is the interaction of treatment and DOY

$(BC)_{jk}$ is the interaction of year and DOY

$(CD)_{kl}$ is the interaction of DOY and WSG(trt)

$(BC^2)_{jk}$ is the interaction used to describe the quadratic relationship of DOY and year

e_{ijkl} is the error term

The statistical model for the neutral detergent fiber of forage offered includes treatment, year, day of year, and WSG nested within treatment as fixed effects; these effects were also tested for interactions. Date was used as a repeated measurement, and the SP(POW) covariance structure for unequally spaced data was used to model the covariance between measurements (e.g., DOY_A and DOY_B).

The full model for the neutral detergent fiber of the forage dry matter offered is:

$$y_{ijkl} = \mu + A_i + B_j + C_k + C_k^2 + D_l + E_m + (AC)_{ik} + (BC)_{jk} + (CD)_{kl} + (BC^2)_{jk} + e_{ijkl}$$

where:

y_{ijkl} is the neutral detergent fiber value observed in i^{th} treatment for the j^{th} year at the k^{th} day of year at on the l^{th} pasture type (WSG or non-WSG) at the m^{th} alfalfa abundance and:

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

B_j is a fixed effect, the j^{th} year (2003, 2004, 2005)

C_k is a fixed effect, the k^{th} DOY

C_k^2 is the square of the k^{th} day of year

D_l is a blocking effect, the l^{th} pasture type sampled (WSG or non-WSG)

E_m is a blocking effect, the l^{th} alfalfa abundance (abundant, not abundant)

$(AC)_{ik}$ is the interaction of treatment and DOY

$(BC)_{jk}$ is the interaction of year and DOY

$(BE)_{ik}$ is the interaction of year and alfalfa abundance

$(CD)_{kl}$ is the interaction of DOY and WSG(trt)

$(BC^2)_{jk}$ is the interaction used to describe the quadratic relationship of year and DOY

Second Analysis

Because the 2002 switchgrass seeding failed to be established by the summer of 2003, one could argue that failing to examine the treatment by year interaction could lead to erroneous conclusions about treatment performance. To address this concern, the acid detergent fiber, neutral detergent fiber, and crude protein data was analyzed a second time with the treatment by year interaction included in the model, even though it was known that the interactions were not significant. The treatment by year interaction was already known to be statistically significant for dry matter and it is included in the original full model (above). This resulted in the term $(AB)_{ij}$, representing the interaction of treatment and year, being inserted into the model for crude protein, acid detergent fiber, and neutral detergent fiber; this term was already part of the full model of dry matter. The Tukey method was used to reduce Type I error. The best covariance structure for acid detergent fiber when the treatment*year interaction was included was spherical exponential.

Weather

Southwest Lower Michigan is a dry area of the state and the agronomic consequences of this are accentuated by the relatively course textured Kalamazoo series soils. Tabular data for precipitation, average temperatures, and average high temperatures are presented in Appendix I, Figures A.3-A.5.

April and May 2003 were typical relative to precipitation and mean air temperature; while June and July precipitation was lower than average, causing a pronounced decline in forage production. Average monthly air temperatures throughout the 2004 grazing season were very close to the 17-year average, while precipitation was higher than normal, particularly in May, which had 25 cm of rainfall. This, coupled with other well distributed precipitation throughout the 2004 grazing season led to relatively uniform forage growth throughout the grazing season.

March, April, May, August and September of 2005 were extremely dry while June and July both received more precipitation than normal. The March-May 2005 precipitation patterns seem to have prevented the normal spring flush of pasture growth, while the unusually high precipitation in June and July caused the “spring flush” of forage growth to occur in July-August. June through September 2005 was also characterized by higher than normal average temperatures. The potential dormancy-inducing effect of these above average temperatures on pastures was likely offset by the unusually high precipitation in June and July as well as the lack of precipitation in March-May.

RESULTS AND DISCUSSION

Forage dry matter and yield quality: first analysis

Dry matter offered over time

Forage dry matter and quality were modeled using day of year (DOY) as the independent variable. Table 1.4 relates DOY to dates. In this model, DOY 117 is the starting date for grazing, and the data is plotted over time using ten day intervals which end on DOY 257. The interaction between treatment and year existed for dry matter-

offered is described in Figures 1.1-1.3. These figures demonstrate the two results of setting aside one-third of the pasture acreage to big bluestem and switchgrass. First, it is intuitive that the dry matter offered in the CS-Only treatment was higher earlier in the grazing season because the entire pasture was available for grazing by early-May whereas the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments, respectively, were not grazed until early- to mid-June (Barnhart, 1994). Second, as expected, the peak in dry matter-offered occurred between 20 and 30 days earlier in the CS-Only treatment than in the other treatments (Bartholomew, 1995)

It is important to note that in 2004 and 2005, refused big bluestem and switchgrass forage from the CS-BBS and CS-SG treatments was not mowed, which resulted in the rapid accumulation big bluestem and switchgrass residue, much of which reached the reproductive stage. By mid-summer the big bluestem and switchgrass pastures had accumulated a large volume of low quality forage (Coleman, 2004), much of this residue remained at the time that grazing of the big bluestem and switchgrass pastures was terminated in 2004 and 2005. Thus, while the overall amount of forage offered to the livestock at certain times was higher for the CS-SG and CS-BBS treatments, much of it was selectively grazed and did not correlate with total pasture system productivity (i.e., animal gain per hectare).

Forage quality modeled over time

The effect of treatment also was significant for crude protein, acid detergent fiber, and neutral detergent fiber, but there was no interaction between treatment and year (Tables 1.5-1.7, Figures 1.4-1.6). Acid detergent fiber and neutral detergent fiber both had a quadratic relationship with time, while crude protein had a linear relationship.

When data from all years of the experiment was used to model the changes in forage percent crude protein over time the slope of the line is flatter (i.e., less negative) for the CS-Only treatment than it is for the other treatments (see Figure 1.4 and Table 1.5). The crude protein levels of the CS-BBS and CS-SG treatments did not differ significantly from each other throughout the grazing season, probably because the cool-season components of each system contributed to the overall model and diluted any differences that existed. During the beginning of the grazing season, forage percent crude protein is actually higher in the CS-BBS and CS-SG systems, most likely because the cool-season portions of those pastures were rotated slightly more frequently during the early part of the grazing season because one-third of the entire pasture area had been converted to either big bluestem or switchgrass pasture.

As the grazing season continued, the livestock did not graze the big bluestem or switchgrass pastures completely or uniformly due to the sheer volume produced within a relatively short time and because of the rapid decline in forage quality (Coleman, 2004) as the plants became more physiologically mature. The crude protein data, modeled with data from 2003-2005 shows that forage in the CS-Only treatment maintained a crude protein level between 15 and 20% while the both other treatments were near or below 10% crude protein by the end of the season. These results correlate with the findings of Moore et al. (2004) who concluded that, under most circumstances it is more advantageous to leave livestock on cool season pastures at a lower stocking rate than to move the whole larger group of animals to native grasses, primarily because of the low and rapidly declining forage quality of mid-summer warm-season grasses.

As with crude protein, forage acid detergent fiber and neutral detergent fiber percentages remained more constant in the CS-Only treatment than in the CS-BBS or CS-SG treatments (Moore et al., 2004) (see Figures 1.5-1.6 and Tables 1.6-1.7). Although big bluestem is generally known to maintain higher forage quality during late summer (Moser, 1995), neither the acid detergent fiber nor neutral detergent fiber levels of the CS-BBS and CS-SG treatments differed from each other, probably because cool-season forages were also part of the grazing system. Acid detergent fiber levels for the CS-Only treatment peaked at approximately 30%, remaining between 25% and 30% from DOY 147 through DOY 257, significantly lower than the levels described for the CS-BBS and CS-SG treatments at each interval except from DOY 167-187 (see Table 1.4 to correlate DOY to date). The levels of acid detergent fiber found in the CS-BBS and CS-SG treatments between DOY exceeded 30% acid detergent fiber from DOY 167 onward, peaking around DOY 237. *Neutral* detergent fiber for the CS-Only treatment peaked at nearly 54%, remaining between 38% and 51% from DOY 117 through DOY 257, significantly lower than the levels described for both the CS-BBS and CS-SG treatments from DOY 157 onward.

Forage dry matter and yield quality: second analysis

Analysis of the treatment by year interactions for ADF and NDF revealed analogous results to the effect of treatment alone: the CS-Only treatment generally had a flatter curve and lower levels of ADF and NDF than the CS-BBS and CS-SG treatments (Moore et al., 2004), which were very similar to each other (see Figures 1.10-1.15). Analysis of the same interaction for crude protein revealed results analogous to the effect of treatment alone: the slope of the line representing CP over time is generally higher

(Moore et al., 2004) and always more positive for the CS-Only treatment than for either of the other treatments (see Figures 1.7-1.9). The effect of environment on overall levels of CP and grazing management are obvious in 2004 when there was record rainfall (Appendix I, Figure A.3) and explosive pasture growth. The CS-Only treatment model for 2004 actually shows increasing crude protein of forage offered from the beginning through the end of the season due to the time it took for the livestock to consume the rapidly accumulating forage.

While the interactions of treatment and year for ADF, NDF, and CP were not significant, considering the forage quality and yield data in each year may give direction to future investigation. Dry matter offered was higher in the late summer for the CS-BBS and CS-SG systems, but the forage quality was uniformly poor. Any of the treatments offer opportunities to manage forage quality and production by harvesting excess forage rather than stockpiling, but in the CS-BBS and CS-SG treatments, this practice would seem to undermine the objective of having forage available during the summer slump: if big bluestem or switchgrass were harvested on about July 1, when the forage is very high quality, there would be very little forage available in the event of an August drought.

Botanical composition⁶

Fifty nine plant species were found in pastures throughout the experiment. Pasture botanical composition is described in terms of species and plant category over time. The four categories used to describe pasture plants include: forage grass, forage legume, palatable weed, and undesirable weed. In this context, 'palatable' means that when a

⁶ The botanical composition trends over time and among treatments are discussed more exhaustively in Appendix II

given plant species is in a vegetative stage the plant is not selectively refused by grazing animals (e.g., dandelion). “Undesirable” pasture plants are either clearly selectively refused plants (e.g., bull thistle) or those that are generally known to be eaten rarely by cattle (e.g., corn speedwell).

Botanical Composition by Experimental Treatment: Pasture Plant Categories

Palatable pasture weed dry matter fluctuated between 3% and 12% throughout the experiment; trends were similar among treatments. Treatment differences of percent pasture dry matter made up of undesirable pasture weeds were greatest in 2003 and tended to converge over time, although seasonal fluctuations were evident.

In all treatments of this study three trends emerged from botanical composition data relative to plant type:

- Forage grass dry matter percent remained at similar levels among treatments over time.
- Grass and legume dry matter percent remained relatively stable over time.
- Undesirable weeds declined from 2003 to 2005.
- Palatable weeds were stable or increased slightly over the course of the experiment.

CONCLUSIONS

As expected, the inclusion of big bluestem and switchgrass pastures as components of grazing systems did not improve forage quality. The effect of treatment on the distribution of forage dry matter offered varied by year; inclusion of either switchgrass or big bluestem as a component of the grazing season significantly shifted the distribution of forage dry matter offered to the later part of the grazing season. While each livestock production operation is somewhat unique and judgments about the

distribution of treatment dry-matter distribution will be somewhat subjective, many producers would not accept the loss of one third of the early-spring and early-fall pasture due to the management constraints of big bluestem and switchgrass pastures. The CS-BBS and CS-SG systems tended to have later and higher peaks of forage productivity and were less likely to have overly mature cool-season pastures early in the spring.

Based on this research, any perceived advantages to using switchgrass rather than big bluestem in an integrated cool-season/warm-season pasture grazing system would not be related to forage quality or productivity. These findings suggest that, compared to the CS-Only treatment, the CS-SG or the CS-BBS treatments probably will not improve livestock gain or improve the distribution of animal grazing days throughout the summer.

Table 1.1. Dates and rates of urea application.

Date	kg ha ⁻¹ actual N	CS (all)	BBS and SG
May 8, 2003	67	x	x
June 18, 2003	66	x	
May 27, 2004	73	x	x
August 2, 2004	57	x	
May 11, 2005	63	x	x
July 13, 2005	70	x	

Table 1.2. Grazing initiation and termination dates by year.

Year	Grazing Initiated	Grazing Terminated
2003	29-Apr	9-Sep
2004	27-Apr	8-Oct
2005	21-Apr	8-Sep

Table 1.3. Transformations used to normalize studentized residuals of forage quantity and quality parameters.

Parameter	Effect	Transformation
DM (Mg/ha)		$\sqrt{\text{abs}(\text{abs}(1 - \text{DM}) - 0.3)}$
CP (%)	treatment and treatment*year	$\sqrt{(\text{CP} \times 0.05)}$
ADF (%)	treatment	$\sqrt{\text{abs}(\text{abs}(31 - \text{ADF}) - 2)}$
ADF (%)	treatment*year	$\sqrt{\text{abs}(\text{abs}(31 - \text{ADF}) - 2.4)}$
NDF (%)	treatment	$\sqrt{\text{abs}(\text{abs}(52 - \text{NDF}) - 3)}$
NDF (%)	treatment*year	$\sqrt{\text{abs}(\text{abs}(55 - \text{NDF}) - 3)}$

Table 1.4. DOY and corresponding dates.

DOY	Date
117	27-Apr
127	7-May
137	17-May
147	27-May
157	6-Jun
167	16-Jun
177	26-Jun
187	6-Jul
197	16-Jul
207	26-Jul
217	5-Aug
227	15-Aug
237	25-Aug
247	4-Sep
257	14-Sep

Figure 1.1. Forage dry matter offered over time during the 2003 grazing season for the CS-BBS and CS-Only treatments.

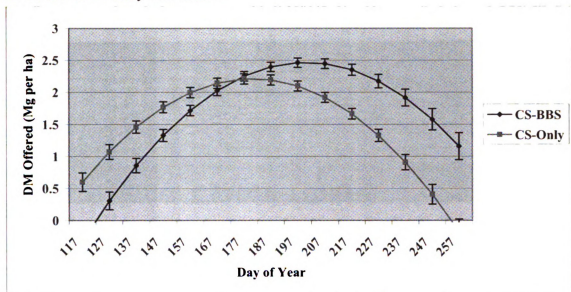


Figure 1.2. Forage dry matter offered over time during the 2004 grazing season.

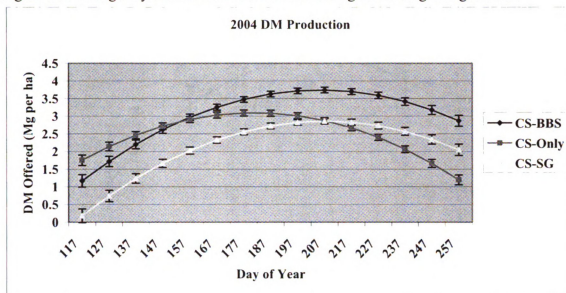


Figure 1.3. Forage dry matter offered over time during the 2005 grazing season.

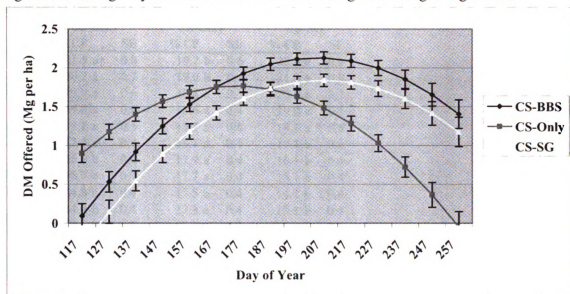


Table 1.5. Crude protein percentage of forage dry matter offered over time, modeled with yield data from 2003-2005.

DOY	CS-BBS		CS-Only		CS-SG	
	% CP	SE	% CP	SE	% CP	SE
117	21.5 a†	0.8	19.2 b	0.6	22.0 a	0.9
127	20.7 a	0.7	19.0 b	0.6	21.0 a	0.8
137	19.9 a	0.6	18.8 a	0.5	20.0 a	0.7
147	19.0 a	0.6	18.6 a	0.4	19.0 a	0.6
157	18.2 a	0.5	18.3 a	0.4	18.1 a	0.5
167	17.3 a	0.4	18.1 a	0.4	17.1 a	0.5
177	16.5 b	0.4	17.9 a	0.4	16.1 b	0.4
187	15.7 b	0.4	17.7 a	0.4	15.1 b	0.4
197	14.8 b	0.4	17.5 a	0.4	14.1 b	0.4
207	14.0 b	0.4	17.3 a	0.4	13.1 b	0.4
217	13.1 b	0.5	17.0 a	0.5	12.1 b	0.5
227	12.3 b	0.6	16.8 a	0.5	11.1 b	0.6
237	11.4 b	0.7	16.6 a	0.6	10.1 b	0.7
247	10.6 b	0.7	16.4 a	0.7	9.2 b	0.8
257	9.8 b	0.8	16.2 a	0.7	8.2 b	0.9

† Means within a row with different letters are significantly different at $P < 0.05$

Figure 1.4. Crude protein content of forage dry matter offered over time, modeled with yield data from 2003-2005.

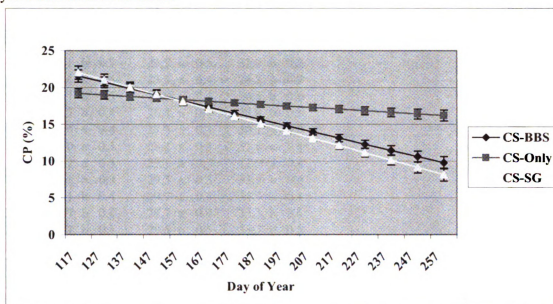


Table 1.6. Acid detergent fiber content of forage dry matter offered over time, modeled with yield data from 2003-2005.

wheat yield data from 2005-2009:									
	CS-BBS			CS-Only		CS-SG			
DOY	ADF	SE		ADF	SE	ADF	SE		
117	19.5	b	0.9	19.6	a	0.6	19.3	b	1.0
127	22.1	b	0.7	21.7	a	0.5	21.9	b	0.8
137	24.6	b	0.6	23.5	a	0.4	24.3	b	0.7
147	26.7	b	0.5	25.0	a	0.4	26.5	b	0.6
157	28.7	b	0.4	26.4	a	0.3	28.4	b	0.5
167	30.4	a	0.4	27.5	a	0.3	30.1	a	0.5
177	32.0	a	0.3	28.4	a	0.3	31.6	a	0.4
187	33.2	a	0.3	29.1	a	0.3	32.9	a	0.4
197	34.3	b	0.3	29.5	a	0.3	33.9	b	0.4
207	35.1	b	0.4	29.7	a	0.4	34.7	b	0.4
217	35.7	b	0.4	29.7	a	0.4	35.3	b	0.4
227	36.1	b	0.5	29.5	a	0.5	35.7	b	0.5
237	36.3	b	0.6	29.1	a	0.5	35.8	b	0.6
247	36.2	b	0.7	28.4	a	0.7	35.7	b	0.8
257	35.9	b	0.9	27.5	a	0.8	35.4	b	0.9

† Means within a row with different letters are significantly different at $P < 0.05$

Figure 1.5. Acid detergent fiber content of forage dry matter offered over time, modeled with yield data from 2003-2005.

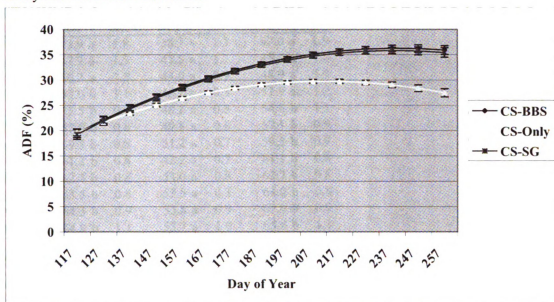


Table 1.7. Neutral detergent fiber content of forage dry matter offered over time, modeled with yield data from 2003-2005.

DOY	CS-BBS		CS-Only		CS-SG	
	NDF	SE	NDF	SE	NDF	SE
117	43.9 a	1.8	38.7 a	1.3	42.0 a	1.9
127	47.2 a	1.5	41.5 a	1.1	45.6 a	1.6
137	50.2 a	1.3	44.0 a	0.9	48.9 a	1.4
147	53.0 b	1.1	46.2 a	0.8	51.9 ab	1.2
157	55.5 b	0.9	48.2 a	0.8	54.6 b	1.1
167	57.6 b	0.8	49.8 a	0.8	57.1 b	0.9
177	59.5 b	0.8	51.2 a	0.7	59.2 b	0.9
187	61.2 b	0.8	52.2 a	0.7	61.1 b	0.8
197	62.5 b	0.8	53.0 a	0.8	62.7 b	0.8
207	63.5 b	0.8	53.5 a	0.8	64.0 b	0.8
217	64.3 b	0.9	53.8 a	0.9	65.0 b	0.9
227	64.8 b	1.1	53.7 a	1.0	65.8 b	1.1
237	65.0 b	1.3	53.4 a	1.2	66.2 b	1.3
247	64.9 b	1.5	52.7 a	1.5	66.4 b	1.6
257	64.5 b	1.9	51.8 a	1.8	66.2 b	2.0

† Means within a row with different letters are significantly different at $P < 0.05$

Figure 1.6. Neutral detergent fiber content of forage dry matter offered over time, modeled with yield data from 2003-2005.

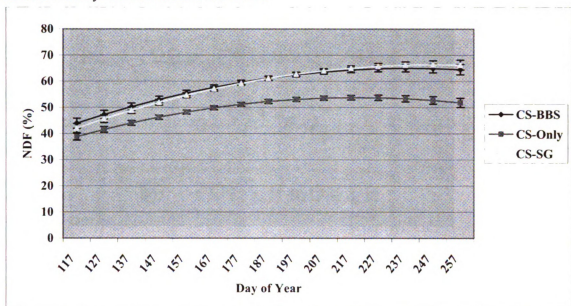


Figure 1.7. Crude protein content of forage dry matter offered over time from the CS-BBS and CS-Only treatments, modeled with yield data from 2003.

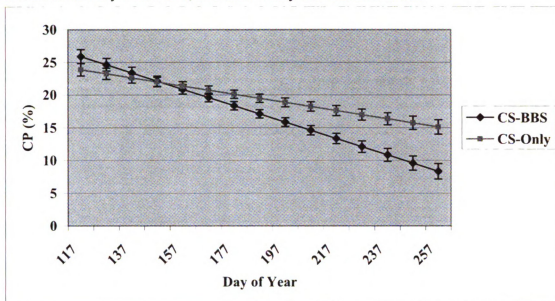


Figure 1.8. Crude protein content of forage dry matter offered over time from all treatments, modeled with yield data from 2004.

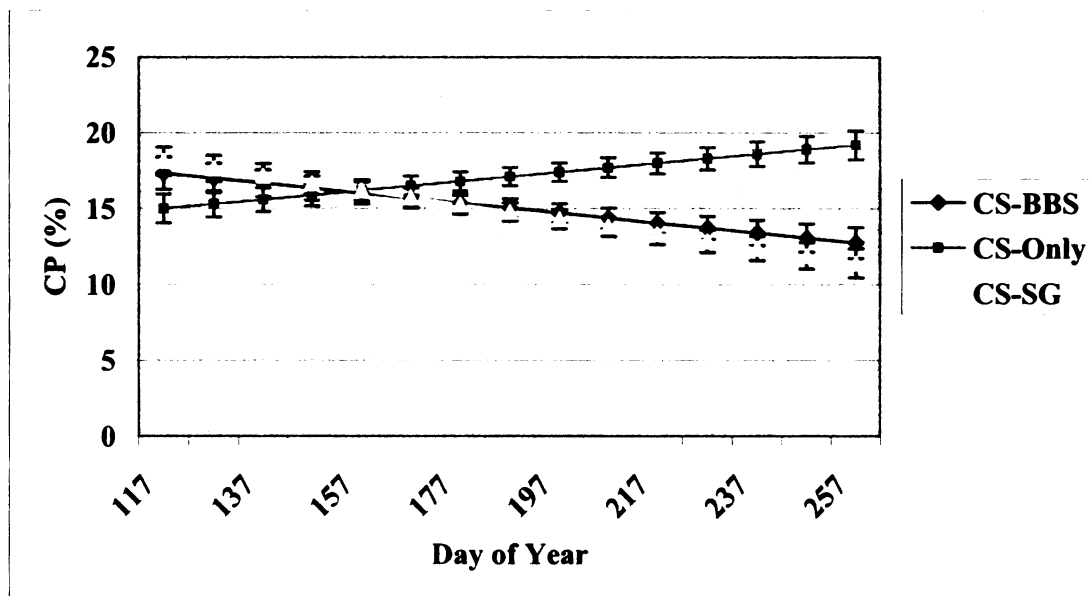


Figure 1.9. Crude protein content of forage dry matter offered over time from all treatments, modeled with yield data from 2005.

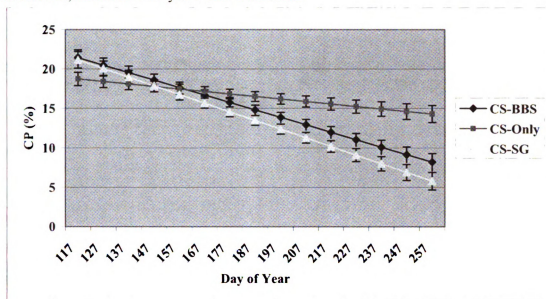


Figure 1.10. Acid detergent fiber content of forage dry matter offered over time from the CS-BBS and CS-Only treatments, modeled with yield data from 2003.

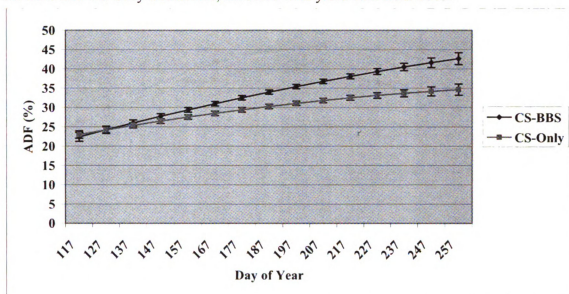


Figure 1.11. Acid detergent fiber content of forage dry matter offered over time from all treatments, modeled with yield data from 2004.

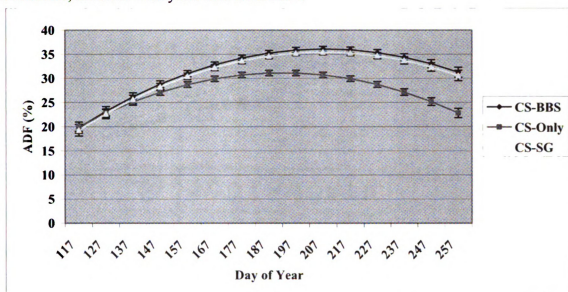


Figure 1.12. Acid detergent fiber content of forage dry matter offered over time from all treatments, modeled with yield data from 2005.

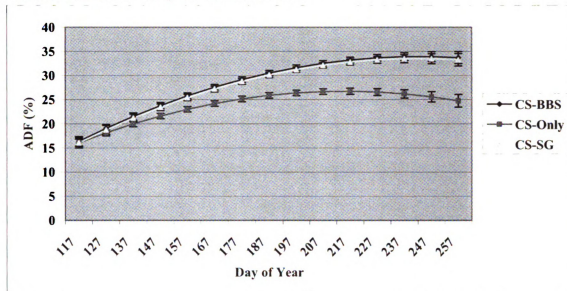


Figure 1.13. Neutral detergent fiber content of forage dry matter offered over time from the CS-BBS and CS-Only treatments, modeled with yield data from 2003.

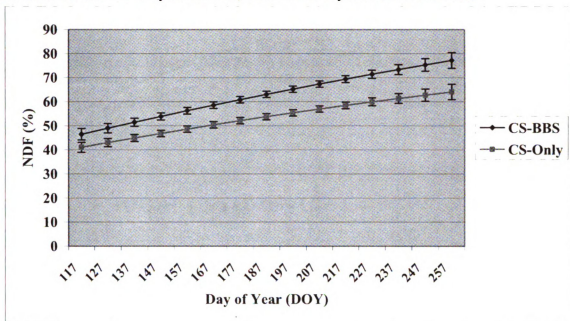


Figure 1.14. Neutral detergent fiber content of forage dry matter offered over time from all treatments, modeled with yield data from 2004.

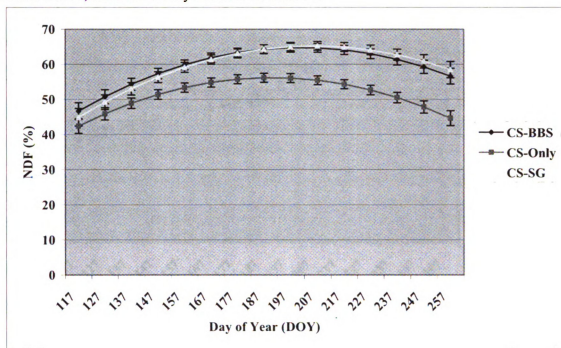
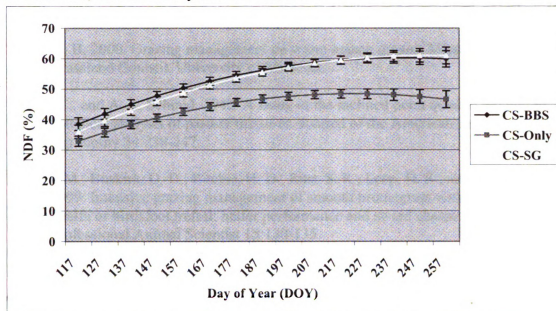


Figure 1.15. Neutral detergent fiber content of forage dry matter offered over time from all treatments, modeled with yield data from 2005.



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Chapter 2

INTEGRATED WARM- AND COOL- SEASON GRASS AND LEGUME PASTURES: STEER AND PASTURE PERFORMANCE

ABSTRACT

High temperatures and lack of precipitation often cause the productivity of cool-season pastures in Michigan to decline during the summer. Our objective was to determine the effect of integrating monocultures of switchgrass or big bluestem with cool-season pastures on pasture and steer productivity. Cool-season grass and legume pastures (CS-Only) were compared to integrated big bluestem and cool-season grass and legume pastures (CS-BBS) and integrated switchgrass and cool-season grass and legume pastures (CS-SG). Dynamics of pasture quality and productivity were compared by describing total livestock weight gain per hectare, accumulation and distribution of animal-unit grazing days, and average daily gain of Holstein steers. The CS-Only treatment resulted in more total animal weight gain per hectare than either the CS-BBS or the CS-SG treatments, and the CS-BBS treatment resulted in more total animal weight gain per hectare than the CS-SG treatment. The inclusion of big bluestem or switchgrass in a grazing system did not result in the accumulation of more animal unit grazing days per hectare in any year and only resulted in the accumulation of more animal unit grazing days per hectare during two time intervals. Treatment had no effect on steer average daily gain, likely because livestock tend to graze selectively in poor pastures and because they were only on the big bluestem and switchgrass portions of their respective treatments for short time intervals. Although the inclusion of big bluestem or switchgrass in the grazing systems did not reduce the average daily gain, it did not regularly improve

that parameter or the other measurements of pasture performance. Producer adoption of the grazing systems similar to the CS-BBS and CS-SG treatments, will depend on: the class of livestock that characterizes the livestock operation; the flexibility of the producer to either sell cattle or feed stored forage during periods of time when cool-season pasture productivity is inadequate; and the willingness of the producer to design, establish, and manage a more complex pasture system while waiting several years or more before recapturing their investment.

INTRODUCTION

Switchgrass and big bluestem have been promoted as forage for livestock (Anderson, 2000; Barnhart, 1994; Bartholomew, 1995) and are also known to provide valuable wildlife habitat (Delisle and Savidge, 1997; Sample and Mossman, 1997). Thus far, little research has been conducted in the Great Lakes region to describe livestock on grazing systems that include big bluestem or switchgrass. Because livestock performance is closely related to forage quality and abundance, it is important to measure these parameters in addition to the response of the grazing animal. In order to explain animal response, it is helpful to describe pasture system dynamics in terms of forage dry matter yield, and forage quality parameters including crude protein, acid detergent fiber, and neutral detergent fiber.

One of the primary objectives of the experiment was to compare the productivity of a traditional Michigan cool season grass and legume grazing system with the productivity of two model systems that include warm season grasses, in the first three years after planting the warm season grasses. The associated hypotheses were:

1. The grazing system models that are integrated with warm season grasses will result in higher total livestock weight gains per hectare (henceforth, 'gain ha⁻¹') than a typical Michigan grazing system model which includes only cool season grasses and legumes.
2. An integrated grazing system that includes big bluestem will result in higher gain ha⁻¹ than an integrated grazing system that includes switchgrass.

These hypotheses were evaluated in Chapter 3 of this dissertation. The subject of this chapter is pasture quality and the dynamics of forage dry matter offered to the grazing

animals, both of which will help to understand why the above hypotheses were or were not validated.

LITERATURE REVIEW

Grazing experiment concepts: method of stocking

Grazing experiments are conducted either using: 1) fixed stocking rates, where a certain number of animals are kept on a pasture for the season, year, or the duration of the experiment; or 2) variable stocking rates (put-and-take), where the grazing pressure is adjusted as forage availability requires (Wheeler et al., 1973), but a certain minimum number of livestock are left on the pasture to determine parameters such as average daily gain (ADG). Bransby (1989) argues that grazing experiments should have multiple levels of grazing pressure (i.e. high, medium, and low), but acknowledges that resources frequently may not permit this. Because of this, the put-and-take method described by Mott (1960) is often the method of choice for experiments that have limited resources (Bransby, 1989). Mott explains that because pasture productivity within the same experiment can vary widely, it is not reasonable to attempt to maintain identical stocking rates among treatments or replications. Rather, it is more reasonable to manage each pasture optimally, adjusting the grazing pressure so that no treatment or replication is grazed more intensely than another. Wheeler et al. (1973) points out that the put-and-take method is frequently criticized for lacking objectivity, but contends that this objection can be overcome by using a team of plant and animal scientists; using multiple grazing pressures can also help overcome this objection (Mott, 1952), but this very expensive and is rarely done (Wheeler et al., 1973), because of the expense involved.

The debate between those in favor of fixed stocking rate studies vs. variable stocking rate studies has been intense, but Wheeler et al. (1973) provides a balance by pointing out that fixed stocking rates are used successfully in areas where: 1) forage does not fluctuate drastically between seasons; 2) excess forage can be left standing for later use; or 3) economic animal production takes place before or during the time when the available forage becomes insufficient to maintain animal weight. The put-and-take method is used where research is being performed on cultivated and improved pastures rather than on native pastures (Mott, 1952); in short-term instead of year-round studies; in temperate-humid zones rather than rangeland; and in the U.S. and Europe rather than Australia or New Zealand (Wheeler et al., 1973).

Bransby (1989) suggests that grazing trials can be terminated [i.e. concluded for the year] by either terminating the grazing of all pastures simultaneously or at different times. Termination of grazing of different pastures at different times should be based on pasture descriptor goals or some predetermined per-animal production level.

Grazing experiment concepts: animal measurement and treatment

The experimental unit in grazing trials is the pasture unit, not the animals on the pasture. Using the animals as the experimental units artificially increases the degrees of freedom and increases the likelihood of declaring differences between treatments when no difference exists. Animals in the experiments are the sub-units and the source of the experimental error for the trial (Fisher, 1999). Much of the data used to describe differences between systems is related to animal weight and weight gain: average daily gain (ADG) per animal, animal unit days (AUD) per hectare, average seasonal gain per animal, etc. Because grazing animals are large and the status of their digestive systems

can cause the weight of individual animals to fluctuate drastically within and between days, a method to accurately determine animal weights must be used. Baker (1942) explains that daily variation in cattle weight occurs for two reasons. First, there are environmental conditions that affect all animals in the same way. Second, there are individual characteristics of animals that cannot be explained by environmental phenomena. Because individual characteristics cannot be controlled, the goal of the researcher is to minimize the variation caused by the environment. This is generally done in one of two ways: 'shrinking', or multiple consecutive weighing events. Shrinking is usually accomplished by depriving all animals of food and water for 12-16 hours before weighing (Stuedemann, 1989), and some managers prefer not to use this method. Koch et al. (1958) demonstrated that using three-day average weight was an effective way to reduce variation due to fill. Baker (1942), Koch et al. (1958), and Patterson (1947) contend that greater accuracy is achieved by weighing more animals per experiment than weighing fewer animals multiple times. Patterson also concluded that weighing animals three times in three days reduced the standard error for the weight, although not as dramatically as one might expect. Koch et al. (1958) concluded that using an average of three weights taken over the course of three days can help minimize the problems presented by fluctuations in rumen fullness and that two or three day averages are recommended when comparing individual animals. Mott (1959) states that environmental factors can cause weight to vary within a day, and that all treatments should be weighed on the same day in the same relatively short period of time.

Animals must be weighed at the beginning and end of the experiment, and should be weighed periodically throughout the experiment. Single-day monthly weighing is

recommended to monitor animal health (Buskirk, 2003), but these weights should not be used to compare treatments because of the differences in rumen fill that are due to factors other than the treatment (such as freshness of the paddock in the rotation) (Mott, 1959). When the put-and-take stocking method is used and adjustments in the stocking rate are necessary, animals should be weighed each time they are added to or taken from a pasture; those weights should be used to calculate animal unit grazing days (AUGD) (Fisher, 2003).

Because the conditions (i.e., pasture height, density, and quality) among the pasture treatments and replications may vary at the time of the trial termination, there may be differences in rumen fullness among animals that could affect the seasonal gain calculations and the standard error. Buskirk (2003) suggests that gut-fill can be standardized to a great degree if all animals are fed hay for seven days, beginning on the day that the grazing trial is terminated, and then weighing them on the eighth and ninth days. The mean of these two weights can be used to calculate the final animal weight, which can be used to calculate the seasonal gain for each animal.

Units such as “animal grazing days” are sometimes used. However, when the sizes of experimental animals are variable, the amount of forage dry-matter consumed in one day of grazing is also variable. Because of this, it is helpful to standardize the animals mathematically. An ‘animal unit’ is defined as, “one mature, non-lactating bovine weighing 500 kg and fed at maintenance level, or the equivalent, expressed as $(\text{weight})^{0.75}$, in other kinds or classes of animals” (Allen, 1991). This terminology allows units such as animal unit days (AUD) on pasture, and animal unit grazing days per hectare (AUGD ha⁻¹).

Use of hormone implants is accepted industry practice in Michigan (Bartlett, 2003; Ritchie, 1998) and improve profitability by increasing animal gains and improving several carcass characteristics (Chester-Jones, 2002).

The objective of this experiment was to compare the productivity of a conventional cool-season grazing system over three years with the productivity of two C₃/C₄ integrated grazing systems that included either switchgrass or big bluestem. Our hypotheses were 1) that the C₃/C₄ integrated grazing systems would have greater gain ha⁻¹ than typical Michigan grazing system model which includes only C₃ pasture species, and 2) that the integrated system that included big bluestem would result in greater gain ha⁻¹ than an integrated grazing system that included switchgrass.

MATERIALS AND METHODS

This grazing experiment was conducted at W. K. Kellogg Biological Station in Hickory Corners, MI, on Kalamazoo series (fine-loamy, mixed, mesic Typic Hapludalfs) soils. Four replications of three treatments were assigned to the experimental area using a completely randomized design. The experimental layout is described in Appendix I Figure A.1.

The three treatments included:

- A cool-season grass-legume pasture representative of pastures found throughout the Lower Peninsula of Michigan. These pastures were comprised primarily of perennial ryegrass (*Lolium perenne*), quackgrass (*Agropyron repens*), alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*).

- An integrated switchgrass and cool-season grass-legume pasture. One-third of the system was a monoculture of switchgrass that was planted in 2002, and two-thirds was composed of the cool-season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).
- An integrated big bluestem and cool-season grass-legume pasture. One-third of the system was a monoculture of big bluestem that was planted in 2002, and two-thirds was composed of the cool-season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).

Mid-season grazing pressure was adjusted using the put-and-take method¹ of pasture stocking (Mott, 1960). The animals used in this study were Holstein steers that weighed approximately 240 kg at the beginning of the grazing season. After the steers were initially received at the experimental area, they were weighed and then ranked by weight. Proceeding from the heaviest to the lightest, complete sets of randomized numbers between one and twelve were applied to the ranked animals. The number that each steer receives corresponded to the pasture to which they were assigned.

All animals were weighed twice before the experiment began in order to establish a more accurate beginning weight (Koch et al., 1958). After the weighing events, the steers were placed on pasture and were weighed once every four weeks (Table 2.1). Weights recorded for each steer on consecutive dates within year were averaged to establish beginning and ending weights for each animal with the exception of individual replications of treatments that were terminated early due to poor pasture conditions. Tester animals from treatment replications that had to be terminated early due to pasture

¹ See Technical Note 1 in Appendix III

conditions were weighted twice consecutively after being taken from their respective pastures.

Weighing of the steers every four weeks was primarily intended to monitor animal health. Data from the 28-day weighing intervals was not used to describe treatment differences in ADG. At the end of the season, the animals were removed from the pasture and fed hay for seven days and weighed on the eighth and ninth days after being removed from the pasture. The mean of these weighing events represented the end-of-season weight and was used to calculate the seasonal gain for each steer (Buskirk, 2003).

Gain ha^{-1} was calculated by multiplying the number of animal grazing days per hectare accumulated on each pasture throughout each grazing season by the ADG of the testers on that pasture during that grazing season:

Total gain ha^{-1} = (animal grazing days per hectare) X (average daily gain)

While gain ha^{-1} is an important comparison to make among treatments, it is an incomplete description of livestock performance over time. The put-and-take method of pasture stocking was used: steers were added to and taken from the pasture depending on existing and anticipated forage dry matter availability. This management strategy allowed the number of AUGD accumulated by a pasture during a period of time to be directly linked to the forage *productivity* of that pasture during that time period, while the average ADG of a group of steers reflected the forage *quality*. Together, the ADG, AUGD, and forage quality parameters allowed us to describe the dynamics of forage quality and quantity over time.

Animals that remained on the same pasture throughout the entire grazing seasons are referred to as ‘testers,’ while those that are used to adjust grazing pressure are referred to as put-and-take animals (PT). The original protocol called for a minimum of four testers for each treatment; in certain circumstances, however, it was necessary to reduce the number to two or three, in order to continue collecting data without degrading the pasture.

In the context of this study, one animal unit (AU) is standardized at $500 \text{ kg}^{0.75}$ (Allen, 1991). This standard was used to calculate the metabolic body weight of individual animals at particular times as follows:

$$\text{Number of AU} = (\text{body weight (kg)})^{0.75} / 500 \text{ kg}^{0.75}$$

The following rules were used to calculate the number of AU represented by a steer during a particular pasture during each time interval that they were on that pasture.

- Each time a PT was added to or taken from a pasture in order to adjust grazing intensity, it was weighed (Fisher, 2003).
- If a PT was put on a pasture and taken off the pasture between 28-day weighing events, the ‘on’ and ‘off’ weights were averaged to calculate the average AU of that animal during that time period.
- If a PT was on pasture through two or more consecutive weighing events, the weights at the beginning and end of each of the 28-day intervals were averaged to calculate AU for that time interval.
- If a PT was taken off pasture between weighing events, the ‘off’ weight and the weight from the most recent 28-day weighing event day were used for the AU calculation.

- If a PT was introduced to a pasture on a weigh day and taken off pasture before the next weigh day, the 'off' weight and 'on' weights were averaged to determine AU.

Animal unit grazing days (AUGD) were used to standardize the units used to describe grazing intensity in each system. Animal unit grazing days were calculated for each animal by multiplying the number of days by the number of AU calculated for that animal during that time interval. Using these procedures, total AUGD accumulated by each treatment in a particular time period or over the whole year can be compared. Tables 2.2a and 2.2b contain an example of calculating the AUGD of a hypothetical case of a steer being put on a pasture on the day of a 28-day weighing event, weighed 28 days later (and put back on pasture), and taken off pasture after 17 more days, for a total of 45 grazing days (GD).

Time-series average daily gains (ADG) were calculated based on change in body weight between two weighing events (generally 56 days) in order to reduce error related to large variations in rumen fullness. The exception to this was the calculation of the ADG for the entire grazing season, in which case the total number of days on pasture was used. Table 2.4 contains the dates used to calculate time-series average daily gain. Statistical analysis for all parameters was performed using PROC MIXED in SAS (SAS Institute, 2000-2003).

All pastures had an area of 1.6 ha with the exception of two which, because of the shape of the experimental area and existing permanent fencing, differed were somewhat larger or smaller. The cool-season portions of all treatments predated this experiment and were composed primarily of perennial ryegrass, Kentucky bluegrass, white clover,

quackgrass, and alfalfa. In the planning stages of this experiment, differences in species abundance between replications were considered negligible and blocking was not considered. After the experiment began, it became apparent that the variability in 'alfalfa abundance' was significant and should be considered a blocking effect. All pastures which were planted with alfalfa in 1994 were considered were included in 'alfalfa abundant' block. The pasture layout with respect to experimental treatments and alfalfa abundance is described in Appendix I, Figure A.2.

All forage samples collected in this study were placed in paper bags and dried for a minimum of 48 hours at 43°C², and then weighed. When grazing was initiated each year, dry matter availability was determined by harvesting plant tissue from within six 0.25 m² quadrats. Each time the rotation sequence brought steers to a cool-season portion of their respective treatment, plants within the quadrats were clipped at a height of approximately 5 cm. When steers were moved into the big bluestem or switchgrass portions of treatments, plants within quadrats were harvested at approximately 13 cm. When rotations began, dry matter availability was determined using a rising-plate meter (Gabriels, 1993; Harmony et al., 1997; Michell, 1982) unless conditions (lodging of forage, rain) were not appropriate, in which case quadrat clippings were used instead. In 2003 and 2004, yield for the big bluestem and switchgrass monocultures yield was determined using the rising-plate meter when conditions (precipitation, wind) permitted; in 2005, quadrats were used exclusively.

Forage quality parameters including crude protein, neutral detergent fiber, and acid detergent fiber were determined by using wet-chemistry techniques. In-house

² See Technical Note 2 in Appendix III

modifications³ of the Modified Van Soest method (Stern, 1991) were used to determine neutral detergent fiber and acid detergent fiber concentrations. The Hach modified Kjeldahl procedure (Hach, 1985; Watkins, 1987) was used to determine total N concentration in the forage. For a full description of this data, see Chapter 2 of this dissertation. In addition to forage quality and forage dry matter presented, data was collected to describe pasture botanical composition over the course of the experiment (see Appendix II). Cost and value assumptions were also applied to pasture establishment, maintenance, and animal performance in order to compare the net income per hectare of the treatments (see Chapter 4 of this dissertation).

Herd Health

One estradiol implant (Encore[®], VetLife) was placed between the skin and cartilage of the middle one-third of one ear of each steer used in this experiment. At the time the implants were installed, an ear tag identifying each animal was also placed in one ear. Insecticidal ear tags were also used to reduce stress from flies and to reduce the incidence of pinkeye spread by face flies. Animal health was monitored by all workers and problems were addressed by the W. K. Kellogg Dairy herdsman, who consulted with veterinarians as needed. Flies and parasites were controlled by applying a pour-on ivermectin (see Table 2.1 for dates of application). While on pasture, the steers were given free access to a mineral supplement described in Table 2.3. During part of the 2004 grazing season, the steers were over-consuming the supplement to the degree that a decision was made to add increasing amounts of granular sodium chloride to the Pro Phos 8[®] (Land O' Lakes) supplement until the steers reduced their intake to recommended

³ See Technical Note 4 in Appendix III

rates. When it became apparent that the addition of sodium chloride was not reducing consumption of the supplement, the practice of adding more sodium chloride to the mineral supplement was ended and Pro Phos 8[®] again offered free choice.

Statistical analysis procedures

Gain ha⁻¹, AUGD, and ADG

For analysis of gain ha⁻¹, AUGD, and ADG for each year and for the whole experiment, 'proc mixed' (SAS V8) was used to conduct an ANOVA test. The fixed effects used in the analysis of each parameter are detailed in Table 2.5.

For gain ha⁻¹, the statistical model is:

$$y_{ijk} = \mu + A_i + B_j + C_k + e_{ijk}$$

where:

y_{ijk} is the gain ha⁻¹ observed in i^{th} year for the j^{th} treatment at the k^{th} alfalfa abundance

μ is the overall mean

A_i is a fixed effect, the i^{th} year (2003, 2004, 2005)

B_j is a fixed effect, the j^{th} treatment (CS-BBS, CS-Only, CS-SG)

C_k is a blocking effect, the k^{th} alfalfa abundance (abundant, not abundant)

e_{ijk} is the error term

Average daily gain (ADG) of steers over time

To describe of ADG data over time, 'proc mixed' (SAS V8) was used to conduct a repeated measures ANOVA test as described in Table 2.5. Fixed effects included

treatment, time period, year, and alfalfa abundance; these effects were also tested for interactions. Time period (e.g., Time 1-2, Time 2-3) was used as a repeated measurement, and a heterogeneous compound symmetry covariance structure was used.

$$y_{ijkl} = \mu + A_i + B_j + C_k + D_l + (ABC)_{ijkl} + e_{ijkl}$$

where:

y_{ijkl} is the ADG observed in i^{th} year for the j^{th} treatment at the k^{th} time

μ is the overall mean

A_i is a fixed effect, the i^{th} year (2003, 2004, 2005)

B_j is a fixed effect, the j^{th} treatment (CS-BBS, CS-Only, CS-SG)

C_k is a fixed effect, the k^{th} time (Times 1, 2, 3, 4, 5, 6)

D_l is a blocking effect, the l^{th} alfalfa abundance (abundant, not abundant)

$(ABCD)_{ijkl}$ is the interaction among year, treatment, time, and alfalfa abundance, and

e_{ijkl} is the error term

To describe whole-year ADG data, the statistical model is:

$$y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + e_i$$

where:

y_i is the ADG observed in i^{th} year

μ is the overall mean

A_i is a fixed effect, the i^{th} year (2003, 2004, 2005)

B_j is a fixed effect, the j^{th} treatment (CS-BBS, CS-Only, CS-SG)

$(AB)_{ij}$ is the interaction among year and

e_i is the error term

Animal unit grazing days per hectare over time

To describe the distribution of AUGD over time, 'proc mixed' (SAS V8) was used to conduct a repeated measures ANOVA test as described in Table 2.5. Fixed effects included treatment, year, and time period (e.g. Time 1, Time 2); these effects were also tested for interactions. Time was used as a repeated measurement, and an autoregressive covariance structure was used.

$$y_{ijk} = \mu + A_i + B_j + C_k + (ABC)_{ijk} + e_{ijk}$$

where:

y_{ijk} is the number of AUGD ha^{-1} observed at in i^{th} treatment for the j^{th} year in the k^{th} time period

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

B_j is a fixed effect, the j^{th} year (2003, 2004, 2005)

C_k is a fixed effect, the k^{th} time period (Times 1, 2, 3, 4, 5, 6)

$(ABC)_{ijk}$ is the interaction among year, treatment, and time period

e_{ijk} is the error term

To describe whole-year AUGD data, the statistical model is:

$$y_{ijk} = \mu + A_i + B_j + C_k + (AB)_{ij} + e_{ijk}$$

where:

y_{ijk} is the number of AUGD observed in i^{th} year for the j^{th} treatment for the k^{th} alfalfa abundance

μ is the overall mean

A_i is a fixed effect, the i^{th} year (2003, 2004, 2005)

B_j is a fixed effect, the j^{th} treatment (CS-BBS, CS-Only, CS-SG)

C_k is a blocking effect, the k^{th} alfalfa abundance (abundant, not abundant)

$(AB)_{ij}$ is the interaction between year and treatment

e_{ijk} is the error term

RESULTS AND DISCUSSION

Gain per hectare

While ADG and total grazing days per season are important pieces of information, gain ha^{-1} provides crucial information for economic comparisons of treatments. Hypothesis 1a and 1b (from Chapter 1) are:

- *Hypothesis 1a:* The grazing system models that are integrated with warm season grasses will result in greater gain ha^{-1} than a typical Michigan grazing system model which includes only cool season grasses and legumes.
- *Hypothesis 1b:* An integrated grazing system that includes big bluestem will result in greater gain ha^{-1} than an integrated grazing system that includes switchgrass.

Statistical analysis of gain ha^{-1} revealed that treatment, presence of alfalfa, and 'year' all were significant variables, but there were no interactions (Table 2.6).

Gain ha^{-1} in CS-Only system was significantly higher than the CS-BBS and CS-SG treatments. Also, the CS-BBS treatment yielded more gain ha^{-1} than the CS-SG. This result should be qualified by noting that one-third of the CS-SG pasture was unavailable for grazing in 2003 due to the failure of the switchgrass portion to establish. If the switchgrass portion of pasture had not failed to establish by 2003, it is likely that there would not be a significant difference in gain ha^{-1} between the CS-BBS and CS-SG treatments.

The effect of year on steer gain ha^{-1} was significant and likely due to precipitation patterns (Appendix I, Figure A.3). May of 2004 had record rainfall, and 2004 had the highest gain ha^{-1} ; 2005 had the next highest level of gain ha^{-1} , as well as high levels of precipitation in June and July; 2003 had the lowest level of gain ha^{-1} due partially to the failure of switchgrass pastures (which were not grazed), and a generally dry late-summer. Overall, 2004 yielded more than twice the gain ha^{-1} of 2003. Alfalfa abundance was included in the statistical model for gain ha^{-1} and average daily gain over time because it was determined to be a significant variable and because the presence of alfalfa as a dominant forage species is known to significantly increase animal weight gain ha^{-1} (Barker, 1999).

Hypothesis 1a must be rejected because the CS-Only treatment resulted in more gain ha^{-1} than either the CS-BBS or the CS-SG treatments. Hypothesis 1b cannot be

rejected because the CS-BBS treatment resulted in more gain ha^{-1} than the CS-SG treatment.

Average daily gain

Seasonal average daily gain was significantly influenced by ‘year,’ but not by ‘treatment’ or alfalfa abundance (Figures 2.1-2.4). Differences in ADG among years are related primarily to differences in temperature and amount and distribution of precipitation in each year (Appendix I, Figures A.3-A.5). High temperatures increase the proportion of plant cell wall constituents, thereby reducing forage digestibility (Ford, 1979), which leads to lower livestock gains. Alternately excessive moisture can lead to such rapid accumulation of physiologically mature forage plants. In general, cool-season pasture grasses and alfalfa decrease in digestibility as the plants advance in physiological maturity (Karn, 2006; Morrison, 1956) which can reduce average daily gain.

Analysis of time-series ADG data indicated a significant interaction between year, treatment, and alfalfa abundance (Table 2.7). The presence of abundant alfalfa was sometimes beneficial and other times detrimental, without an obvious pattern among or within years, times, or treatments. Anecdotally, it appeared that alfalfa contributed to forage quality and pasture performance during periods of heat and moderate drought (Sleugh, 2000). On the occasion that the alfalfa component of a pasture was overly mature and thus of lower forage quality than the other significant pasture species, gains were likely reduced by the low forage quality of that alfalfa.

Animal unit grazing days

The distribution of grazing days within each treatment and each year are summarized in Table 2.9 and Figures 2.5-2.7.

A significant reduction in forage dry matter availability in the CS-Only system relative to the other two treatments was expected during the warmer and drier weeks of the summer. However, the data does not show that the CS-BBS or the CS-SG systems accumulated more AUGD than the CS-Only system during any time periods except for Times 4 and 5 of 2005.

Animal unit grazing day trends

Because of the CS-SG treatment failed to establish by the summer of 2003 was due to insect damage (and Stewart's bacterial wilt) which, if anticipated, could have been prevented, general comments comparing treatments will be made with the assumption that failure to establish switchgrass is atypical, and performance of the CS-SG treatment in 2004 and 2005 is typical.

During times 1 and 2 in each year, the AUGD accumulated by the CS-BBS and CS-SG do not differ significantly from each other, but the CS-Only treatment accumulated significantly more AUGD than either of the other treatments. This is because during Times 1-2, entire pasture area of the CS-Only treatment was available to graze, whereas the big bluestem and switchgrass portions of their respective treatments were not generally ready to be grazed until mid-June. By Time 3 of 2004 and 2005, the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments were ready to graze, and the difference between the numbers of AUGD accumulated by treatment diminish or disappear altogether until Time 5. In Time 5 of each year, the CS-BBS and CS-SG treatments equaled or exceed the number of AUGD accumulated by the CS-Only treatment. By early September, grazing on the big bluestem and switchgrass portions of their respective treatments was terminated for the season. Thus, the pasture area

available for grazing on those treatments was essentially reduced by 33% compared to the CS-only treatment, until the end of the grazing season for the cool-season pasture. In years when the grazing season for the cool-season pastures goes beyond early-September, this can result in significantly fewer AUGD being accumulated by the CS-BBS and CS-SG treatments. However, this situation only occurred in the second year of this experiment.

After a killing frost, it is possible to re-introduce livestock to dormant switchgrass or big bluestem pastures, but this may not be optimal for three reasons:

1. Dormant warm season grasses have lower forage quality and mineral supplementation may be necessary.
2. The possibility of damage to the plant crown by the hooves of grazing animals
3. A reduction in above-ground plant material would make burning a less effective management option.

Yearly accumulation of AUGD by treatment

Because the livestock on all treatments were increasing in size throughout the summer, the accumulated grazing days needed to be standardized for the size of the animals on the pasture, which is what AUGD represents. A flat (as opposed to volatile or sharply declining) distribution of AUGD over the course of the grazing season would indicate that the grazing system was successful in distributing forage availability across the grazing system.

Animal weight gain data from this study does not correlate with the findings of Moore et al. (2004), who found that, except in limited circumstances, the inclusion of switchgrass and/or big bluestem in an integrated cool- and warm-season grazing system

reduced animal weight gain. The primary weakness of the integrated system in the environment of Southern Michigan is related to the total number AUGD per season and the failure of the integrated systems to significantly improve the distribution of AUGD across the grazing season.

Due to the failure of the stand to establish in 2002, the switchgrass portion of the CS-SG treatment had to be re-seeded and was in the establishment phase again in 2003. In 2003, the switchgrass portion of the CS-SG treatment was not grazed but the total area for each replication (including the ungrazed switchgrass portion) was used in the calculation of AUGD for this treatment.

During Times 3, 4, and 5 of 2003, the CS-SG treatment accumulated significantly fewer AUGDs than either of the other treatments due to the fact that the switchgrass portion of the treatment had failed to establish in 2002 and had to be re-established in 2003. In 2003, the CS-Only treatment accumulated the most AUGD, followed by the CS-BBS treatment, and then the CS-SG treatment. Figure 2.5 demonstrates that none of the treatments yielded a flat distribution of AUGD across the 2003 grazing season.

The weather throughout the 2004 grazing season was unusually cool and wet (record precipitation in the month of May), favoring the cool-season grasses and legumes in general (Appendix I, Figure A.3). In 2004, the CS-Only treatment accumulated more AUGD than either of the other treatments in Times 1, 2, and 6. In the case of Times 1 and 2, the big bluestem and switchgrass had not yet accumulated enough top-growth to allow grazing without potentially reducing stand vigor. By Time 6 of each year, the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments was terminated to allow root carbohydrate reserves to regenerate prior to a killing frost (Barnhart, 1994;

Wolf, 1996), which comes much earlier for warm-season grasses than for cool-season grasses.

As in the previous two years, in 2005 the CS-BBS and CS-SG treatments accumulated fewer AUGD in Times 1 and 2. Because the steers from all treatments were removed their respective pastures by September 8, the CS-Only treatment did not accumulate more AUGD than the CS-BBS and CS-SG treatments during the final grazing interval as had been the case in 2004. All steers were removed from all treatments by September 8 because the soil was dry enough and the plants weakened to the point that many whole pastures plants were being plucked from the soil as the steers attempted to graze the remaining forage.

In the third year after establishment (2005) the CS-BBS and CS-SG distributions of AUGD over time were almost identical. While the CS-Only treatment differed from the other treatments in its seasonal distribution of AUGD, it was not substantially more or less 'flat,' although the AUGD tended to increase over time rather than decreasing. In 2005, precipitation was scarce in early spring and a series of rainfall events occurred in mid-July (Appendix I, Figure A.3). This result of this rainfall event, coupled with a lack of early-spring rain, was an unusual abundance of high-quality forage from late-July through early-August.

The effect of 'year' on the forage distribution among treatments experiment can be observed by comparing the total number of AUGD accumulated by each treatment during each growing season. In each treatment-by-time comparison, the AUGD accumulated in 2004 is greater than or equal to those accumulated in 2003 and 2005.

In all treatments, the distribution of AUGD throughout each year is affected by levels of precipitation. Spring and summer of 2003 were characterized by generally low levels of precipitation while 2004 had record high precipitation in May, and 2005 had low levels of spring precipitation and unusually high levels of precipitation in mid-June through early-July.

In 2003 the CS-Only treatment had a typical decline of AUGD over time. In 2004, which had unusually high rainfall and low temperatures, there was a decline in AUGD over time from Time 1 through Time 4, but the difference between the maximum and minimum number accumulated per time period was fewer than 20 AUGD, whereas in 2003 the difference was 46 AUGD. In 2005, low levels of spring precipitation combined with high levels of summer precipitation caused a flatter distribution of AUGD over time than in either 2003 or 2004.

The low number of AUGD accumulated in the CS-SG treatment in 2003 and the downward trend over time is due to the failure of the switchgrass portion of the pasture to establish between 2002 and 2003. The switchgrass portion of the CS-SG treatment accounted for one third of the total pasture area, to establish.

Implications of AUGD data

Animal unit grazing day (AUGD) data is useful for determining whether big bluestem and switchgrass are capable of delivering enough forage of acceptable quality during the mid-summer to meet the needs of livestock when the C₃ pasture productivity has declined. The only time that either the CS-BBS or CS-SG treatments accumulated significantly more AUGD in the mid-summer grazing period than the CS-Only treatment was in Times 4 and 5 of 2005. This is likely because the unusually dry spring of 2005

prevented the usual flush of spring pasture growth. When significant quantities of precipitation finally occurred in 2005 (late-June and early-July), the pastures produced large volumes of high quality C₃ forage. This was the case for all treatments, allowing the livestock on the CS-BBS and CS-SG treatments to accumulate more AUGD from the cool-season portions of their pastures than otherwise would be expected. In 2003 and 2004, however, there were no significant differences among the treatments in the number of AUGD accumulated in Time 3 through Time 5, except those differences which were due to the failure of the switchgrass portion of the CS-SG treatment to establish by 2003.

Many graziers have more acreage than their livestock can effectively graze in the spring, and they often set aside about one third of the pasture to harvest one or two cuttings of hay for sale or feeding at a later time. After the first or second cutting has been harvested, the pastures that had been set aside for hay production can begin to be grazed. Some producers, however, would prefer to keep their livestock on pasture as much as possible and would prefer to purchase hay of known quality rather than be forced to produce hay – especially if they have limited time, equipment, or labor resources. Many have suggested that warm-season grasses can help accomplish this (Balasko, 2003; Barnhart, 1994; Peterson, 2007). However, in all years of this study, the big bluestem and switchgrass were ready for grazing before the C₃ pasture species declined in productivity. In this situation, the Anderson (2000) recommends that mixed or solid stands of switchgrass be grazed when they are ready, regardless of whether the cool-season pastures are still productive. He advises that it is better to harvest or stockpile excess C₃ forage and to graze the big bluestem and switchgrass while their forage volume and quality are optimal. This was practiced in this experiment, but it adds

more complexity than most graziers are accustomed to in traditional grazing systems. The producer's willingness to set aside one third of his pasture acreage for hay production or warm-season grass pasture will, in part, be related to their capacity (equipment, storage, time) to harvest quality hay from a traditional grazing system and/or their willingness to increase the complexity of their system in order to keep their livestock on pasture.

CONCLUSIONS

Depending on the availability of a dry-lot and the price/availability of feed, a livestock manager may or may not be willing to reduce stocking density as pasture forage productivity declines as the summer progresses. An assumption in this experiment was that including big bluestem and switchgrass monocultures species as part of the grazing system would effectively reduce the number of acres available for grazing in the early spring months, eliminating the need for the pasture manager to mow or harvest a portion of the pasture for hay due to excessive growth and/or declining forage quality associated increasingly mature C₃ forage species. Alternately, if the number of livestock on spring pasture is sufficient to keep pace with spring pasture growth, that same number of livestock will need more mid-summer forage than that pasture can produce because of livestock growth and/or pasture decline. In this case, some of the livestock would need to be sold or would need stored forage during the summer decline in pasture productivity.

Because the livestock on all treatments were increasing in size throughout the summer, the accumulated grazing days needed to be standardized for the size of the animals on the pasture, which is what AUGD represents. A flat (as opposed to volatile or sharply declining) distribution of AUGD over the course of the grazing season would

indicate that the grazing system was successful in distributing forage availability across the grazing system. Neither the CS-BBS nor CS-SG treatments resulted in consistently flatter distributions of AUGD over time (Tables 2.9 and 2.10; Figures 2.5-2.7 and 2.8-2.10).

Because pasture managers vary in their ability to harvest and otherwise control excessive spring growth and/or move livestock to a dry lot to be fed stored forage during periods of pasture shortage, the acceptable distribution of grazing days over the course of the grazing season will vary among producers; thus, sweeping statements about the relative fitness of the CS-BBS, CS-Only, and the CS-SG systems for Southern Michigan cannot be made. However, it is clear that Hypothesis 1a should be rejected, because neither CS-BBS nor the CS-SG treatments yielded more gain ha^{-1} than the CS-Only treatment; in fact, the opposite was true. Also, Hypothesis 1b should not be rejected, because the CS-BBS treatment did yield more gain ha^{-1} than the CS-SG treatment.

Although forage quality of big bluestem and switchgrass harvested from quadrats is much lower than that from a cool-season pasture during the mid- to late-summer, it did not have a significant impact on ADG. This is likely due to the ability of livestock to selectively graze in poor pastures as well as the short time intervals that the livestock were on the big bluestem and switchgrass monocultures.

The practical implications of this research will vary by livestock production operation, depending on several characteristics:

- The class of livestock that characterizes the livestock operation.

- The operational flexibility of the producer to either sell cattle or feed stored forage during periods of time when C_3 pasture productivity is inadequate (Moore et al., 2004).
- The willingness of the producer to:
 - design, establish, and manage a more complex pasture system.
 - wait for several years before recapturing their investment.

Table 2.1. Weighing events by year[†]

2003	2004	2005
<i>28-Apr</i> †	<i>26-Apr</i>	<i>20-Apr</i>
<i>29-Apr</i>	<i>27-Apr</i>	<i>21-Apr</i> ‡
<i>28-May</i> ‡	<i>25-May</i> ‡	<i>19-May</i>
<i>24 June</i> ‡	<i>22 June</i> ‡	<i>16 June</i> ‡
<i>22-July</i> ‡	<i>20-July</i> ‡	<i>14-July</i>
<i>19-Aug</i>	<i>14-Aug</i>	<i>11-Aug</i> ‡
<i>17-Sep</i>	<i>22-Sep</i>	<i>8-Sep</i>
<i>18-Sep</i>	<i>23-Sep</i>	<i>16-Sep</i>
		<i>17-Sep</i>

[†]Weights from italicized dates were used to establish beginning- and end- of season weights.

[‡]Indicates dates of application of ivermectin pour-on

Table 2.2a. Example of animal unit grazing day calculation (continued in Table 2.2b)

Date	Event/Action	Weight	AU Calculation	Animal Units
21-Apr	Put PT on pasture	273 kg	$(273 \text{ kg } 0.75) / 5000.75$	0.55
19-May	Weigh day	309 kg	$(3090.75) / 5000.75$	0.62
5-Jun	Remove PT	325 kg	$(3250.75) / 5000.75$	0.65

Table 2.2b. Example of animal unit grazing day calculation (continued).

Interval	Time (GD)	AU Average During Interval	AU	Calculation for AUGD	AUGD
21-Apr - 19-May	28	$(0.55 + 0.62)/2$	0.585	0.585 AU X 28 GD	16.4
20-May - 5-June	17	$(0.62 + 0.65)/2$	0.635	0.635 AU X 17 GD	10.8
				Total AUGD	27.2

Table 2.3. Guaranteed analysis of Land O'Lakes Pro Phos 8 granular mineral supplement.

Mineral/vitamin	Content	Unit
Calcium (Ca), Min	12.00%	
Calcium (Ca), Max	14.00%	
Phosphorus (P), Min	8.00%	
Salt (NaCl), Min	16.00%	
Salt (NaCl), Max	18.50%	
Magnesium (Mg), Min	2.00%	
Potassium (K), (Min)	0.10%	
Zinc (Zn), Min	4,375	ppm
Manganese (Mn), Min	2,500	ppm
Copper (Cu), Min	1,300	ppm
Iodine (I), Min	130	ppm
Selenium (Se), Min	22	ppm
Vitamin A, Min	330,000	I.U./kg
Vitamin D, Min	26,000	I.U./kg
Vitamin E, Min	130	I.U./kg

Table 2.4. Beginning and ending dates of grazing intervals used to calculate time-series ADG for the 2003 through 2005 grazing seasons.

Year	2003		2004		2005	
Interval	Beginning	Ending	Beginning	Ending	Beginning	Ending
Time 1-2	29-Apr	24-June	27-Apr	22-June	21-Apr	16-June
Time 2-3	29-May	22-July	26-May	20 July	20-May	13-July
Time 3-4	25-June	19-Aug	23-June	17-Aug	17-June	11-Aug
Time 4-5	23-July	9-Sep	21-June	14-Sep	14-July	8-Sep

Table 2.5. Fixed effects and interactions used in the full model of gain ha⁻¹, animal unit grazing days (AUGD), and average daily gain (ADG).

Parameter	Treatment	Year	AA†	Treatment X Year
Gain per hectare	x	x	x	
AUGD	x	x	x	x
ADG		x ‡		

†AA: alfalfa abundance

‡ Occasional interaction with alfalfa abundance (also see Table 7).

Table 2.6. Gain ha⁻¹ by treatment, year, and alfalfa abundance.

Effect	Gain per hectare	SE
Treatment		
CS-BBS	624.4 b	16.2
CS-Only	721.0 a	16.2
CS-SG	572.9 c	14.0
Year		
2003	453.4 c	15.5
2004	907.1 a	15.5
2005	558.9 b	15.5
Alfalfa abundance		
AA	669.4 a	12.7
ANA	610.1 b	12.7

Means within effect with different letters are significantly different ($p < 0.05$).

Table 2.7. Average daily gain of steers by treatment and year at time intervals throughout the 2003-2005 grazing seasons.

Year	Treatment	Time 1-2		Time 2-3		Time 3-4		Time 4-5	
		ADG	SE	ADG	SE	ADG	SE	ADG	SE
		----- kg day ⁻¹ -----				-----			
2003	CS-BBS	1.72 a	0.09	1.38 a	0.09	0.79 a*	0.06	0.98 a*	0.08
2003	CS-Only	1.81 a	0.07	1.50 a	0.08	0.69 a*	0.06	0.99 a*	0.07
2003	CS-SG	1.72 a	0.08	1.48 a	0.08	0.72 a	0.06	1.09 a*	0.09
2004	CS-BBS	1.72 a	0.05	1.32 a	0.06	1.11 a*	0.04	0.46 b*	0.05
2004	CS-Only	1.84 a	0.06	1.34 a	0.06	0.99 ab*	0.05	0.73 a*	0.06
2004	CS-SG	1.75 a	0.05	1.26 a	0.06	0.96 b*	0.04	0.57 b	0.05
2005	CS-BBS	1.81 a*	0.06	1.48 a*	0.06	0.79 a*	0.05	0.91 b*	0.06
2005	CS-Only	1.52 b*	0.06	1.32 ab*	0.07	0.72 ab*	0.05	1.10 a*	0.06
2005	CS-SG	1.44 b*	0.06	1.29 b*	0.06	0.65 b*	0.04	0.83 b*	0.05

Means within year with different letters are significantly different ($p < 0.05$).

*Indicates an interaction with alfalfa abundance during that time period

Figure 2.1. Average daily gain of steers by treatment and year at intervals throughout the 2003 grazing seasons.

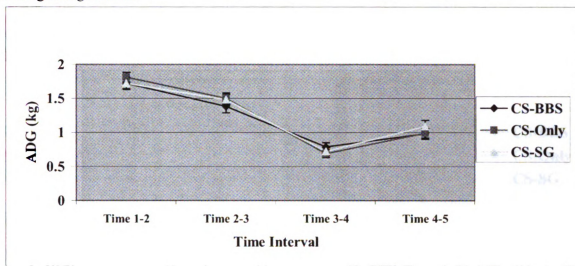


Figure 2.2. Average daily gain of steers by treatment and year at intervals throughout the 2004 grazing seasons.

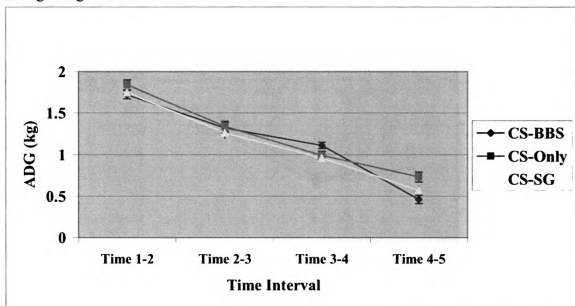


Figure 2.3. Average daily gain of steers by treatment and year at intervals throughout the 2005 grazing seasons.

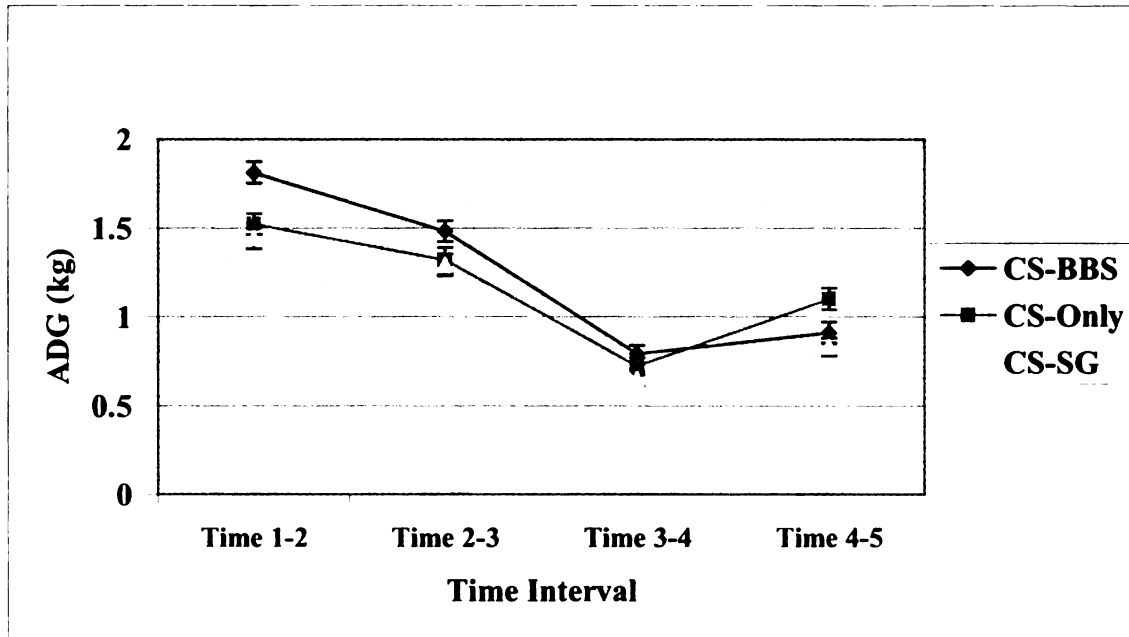
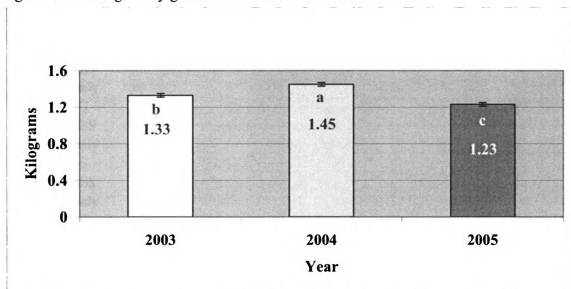


Table 2.8. Average daily gain of steers by treatment and year at intervals throughout the 2003-2005 grazing seasons.

Year	Treatment	ADG
2003	CS-BBS	1.30 a
2003	CS-Only	1.34 a
2003	CS-SG	1.36 a
2004	CS-BBS	1.45 a
2004	CS-Only	1.47 a
2004	CS-SG	1.42 a
2005	CS-BBS	1.29 a
2005	CS-Only	1.27 a
2005	CS-SG	1.12 b

Means within year with different letters are significantly different (SE = 0.04; $p < 0.10$).

Figure 2.4. Average daily gain of steers between 2003 and 2005.



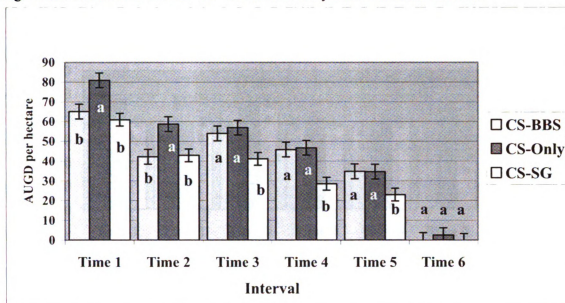
Means with different letters are significantly different ($p < 0.05$). SE = 0.02.

Table 2.9. Animal unit grazing days accumulated by treatment and year at intervals throughout the 2003-2005 grazing seasons

Year	Treatment	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Season
		-----AUGD/ha-----						
2003	CS-BBS	65.1 b	42.2 b	54.0 a	44.1a	34.8 a	0.0 a	240.2 b
2003	CS-Only	80.9 a	58.8 a	56.9 a	47.3 a	34.6 a	2.5 a	281.0 a
2003	CS-SG	61.0 b	42.9 b	41.1 b	28.5 b	23.0 b	0.0 a	196.5 c
2004	CS-BBS	72.8 b	76.2 b	88.7 a	74.2 a	71.1 a	52.7 b	435.6 b
2004	CS-Only	95.5 a	97.9 a	88.9 a	78.6 a	77.5 a	87.8 a	526.1 a
2004	CS-SG	74.9 b	75.9 b	91.8 a	72.1 a	74.5 a	46.0 b	435.1 b
2005	CS-BBS	62.9 b	58.4 b	67.0 a	76.0 a	70.6 a	0.0 a	335.0 a
2005	CS-Only	81.1 a	74.4 a	64.8 a	61.2 b	58.8 b	0.0 a	340.3 a
2005	CS-SG	62.3 b	55.9 b	67.2 a	74.3 a	61.6 ab	0.0 a	321.3 a

Means within the same column and year with different letters are significantly different ($p < 0.05$). The standard error for CS-BBS = 3.7; CS-Only = 3.7; CS-SG = 3.2.

Figure 2.5. Number of AUGD ha⁻¹ accumulated by each treatment in 2003.



Means within the same time interval with different letters are significantly different ($p < 0.05$).

Figure 2.6. Number of AUGD ha⁻¹ accumulated by treatment in 2004.

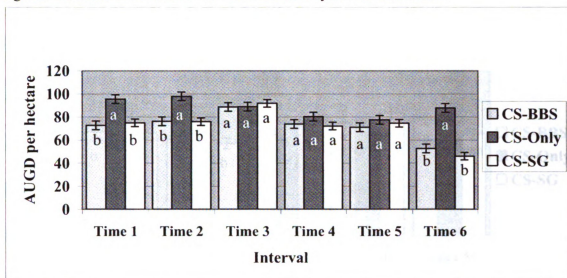
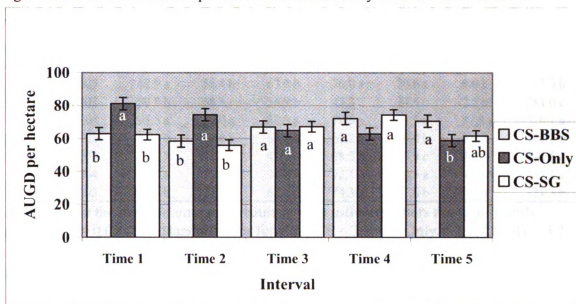


Figure 2.7. Number of AUGD per hectare accumulated by each treatment in 2005.



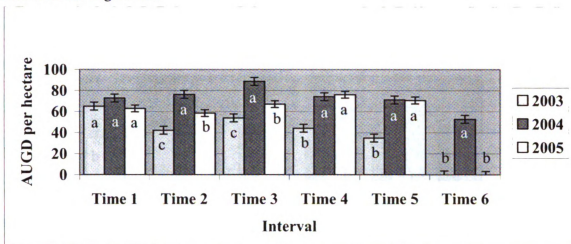
Means within the same time interval with different letters are significantly different ($p < 0.05$).

Table 2.10. Treatment across year comparison of AUGD per hectare over time

Treatment	Year	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Season
		-----AUGD/ha-----						
CS-BBS	2003	65.1 a	42.2 c	54.0 c	44.1 b	34.8 b	0.0 b	240.2 c
CS-BBS	2004	72.8 a	76.2 a	88.7 a	74.2 a	71.1 a	52.7 a	435.6 a
CS-BBS	2005	62.9 a	58.4 b	67.0 b	76.0 a	70.6 a	0.0 b	335.0 b
CS-Only	2003	80.9 b	58.8 c	56.9 b	47.3 c	34.6 c	2.5 b	281.0 c
CS-Only	2004	95.5 a	97.9 a	88.9 a	78.6 a	77.5 a	87.8 a	526.1 a
CS-Only	2005	81.1 b	74.4 b	64.8 b	61.2 b	58.8 b	0.0 b	340.3 b
CS-SG	2003	61.0 b	42.9 c	41.1 c	28.5 b	23.0 c	0.0 b	196.5 c
CS-SG	2004	74.9 a	75.9 a	91.8 a	72.1 a	74.5 a	46.0 a	435.1 a
CS-SG	2005	62.3 b	55.9 b	67.2 b	74.3 a	61.6 b	0.0 b	321.3 b

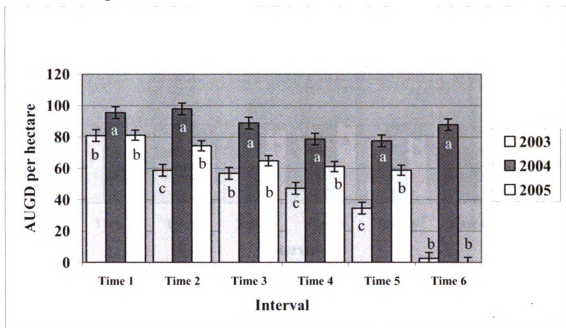
Means within the same column and treatment with different letters are significantly different ($p < 0.05$). The standard error for CS-BBS = 3.7; CS-Only = 3.7; CS-SG = 3.2.

Figure 2.8. Mean number of AUGD per hectare accumulated by the CS-BBS treatment from 2003 through 2005.



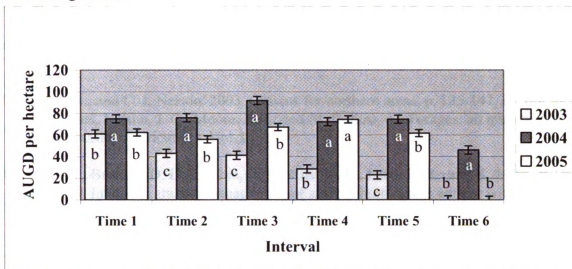
Means within the same time interval with different letters are significantly different ($p < 0.05$).

Figure 2.9. Mean number of AUGD per hectare accumulated by the CS-Only treatment from 2003 through 2005.



Means within the same time interval with different letters are significantly different ($p < 0.05$).

Figure 2.10. Mean number of AUGD ha⁻¹ accumulated by the CS-SG treatment from 2003 through 2005.



Means within the same time interval with different letters are significantly different ($p < 0.05$).

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Chapter 3

ECONOMIC PERFORMANCE OF COOL-SEASON PASTURES INTEGRATED WITH SWITCHGRASS AND BIG BLUESTEM

ABSTRACT

High temperatures and lack of precipitation often cause the productivity and quality of cool-season pastures in Michigan to severely decline for an extended period during the summer. Our objective was to compare the profitability of three pasture systems over three years of experimentation. Cool-season grass and legume pastures (CS-Only) were compared to integrated big bluestem and cool-season grass and legume pastures (CS-BBS) and integrated switchgrass and cool-season grass and legume pastures (CS-SG). Accumulated animal grazing-days per hectare and average daily gain per steer and variable expenses related to treatment were used to calculate net income per hectare for each treatment. The CS-Only, CS-BBS and CS-SG treatments had three-year net returns of \$2,035, \$1,665, and \$1,495 per hectare, respectively. The differences were primarily due to the high cost of establishing big bluestem and switchgrass monocultures and the pasture management constraints that limit the grazing of these pastures before mid-June and after early-September. These management constraints reduce the pasture area available for grazing on the CS-BBS and CS-SG treatments by 33% in the spring and occasionally during the last part of the grazing season, resulting in the accumulation of fewer animal grazing days. While producers in Southern Michigan could reduce the risk of running out of mid-summer pasture by adopting pasture systems similar to the CS-BBS or CS-SG treatments, the management constraints of these systems will frequently induce an opportunity cost (i.e., the annual loss of animal grazing days in the spring and frequent loss in the fall) that seems to outweigh the value of reducing that risk.

INTRODUCTION

During the mid-summer months of most years, Michigan producers who keep livestock on pasture are faced with a choice: to remove their livestock from dormant summer pastures to locations where they are fed stored forage, or to allow their livestock to continue grazing. The choice to leave livestock on pasture during periods of inadequate pasture productivity can result in overgrazing. Overgrazing often reduces pasture productivity (Coleman, 2007) resulting in weed invasion (Hazell, 1967), and therefore may require pasture renovation or replanting. In southwest Lower Michigan, spring and fall cool season grass-legume growth is excellent due to mild temperatures and adequate rainfall, but drought stress during the summer months often causes these grasses and legumes to become dormant (Laude, 1953). Several state universities in the North Central Region promote the use of native perennial warm season grasses, such as switchgrass and big bluestem as summer forage in some circumstances (Anderson, 2000; Barnhart, 1994a; Bartholomew, 1995). These grasses have the potential to provide large volumes of high quality mid-summer forage when cool season grasses and legumes are less productive (Balasko, 2003). While both species are indigenous to Michigan, no grazing research has been conducted to determine if using these species in a pasture system is a viable option. Beyond their capacity to produce large quantities of biomass, switchgrass and big bluestem grow well in marginal soils and can provide excellent cover for nesting birds (George et al., 1979; Tober, 1992) and for other types of wildlife and can reduce the loss of sediment, nitrogen, and phosphorus in areas prone to erosion (Blanco-Canqui, 2004). Switchgrass (Ma, 2000) and other native tallgrass prairie species

are believed to sequester large amounts of carbon in the soil, and grasslands in general present great aesthetic appeal (Keeney, 2007), particularly in the summer and fall.

The Michigan Hay and Grazing Council has described alternative forage research as one of its top priorities (Lindquist, 2002). Both the Michigan Department of Natural Resources (Sargent, 1999) and the USDA Natural Resource Conservation Service (USDA-NRCS, 1996) have encouraged Michigan graziers to include native warm season grasses in their grazing systems. However, graziers may be reluctant to use these grasses without knowledge of their performance in Michigan.

'Optimal' management of grazing systems

'Optimal' management of a perennial pasture can be defined as: pasture management which allows the livestock in the grazing system to maintain or exceed established (i.e. normal) levels of weight gain or maintenance and stocking rate for that livestock class, without causing undue pasture degradation. This definition assumes that the grazing management occurs within the normal range of environmental conditions for that particular location.

Livestock producers are not just interested in adopting the system with the most potential to maximize net profit per hectare; rather, they are interested in maximizing net return per acre while keeping their level of risk in balance (Parch, 1989). This balance applies not only to finding the 'optimal' stocking rate, but also to the pasture species that a producer decides to adopt, since seasonal environmental dynamics influence the productivity of a pasture over time (Barnhart, 1999) and will affect what constitutes a low- to moderate-risk stocking rate at different points throughout the year. Further, the

optimal management of a particular grazing system will vary with plant species (and combinations), environmental conditions, and class of livestock.

Economic comparisons of grazing systems

The net profitability of a system is defined as the difference between the gross revenue and the total costs of production (Parch, 1989). For the purpose of economic comparisons, the variable costs of production are included in calculations while fixed costs of production (e.g., depreciation of fencing and watering systems) are often not included, as long as those costs are equivalent among treatments being compared (Black, 2007). The basis for calculating gross revenue generated from a grazing system in a particular environment depends on the type of livestock production operation being modeled and the types of challenges that livestock production systems in that environments face. Parameters used to calculate gross revenue for these systems can include, average daily gain (ADG) (Parch, 1989), or the total amount of milk or meat produced per hectare during a given period of time. Units such as “animal grazing days” per hectare are also sometimes used. However, when the sizes of experimental animals are variable, the amount of forage dry-matter consumed in one day of grazing is also variable. Because of this, it is helpful to standardize the animals mathematically. An ‘animal unit’ is defined as, “one mature, non-lactating bovine weighing 500 kg and fed at maintenance level, or the equivalent, expressed as $(\text{weight})^{0.75}$, in other kinds or classes of animals” (Allen, 1991). This terminology allows units such as animal unit days (AUD) on pasture, and animal unit grazing days (AUGD) per hectare.

Given that net profit is the difference between gross revenue and total costs of production, stocker-steer pasture managers have two main goals:

1. maximizing animal gain per hectare while balancing risk
2. minimizing costs without compromising the sustainability of the system

While 'true' net profitability is the difference of gross revenue and the total cost of production, both fixed and variable, fixed costs (e.g., depreciation of fencing and watering systems) are often excluded from comparisons of grazing systems as long as those costs are equivalent among treatments being compared (Black, 2007). In pasture research, when forage species are being compared, those activities that differ among treatments are included in calculations (Black, 2007). These activities and expenses can include use of equipment and labor and purchasing pesticides, chemicals, seed, and other necessary inputs.

Determining variable costs

Farm operators often hire custom operators to complete certain types of work; rates for particular custom farm operations vary from region to region (Ward, 2006). Publications of custom farm rates are often a starting place for negotiations between equipment owner/operators and farm managers, and it is common for land-grant cooperative extension services to publish these rates. These rates are sometimes published as an average with a range of one standard deviation (Ward, 2006). To standardize chemical input costs to make comparisons between different production systems, researchers may compile price lists for inputs such as pesticides and associated adjuvants (Sprague, 2007). Some variable costs, such as the average cost of pasture seed, are not readily available, and would be highly subjective if it existed, due to the variability in the performance of different forage varieties. Thus, cost estimates for less

common, proprietary, variable quality, or price-volatile inputs sometimes must be obtained from reputable vendors.

Our objective was to compare the profitability of three pasture systems over three years of experimentation: a conventional cool-season grass and legume grazing system and two systems which were similar except for the substitution of big bluestem or switchgrass monocultures for one-third of the pasture acreage.

MATERIALS AND METHODS

This experiment was conducted from 2003 through 2005 at W. K. Kellogg Biological Station in Hickory Corners, MI, on Kalamazoo series (fine-loamy, mixed, mesic Typic Hapludalfs) soils. Four replications of three treatments were assigned to the experimental area using a completely randomized design. The experimental layout is described in Figure A.1 of Appendix I.

The three treatments included:

1. A cool-season grass-legume pasture representative of pastures found throughout the Lower Peninsula of Michigan. These pastures were comprised primarily of perennial ryegrass (*Lolium perenne*), quackgrass (*Agropyron repens*), alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*).
2. An integrated cool-season grass-legume and big bluestem pasture. One-third of the system was a monoculture of big bluestem that was planted in 2002, and two-thirds was composed of the cool-season grasses and legumes listed above (Barnhart, 1994a; Barnhart, 1994b; Undersander, 2002).

3. An integrated cool-season grass-legume and switchgrass pasture. One-third of the system was a monoculture of switchgrass that was planted in 2002, and two-thirds was composed of the cool-season grasses and legumes listed above (Barnhart, 1994a; Barnhart, 1994b; Undersander, 2002).

All pastures had an area of 1.6 ha with the exception of two which, because of the shape of the experimental area and existing permanent fencing, differed somewhat. The cool-season portions of all treatments predated this experiment. The major cool season species included: perennial ryegrass, Kentucky bluegrass, white clover, quackgrass, and alfalfa. In the planning stages of this experiment, differences in species abundance between replications were considered negligible and blocking was not considered. After the experiment began, it became apparent that the variability in 'alfalfa abundance' was significant and should be considered a blocking effect. All pastures which were planted with alfalfa in 1994 were considered were included in 'alfalfa abundant' block. The pasture layout with respect to experimental treatments and alfalfa abundance is described in Figure A.2 of Appendix I.

Pastures were managed as uniformly as possible, but each was managed separately and optimally (Bransby, 1989). When grazing was initiated each spring, cattle on all treatments were given access to the entire cool-season portion of their respective pastures, with the exception of the fourth replication of the CS-Only treatment, where a concurrent experiment was being carried out which required that livestock be excluded from a portion of the pasture at certain points of time. As the spring flush of cool-season pasture growth intensified, pastures were "staged" (Barker, 1999): cattle were limited to one half, and later, one quarter of the cool-season portion of their treatments at which

point rotational grazing began and continued until the end of the season. During the final grazing event of the season, the cattle were again given access to the entire cool-season portion of their respective pastures. In 2003, the big bluestem portion of the CS-BBS treatments was split into three parts each of which was grazed in rotation (the switchgrass portion of the CS-SG treatment was not grazed in 2003). In 2003, residue of refused big bluestem forage was mowed after grazing as needed in order to make the pasture height more uniform at subsequent grazing events. However, it was noted that the small size of the subdivisions within the big bluestem pasture resulted in excessive trampling of forage which caused a high proportion of plants to re-grow from the crown rather from internodes, thereby increasing the amount of time required for re-growth. Further, the tractor tire tracks left from mowing caused the crushed plants to re-grow from the crown; this re-growth was lush and tended to be grazed preferentially by the livestock. Thus, in 2004 and 2005 the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments were not subdivided or mowed and each of these portions was left undivided and grazed as one of the rotations.

Decisions about timing and duration of rotations were dictated by current and anticipated pasture forage availability rather than using strict dates or interval lengths. Variables such as soil moisture, physiological and re-growth stages of forage species, typical seasonal weather patterns, and weather forecasts were used to make rotation decisions. After the spring flush, the grazing intervals were usually seven days for the CS-BBS and CS-SG treatments; CS-only treatments were usually rotated every ten days and consisted of four subdivisions. Environmental data is described in Figures A.3-A.5 of Appendix I.

Mid-season grazing pressure was adjusted using the put-and-take method¹ of pasture stocking (Mott, 1960). ‘Tester steers’ were left on the same replication of the same treatment for the entire grazing season. Put-and-take steers were added to or removed from a particular replication to increase or reduce the grazing pressure in order to:

- optimize utilization of pasture forage
- prevent the accumulation low-quality forage
- meet but not exceed the current or anticipated forage dry matter production

Within an individual pasture, animals moved to another paddock when one or more of the following was true: 1) paddocks forward in the rotations were about to become over-mature; 2) animals or pasture might be harmed by low forage levels in the current rotation; 3) rapid pasture growth indicated that shorter intervals were needed in the immediate future to prevent accumulation of low-quality forage which would likely be refused.

All animals were weighed twice before the experiment began in order to establish a more accurate beginning weight (Koch et al., 1958). After the weighing events, the steers were placed on pasture and were weighed once every four weeks (see Table 3.1). Weights recorded for each steer on consecutive dates within year were averaged to establish beginning and ending weights for each animal with the exception of individual replications of treatments that were terminated early due to poor pasture conditions. Tester animals from treatment replications that had to be terminated early due to pasture

¹ See Technical Note 1 in Appendix III

conditions were weighted twice consecutively after being taken from their respective pastures.

Weighing of the steers every four weeks was primarily intended to monitor animal health. At the end of the season, the animals were removed from the pasture and fed hay for seven days and weighed on the eighth and ninth days after being removed from the pasture. The mean of these weighing events represented the end-of-season weight and was used to calculate the seasonal gain for each steer (Buskirk, 2003).

Gain per hectare was calculated by multiplying the number of animal grazing days per hectare accumulated on each pasture throughout each grazing season by the ADG of the testers on that pasture during that grazing season:

Total weight gain per hectare = (animal grazing days per hectare) X (average daily gain)

Animals that remained on the same pasture throughout the entire grazing seasons are referred to as 'testers,' while those that are used to adjust grazing pressure are referred to as put-and-take animals (PT). The original protocol called for a minimum of four testers for each treatment; in certain circumstances, however, it was necessary to reduce the number to two or three, in order to continue collecting data without degrading the pasture. Other pasture and animal performance data collected include average daily gain (ADG) and accumulated animal unit grazing days (AUGD) per hectare. Statistical analysis for all parameters was performed using PROC MIXED in SAS (SAS Institute, 2000-2003).

All forage samples collected in this study were placed in paper bags and dried for a minimum of 48 hours at 43°C², and then weighed. When grazing was initiated each year, dry matter availability was determined by harvesting plant tissue from within six

² See Technical Note 2 in Appendix III

0.25 m² quadrats. Each time the rotation sequence brought steers to a cool-season portion of their respective treatment, plants within the quadrats were clipped at a height of approximately 5 cm. When steers were moved into the big bluestem or switchgrass portions of treatments, plants within quadrats were harvested at approximately 13 cm. When rotations began, dry matter availability was determined using a rising-plate meter (Gabriels, 1993; Harmony et al., 1997; Michell, 1982) unless conditions (lodging of forage, rain) were not appropriate, in which case quadrat clippings were used instead. In 2003 and 2004, yield for the big bluestem and switchgrass monocultures yield was determined using the rising-plate meter when conditions (precipitation, wind) permitted; in 2005, quadrats were used exclusively.

In-house modifications³ of the Modified Van Soest method (Stern, 1991) were used to determine neutral detergent fiber and acid detergent fiber concentrations. The Hach modified Kjeldahl procedure (Hach, 1985; Watkins, 1987) was used to determine total N concentration in the forage. For a full description of this data, see Chapter 2 of this dissertation. In addition to forage quality and forage dry matter presented, data was collected to describe pasture botanical composition over the course of the experiment⁴.

Economic Comparison

The objective of this experiment was to compare the profitability of the three grazing systems over three years of experimentation. The correlated hypotheses were:

1. When considering all inputs and outputs, the initial cost of establishing the warm season grass-integrated grazing systems will be offset by their higher productivity by the end of the third year.

³ See Technical Note 4 in Appendix III

⁴ See Appendix II

2. Big bluestem-integrated grazing systems will not be significantly more profitable than switchgrass-integrated grazing systems by the third year of experimentation

Total animal weight gain per hectare was the primary parameter used to calculate net profitability of each treatment. Total animal weight gain per hectare per year is a function of average daily gain per animal and the number of animal grazing-days accumulated per hectare per year (i.e., stocking rate) (Parch, 1989):

Total weight gain per hectare = (animal grazing days per hectare) X (average daily gain)

Average daily gain (ADG), and accumulated AUGD per hectare and total weight gain per hectare are discussed in more detail in Chapter 3 of this dissertation.

Several assumptions were used to make economic comparisons.

- Because there is no treatment x year interaction, the calculated average for gain per hectare for each treatment is a valid estimate for all years
- Fixed expenses that are identical for all treatments are excluded from the net income calculations (Black, 2007)
- Expenses related to treatment are included in the calculation (Black, 2007). These expenses include:
 - Custom rates for field operations including: no-till planting, pesticide application, mowing, and fertilizer application
 - Pesticide costs
 - Fertilizer costs

Because Michigan has no recent estimates for custom rates for field operations, the rates used to estimate variable costs are based on data from Ohio in 2006 (Ward, 2006). Pesticide costs are based on data provided by Michigan State University

(Sprague, 2007) for most pesticides; Jorgensen Farm Elevator (Jorgensen, 2007) for 2,4-D ester; and a BASF website (BASF, 2005) for imazapic. Niagara big bluestem and Cave-in-Rock seed prices are from Ernst Conservation Seed (Ernst, 2007).

RESULTS AND DISCUSSION

Steer gain per hectare in CS-Only system was significantly higher than the CS-BBS and CS-SG treatments (Table 3.4). Also, the CS-BBS treatment yielded more steer gain per hectare than the CS-SG treatment. If the switchgrass portion of pasture had not failed to establish by 2003, it is likely that there would not be a significant difference in gain per hectare between the CS-BBS and CS-SG treatments.

The difference in net income between the CS-Only and the CS-BBS treatments is \$370 per hectare over three years (Table 3.9); the higher cost of establishing the big bluestem portion of the CS-BBS treatment accounts for \$72 of this difference (Table 3.8). On a year-to-year basis, the CS-BBS and CS-SG treatments are less expensive to maintain than the CS-Only treatment because the big bluestem and switchgrass portions of those treatments are not mowed and due to the single (rather than double) application of urea on the big bluestem and switchgrass portions of those treatments (Tables 3.5-3.8). The failure of the switchgrass pasture to establish before 2003 accounts for much of the difference between the CS-BBS and CS-SG treatments.

Because total weight gain per hectare is a function of ADG (Table 3.2) and the number of grazing days accumulated per hectare per year, total weight gain can be improved by either increasing ADG or total number of animal grazing days, or both. During the beginning of each grazing season, the number of AUGD accumulated by the CS-BBS and CS-SG do not differ significantly from each other, but the CS-Only

treatment accumulated significantly more AUGD than either of the other treatments (Table 3.3). This is because entire pasture area of the CS-Only treatment was available to graze beginning in late-April or early-May, whereas the big bluestem and switchgrass portions of their respective treatments were not generally ready to be grazed until mid-June (Barnhart, 1994a; Bartholomew, 1995). By mid-June of 2004 and 2005, the big bluestem and switchgrass portions of the CS-BBS and CS-SG treatments were ready to graze, and the difference between the numbers of AUGD accumulated by treatment diminish or disappear altogether until late-summer. By early-September, grazing on the big bluestem and switchgrass portions of their respective treatments was terminated for the season (Barnhart, 1994a; Bartholomew, 1995). Thus, the pasture area available for grazing on those treatments was essentially reduced by 33% compared to the CS-only treatment, until the end of the grazing season for the cool-season pasture. Differences in ADG among systems were not nearly as pronounced as differences in accumulated AUGD per hectare (Tables 3.2 and 3.3). The major loss in economic performance from the CS-SG and CS-BBS systems results from the lower number of AUGD accumulated in the spring and fall of the grazing seasons due to the management requirements of the switchgrass and big bluestem components.

This experiment compared the three treatments with the assumption that excess forage from the C₃ portion would not be harvested for hay; rather, the stocking rate varied according to current and anticipated pasture productivity. In practice, many graziers have more acreage than their livestock can effectively graze in the spring, and they often set aside some of their pasture to harvest one or two cuttings of hay for sale or feeding at a later time. After the first or second cutting has been harvested, the pastures

that had been set aside for hay production can begin to be grazed. Some producers, however, would prefer to keep their livestock on pasture as much as possible and would prefer to purchase hay of known quality rather than be forced to produce hay – especially if they have limited time, equipment, or labor resources. Many have suggested that warm-season grasses can help accomplish this (Balasko, 2003; Barnhart, 1994a; Peterson, 2007). However, in all years of this study, the big bluestem and switchgrass were ready for grazing before the C₃ pasture species declined in productivity. In this situation, Anderson (2000) recommends that mixed or solid stands of switchgrass be grazed when they are ready, regardless of whether the cool-season pastures are still productive, suggesting that it is better to harvest or stockpile excess C₃ forage and to graze the big bluestem and switchgrass while their forage volume and quality are optimal. This was practiced in this experiment, but it adds more complexity than most graziers are accustomed to in traditional grazing systems.

Moore et al. (2004) suggest that in a situation where a producer does not want to harvest excess pasture forage for hay, they might consider devoting part of their pasture acreage to switchgrass or big bluestem. In fact, a producer could reduce the risk of running out of mid-summer pasture using this strategy in Southern Michigan, but the management constraints of these grasses induce an opportunity cost (i.e., the annual loss of grazing days in the spring and fall) that seems to outweigh the potential for reducing risk. Ultimately, producer's willingness to set aside one third of his pasture acreage for hay production or warm-season grass pasture will be related to their:

- capacity (equipment, storage, time) to harvest quality hay from a traditional grazing system.

- willingness to increase the complexity of their system in order to keep their livestock on pasture.
- assessment of the severity of the summer slump on their pastures and the capacity of warm-season grasses to complement the distribution of the C3 pasture productivity.
- opinion of how well the forage quality matches the class of livestock on their pastures.

Table 3.1. Weighing events by year[†].

2003	2004	2005
<i>28-Apr</i> †	<i>26-Apr</i>	<i>20-Apr</i>
<i>29-Apr</i>	<i>27-Apr</i>	<i>21-Apr</i> ‡
<i>28-May</i> ‡	<i>25-May</i> ‡	<i>19-May</i>
<i>24 June</i> ‡	<i>22 June</i> ‡	<i>16 June</i> ‡
<i>22-July</i> ‡	<i>20-July</i> ‡	<i>14-July</i>
<i>19-Aug</i>	<i>14-Aug</i>	<i>11-Aug</i> ‡
<i>17-Sep</i>	<i>22-Sep</i>	<i>8-Sep</i>
<i>18-Sep</i>	<i>23-Sep</i>	<i>16-Sep</i>
		<i>17-Sep</i>

[†]Weights from italicized dates were used to establish beginning- and end- of season weights.

‡Indicates dates of application of ivermectin pour-on

Table 3.2 Average daily gain of steers by treatment and year at time intervals throughout the 2003-2005 grazing seasons.

2003-2005 Grazing Seasons:									
Year	Treatment	Time 1-2		Time 2-3		Time 3-4		Time 4-5	
		ADG	SE	ADG	SE	ADG	SE	ADG	SE
					kg day ⁻¹				
2003	CS-BBS	1.72 a	0.09	1.38 a	0.09	0.79 a*	0.06	0.98 a*	0.08
2003	CS-Only	1.81 a	0.07	1.50 a	0.08	0.69 a*	0.06	0.99 a*	0.07
2003	CS-SG	1.72 a	0.08	1.48 a	0.08	0.72 a	0.06	1.09 a*	0.09
2004	CS-BBS	1.72 a	0.05	1.32 a	0.06	1.11 a*	0.04	0.46 b*	0.05
2004	CS-Only	1.84 a	0.06	1.34 a	0.06	0.99 ab*	0.05	0.73 a*	0.06
2004	CS-SG	1.75 a	0.05	1.26 a	0.06	0.96 b*	0.04	0.57 b	0.05
2005	CS-BBS	1.81 a*	0.06	1.48 a*	0.06	0.79 a*	0.05	0.91 b*	0.06
2005	CS-Only	1.52 b*	0.06	1.32 ab*	0.07	0.72 ab*	0.05	1.10 a*	0.06
2005	CS-SG	1.44 b*	0.06	1.29 b*	0.06	0.65 b*	0.04	0.83 b*	0.05

Means within year with different letters are significantly different ($p < 0.05$).

*Indicates an interaction with alfalfa abundance during that time period

Table 3.3. Animal unit grazing days accumulated by treatment and year at intervals throughout the 2003-2005 grazing seasons.

Year	Treatment	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Season
		----- AUGD/ha -----				-----		
2003	CS-BBS	65.1 b	42.2 b	54.0 a	44.1 a	34.8 a	0.0 a	240.2 b
2003	CS-Only	80.9 a	58.8 a	56.9 a	47.3 a	34.6 a	2.5 a	281.0 a
2003	CS-SG	61.0 b	42.9 b	41.1 b	28.5 b	23.0 b	0.0 a	196.5 c
2004	CS-BBS	72.8 b	76.2 b	88.7 a	74.2 a	71.1 a	52.7 b	435.6 b
2004	CS-Only	95.5 a	97.9 a	88.9 a	78.6 a	77.5 a	87.8 a	526.1 a
2004	CS-SG	74.9 b	75.9 b	91.8 a	72.1 a	74.5 a	46.0 b	435.1 b
2005	CS-BBS	62.9 b	58.4 b	67.0 a	76.0 a	70.6 a	0.0 a	335.0 a
2005	CS-Only	81.1 a	74.4 a	64.8 a	61.2 b	58.8 b	0.0 a	340.3 a
2005	CS-SG	62.3 b	55.9 b	67.2 a	74.3 a	61.6 ab	0.0 a	321.3 a

Means within the same column and year with different letters are significantly different ($p < 0.05$). The standard error for CS-BBS = 3.7; CS-Only = 3.7; CS-SG = 3.2.

Table 3.4. Animal gain ha⁻¹ by treatment.

Treatment	Gain (kg/ha) [†]	SE
CS-BBS	624.5 b	16.2
CS-Only	722.0 a	16.2
CS-SG	572.9 c	14.0

[†] Means with different letters are significantly different ($p < 0.05$).

Table 3.5. The cost of three years of cool-season grass and legume pasture maintenance.
Costs of Three Years of CS Pasture Maintenance

Time	Activity	Area	Rate‡	Cost	
				Per hectare	Per 0.67 ha
Year 1	spring fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	summer fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	mowing	1		\$25.95	\$17.38
			Year 1 Total	\$115.67	\$77.50
Year 2	spring fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	summer fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	mowing	1		\$25.95	\$17.38
			Year 2 Total	\$115.67	\$77.50
Year 3	spring fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	summer fertilizer	1	171	\$34.11	\$22.86
	custom fertilizer application	1		\$10.75	\$7.20
	mowing	1		\$25.95	\$17.38
			Year 3 Total	\$115.67	\$77.50
			3-Year Total	\$347.01	

‡Fertilizer rates are in kilograms of urea per hectare, with a cost of \$0.44 kg⁻¹.

Table 3.6. The cost of establishment of big bluestem pasture and three years of maintenance.

Costs of BBS Pasture Establishment and Two Years of Maintenance					
Time	Activity	Area	Rate‡	Cost	
				Per hectare	Per 0.33 ha
Year Prior	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>2,4-D ester</i>	0.33	0.84	\$8.52	\$2.81
	<i>dicamba</i>	0.33	0.54	\$26.47	\$8.74
	AMS+NIS	0.33		\$8.43	\$2.78
	custom no-till planting	0.33		\$30.39	\$10.03
	seed	0.33	10.1	\$161.60	\$53.33
Year 1	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>imazapic</i>	0.33	0.07	\$34.19	\$11.28
	AMS+NIS	0.33		\$8.43	\$2.78
	Year-1 Total			\$333.68	\$110.11
Year 2	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>2,4-D ester</i>	0.33	0.84	\$8.52	\$2.81
	<i>dicamba</i>	0.33	0.54	\$26.47	\$8.74
	AMS+NIS	0.33		\$8.43	\$2.78
	spring fertilizer	0.33	171	\$34.11	\$11.26
	custom fertilizer application	0.33		\$10.75	\$3.55
	Year-2 Total			\$116.10	\$38.31
Year 3	spring fertilizer	0.33	171	\$34.11	\$11.26
	custom fertilizer application	0.33		\$10.75	\$3.55
	Year-3 Total			\$44.86	\$14.80
3-Year Total				\$494.64	\$163.23

‡Herbicide rates are in kilograms active ingredient (a.i.) per hectare; seed rates are in units of kilograms per hectare; fertilizer rates are in kilograms of urea per hectare.

Table 3.7. The cost of establishment of switchgrass pasture and three years of maintenance.

Costs of SG Pasture Establishment and Three Years of Maintenance					
Time	Activity	Area	Rate‡	Cost	
				Per hectare	Per 0.33 ha
Year Prior	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>2,4-D ester</i>	0.33	0.84	\$8.52	\$2.81
	<i>dicamba</i>	0.33	0.54	\$26.47	\$8.74
	<i>AMS+NIS</i>	0.33		\$8.43	\$2.78
Year 1	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>imazethapyr</i>	0.33		\$38.63	\$12.75
	<i>AMS+NIS</i>	0.33		\$8.43	\$2.78
	custom no-till planting	0.33		\$30.39	\$10.03
	seed	0.33	10.1	\$90.00	\$29.70
Year 1	custom insecticide application	0.33		\$13.22	\$4.36
	<i>carbaryl</i>	0.33	1.68	\$26.69	\$8.81
	<i>carbaryl</i>	0.33	1.68	\$26.69	\$8.81
	Year-1 Total			\$333.12	\$109.93
Year 2	custom herbicide application	0.33		\$13.22	\$4.36
	<i>glyphosate</i>	0.33	1.08	\$14.60	\$4.82
	<i>2,4-D ester</i>	0.33	0.84	\$8.52	\$2.81
	<i>dicamba</i>	0.33	0.54	\$26.47	\$8.74
	<i>AMS+NIS</i>	0.33		\$8.43	\$2.78
	spring fertilizer	0.33	171	\$34.11	\$11.26
	custom fertilizer application	0.33		\$10.75	\$3.55
	Year-2 Total			\$116.10	\$38.31
Year 3	spring fertilizer	0.33	171	\$34.11	\$11.26
	custom fertilizer application	0.33		\$10.75	\$3.55
	Year-3 Total			\$44.86	\$14.80
3-Year Total				\$494.08	\$163.05

‡Herbicide rates are in kg active ingredient (a.i.) ha⁻¹; seed rates are in units of kg ha⁻¹; fertilizer rates are in kilograms of urea ha⁻¹.

Table 3.8. Summary of maintenance and establishment costs of treatments.

CS-BBS Expenses			
	Year 1*	Year 2	Year 3
CS portion	\$77.50	\$77.50	\$77.50
BBS portion	\$110.11	\$38.31	\$14.80
CS-BBS Year Total	\$187.61	\$115.81	\$92.30
3-Year Total			\$395.73
 CS-Only Expenses			
	Year 1	Year 2	Year 3
CS-Only	\$115.67	\$115.67	\$115.67
3-Year Total			\$347.01
 CS-SG Expenses			
	Year 1*	Year 2	Year 3
CS portion	\$77.50	\$77.50	\$77.50
SG portion	\$109.93	\$38.31	\$14.80
CS-SG Year Total	\$187.43	\$115.81	\$92.30
3-Year Total			\$395.54

*Also includes establishment costs from year prior to initiation of grazing.

Table 3.9. Summary of gross income, expenses, and net income of treatments by year.

Year	Treatment	gain (kg/ha)	Value per kg	Gross	Expenses	Net
1	CS-BBS	624.5	\$1.10	\$687	\$188	\$499
1	CS-Only	722.0	\$1.10	\$794	\$116	\$678
1	CS-SG	572.9	\$1.10	\$630	\$187	\$443
2	CS-BBS	624.5	\$1.10	\$687	\$116	\$571
2	CS-Only	722.0	\$1.10	\$794	\$116	\$678
2	CS-SG	572.9	\$1.10	\$630	\$116	\$514
3	CS-BBS	624.5	\$1.10	\$687	\$92	\$595
3	CS-Only	722.0	\$1.10	\$794	\$116	\$678
3	CS-SG	572.9	\$1.10	\$630	\$92	\$538
3-Year Total	CS-BBS	1873.4	\$1.10	\$2,061	\$396	\$1,665
3-Year Total	CS-Only	2165.9	\$1.10	\$2,382	\$347	\$2,035
3-Year Total	CS-SG	1718.8	\$1.10	\$1,891	\$396	\$1,495

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Chapter 4

RELATIVE ABUNDANCE OF GRASSLAND BIRDS IN COOL-SEASON PASTURES AND GRAZING SYSTEMS INTEGRATED WITH SWITCHGRASS AND BIG BLUESTEM

ABSTRACT

This experiment compares the relative abundance of grassland birds observed within each of three treatments of a grazing trial that was conducted in Southwest-Lower Michigan. The three treatments included: cool-season grass and legume pastures (CS-Only); integrated big bluestem and cool-season grass and legume pastures (CS-BBS); and integrated switchgrass and cool-season grass and legume pastures (CS-SG). The CS-BBS pastures had an average of 2.6 birds per transect, while the CS-Only and CS-SG treatments had 1.9 and 1.7, respectively, and the differences were not statistically significant. While the combined area of the big bluestem and switchgrass monocultures comprised about 23% of the experimental area, only 8% of the birds counted were within those pastures. This may be due to: insufficient plot size; intensive forage residue management; slow spring growth of switchgrass and big bluestem; the lack of fencing (serving as perches) within switchgrass and big bluestem monocultures and the presence of subdividing fences in the cool-season portions of the treatments; and/or the lack of plant structure heterogeneity in the switchgrass or big bluestem monocultures. While periodic mowing is realistic part of pasture management, grazing and mowing activity can be very disruptive to nesting birds, and probably confounded the objective. Studies designed to describe the effect of big bluestem or switchgrass on grassland birds populations in integrated grazing systems should begin earlier in the spring, on a much larger experimental area, and include a treatment where the pastures are not mowed.

INTRODUCTION

The post-settlement decline of grassland bird populations

The populations of many Midwestern grassland bird species have declined significantly since pre-settlement times. Many have attempted to describe the nature and causes of these declines (Sauer et al., 1996) and possible solutions to the problem. The North American Breeding Bird Survey has been used extensively to describe population trends and to deduce possible causes for population changes. Although useful for some types of population analysis, correlation data from the Breeding Bird Survey is not useful for identifying precise causes of population changes (Sauer et al., 1996). Rather than yielding simple solutions, the grassland wildlife research of the past thirty years has produced management principles which have the potential to mitigate or improve the avian productivity of grassland ecosystems and landscapes that contain cover with structure similar to native grasslands. There have also been many attempts to design land management protocols that reflect the principles derived from such research, especially by the USDA-NRCS and state departments of natural resources. Examples of such programs include the Conservation Reserve Program (CRP), Grassland Reserve Program (GRP), and the Wetland Reserve Program (WRP). The likelihood of adoption and survival of government programs such as the Grassland Reserve Program by producers depends on how producers perceive the compatibility of their objectives with those of required practices as well as the agency promoting the program.

One grassland management practice that has been promoted by government agencies is the use of native warm season grasses such as switchgrass (*Panicum virgatum*) and big bluestem (*Andropogon gerardii*) as a dual purpose crop (George et al.,

1979). Implicit in these recommendations is that these grasses provide adequate forage quantity and quality for certain classes of livestock and, if managed appropriately, adequate habitat for grassland bird species.

In Michigan, approximately 360,000 hectares are grazed annually (Matthews, 2003) and another 410,000 hectares are harvested for hay (MASS, 2002). Keeping livestock on pasture offers several advantages over confinement feeding including lower time, labor and capital inputs; superior manure distribution; improved animal health; lower energy use per pound of animal produced; and reduced land degradation.

During the mid-summer months of most years, Michigan producers who keep livestock on pasture are faced with a choice: to remove their livestock from dormant summer pastures to locations where they are fed stored forage, or to allow their livestock to continue grazing. Overgrazing often reduces pasture productivity (Coleman, 2007) resulting in weed invasion (Hazell, 1967), and therefore may require renovation or replanting. In Michigan, spring and fall cool season grass-legume growth is excellent due to mild temperatures and adequate rainfall, but the hot, dry summer months cause most of these grasses and legumes to become dormant. Several state universities in the North Central Region promote the use of native perennial warm season grasses, such as switchgrass and big bluestem as summer forage. These grasses have the potential to provide large volumes of high quality mid-summer forage when the cool season grasses and legumes are dormant. While both of these species are indigenous to Michigan, no grazing research has been conducted to determine if using these species in a pasture system is a viable option. Beyond their capacity to produce large quantities of biomass,

switchgrass and big bluestem grow well in marginal soils and are excellent nesting and holding habitat for wild game and song birds.

The Michigan Hay and Grazing Council has described alternative(Lindquist, 2002) forage research as one of its top priorities (Lindquist, 2002). Both the Michigan Department of Natural Resources (Sargent, 1999) and the USDA Natural Resource Conservation Service (USDA-NRCS, 1996) have encouraged Michigan graziers to include native warm season grasses in their grazing systems. However, graziers may be reluctant to use these grasses without knowledge of their performance in Michigan. This project was designed to demonstrate how livestock perform when these grasses are integrated into the typical grazing systems in Southern Michigan. This project was designed to demonstrate how livestock perform when these grasses are integrated into the proposed grazing system models in Southern Michigan.

Warm season grasses in Michigan forage systems

In Southern Michigan, cool season grass and legume pastures often are grazed beginning in late-April; hay harvest often begins in mid-to late-May; this timing is particularly detrimental to nesting grassland birds (Frawley and Best, 1991). However, native warm season grasses have a very different seasonal growth dynamics, reaching optimal quality and yield in early- to mid-June in Southern Michigan. Further, because under optimal summer forage management the grazing of native warm-season grasses should stop when the canopy height is reduced to 20 cm (Peterson, 2007), more cover is left for wildlife after each grazing cycle. While these facts seem to suggest that the use of native warm season grasses as a major component of grazing systems could solve

multiple problems simultaneously, until now no specific research has been done on this topic in Michigan.

Introduction to switchgrass and big bluestem

Switchgrass and big bluestem are both erect-growing native perennial warm season grasses. They have C₄ metabolism, so peak biomass production occurs at a leaf temperature of 37°C, in contrast to cool season grasses which peak between 20 and 25°C and dramatically decline at temperatures above 27°C (Nelson, 1995). This physiological characteristic makes warm season grasses most productive in mid-summer. Big bluestem, switchgrass, and indiangrass have been used extensively in U.S. government programs such as the Soil Bank and the Conservation Reserve Program since the 1930's, resulting in several million hectares being replanted with either mixtures or monocultures of these grasses (Moser, 1995). The extensive use of these grasses in the Conservation Reserve Program demonstrates their contribution to grassland ecosystems and their role in providing wildlife habitat (USDA-NRCS, 1999; USDA-NRCS, 2007). The ecological importance of these grasses is widely recognized (Harvey, 2000; Henning, 1993; USDA-NRCS, 1999) and they can be planted along railroad right-of-ways and roadsides, near waterways, for wildlife cover (Moser, 1995), for erosion control (Blanco-Canqui, 2004; Rankins, 2001), and can function well as vegetative conservation buffers to prevent soil pesticide loss via surface water (Rankins, 2001). Both big bluestem and switchgrass tolerate a soil pH of 4.5 and 4.9, respectively (Duke, 1978) and thus can be planted in areas that are not typically used for crop production. Switchgrass and big bluestem both have extensive root systems that penetrate the soil to depths of more than two meters (Weaver, 1954) and show great potential for carbon sequestration. Beyond having vast

potential for wildlife habitat, erosion control, and carbon sequestration, these grasses are recommended by many research and extension institutions for summer grazing. Mitchell (1996) suggests that summer grazing is more efficient if separate pastures of warm and cool season grasses are maintained; placing grazing animals in the warm season pastures during mid-summer, and then returning them to cool season pastures after cool season pasture recovery. Henning (1993) points out that a combination of cool season and warm season grass pastures can provide a more constant supply of high-quality feed through the summer than either cool or warm season grass pastures can provide alone. Barnhart (1994) indicates that pasture efficiency may be increased by converting one-fourth to one-third of the cool season grass pasture acreage to a warm season grass pasture to be grazed at different times during the grazing season. This allows the cool season grasses to be grazed in the spring and early summer, occasionally throughout the summer, and in the fall, while utilizing the warm season grass pasture more intensively during periods of low cool season grass productivity. Also, this strategy allows greater rest periods for cool season pastures, which will increase their vigor and productivity for late summer through early fall grazing.

Recommendations for inclusion of warm season grasses in grazing systems are supported by numerous studies in many states. Krueger and Curtis (1979) conducted a study in South Dakota comparing switchgrass, big bluestem, indiangrass (*Sorghastrum nutans* (L.) Nash), and sideoats grama (*Bouteloua curtipendula*) for mid-summer grazing and concluded that switchgrass and big bluestem are useful species for beef production in July and August. (George, 1996) demonstrated that grazing either big bluestem or switchgrass pastures in mid-summer can result in impressive steer weight gains (1.42 and

1.11 kg day⁻¹, respectively) and that rotational grazing management is superior to continuous grazing management for both switchgrass and big bluestem. In an Iowa study, (Moore, 2001) concluded that grazing systems in which cool season grasses and warm season grasses are grazed sequentially can improve seasonal productivity.

Switchgrass matures earlier in the summer than big bluestem and the forage quality of big bluestem does not drop off as rapidly as it does with switchgrass (Moser, 1995). Both switchgrass and big bluestem pastures must be managed differently than cool season grass pastures. Neither species tolerates close grazing and both require rest periods of 21 to 45 days between grazing events, depending on environmental conditions (Anderson, 2000; Henning, 1993; Mitchell, 1996).

Objective and Hypothesis:

Objective three, as stated in the introductory chapter of this dissertation, is: to describe songbird species diversity in the respective pasture systems, describing apparent relationships between species spatial distribution and type of pasture system. The associated hypothesis is that pasture systems that include switchgrass and big bluestem will have a higher songbird species diversity, nesting success, and evidence greater use by raptors feeding on mice and other rodents.

LITERATURE REVIEW

The most useful habitats for grassland wildlife include old fields, lightly or moderately, grazed pastures, fallow fields, meadows, and grass and grass/legume hay that is harvested late (Sample and Mossman, 1997). These vegetation cover types are becoming rare as such land is either converted to more conventionally managed forage production, row crops, residential development, or subdivided recreational land. While

habitat fragmentation is linked to avian population changes, research in this area can be complicated due to confounding factors such as land use change (Donovan and Flather, 2002). The complexity of the decline of many native Midwestern avian species seems to be surpassed only by the difficulty of finding realistic and practical ways to slow or reverse the trend. Some of the most difficult aspects of ecological restoration are deciding which species are of primary concern, which land should be targeted for change, who should manage that restoration, and how the landowner should be compensated.

The relationship of cropping systems to bird populations

State level Breeding Bird Survey data from between 1980 and 1998 indicates that grassland bird species are declining and that this is due in part to changes in agricultural land use, such as a decline in range land and a decline in the use of cover crops (Murphy, 2003). While cropping systems vary by region and by individual farm, research on the influence of these cropping systems on avian populations has demonstrated major weaknesses of these systems for sustaining avian population and diversity. In a study conducted in Iowa, (Patterson and Best, 1996) identified the nests of sixteen bird species in CRP fields and two in row crop fields – the vesper sparrow (*Pooecetes gramineus*) and the horned lark (*Eremophila alpestris*). In both habitat types, predation was the primary cause of nest loss. Bird use of strip intercropping systems was also evaluated in Iowa (Stallman and Best, 1996). Stallman and Best concluded that strip cropping increases species diversity and abundance but nest failure is very high and the system ends up being an ecological trap. Farmers using strip cropping systems frequently use mechanical methods of weed control, resulting in the destruction of many nests; using herbicides

rather than mechanical weed control would likely result in higher avian productivity (Stallman and Best, 1996).

Hedge rows between crop fields are commonly thought of as the primary source of wildlife habitat in crop land. Some ecologists have suggested that hedge rows frequently function as ecological traps. Warner (1994) suggests that such conclusions are simplistic because at least two scenarios can improve the usefulness of hedge row cover by birds: heterogeneity of cover type and connection of the linear habitat to the surrounding landscape. Nest densities and species survival were highest on plots where there were heterogeneous cover types. The connection of the linear habitat to the surrounding landscape improved the nest density and species diversity of the linear habitat. Research conducted in the 1940s suggests that whether they function as ecological traps or not, some species are certainly attracted to hedge rows, while others are not (Good and Dambach, 1943).

Government sponsored conservation programs

The USDA Conservation Reserve Program and Canada's Permanent Cover Program (PCP) represent two major federal efforts to conserve easily degradable agricultural land with corollary benefits of improved habitat for grassland bird species. In the CRP, producers are paid to take crop land out of production and plant and manage species of plants known to provide cover for wildlife. After studying land enrolled in the PCP, (McMaster and Davis, 2001) concluded that PCP acreage is characterized by more dense and heterogeneous vegetative structure than cropland and that nine out of ten studied bird species were present at higher frequencies than in cropland. The importance of habitat quality is underscored by (Fahrig, 2001) who reports that up to 58% less habitat

area is needed for species persistence if a low quality habitat matrix is converted to one of high quality.

While the CRP has resulted in hundreds of thousands of acres being set aside for conservation purposes its impact has been isolated to certain regions or small tracts within regions. One limitation that applies to all conservation programs is that of tract size. A unit of cover that has excellent plant and residue structure for a bird species might still be refused by that species due to the insufficient area of the otherwise acceptable habitat (Vickery et al., 1994). For example, grasshopper sparrows (*Ammodramus savannarum*) and vesper sparrow preferentially utilize smaller strips of nesting territory whereas bobolinks (*Dolichonyx oryzivorus*), red-winged blackbirds (*Agelaius phoeniceus*), and meadowlarks (*Sturnella* spp.) prefer larger tracts over narrow strips. Pheasants (*Phasianus* spp.), quail (*Coturnicops* spp.), and dickcissels (*Spiza Americana*) do not demonstrate strong preferences for larger or smaller tracts of nesting territory (Good and Dambach, 1943).

The CRP offers breeding habitat for species that have had decreasing population trends and could actually reverse those trends (Johnson and Schwartz, 1993; Veech, 2006). Although the CRP has probably not yet reversed the overall decline of most species of the indigenous grassland bird population of the United States, it is clearly superior bird habitat compared to row crop fields. A 1997 report suggests that CRP has between 1.5 and 10 times greater bird species abundance, about three times more species of nesting birds, and 13.5 times more nests than row crop fields (Best et al., 1997).

While annual crops such as corn and soybeans clearly do not provide adequate cover for most birds, the shortcomings go beyond excessive or insufficient biomass.

Total bird abundance is associated with vertical density, litter cover, litter depth, ratio of grass to forb cover, and bare ground cover, although the relationships can be positive or negative, depending on bird species. For example, bobolink abundance is negatively correlated with vertical density and positively correlated with percent litter cover, but some species prefer structural complexity (Delisle and Savidge, 1997; Sample and Mossman, 1997). The requirement for structural complexity and varying forms of structural complexity is addressed at some level in the CRP by the two different types of seed mixtures that landowners can plant. The CP1 option requires the landowner to plant cool-season grasses and legumes, while the CP2 option requires them to plant native warm season grasses – each which have different vegetative characteristics. Research conducted in southeast Nebraska suggests that whereas total bird abundance may not differ between CP1 (cool-season grasses and legumes) and CP2 (native warm season grasses), particular species demonstrate preferences for vegetative characteristics of one over the other (Delisle and Savidge, 1997).

Although the Permanent Cover Program of Canada differs from the CRP of the United States, it also provides more dense and heterogenous vegetative structure than cropland (McMaster and Davis, 2001). Whether part of a government conservation program or a private effort to improve bird habitat to promote avian diversity, vegetative structural diversity should be promoted within and among particular blocks of habitat, the landscape, natural divisions, and even within the states (Sample and Mossman, 1997).

Ecological principles with implications for grassland management

The differences in avian productivity between land devoted to row crops and grasslands might lead some to deduce that removing row-crop acreage from production

will necessarily improve habitat for grassland birds. However, land at certain stages of succession can be very poor habitat for nesting grassland birds due to the uncontrolled growth of woody species which provide structure for predators and parasitic species such as hawks and brown-headed cowbirds (*Molothrus ater*) (Johnson and Temple, 1990).

A study of five grassland bird species nesting in tallgrass prairie fragments in Minnesota revealed that nest predation and parasitism was greatest within 45 meters of a wooded edge, when woody vegetation had encroached, and when it had been three or more years since the vegetation had been burned. Where grassland bird management is a priority, tracts of habitat should be large, far from wooded edges, and burned on a regular basis (Johnson and Temple, 1990). Data from a study conducted in Michigan shows that CRP fields that were one or two years old and characterized by a combination of forbs and bare ground had the greatest diversity and relative abundance of avian species; older CRP fields that were characterized by deeper litter cover and grasses had the highest level of avian productivity (Millenbah et al., 1996). Management protocols for landowners who have enrolled in the CRP reflect the need to manage their acreage in a manner that will optimize the heterogeneity of the landscape in terms of forb, grass, and bare ground cover, and litter cover and depth. Such protocols include land management obligations such as mowing or burning the accumulated biomass every several years, which reduces or eliminate the encroachment of woody species. Robel et al. (1998) suggest that burning CRP land every 2-3 years is sufficient to prevent encroachment by woody plant species and that, although spring burning of CRP fields reduces bird nest numbers and total avian abundance in the season after burning, avian species richness and nesting success are not different than in unburned CRP fields.

Delisle and Savidge (1997) point out that late-season burning or mowing can decrease the value of CRP fields as winter cover. Askins (2001) uses a different approach to arrive at similar conclusions to the studies above. He suggests that before settlement, many grassland and shrubland species in eastern North America depended on natural disturbances such as wildfires to create appropriate habitat. Early post-settlement forms of agriculture simulated many of those disturbances, and these species have declined with the decline of those forms of agriculture (Askins, 2001). Because pre-settlement habitats experienced varying degrees of disturbances by phenomena such as wildfires, land enrolled in programs such as the CRP should experience periodical disturbances by fire or mowing in order to meet the goal of habitat restoration (Askins, 2001).

Habitat area requirements vary by bird species. Habitat that is appropriate for a given species due to the plant and residue structure may be refused by certain species of birds due to the overall area of the otherwise acceptable habitat (Good and Dambach, 1943; Herkert, 1994). Herkert observed that distributions of 8 of 15 bird species studied in habitat fragments were affected by habitat area. Six of the species were affected by habitat structure only, and the dickcissel was affected by neither structure nor fragment size. Herkert further observed that among five of the area-sensitive species, the minimum area requirement ranged from 5 to 55 hectares. Good and Dambach (1943) also noted that grasshopper sparrows and vesper sparrow preferentially utilize smaller strips of nesting territory whereas bobolinks, red-winged blackbirds, and meadowlarks prefer larger tracts over narrow strips. Pheasants, quail, and dickcissels do not demonstrate strong preferences for larger or smaller tracts of nesting territory (Good and Dambach,

1943). Alternately, grassland birds may settle in suitable microenvironments in otherwise less acceptable habitats (Sample and Mossman, 1997). Research conducted in grassland barren sites in Maine has shown that the optimal tract size for maximum grassland bird diversity is 200 ha. Upland sandpipers (*Bartramia longicauda*) had the greatest requirement for land area, requiring 200 ha to reach 50% incidence; the savannah sparrow (*Passerculus sandwichensis*) reached 50% incidence at 10 ha. Field sparrows (*Spizella pusilla*) incidence was not strongly associated with tract size, while edge species such as the song sparrow was negatively correlated with grassland tract size (Vickery et al., 1994).

The major causes of nesting failure in CRP-type habitat is predation (Best et al., 1997); in roadsides adjacent to row crop fields, mowing, plant lodging, weather, and cowbird parasitism can also contribute to nest failure (Camp and Best, 1994). Because not all land is enrolled in the CRP, the influence of “edges” on bird populations near the borders of a particular tract of CRP land is inevitable. Some have contended that edges of such habitat can function as ecological traps. Ratti and Reese (1988) used artificial bird nest containing Japanese quail (*Coturnix japonica*) eggs to test the ecological trap hypothesis as described by Gates and Gysel (Gates, 1978; Ratti and Reese, 1988). Their research affirmed the conclusions of Gates and Gysel and suggested that critical factor determining whether an edge functions as a sink is the abruptness of the edge, contending that a feathered edge provides superior nesting habitat due to its vegetative complexity and its reduction of predator efficiency (Ratti and Reese, 1988). A study of five grassland bird species nesting in tallgrass prairie fragments in Minnesota revealed that nest predation and parasitism was greatest within 45 meters of a wooded edge, when

woody vegetation had encroached, and when it had been three or more years since the vegetation had been burned. The authors concluded that where grassland bird management is a priority, tracts of habitat should be large, far from wooded edges, and burned on a regular basis (Johnson and Temple, 1990).

Ecological principles with implications for pasture and hay land management

Hay fields and pastures are well known havens for certain species of grassland birds, although they differ in harvest timing and vegetative structure. Studies conducted on pastures and hay land enrolled in the Permanent Cover Program confirmed that fields that are hayed or grazed have significantly different vegetative structure and bird community composition but similar species richness or evenness (McMaster and Davis, 2001). Further, 70% of common bird species were detected at higher frequencies in hay and pasture land than in crop land (McMaster and Davis, 2001). Some species rely on hay fields for their survival. For example, bobolinks thrive in large, old, late-mown hay fields, and their population currently *depends* on hay fields since the original Midwest prairies have mostly disappeared. In a study conducted in west-central New York, (Bollinger et al., 1990) estimated that 74% of the bobolinks in the area studied nested in hay fields.

Whereas predation is the greatest cause of nest failure in CRP land (Best et al., 1997), mowing is the greatest cause of mortality of grassland birds such as bobolinks and pheasants in hay land (Bollinger et al., 1990; Dale et al., 1997; Warner and Etter, 1989) and it should be discouraged in areas where nesting success is critical (Camp and Best, 1994; Frawley and Best, 1991). Grazing intensity and patterns and residue control affect the suitability of pasture habitat for particular bird species. Birds that like short

vegetation will be more prevalent in intensely grazed pastures (Sample and Mossman, 1997). Heavily grazed pastures probably do not offer habitat suitable to grassland bird species that require intermediate or tall vegetation (McMaster and Davis, 2001).

The type of grazing that different species of grassland birds will tolerate/prefer varies:

- Light grazing: bobolink, eastern meadowlark (*Sturnella magna*), dickcissel, and northern harrier (*Circus cyaneus*)
- Moderate grazing: upland sandpiper, savanna and grasshopper sparrows, western meadowlark (*Sturnella neglecta*), brewers blackbird (*Euphagus cyanocephalus*)
- Heavily grazed – horned lark (*Eremophila alpestris*) and killdeer (*Charadrius vociferus*) (Sample and Mossman, 1997)

It is clear that land managed for hay or pasture offers significantly different structure and levels of disturbance than idle land. Frawley and Best (1991) concluded that mowing fields for hay and songbird reproduction are not compatible practices, while acknowledging that management does make a difference, noting that early mowing is far worse for songbird populations than late mowing (Frawley and Best, 1991). Pulliam argues that reproductive surpluses from source habitats overflow into sink habitats, which are areas that give the appearance of good habitat, but which have a fundamental characteristic that prevents the majority of the population from carrying out successful reproductive cycles (Pulliam, 1988). In the case of pastures and hay production fields where mowing, trampling, predation, and parasitism are common, it is obvious that while many nesting birds are present, the habitat is probably functioning as a sink.

Some level of nest disturbance is inevitable in all haying and grazing systems, which raises the question about the overall avian productivity of these habitats and the abilities

and strategies of different bird species to recover from those disturbances. Whereas mowing cannot avoid severely disrupting the majority of nests (Bollinger et al., 1990), grazing is less systematic and at certain intensities allows a range of nesting success (Temple et al., 1999). In addition to the degree of disruption caused by mowing and grazing, a short harvest interval can often prevent successful fledging (Bollinger et al., 1990; Temple et al., 1999). Studies of grassland birds in Saskatchewan suggest that that productivity of savanna sparrows can decline by up to 80% after mowing (Dale et al., 1997).

In research conducted in Wisconsin, investigators observed that when hen pheasants were disturbed and subsequently re-nested, they usually did so in a different type of cover than they initially nested in and chose a location about 400 m from their first nest (Dumke, 1979). Several management practices to improve the nesting success of grassland birds have been suggested. Research conducted in Iowa suggests that properly managed native warm season grasses can provide both forage for livestock and suitable habitat for upland birds (George et al., 1979). These grasses mature later in the spring, providing the optimal quality and quantity for harvest at a much more optimal time for nesting birds. Another management practice that could be used is establishing tracts of undisturbed cover suitable for nesting ("refuge") near or within large hay fields could greatly increase the success of re-nesting efforts of grassland birds disturbed by haying or grazing activity (Temple et al., 1999; Warner and Etter, 1989). Others have suggested that harvesting individual fields every other year, leaving the remainder idle for three years or more would increase the productivity of grassland bird species that prefer dense cover (Dale et al., 1997). A common practice for governmental agencies overseeing

conservation programs has been to allow harvesting land enrolled in those practices only after a certain calendar date (Dierberger, 2008). Because fledging dates vary among years, using calendar dates to establish harvest dates may not be appropriate (Dale et al., 1997).

Specific grazing practices vary by region, livestock class, and producer. One question often raised is whether continuous or rotational grazing is more beneficial to avian species. While this may vary by region, research conducted in Oklahoma demonstrated that even low stocking densities significantly disturb grassland birds; nests are particularly vulnerable to trampling at grazing densities of 10 head per hectare or more (Jensen et al., 1990). In native rangeland characteristic of the southwest where stocking densities are typically low, short duration grazing does not result in significantly more nest trampling than continuous grazing (Koerth et al., 1983). Conclusions from research conducted to describe the relationship of stocking densities to nest destruction by trampling suggest that stocking densities of 10 head of cattle per hectare are particularly disruptive to ground nesting birds (Jensen et al., 1990). Sample and Mossman also concluded that due to nest trampling and short pasture rest periods, intensive rotational grazing is not beneficial to most grassland bird species (Sample and Mossman, 1997).

Temple *et al.* (1999) compared three types of systems to see how they differed in grassland bird abundance, diversity, and nesting success: ungrazed grasslands, continuously grazed pastures, and rotationally grazed pastures. Significant differences existed for all three of the measured parameters. Density, diversity, and nesting success were greatest on the ungrazed grassland treatment. Density and diversity were

intermediate on rotationally grazed pastures and lowest on continuously grazed pastures. Nesting success was lowest on rotationally grazed pastures and highest on ungrazed grasslands. Even though a “pro-bird” rotational grazing system with a 1:2 ratio of refuge to grazed land is better than the typical forms of rotational or continuous grazing, the annual losses of some bird species associated with the non-refuge portion of the system are too great to be offset by the refuge portion of the system (Temple et al., 1999). Paine et al. (1996) conducted an experiment to show the effect of rotation frequency and stocking density on nest trampling. The stocking densities and durations included 8 head per hectare for 7 days, 15 head per hectare for 4 days, and 60 head per hectare for 1 day; trampling damage averaged 75 percent of the nests for all treatments. Further, nest trampling was inversely related to vegetation height-density, and percent ground cover.

Research-based recommendations for grassland bird habitat management

Most recommendations for grassland bird habitat management fall into one of three categories, 1) protocol suggestions for land managed specifically for bird habitat, and 2) creation and management of refuge areas near hay land and pasture, and 3) pasture and hay land management strategies to improve nesting success of grassland birds

Management of plant and residue structure by disturbances and planting

Frawley and Best (1991) claim that mowing and songbird reproduction are mutually exclusive. Native prairie grasses that are managed for bird nesting habitat should be disturbed as little as possible to maximize cover for nesting during the following spring (George et al., 1979). This management recommendation is qualified by others who indicate that periodic disturbance (i.e., mowing or burning) is a part of good grassland bird habitat management (Johnson and Temple, 1990) and can help

provide suitable habitat while controlling excessive residue and the encroachment of woody plants (George et al., 1979). While periodic disturbance is good, (Robel et al., 1998) point out that it should not be excessive; adverse impacts on grassland birds that rely on CRP land for nesting habitat can be reduced by avoiding annual burning. (Millenbah et al., 1996) suggest that every 3-5 years, CRP fields should be manipulated to provide a range of successional stages in order to optimize avian productivity, diversity, and abundance. Dale et al. (1997) advocate harvesting individual fields every other year at a date later than is typical for hay production in order to provide habitat and increase the productivity of grassland bird species that prefer dense cover. Mowing should be discouraged in areas where nesting success is critical (Camp and Best, 1994). When mowing dates must be established as part of a protocol, early cutting dates are more detrimental to nesting success than late cutting dates (Frawley and Best, 1991). When mowing right-of-ways, avoid unnecessary disturbance of vegetation suitable for nesting grassland birds by mowing only the shoulder of the roadside (Camp and Best, 1994). Camp and Best (1994) go on to suggest that native grasses should be included in the seeding mixtures used for road side right-of-ways in order to attract grassland birds and that roadside vegetation should be burned periodically to increase plant vigor and structural heterogeneity.

Creation and management of refuge areas near hay land and pasture

Several authors advocate the creation and maintenance of undisturbed cover suitable for nesting (i.e., “refuge”) near or within large hay fields in order to increase the success of resting efforts of grassland birds disturbed by haying or grazing activity (Temple et al., 1999; Warner and Etter, 1989). Where grassland bird management is a

priority, tracts of habitat should be large and far from wooded edges (Johnson and Temple, 1990). The topic of landowner compensation for management of grassland bird habitat is complex because the optimal program would be simple, effective, flexible, 'fair,' and would reward positive results. Musters (2001) suggest that producers be paid for nesting success rather than for following a protocol of government prescribed practices or for production losses. Because the optimal tract size for maximum grassland bird diversity is 200 ha (Vickery et al., 1994), perhaps there should be a premium value associated with such large tracts enrolled in conservation programs. Also, because of the large degrees of variability in environmental conditions in different zones of activity, local representative of governmental conservation agencies should be given great latitude in adjusting land management protocols and compensation packages.

Pasture and hay land management strategies to improve nesting success of grassland birds

Camp and Best (1994) agree, saying that mowing should be discouraged in areas where nesting success is critical. In order to increase grassland bird nesting success in Saskatchewan, (Dale et al., 1997) suggest delaying the first cutting until July 15 or later. George et al. (1979) suggest that in south-central Iowa, native warm-season grasses could be managed as nesting cover and forage if hay harvest began in early-July, grazing began in July-August, or if the stand was harvested for seed in September, as long as the particular activity did not reduce the residue height below 20-25 cm. For the conditions found in west-central New York, (Bollinger et al., 1990) suggest that bobolinks can benefit from management practices in which hay fields only are harvested every two or three years and not before mid-July in the year of harvest. Jensen et al. (1990) point out

that when nesting areas must be grazed, stocking intensity must be kept at levels consistent with land management objectives, understanding that higher stocking densities are more disruptive to ground nesting birds. Many of the management protocols that promote nesting success and increase avian productivity result in decreased forage quality due to advanced plant maturity advanced maturity stage (Collins, 2003) and decreased forage yield, as would be the case if the field was only harvested after July 15 every third year.

The initial objective of this study was to describe songbird species diversity in the respective pasture systems, describing apparent relationships between species spatial distribution and type of pasture system.

MATERIALS AND METHODS

Grazing Experiment

This experiment was conducted at W. K. Kellogg Biological Station in Hickory Corners, MI, on Kalamazoo series (fine-loamy, mixed, mesic Typic Hapludalfs) soils. Four replications of three treatments were assigned to the experimental area using a completely randomized design. The experimental area covered 19.4 ha, and was rectangular with dimensions of 268 m by 789 m, with 0.70 ha missing from the southeast corner. The long axis of the pasture had a north-south orientation. The layout is described in Figure A.1 of Appendix I. Both permanent and temporary fencing materials were used. The perimeter fence and five east-west fences were made of high-tensile wire and wooden fence posts. One semi-permanent fence divided the experimental area in half from north to south and was constructed of fiberglass posts, steel corner braces, and

aluminum wire and polywire. Inner temporary fences were constructed of plastic step-in posts and polywire.

The three treatments included:

1. A cool season grass-legume pasture representative of pastures found throughout the Lower Peninsula of Michigan. These pastures were comprised primarily of perennial ryegrass (*Lolium perenne*), quackgrass (*Agropyron repens*), alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*).
2. An integrated switchgrass and cool season grass-legume pasture. One-third of the system is a monoculture of switchgrass that was planted in 2002, and two-thirds is composed of the cool season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).
3. An integrated big bluestem and cool season grass-legume pasture. One-third of the system is a monoculture of big bluestem that was planted in 2002, and two-thirds is composed of the cool season grasses and legumes listed above (Barnhart, 1994; Undersander, 2002).

All pastures had an area of 1.6 hectares with the exception of two which, because of the shape of the experimental area and existing permanent fencing, differed somewhat.

The cool-season portions of all treatments predated this experiment. The major cool season species included: perennial ryegrass, Kentucky bluegrass, white clover, quackgrass, and alfalfa. In the planning stages of this experiment, differences in species abundance between replications were considered negligible and blocking was not

considered. After the experiment began, it became apparent that the variability in 'alfalfa abundance' was significant and should be considered a blocking effect. All pastures which were planted with alfalfa in 1994 were considered were included in 'alfalfa abundant' block. The pasture layout with respect to experimental treatments and alfalfa abundance is described in Figure A.2 of Appendix I.

The animals used in this study were Holstein steers that weighed approximately 240 kg at the beginning of the grazing season. Pastures were managed as uniformly as possible, but each was managed separately and optimally (Bransby, 1989). When grazing was initiated each spring, cattle on all treatments were given access to the entire cool-season portion of their respective pastures, with the exception of the fourth replication of the CS-Only treatment, where a concurrent experiment was being carried out which required that livestock be excluded from a portion of the pasture at certain points of time. As the spring flush of cool-season pasture growth intensified, pastures were "staged" (Barker, 1999): cattle were limited to one half, and later, one quarter of the cool-season portion of their treatments at which point rotational grazing began and continued until the end of the season. During the final grazing event of the season, the cattle were again given access to the entire cool-season portion of their respective pastures. In 2003, the big bluestem portion of the CS-BBS treatments was split into three parts each of which was grazed in rotation (the switchgrass portion of the CS-SG treatment was not grazed in 2003). In 2003, residue of refused big bluestem forage was clipped after grazing as needed in order to make the pasture height more uniform at subsequent grazing events. However, it was noted that the small size of the subdivisions within the big bluestem pasture resulted in excessive trampling of forage which caused a

high proportion of plants to re-grow from the crown rather from internodes, thereby increasing the amount of time required for regrowth. Further, the tractor tire tracks left from mowing caused the crushed plants to regrow from the crown; this regrowth was lush and tended to be grazed preferentially by the livestock. Thus, in 2004 and 2005 the WSG portions of the CS-BBS and CS-SG treatments were not subdivided or clipped and each WSG portions was left undivided and grazed as one of the rotations.

Decisions about timing and duration of rotations were dictated by current and anticipated pasture forage availability rather than using strict dates or interval lengths. Variables such as soil moisture, physiological and re-growth stages of forage species, typical seasonal weather patterns, and weather forecasts were used to make rotation decisions. After the spring flush, the grazing intervals were usually seven days for the CS-BBS and CS-SG treatments; CS-only treatments were usually rotated every ten days and consisted of four subdivisions.

Mid-season grazing pressure was adjusted using the put-and-take method¹ of pasture stocking (Mott, 1960). ‘Tester steers’ were left on the same replication of the same treatment for the entire grazing season. Put-and-take steers were added to or removed from a particular replication to increase or reduce the grazing pressure in order to:

- optimize utilization of pasture forage
- prevent the accumulation low-quality forage
- meet but not exceed the current or anticipated forage dry matter production

¹ See Technical Note 1 in Appendix III

Within an individual pasture, animals were rotated when one or more of the following was true: 1) paddocks forward in the rotations were about to become over-mature; 2) animals or pasture might be harmed by low forage levels in the current rotation; 3) rapid pasture growth indicated that shorter intervals were needed in the immediate future to prevent accumulation of low-quality forage which would likely be refused.

The anticipated date for termination of grazing was October 1, but pasture conditions including plant stress, drought, and forage dry matter availability were the primary considerations for termination of grazing for the season (Bransby, 1989; Leep, 2003). Dates of grazing and termination dates for each year are listed in Table 1.2 of Chapter 1 of this dissertation.

Bird Study

Data was collected from transects (Hostetler, 2006) walked on June 4, June 14, and July 2 of 2004 and July 9 of 2005. Transects had an east-west orientation and were 50 m wide, centered within the experimental units. The locations and species of birds were determined by sight and/or sound and recorded. A zig-zag pattern was used within each transect and only birds present within the transect were counted. On each of the four dates, surveys began approximately 30 minutes after sunrise, and took between 69 and 121 minutes to complete. All sample dates were at least partly sunny, calm, and between 12 and 21 °C.

Rodents were not recorded as suggested by the hypothesis. Birds species observed during counting events included savanna sparrow, bobolink, red-winged blackbird,

Canada geese, common grackle, house sparrows, barn swallows, cliff swallows, phoebe, and American robin, were not always included in the data set.

- Birds that were on the fence between experimental units (individual pastures) or on the perimeter fence were not counted.
- If a species was observed less than six times throughout the study, they were not included in the data set
- Although nest-defending behavior was occasionally noted it was not included in the analysis
- Canada geese were excluded from the analysis

The bird species that were present with sufficient frequency according to the above criteria were the savanna sparrow, red-winged blackbird, bobolink, and barn swallow. Because of the small size of the experimental units, even these species were present in low numbers, so their numbers were combined for data analysis. Table 4.1 lists the bird species found within the respective treatments during the observation periods.

Other species observed in, around, and over the experimental area during the course of the experiment include: cattle egret (*Bubulcus ibis*), Canada goose (*Branta Canadensis*), red-tailed hawk (*Buteo jamaicensis*), sandhill crane (*Grus Canadensis*), killdeer, snipe (*Gallinago spp.*), phoebe (*Sayornis spp.*), horned lark, eastern bluebird (*Sialia sialis*), American robin (*Turdus migratorius*), common grackle (*Quiscalus quiscula*), house sparrow (*Passer domesticus*), tree swallow (*Tachycineta bicolor*), mallard duck (*Anas platyrhynchos*), European starling (*Sturnus vulgaris*), American goldfinch (*Carduelis tristis*), American crow (*Corvis brachyrhynchos*), mourning dove

(*Zeniada macroura*), chipping sparrow (*Spizella passerine*), field sparrow, kingbird (*Tyrannus spp.*), and rock dove (*Columbia liva*)

Statistical Analysis

Because the low bird numbers and the sub-optimal size of the experimental area, it was not realistic to attempt to statistically evaluate the original hypothesis. Rather, the total numbers of birds observed within each treatment (using the three criteria listed above) were compared.

PROC GLIMMIX of Statistical Analysis Systems (SAS) Version 9.1.3 was used to conduct analysis of variance tests for the bird population data. The following data transformation was used: $\log(\text{total} + 1)$, where ‘total’ represented the combined number of savanna sparrows, red-winged blackbirds, bobolinks, and barn swallows observed in a particular experimental unit on one of the four sampling dates. This data transformation was necessary to normalize the distribution of residuals. Bird counts were taken on day of year (DOY) 155, 165, and 184 (June 4, June 14, and July 2, respectively) of 2004 and DOY 190 (July 9) of 2005.

Treatment, year, and the interaction of treatment and year were evaluated in the statistical model. Year and the treatment by year interaction were not statistically significant, but the effect of treatment was statistically significant. Thus, the statistical model for total bird population includes the effect of treatment only. Day of year was treated as a random effect.

The full model for forage dry matter offered is:

$$y_i = \mu + A_i + e_i$$

where:

y_i is the average number of birds observed in i^{th} treatment on any sampling date.

and:

μ is the overall mean

A_i is a fixed effect, the i^{th} treatment (CS-BBS, CS-Only, CS-SG)

e_i is the error term

RESULTS AND DISCUSSION

While the overall model was statistically significant, the only comparison that approached statistical significance ($p = 0.07$) was between the CS-BBS and CS-SG treatments. Each CS-BBS pasture had an average of 2.6 birds per transect, while the CS-Only and CS-SG treatments had 1.9 and 1.7, respectively (see Table 4.2). Environmental conditions are described in Figures A.3-A.5 of Appendix I.

If the experimental area had been optimally designed for bird research, a less stringent p-value might be appropriate. The greatest weakness of the bird portion of this study was the size of the experimental units. Vickery et al. (1994) point out that even if a unit of cover has excellent plant and residue structure for a bird species, it might still be refused by that species due to the insufficient area of the otherwise acceptable habitat. Another difficulty was that replications of different treatments were immediately adjacent to each other and it is very likely that the sphere of influence of one treatment overlapped into adjacent treatments or that the territory of one bird might overlap into as many as four different experimental units, given that the size of red-winged blackbird and savannah sparrow territories can both exceed 1 ha (Albers, 1978; Weins, 1973).

Very few birds were documented in the big bluestem or switchgrass portions of their respective treatments. Excluding the birds observed between experimental units or on the perimeter fence, a total of 96 birds were counted within the experimental area. Of these, only eight were observed in the big bluestem and switchgrass pastures, combined. While the combined area of the big bluestem and switchgrass pastures comprised about 23% of the experimental area, only 8% of the birds counted were within those pastures. There may be several reasons for this beyond insufficient size. The first is that residue was always burned prior to the next grazing season, which left little or no cover suitable for early-spring nesting (George et al., 1979). Big bluestem and switchgrass residue was burned in the spring of 2004, prior to initiation of active growth and again in the fall of 2004 (rather than in the spring of 2005). Second, spring growth of switchgrass and big bluestem is slow and little cover or structure is created until much later than in the cool-season portions of the respective treatments. Third, because the switchgrass and big bluestem pastures were managed with the goal of creating/maintaining a monoculture, there tended to be less plant structural heterogeneity (McMaster and Davis, 2001) than in the cool-season portions of the experimental area. The periodic mowing and moderate grazing intensity probably attracted savannah sparrows and bobolinks, although it probably reduced nesting success for those and other bird species (Bollinger et al., 1990; Dale et al., 1997; Warner and Etter, 1989). Albers (1978) noted that red-winged blackbirds abandon their territories within 48 hours of mowing, and this is likely true of other species. It is possible that an experimental unit that is preferred by one or several bird species could be mowed and the adult birds with territories within that area could quickly move to adjacent or distant experimental units which may or may not be a

replication of the same treatment. This clearly would confound treatment effects.

Fourth, the disparity in the number of birds counted in cool-season pastures compared with the number observed in switchgrass and big bluestem pastures could be partially due to the presence of subdividing temporary fence (functioning as perches) in the cool-season pastures and the absence of those fences in the big bluestem and switchgrass pastures. Finally, the intersection of the big bluestem and switchgrass pastures with the cool-season portions of the treatments also presented an abrupt edge which may have increased bird predation (Gates, 1978; Ratti and Reese, 1988). Anecdotally, nesting activity was noted beneath the temporary fences, probably the result of re-nesting activity following nest destruction due to grazing or mowing; these areas tended to be less disturbed by grazing and mowing activities.

The earliest date that surveys began in either year was June 4. Bird studies that hope to be able to describe something about the seasonal dynamics of bird populations and/or nesting success typically begin by early-May; examples of this can be found in many other studies of grassland bird populations including: DeLislie and Savidge (1997), Frawley and Best (1991), Herkert (1994), and Millenbah et al. (1996). While beginning the surveys earlier in the spring almost certainly would have demonstrated greater bird species richness and the total number of birds observed in each transect, the small size of the study area still would have greatly limited the interpretation of the superior dataset.

CONCLUSION

A significant difference in the number of birds among the pasture treatments was not found. The size and design of the greater grazing experiment was not suitable for rigorous research on the effect of native warm season grasses in grazing systems on

grassland bird species. While periodic mowing is realistic agronomic management, grazing (Temple et al., 1999) and mowing activity (Bollinger et al., 1990; Frawley and Best, 1991) can be very disruptive to nesting birds, and probably confounded the objective. Studies designed to describe the effect of big bluestem or switchgrass on grassland birds populations in integrated grazing systems should begin earlier in the spring, on a much larger experimental area, and include a treatment where the pastures are not mowed.

Table 4.1. Birds observed within each treatment during observation periods.

Bird Species	Treatment		
	CS-BBS	CS-Only	CS-SG
american robin		X	
barn swallow	X	X	X
bobolink	X	X	X
Canada goose		X	
common grackle		X	
house sparrow			X
red winged blackbird	X	X	X
savanna sparrow	X	X	X

Table 4.2. Average number of birds per transect as affected by treatment.

Treatment	Average Bird Count*	SE
CS-BBS	2.6 a	0.3
CS-Only	1.9 a	0.3
CS-SG	1.7 a	0.3

*Numbers within the column with the same letter are not statistically different ($P \leq 0.05$)

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Appendix I: Experimental Design and Environmental data

Figure A.1. Positioning of treatment replications within the experimental area.



Figure A.2. Pasture layout with respect to alfalfa abundance

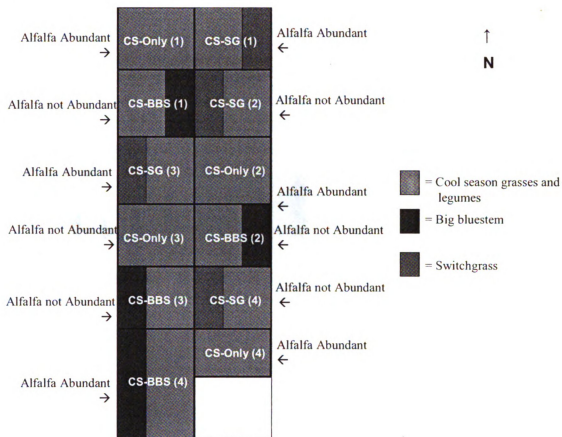


Figure A.3. Precipitation by month for Hickory Corners, MI (KBS-LTER, 2005).

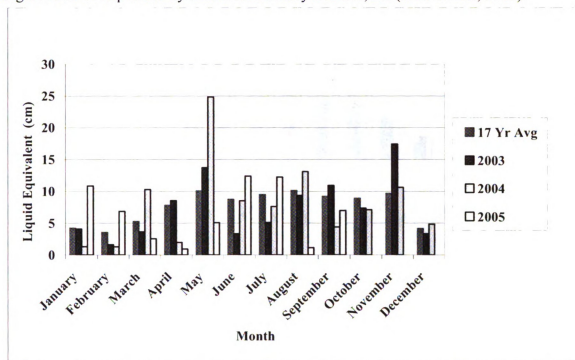


Figure A.4. Mean air temperature by month for Hickory Corners, MI (KBS-LTER, 2005).

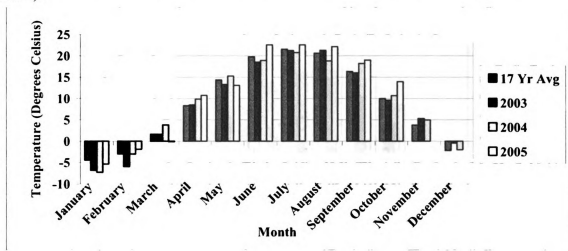
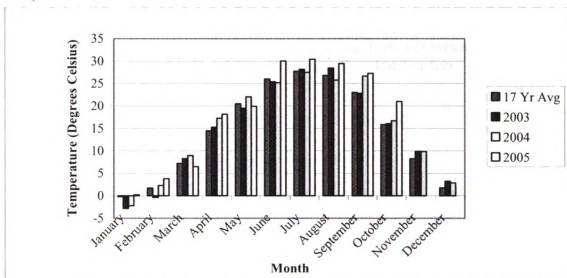


Figure A.5. Maximum air temperature by month for Hickory Corners, MI (KBS-LTER, 2005).



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Appendix II: Botanical Composition

Fifty nine plant species were found in pastures throughout the experiment (see Tables B.1-B.2). Pasture botanical composition is described in terms of species and plant category over time. The four categories used to describe pasture plants include: forage grass, forage legume, palatable weed, and undesirable weed. In this context, ‘palatable’ means that when a given plant species is in a vegetative stage the plant is not selectively refused by grazing animals (e.g., dandelion). “Undesirable” pasture plants are either clearly selectively refused plants (e.g., bull thistle) or those that are generally known to be eaten rarely by cattle (e.g., corn speedwell).

Botanical Composition by Experimental Treatment: Pasture Plant Categories

Forage grass DM percent remained at similar levels among treatments over time (Figure B.1).

Forage legume DM percent differences among treatments were greatest at the time of the first data collection in 2003 (Figure B.2). Clover was no-tilled twice into the CS portion of all treatments in 2003. At the time of the first botanical composition assessment in 2004, the legume percentage of forage DM was similar among treatments and remained similar for the duration of the experiment.

Palatable pasture weed dry matter fluctuated between 3% and 12% throughout the experiment; trends were similar among treatments (Figure B.3). Treatment differences of percent pasture DM made up of undesirable pasture weeds were greatest in 2003 and tended to converge over time, although seasonal fluctuations were evident (Figure B.4)

Treatment botanical composition by plant type

Weed dynamics in particular agricultural systems are influenced by the patterns of disturbance of plants and soil. In the case of grazing systems which range from continuous to intensive rotational in nature, specific weed species can either be favored or selected against. For example, Canada thistle is favored by continuously grazing pastures, while high-intensity, low-frequency grazing causes the frequency of Canada thistle (De Bruijn, 2006). Alternately, excessive grazing under particular conditions can cause other weed species to proliferate (Harker, 2000). In all treatments of this study three trends emerged from botanical composition data relative to plant type:

- Grass and legume dry matter percent were relatively stable (Figures B.1-B.2)
- Palatable weeds were stable or increased slightly over the course of the experiment (Figure B.3)
- Undesirable weeds declined from 2003 to 2005 (Figure B.4).

Botanical Composition by Experimental Treatment: Major Pasture Plant Species

Orchardgrass, tall fescue, and white clover were no-till seeded in the CS portions of all treatments in 2003. Tables B.3-B.5 show the contribution of major plant species to botanical composition of each treatment over time. In each treatment, the percent dry matter contributed by orchardgrass increased from August of 2004 through July of 2005. For pasture plant species that are very sensitive to drought conditions, true differences in botanical composition due to pasture management should be more evident after periods of adequate soil moisture. The DM contributed to each treatment by white clover increased markedly from May 2003 to June 2004 and May 2005 while the DM contributed by alfalfa declined over those same years and months. In each treatment,

perennial ryegrass was the major forage grass species, while quackgrass contributed significantly to each treatment at different times.

Prior to the assignment of treatment replications to the subdivisions within the area allotted for the experiment, differences in forage species abundance among the experimental units were considered negligible. After the experiment began, it became apparent that 'alfalfa abundance' should be considered as a blocking effect. The result of the random assignment of treatments to the available pasture areas irrespective of alfalfa abundance resulted in the CS-BBS treatment only being assigned to one replication with 'abundant alfalfa' while three of the CS-Only and two of the CS-SG replications had abundant alfalfa (Appendix I, Figure A.2). Thus, when botanical composition by treatment is considered, the CS-Only treatment clearly contains a higher percentage of legume (primarily alfalfa) than the CS-BBS treatment. The disparity of legume content between treatments was recognized in early-Spring of 2003, and white clover was planted (no-till) into the living sod the CS portion of each treatment. The percentages of legumes in each of the treatments converge in June of 2004 and remain roughly parallel after that point.

WSG botanical composition

The big bluestem and switchgrass monocultures generally remained at or above 80% crop dry matter at the height harvested (Figure B.5). Crabgrass growth below the sampling height was often dense in the switchgrass portion of the CS-SG treatment. Anecdotally, the steers preferred crabgrass over switchgrass, and the crabgrass contributed significantly to the quantity and the quality of the forage consumed. In 2003 and 2004, there was significant competition from quackgrass in the switchgrass and big

bluestem portions of their respective treatments; this problem was mitigated by an application of glyphosate to dormant big bluestem and switchgrass monocultures in April 2005 (See Chapter 1 Materials and Methods).

Table B.1. Latin and common names of forage and palatable non-forage species found in the CS portions of all treatments throughout the experiment.

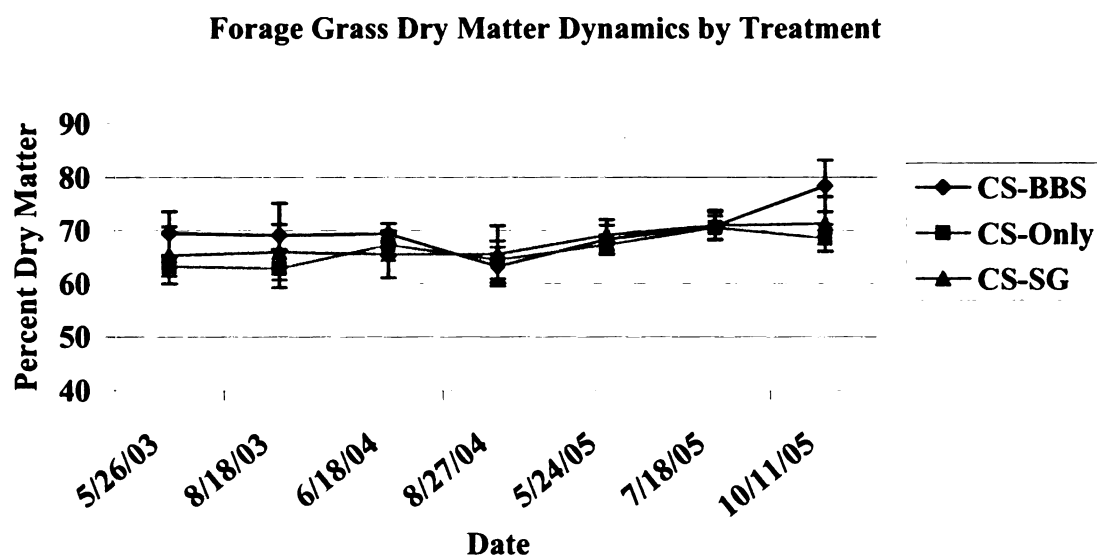
Latin Name	Common Name	Type*
<i>Agropyron repens</i> (L.) Beauv	quackgrass	FG
<i>Agrostis stolonifera</i> L. var. <i>palustris</i> (Huds.) Farw.	bentgrass	FG
<i>Bromus inermis</i> Leyss.	smooth brome grass	FG
<i>Dactylis glomerata</i> L.	orchardgrass	FG
<i>Festuca arundinacea</i> Schreb.	tall fescue	FG
<i>Lolium perenne</i> L.	perennial ryegrass	FG
<i>Lolium perenne</i> L. x <i>Schedonorus pratensis</i> (Huds.) Beauv.	festulolium	FG
<i>Phleum pratense</i> L.	timothy	FG
<i>Poa pratensis</i> L.	Kentucky bluegrass	FG
<i>Lotus corniculatus</i> L.	birdsfoot trefoil	FL
<i>Medicago lupulina</i> L.	black medic	FL
<i>Medicago sativa</i> L.	alfalfa	FL
<i>Trifolium ambiguum</i> Bieb.	kura clover	FL
<i>Trifolium hybridum</i> L.	alsike clover	FL
<i>Trifolium pratense</i> L.	red clover	FL
<i>Trifolium repens</i> L.	white clover	FL
<i>Digitaria ischaemum</i> (Schreb. ex Schweig.) Schreb. ex Muhl	smooth crabgrass	PG
<i>Digitaria sanguinalis</i> (L.) Scop.	large crabgrass	PG
<i>Eleusine indica</i> L. Gaertn.	goosegrass	PG
<i>Poa annua</i> L.	annual bluegrass	PG
<i>Stellaria media</i> (L.) Vill.	common chickweed	PB
<i>Taraxacum officinale</i> Weber	dandelion	PB
<i>Chenopodium album</i> L.	lambsquarters	PB
<i>Cerastium vulgatum</i> L.	mouseear chickweed	PB
<i>Amaranthus retroflexus</i> L.	redroot pigweed	PB
<i>Silene latifolia</i> Poir.	white campion	PB

*FG: forage grass; FL: forage legume; PG: palatable grass weed; PB: palatable broadleaf weed

Table B.2. Latin and common names of undesirable plant species found in the CS portions of experimental pastures

Latin Name	Common Name
<i>Erigeron annuus</i> (L) Pers.	annual fleabane
<i>Plantago aristata</i> Michx.	bracted plantain
<i>Plantago major</i> L.	broadleaf plantain
<i>Cirsium vulgare</i> (Savi) Tenore	bull thistle
<i>Cirsium arvense</i> (L.) Scop.	canada thistle
<i>Bromus tectorum</i> L.	cheat/downy brome
<i>Malva neglecta</i> Wallr.	common mallow
<i>Ambrosia artemisiifolia</i> L.	common ragweed
<i>Rumex acetosella</i> L.	common red sorrel
<i>Veronica arvensis</i> L.	corn speedwell
<i>Oxalis corniculata</i> L.	creeping woodsorrel
<i>Rumex crispus</i> L.	curly dock
<i>Panicum dichotomiflorum</i> Michx.	fall panicum
<i>Thlaspi arvense</i> L.	field pennycress
<i>Glechoma hederacea</i> L.	ground ivy
<i>Lamium amplexicaule</i> L.	henbit
<i>Conyza canadensis</i> (L.) Cronq.	marestail
<i>Plantago lanceolata</i> (L.)	narrowleaf plantain
<i>Veronica persica</i> Poir.	persian speedwell
<i>Matricaria matricaroides</i> (Less.) Porter	pineapple weed
<i>Lactuca serriola</i> L.	prickly lettuce
<i>Polygonum arenastrum</i> Jord. ex Bor.	prostrate knotweed
<i>Portulaca oleracea</i> L.	purslane
<i>Daucus carota</i> L.	Queen Anne's lace
<i>Potentilla norvegica</i> L.	rough cinquefoil
<i>Erigeron strigosus</i> Muhl. Ex Willd.	rough fleabane
<i>Capeslla bursa-pastoris</i> (L.) Medic.	shepherd's purse
<i>Centaurea maculosa</i> Lam.	spotted knapweed
<i>Rhus</i> or <i>Toxicodendron</i>	sumac
<i>Sisymbrium altissimum</i> L.	tumble mustard
<i>Amaranthus albus</i> L.	tumble pigweed
Several unknown species	unknown
<i>Abutilon theophrasti</i> Medic.	velvetleaf
<i>Barbarea vulgaris</i> R. Br.	yellow rocket
<i>Oxalis stricta</i> L.	yellow woodsorrel

Figure B.1. Forage grass percentage of total CS pasture dry matter from 2003-2005.



Percent forage grass is relatively constant over time and changes are roughly parallel among treatments.

Figure B.2. Forage legume percentage of total CS pasture dry matter from 2003-2005.

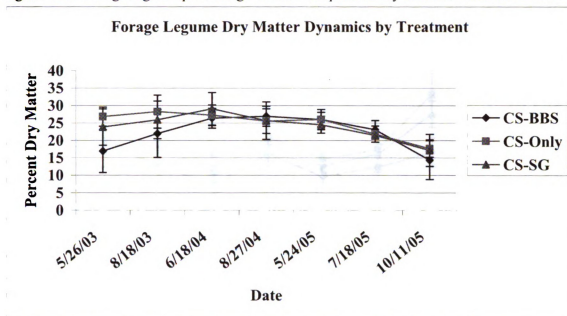


Figure B.3. Palatable weed percentage of total CS pasture dry matter from 2003-2005.

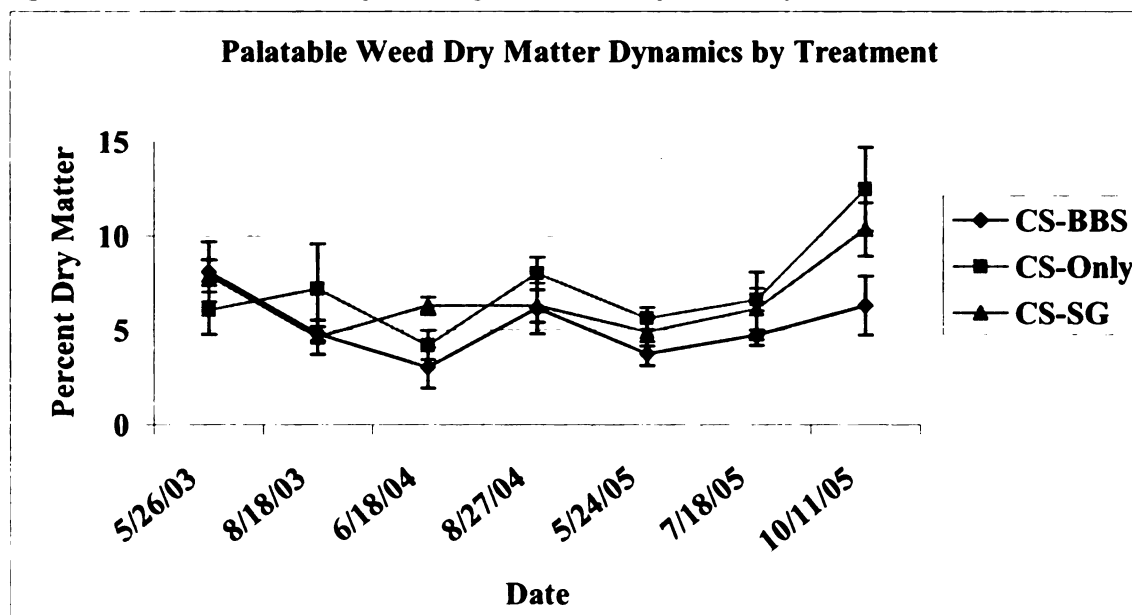


Figure B.4. Undesirable weed percentage of total CS pasture dry matter from 2003-2005.

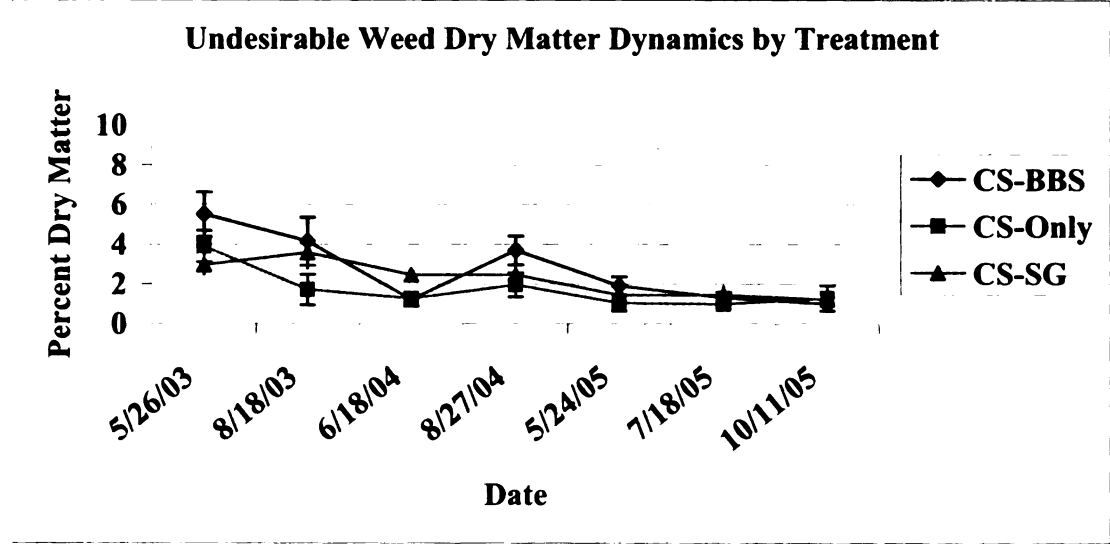


Table B.3. Contribution of major pasture plant species to botanical composition of the cool-season portion of the CS-BBS treatment.

Species	Date	5/26/03	8/18/03	6/18/04	8/27/04	5/24/05	7/18/05	10/11/05
Kentucky bluegrass	avg	4.6	4.2	5.6	4.2	9.3	3.9	11.7
	SE	1.6	1.8	1.7	1.7	2.9	2.5	4.2
orchardgrass	avg	0.8	0.7	0.9	2.0	5.7	17.2	16.9
	SE	0.1	0.0	0.5	0.7	1.7	3.5	2.9
perennial ryegrass	avg	45.2	43.9	48.3	46.9	45.6	46.0	36.3
	SE	3.5	5.9	2.5	2.4	0.8	4.2	2.2
quackgrass	avg	19.2	20.3	15.3	10.2	7.5	3.8	12.2
	SE	1.9	2.0	3.3	2.4	2.4	1.6	2.1
alfalfa	avg	8.0	10.9	3.2	5.7	1.6	5.0	5.1
	SE	7.6	9.3	3.0	4.2	1.3	3.9	3.5
white clover	avg	8.6	4.2	16.9	14.1	19.0	7.5	8.5
	SE	1.5	0.5	2.7	3.9	3.5	2.6	3.2
dandelion	avg	2.5	3.0	1.2	3.6	2.2	4.1	6.2
	SE	1.0	0.5	0.2	0.2	0.3	0.4	1.6
curly dock	avg	3.3	2.7	1.0	3.3	1.4	1.1	0.7
	SE	1.1	0.9	0.3	0.9	0.4	0.3	0.2
Type								
forage legume	avg	16.9	22.0	26.4	26.9	26.0	23.1	14.4
	SE	6.2	6.9	2.9	2.9	2.9	2.6	5.5
forage grass	avg	69.5	69.1	69.4	63.2	68.3	70.8	78.3
	SE	4.1	6.0	1.9	3.7	2.6	2.7	4.8
palatable weeds	avg	8.1	4.8	3.0	6.2	3.8	4.7	6.3
	SE	1.6	0.4	1.1	1.4	0.6	0.3	1.6
undesirable weeds	avg	5.5	4.1	1.2	3.7	1.9	1.3	1.0
	SE	1.1	1.2	0.3	0.7	0.5	0.3	0.3

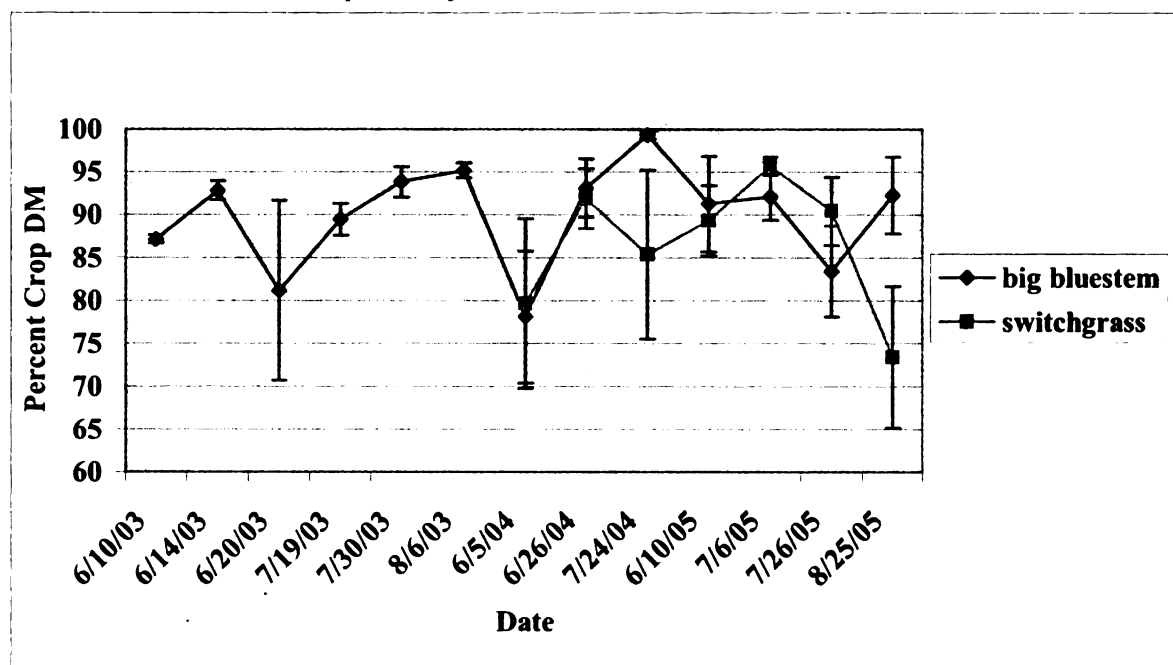
Table B.4. Contribution of major pasture plant species to botanical composition of the CS-only treatment

Species	Date	5/26/03	8/18/03	6/18/04	8/27/04	5/24/05	7/18/05	10/11/05
Kentucky bluegrass	avg	0.6	1.0	1.7	2.1	2.2	2.0	2.2
	SE	0.2	0.5	1.1	0.5	1.0	0.4	0.4
orchardgrass	avg	0.3	2.1	2.4	3.4	4.8	10.4	8.2
	SE	0.0	1.0	1.5	2.1	2.2	1.8	0.7
perennial ryegrass	avg	50.8	50.7	53.8	50.9	51.7	51.8	45.4
	SE	2.7	2.9	1.8	2.2	3.8	3.3	3.3
quackgrass	avg	12.0	10.3	9.9	7.9	8.7	5.8	11.0
	SE	2.0	1.4	0.9	1.4	2.6	1.9	1.8
alfalfa	avg	15.1	18.6	8.9	8.6	7.0	9.6	7.5
	SE	4.9	5.8	2.9	2.9	2.4	3.2	2.3
white clover	avg	11.4	7.3	16.3	13.6	16.3	8.6	7.1
	SE	2.3	2.5	1.6	2.8	2.3	1.5	2.4
dandelion	avg	3.4	7.0	3.1	6.9	4.4	6.2	12.4
	SE	1.4	2.3	0.6	1.0	0.6	0.6	2.2
curly dock	avg	1.7	0.9	0.9	1.1	0.6	0.7	0.9
	SE	0.6	0.6	0.2	0.5	0.3	0.2	0.4
Type								
forage legume	avg	26.8	28.2	27.2	25.5	26.0	21.8	17.7
	SE	2.7	4.7	3.0	3.5	2.1	2.3	2.5
forage grass	avg	63.2	62.9	67.3	64.5	67.3	70.5	68.5
	SE	1.8	3.6	2.2	3.5	1.9	2.2	2.6
palatable weeds	avg	6.1	7.2	4.2	8.0	5.6	6.6	12.5
	SE	1.3	2.4	0.8	0.9	0.6	0.6	2.2
undesirable weeds	avg	3.9	1.7	1.3	2.0	1.0	1.0	1.3
	SE	0.8	0.8	0.3	0.6	0.4	0.3	0.6

Table B.5. Contribution of major pasture plant species to botanical composition of the cool season portion of the CS-SG treatment.

Species/type	Date	5/26/03	8/18/03	6/18/04	8/27/04	5/24/05	7/18/05	10/11/05
Kentucky bluegrass	avg	1.3	1.5	1.1	2.1	1.8	4.6	3.9
	SE	0.8	0.4	0.4	0.5	0.9	1.7	0.8
orchardgrass	avg	0.9	0.3	0.7	2.2	2.9	6.3	9.8
	SE	-	0.1	0.4	0.7	1.4	1.4	1.8
perennial ryegrass	avg	53.5	55.5	53.7	54.2	56.1	56.3	50.3
	SE	7.5	6.6	6.7	7.2	3.8	3.2	3.9
quackgrass	avg	10.5	8.9	10.1	6.6	8.3	3.6	6.3
	SE	3.1	1.5	2.7	1.8	2.6	1.2	1.7
alfalfa	avg	13.3	13.3	6.1	5.4	4.8	8.5	4.7
	SE	6.3	6.1	3.0	2.7	2.7	4.5	2.4
white clover	avg	10.3	10.3	19.9	17.2	16.7	9.2	10.9
	SE	1.3	2.2	3.8	4.4	2.2	1.7	3.7
dandelion	avg	3.4	4.1	2.8	5.5	3.4	5.7	10.2
	SE	1.1	0.8	0.6	0.8	0.6	1.8	1.4
curly dock	avg	1.0	1.2	0.2	1.3	1.0	0.5	0.6
	SE	0.3	0.4	0.1	0.4	0.1	0.2	0.2
forage legume	avg	23.8	25.9	29.1	25.7	24.5	21.4	17.2
	SE	5.2	5.4	4.7	5.4	2.4	1.1	4.6
forage grass	avg	65.3	65.9	65.6	65.6	69.2	71.0	71.3
	SE	5.4	5.2	4.4	5.4	2.9	2.8	5.1
palatable weeds	avg	7.9	4.6	6.3	6.3	4.9	6.1	10.4
	SE	0.8	0.9	0.5	0.9	0.7	2.0	1.4
undesirable weeds	avg	3.0	3.6	2.5	2.5	1.4	1.4	1.2
	SE	0.5	0.8	0.3	0.6	0.3	0.4	0.5
total	avg	100	100	100	100	100	100	100

Figure B.5. Crop percentage of big bluestem and switchgrass pastures from the CS-BBS and CS-SG treatments, respectively.



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- MDNR. No date. Plant species: rough cinquefoil (*potentilla norvegica*). [Online]. http://www.michigan.gov/dnr/0,1607,7-153-10370_12146_12213-36280--,00.html (verified 05/23/08).

Appendix III: Technical Notes

Technical Note 1:

Testers were assigned differently in each year, but within each year they were assigned in the same manner for each treatment.

2003: Testers were not assigned at the beginning of the season. At the beginning of the grazing season all animals were put on their respective pasture as described in Chapter 3. As the grazing season progressed and pasture growth declined and the animals increased in size, the smaller animals were removed as indicated by pasture condition indicators. Steers that remained on the trial all summer were designated ‘testers’. This minimized social disturbance resulting from taking a more dominant animal from the pastures.

2004: The poor gainers were taken off first. Some of the low gains seemed anomalous and it was believed that they would severely, artificially, and adversely affect the mean ADG for the replication. The steers used in this experiment were from an auction and were presumably of the Holstein breed. While most of them appeared to be Holsteins and were relatively uniform in size, there seemed to be some variability in age and previous treatment. To avoid biasing the averages, we continued to take the lesser gainers off, assigning them ‘put-and-take’ status in order to avoid confounding the averages. Hill (2004) indicated that using the top number of animals (the same proportion of lower gainers removed for each before the average is calculated) is defensible in order to remove bias against a particular system.

2005: Testers were assigned beforehand, with the understanding that animals that turned out to be anomalous could be re-classified (i.e., ‘tester’ or ‘put-and-take’) if necessary.

Technical Note 2:

On one occasion, one or more forage samples were dried at a different research farm where the plant tissue oven-driers were set at 60°C (rather than 43°C) for a minimum of 48 hours and then weighed.

Technical Note 3:

On one occasion 80 rising-plate meter readings were recorded taken rather than 100; on all other occasions that the rising plate meter was used, deviation from the protocol of collecting 100 rising-plate meter readings were small and associated with worker error

Technical Note 4:

In house modifications of the Modified Van Soest method described in the laboratory manual of the Department of Animal Science, University of Minnesota (Stern, 1991) were used to determine neutral detergent fiber and acid detergent fiber concentrations:

- 263.0 g of EDTA was used rather than 236.0 g.
- Acid detergent fiber analysis: fiber samples were each rinsed once with acetone rather than twice.
- Weighing ash: after placing crucibles in the muffle furnace for five hours at 500 °C, the crucibles were allowed to cool and then placed in drying oven at 105 °C for a minimum of 12 hours and then weighed.

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- Hill, G.M. 2004. Designating 'testers' in the put-and-take method adjusting grazing pressure, pp. Telephone conversation, *In* D. J. Hudson, (ed.), Hickory Corners, MI.
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