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# INCORPORATION OF SUMMER ANNUAL MIXTURES INTO GRAZING SYSTEMS IN KENTUCKY

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# INCORPORATION OF SUMMER ANNUAL MIXTURES INTO GRAZING SYSTEMS IN KENTUCKY

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DISSERTATION

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A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture, Food and Environment
at the University of Kentucky

By
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2021

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# ABSTRACT OF DISSERTATION

## INCORPORATION OF SUMMER ANNUAL MIXTURES INTO GRAZING SYSTEMS IN KENTUCKY

Utilizing summer annual grass-legume forage mixtures has the potential to improve forage yield and nutritive characteristics, and/or animal performance during times when cool-season pasture growth is limited by high temperatures. Legumes can utilize atmospheric nitrogen, which can increase crude protein and forage digestibility in mixtures. As nitrogen application generally improves both the yield and nutritive characteristics of summer annual forages, but can have a negative effect on legume competitiveness, nitrogen fertilizer recommendations for legume-containing summer annual mixtures are not well established.

Two experiments were conducted to determine the feasibility of utilizing summer annual mixtures in Kentucky, USA. The first experiment was a small plot study. The objective was to evaluate the effects of increasing botanical diversity and N application rates on the yield, botanical composition, and nutritive characteristics of summer annual forage mixtures. The second experiment was a grazing study that evaluated the effects of increasing summer annual species diversity on forage yield and nutritive value, and animal performance.

In the first experiment, N rates of 0, 56, 112, 168, and 224 kg N ha-1 were applied to a sudangrass monoculture, a three-species mixture, and an 11-species mixture. Sward biomass in three out of four environments increased as N application increased (average of 14 kg DM ha-1 per kg N ha-1; $p < 0.05$). As all treatments were dominated by grass species, mixture complexity had no effect on forage DM accumulation for three out of four environments (4000, 5830, and 7280 kg DM ha-1 averaged over N rates for three environments; $p > 0.05$). Swards were dominated by sudangrass and pearl millet (73 and 24% in simple mixtures, and 62 and 22% in complex mixtures, respectively), resulting in low functional diversity, likely due to high grass seeding rates. Mixture complexity also did not affect most nutritive characteristics ($p > 0.05$). Although N application up to 224 kg N ha-1 often had a positive impact on forage quality parameters, forages in three out of four environments would not support the nutritional demands of growing or lactating cattle when averaged across harvests. A sensitivity analyses showed that applying N resulted in positive net returns only when hay prices were very high and N prices were low. When pasture utilization rates and hay feeding/storage losses are accounted for, enterprise budgets determined grazing to have 10% greater expenses than haying.

In the second experiment, yearling angus-cross beef calves were assigned to graze one of three summer annual forage treatments, a sorghum-sudangrass monoculture, a simple three-species mixture, or a complex 12-species mixture. Animals grazed for an average of 40 days per year without supplementation. Forage yield was not different between treatments ($P > 0.85$). Although several forage quality parameters were affected by mixture, none provided useful insight into differences observed in average daily gain (ADG). In 2017 and 2019, calves grazing the monoculture and simple mixture had higher ADG than calves grazing the complex mixture (2017: 0.79 vs. 0.66 kg/day, $P < 0.03$; 2019:

0.59 vs. 0.43 kg/day, $P < 0.03$). In 2018, there were no differences in ADG ($P > 0.3$); however, calves only gained 0.01 kg/day, possibly due to lower nutritive value of more mature forages. Forages in 2018 were abnormally tall and calves were observed to be flightier and more agitated. The added stress of a low-visibility environment may have contributed to poor gains. Taller forages may also have limited dry matter intake and/or sward utilization since calves could not reach the top of the plants.

In these studies, increasing species diversity did not improve forage yield, nutritive characteristics, or animal performance. This was likely due to heavy grass competition and poor legume establishment. If sward diversity is of interest, care must be taken to select compatible species, utilize appropriate seeding rates, and implement management that will promote less well-adapted species. Under the constraints of these experiments, utilizing summer annuals in forage systems in Kentucky would only be economical when hay costs were high, when production costs were low, and when animal performance was enhanced.

KEYWORDS: diversity, N rate, yield, forage quality, average daily gain, economics

Kelly Marie Mercier

04/29/2021

Date

# INCORPORATION OF SUMMER ANNUAL MIXTURES INTO GRAZING SYSTEMS IN KENTUCKY

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To each and every individual that has helped me struggle and muddle through this, I couldn’t have asked for better people. In the famous words of Dr. Chris Teutsch: "You rock!"

To anyone who needs a laugh or motivation to keep it going through the grad school struggle, I’ll supply you with some phrases and words of wisdom that may or may not have described my time as a graduate student:

- Hang on, I’m not dumb, I’m just panicking. -Carson Braun (@cbraun3124), Twitter
- Don’t miss out on something that could be great just because it could also be difficult. -Unknown
- The definition of ‘feckless’: generally incompetent and ineffectual.
- If you’re not breaking stuff, you’re not working hard enough. -2018 Forage Crew Motto
- u ever just…..love cows? Big ‘ol grass puppers…moo -drizzlebub, tumblr
- Complaining about a problem without posing a solution is called whining. -Theodore Roosevelt
- Not my research, not my problem. -Me
- “This isn’t fun at all.” Anonymous Forage Intern
- Remember, you are a kernel of corn in the digestive tract of life: things may get [crappy], but don’t worry, you’ll make it out whole. -Unknown
- My mind not only wanders, it sometimes leaves completely. -Unknown
- [Screwing] around for three days and then making a herculean effort on day four that restores your average progress to what a moderately inept person would have achieved with consistent effort, that’s what it’s all about. -argumate, tumblr
- You gotta get burned out for it to count. -Alex Teutsch
- Have a couple of drinks, accept it, move past it, and don’t mess up tomorrow. -Anonymous

- I like being a pessimist because you’re either right, or you’re pleasantly surprised. -Dr. Ben Goff
- There’s rock bottom, fifty feet of crap, then me. -Rachel from Friends
- Life is like a helicopter. I don’t know how to operate a helicopter. -Unknown
- You can be right or you can be happy. -Gerald G. Jampolsky
- This too shall pass. It may pass like a kidney stone, but it will pass. -Unknown
- Parents: What are you doing with your life? Me: It’s a surprise. Me to me: What AM I doing with my life?
- Life is tough little darlin’, but so are you. -Unknown
- Chase your dreams but always know the road that will lead you home again. -Tim McGraw
- Of all the paths you take in life, make sure a few of them are dirt. -John Muir
- It will all be ok in the end. If it is not ok, it is not the end. -John Lennon
- Happiness can be found even in the darkest of times if only one remembers to turn on the lights. Albus Dumbledore, Harry Potter and the Chamber of Secrets
- All I need to know about life I learned from a Cow:

  If it's good, milk it for all it's worth
  Successful people are "moo-vers and shakers"
  Don't be just one of the herd
  The cream always rises to the top
  Don't stoop to a barnyard mentality
  Don't be bossy
  It's better to have milked and churned than to have never milked at all
  If you need to get somewhere, hoof it
  Some days can be udder frustration
  If you're feeling low, moo yourself a little song
  Chew your food 50 times before swallowing
  Don't let others corral you
  Munch hay while the sun shines
  He who lives with the herd learns to watch his step
  Following your heart will always steer you in the right direction
  Party 'till the cows come home
  Live for-heifer young
  Here a moo, there a moo, ever where a moo-moo
  -Unknown

A collection of my favorite cow jokes.

- What do you call a cow that cuts the grass? A lawn moo-er.
- What do you call a cow with a twitch? Beef jerky.
- A herd of cows walked into a cannabis field. The steaks have never been higher.
- If a cowboy is happy, does that make him a jolly rancher?
- The cow said, “Some guy pulled my teat. How dairy!”
- My grandfather was a knight. His name was Sir Loin.
- What do you call a sleeping cow? A bull-dozer.
- What do you get from a pampered cow? Spoiled milk.
- If a cow won’t give milk does that make her a milk dud or an udder failure?
- Do you know why a milking stool only has three legs? Because the cow has the udder.
- Why should you never tell a cow joke? Because it will just go in one ear and out the udder.
- Why do cows wear bells? Because their horns don’t work.
- What’s a cow in an earthquake called? A milkshake.
- Steer clear! Cows coming through!
- What do you call it when one cow spies on another cow? A steak-out.
- Why do cows have hooves instead of feet? Because they lactose.
- Why does a milking stool only have three legs? Because the cow has the udder.
- Déjà Moo is the feeling that you’ve heard this bull before.

And these memes:


The motto I live by


*Life is full of ups and downs*
Me:


Your life can't fall apart if you never had it together


Supervisor: Did you analyze that data yet?

Me: Yeah I'm working on it now

Me:

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# CHAPTER 1. INTRODUCTION

Over one million beef cows and their calves call Kentucky home and contribute more than $1 billion to the state's economy every year (USDA-NASS, 2019). Kentucky has the largest beef cattle herd in the entire eastern United States, in part due to its unique climate that is well-suited to forage production throughout much of the year (Knopf & Quarles, 2018). As a testament to the importance of the cattle industry in Kentucky, more land is devoted to forage production than either corn or soybeans in this state (USDA-NASS, 2018).

Kentucky is one of several states that falls within "the transition zone" an area that lies between the temperate northern and the subtropical southern United States and encompasses Kentucky, Tennessee, Missouri, the Virginias, North Carolina, and areas of the surrounding states (Burns & Chamblee, 1979). This region is uniquely favorable to beef cattle production on pasture, as both cool- and warm-season forage species are well-adapted.

Pastures in the upper transition zone are dominated by cool-season grasses that exhibit a bimodal forage distribution, with most growth occurring during the cooler spring and fall months (Burns & Bagley, 1996). Production of these species are limited by high temperatures in the summertime which can cause a forage deficit on cattle farms, often referred to as the "summer slump" (Moser & Hoveland, 1996).

Warm-season forage growth is concentrated during the summertime when temperatures are highest. These forages can fill the gap between the peaks of the bimodal distribution of cool-season grass growth. Utilizing both cool- and warm-season pastures can provide more forage growth and subsequent grazing days as compared to either cool- or warm-season pastures alone (Ritz et al., 2020).

Annual warm-season grasses typically have greater nutritive value than their perennial counterparts, making them an attractive option during the summer months (Ball et al., 2001). Unfortunately, these forages are often underutilized due to higher input costs. In annual systems, establishment costs are not depreciated over multiple years, as is the case in perennial systems. However, there are scenarios where utilization may be justified. Instances may include when a source of emergency forage is needed (Rasnake et al., 1981), when livestock classes have a high plane of nutrition during the summer months (Schmidt et al., 2013), or as part of a renovation sequence (Roberts & Andrae, 2004).

One strategy to improve economics of summer annual forage systems may be to plant grass-legume mixtures. Legume inclusion often imparts greater crude protein and digestibility to a sward (Ball et al., 2001). There is also some evidence of annual legumes sharing fixed N with associated grasses which could increase yield, and at the same time reduce N fertilizer needs (Fujita et al., 1990).

Little data exists regarding the use of summer annual mixtures in the transition zone of the United States. The following literature review and experiments assessed the suitability for multi-species summer annual forage mixtures to be utilized in Kentucky and other areas of the transition zone. The objectives of this dissertation were to:

1. evaluate the effects of increasing summer annual species diversity and N fertilization rate on summer annual forage yield, nutritive characteristics, and botanical composition.

2. determine economic optimum N fertilization rates for summer annual mixtures.
3. evaluate the effects of increasing species diversity on summer annual pasture productivity and nutritive characteristics, as well as animal performance.
4. determine the economic feasibility of grazing weaned calves on summer annual mixtures.

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# CHAPTER 2. LITERATURE REVIEW

## Abstract

Kentucky is the largest beef producing state east of the Mississippi River with approximately one million cow/calf pairs and seven million acres devoted to forage production (Knopf & Quarles, 2018; USDA-NASS, 2019). Kentucky is uniquely favorable to pasture and livestock production because it is situated in the "transition zone", the area between the humid northern and sub-tropical southern United States, where both cool- and warm-season grasses have suitable growing conditions (Burns & Chamblee, 1979). However, most Kentucky pastures consist primarily of cool-season forages. While cool-season species produce forage throughout a larger part of the year, they still exhibit a "summer slump" where production decreases during the summer months due to elevated temperatures and decreased precipitation. This literature review will explore the potential for diverse summer annual forage mixtures to be integrated into Kentucky's beef cattle production systems.

## 2.1 Beef Cattle Production in Kentucky

Of the 40,000 beef cattle farms in Kentucky, the majority are cow-calf operations that utilize the traditional spring calving season. However, more producers are adopting a fall calving management system, especially in the western part of the state. In a study conducted in Tennessee under management similar to Kentucky's cow-calf systems in regards to climate and pasture type, Campbell et al. (2013) evaluated spring versus fall calving on herds grazing endophyte infected tall fescue (Schedonorus arundinaceus (Schreb.) Dumort., nom. cons.) over a 19-year timespan. Although fall calving herds had longer calving intervals, lower average daily gains (ADG), and lower adjusted 205-d weaning weights, farm gross income was still increased by $16.21/cow/year. The authors attributed this to greater numbers of weaned calves per cow, higher market prices during June for fall born calves as compared to October for spring born calves, and a reduced need for replacement heifers because of greater cow longevity. The authors also inferred that the increase in cow longevity was due to cooler weather during the breeding season, thus improving conception rates, which has been observed in other studies (Cavestany et al., 1985; Ulberg & Burfening, 1967; West, 2003).

In spring calving operations, cows are bred during the early summer where the effects of grazing toxic tall fescue coupled with increased ambient temperatures negatively affect conception rates (Burke et al., 2001). This is a problem frequently observed in Kentucky and the rest of the “fescue belt” where Kentucky 31 tall fescue dominates most pastures. Campbell and coworkers (2013) further reported that more cows were culled from the spring calving herd due to failure to conceive.

Another factor affecting profitability is the cattle market at time of weaning. Since the majority of producers in the Southeast sell weaned calves in the fall to avoid additional feed costs throughout the winter, prices tend to be lower due to an abundance of calves on the market. Therefore, it is advantageous to sell weaned calves in the spring or summer months when the demand is higher because of a reduced supply. A unique advantage of fall calving is that weaning occurs during the onset of cool-season grass growth which offers the potential to retain calves during a time when most farms have an abundance of forage. Additionally, calves can be retained and marketed in the late summer when the market is traditionally highest.

## 2.2 Incorporating Summer Annuals into Grazing Systems

The dominant perennial forages in Kentucky pastures are cool-season species that exhibit a bimodal distribution of growth occurring during the spring and fall (Burns & Bagley, 1996). While these forages can provide substantial amounts of high quality grazing during the cooler months, their production slows during the summer (Fontenot et al., 1995). This results in a forage deficit during the summer months.

Perennial warm-season pastures can maintain or improve animal production throughout the growing season when integrated in a cool-season forage base. Both milk production from dairy cows and beef steer average daily gain were greater on a rotation between warm- and cool-season perennial forages as compared to just cool-season forages (Brown et al., 2001; Kanno, 1995). This is especially of importance when cool-season pastures are comprised of endophyte infected tall fescue, as was the case in the Brown study. However, some perennial warm-season pastures may be lower in nutritive value as compared to annuals and may not sustain animals with a high nutrient demand (Fribourg, 1995).

Incorporating summer annuals to increase calf gains is only one reason to consider diversifying a farm's forage base. Summer annuals utilize the C4 photosynthetic pathway which imparts increased drought tolerance and nitrogen-use efficiency over that of the C3 pathway characteristic of cool-season species (Ghannoum et al., 2011). These attributes allow for improved summer annual cultivars to produce higher yields than their cool-season counterparts during the summer months (Ritz et al., 2020). For example, results from University of Kentucky cultivar trails showed sorghum-sudangrass yields averaging 6.1 Mg/ha over six environments, while tall fescue averaged 3.8 Mg/ha over eleven environments (Olson et al., 2019a).

Summer annuals may also be planted over a wider range of dates, allowing their production to be distributed throughout the summer (Fribourg, 1995). Because of their rapid establishment, high nutritive value, abundant production, and tolerance to environmental stressors, summer annuals offer an attractive alternative to cool-season pastures as a forage source for brood cows as well as stockers (Tracy et al., 2010).

Warm-season annuals may also be used to facilitate stockpiling of cool-season pastures to extend late fall/winter grazing. While the warm-season annuals may be utilized to fill in the gap in forage production during the summer, the cool-season pastures may be rested and fertilized to produce forage for the late fall/winter months. This system allows for a more even distribution of forage resources throughout the year and reduces the need for hay (Troxel, 2007).

Finally, summer annuals can be used as an effective method of weed control during pasture renovation. The "spray-smother-spray" method has been shown to be effective in the conversion of toxic tall fescue to novel endophyte tall fescue pastures (Bagegni et al., 1994). Pastures can be sprayed using a non-selective herbicide application in late spring and planted to a summer annual crop. Warm-season annual species are generally fast growing, large statured crops that will shade out many weeds. This crop can be grazed or hayed several times during the summer and terminated using a non-selective herbicide at the end of the season to eradicate any remaining toxic tall fescue and weeds that may have grown throughout the summer. The pasture is then ready to be seeded to the desired forage species (Roberts & Andrae, 2004).

## 2.3 Overview of Commonly Planted Warm-Season Annual Species

### 2.3.1 Sorghum x sudangrass (Sorghum bicolor var. bicolor × bicolor)

These hybrids have been used extensively in the southeastern United States due to desirable characteristics that come from both parents. Sorghum (Sorghum bicolor (L.) Moench) imparts high yielding traits while sudangrass (Sorghum bicolor (L.) Moench ssp. drummondii (Nees ex Steud.) de Wet & Harlan)) provides regrowth potential and the fine stems and leafiness make the species more digestible (Jenkins & Berger, 2012; Teutsch, 2009). Sorghum-sudangrass has a high regrowth potential (especially with thinner stemmed cultivars) which makes it suitable for rotational grazing (Ball et al., 2007). Additionally, sorghum-sudangrass is extremely drought tolerant and can outperform corn under moisture limiting conditions (Schittenhelm & Schroetter, 2014).

Mayland and Cheeke (1995) and Arnold and coworkers (2014) provided useful summaries regarding cyanide and nitrate toxicity resulting from members of the sorghum family. These species can accumulate toxins when young or during times of stress, and the toxins can be detrimental to livestock health. However, any negative impacts associated with these toxins may be avoided by utilizing proper management.

Precursors to cyanide reside in plant cells of sorghum species. When plant cells are ruptured, enzymes react with cyanogenic glucosides to produce hydrogen cyanide. These compounds are concentrated in young tissues and released in frost damaged tissues. Grazing should be delayed until plants are approximately 60 cm tall. The most dangerous time of the year for prussic acid (cyanide) poisoning is immediately after the first frost. Grazing may be resumed after forages have dried, generally within 7-10 days (Ball et al., 2007; McKinley & Wheeler, 1999; Undersander, 2003).

Nitrates can accumulate in the plant during cool temperatures or when fertilized with nitrogen prior to a drought, both of which are times when the growth has slowed, resulting in a reduced capacity of the plant to metabolize nitrogen (Mayland & Cheeke, 1995). Grazing should only resume once the plant has had adequate time to mobilize the accumulated nitrates after a period of reduced growth, often one week following the cessation of a drought. Unlike cyanide, nitrate does not dissipate from plant material after frost or when stored as hay (Mayland & Cheeke, 1995). Therefore, it is important to test any hay suspected to have high levels of nitrate.

Sugarcane aphids (Melanaphis sacchari (Zehntner.)) have recently become an increasing pest problem of sorghum species in the United States. Aphid feeding leaves a honeydew-like substance behind. While the honeydew is harmless to livestock, the aphid's feeding disrupts phloem transport in the plant, often resulting in decreased yield and quality of the forage (Lemus & Flint, 2015).

### 2.3.2 Sudangrass

Sudangrass is also a strong candidate for summer annual pastures. This species has finer stems than sorghum-sudangrass which gives it more versatility to be either grazed or harvested for hay due to faster dry-down times (Fribourg, 1995). Newer varieties and sudan x sudan hybrids have improved sudangrass popularity (personal communication, S. R. Smith, 2021). There is still risk for cyanide and nitrate toxicity, however the cyanide risk is less than for sorghum-sudangrass (Teutsch, 2009).

### 2.3.3 Pearl Millet (Pennisetum glaucum (L.) R. Br.)

One of the main benefits of utilizing pearl millet is the absence of cyanide production. However, there is still risk of nitrate toxicity which can occur during drought or with excessive N fertilizer application (Mayland & Cheeke, 1995). Pearl millet is also very leafy and has high regrowth potential, which makes it a high quality summer forage for livestock that have higher nutrient requirements (Anderson & Volesky, 2013).

### 2.3.4 Other Summer Annual Grasses

Both crabgrass (Digitaria spp.) and corn (Zea mays L.) may also be used for summer grazing. Crabgrass has traditionally been a weed in cropping systems but can provide a high quality summer forage (Teutsch et al., 2005b) and “produces good calf gains” (Dalrymple, 1980). Commercial crabgrass cultivars have been developed at the Noble Research Institute in Oklahoma. Improved cultivars are prolific self-reseeders, which reduces the amount of annual inputs required in subsequent years (Brann, 1999; Teutsch, 2009). While crabgrass can be planted in a monoculture or with red clover (Trifolium pretense L.) or annual lespedezas (Kummerowia spp.), it is also well-suited to providing ground cover in mixtures with other tall-growing summer annuals (Brann, 1999).

Although less common than its use for grain or silage, corn may also be grazed during the summer (Ditsch et al., 2004). Corn is very high yielding and has the added flexibility of grazing when both vegetative and mature. Grazing corn has been shown to be more profitable than harvesting for silage due to reduced mechanical and storage costs (Hoorman et al., 2003; Karsten et al., 2003). Although limited corn grazing studies exist, one trial in Iowa showed steer gains of 1.2 kg/day, which is higher than for other summer annual grasses (Practical Farmers of Iowa, 2011; Table 2.1).

### 2.3.5 Summer Annual Legumes

Summer annual legumes have been used to a lesser extent than grasses. One concern with utilizing summer annual legumes such as cowpea (Vigna unguiculata (L.) Walp.) and soybeans (Glycine max (L.) Merr.) is the lack of regrowth potential following grazing or haying. However, this doesn’t mean that they are unsuitable for grazing systems. These may work well when pastures are only grazed one time. In addition to soybeans and cowpea, other less conventional legume species may be used, such as sunn hemp (Crotalaria juncea L.) and Korean lespedeza (Kummerowia stipulacea (Maxim) Makino).

## 2.4 The BMR Advantage

An increasing amount of summer annual species and cultivars of sorghums, pearl millet, and corn have been developed to express the brown midrib (BMR) trait after the first spontaneous occurrence in corn occurring in 1926 (Jorgenson, 1931). Porter and colleagues (1978) chemically induced BMR mutations in sorghum using diethyl sulfate. This treatment resulted in 19 mutants that displayed the characteristic brown midrib coloration, but only bmr-6, -12, and -18 exhibited reduced lignin concentrations and were selected for further cultivar development.

Several loci in both corn and sorghum have been identified to influence the BMR response (Sattler et al., 2010). The bmr-6 mutation demonstrated reduced lignin in the plant by reducing cinnamyl alcohol dehydrogenase activity (Sattler et al., 2009), while bmr-12 and -18 mutations show decreased activity of the caffeic acid O-methyltransferase enzyme resulting in reduced lignin (Bout & Vermerris, 2003).

The BMR trait is usually distinguishable by a characteristic brown or tan midrib coloration on the leaf (Cherney et al., 1991). This is due to a phenotypic expression of the gene mutation which results in lower lignin content of the plant cells (Miller & Stroup, 2003). As lignin concentration is inversely correlated to digestibility (Porter et al., 1978), often forages with the BMR trait are seen to improve animal productivity.

McCuistion and colleagues (2011) predicted cattle grazing a sorghum-sudangrass BMR cultivar under light to moderate stocking rates would gain 7% more than those grazing a photoperiod sensitive sorghum-sudangrass. This increase in gain was attributed to improvements in forage quality, and not due to forage quantity as the BMR variety yielded less. Hilscher and coworkers (2017) also observed greater cattle gains when their diet included 45% BMR as compared to non-BMR corn silage. Oliver and colleageus (2004) reported 16% increase in milk yield of dairy cows fed BMR over conventional forage sorghum. Oba and Allen (1999) showed similar results where intake and milk yield of dairy cows increased by 9 and 7%, respectively, when fed BMR versus non-bmr corn silage. However, Tjardes and coworkers (2000) observed increased intake of beef steers, but no increase in average daily gain when fed BMR compared to conventional corn silage.

While the reduced lignin concentration in BMR cultivars often shows animal production benefits, some cultivars may be susceptible to greater risk of lodging as lignin provides structural support to the plant (Gallais et al., 1980). Results have been inconsistent with several studies reporting no difference in lodging susceptibility between BMR and non-BMR cultivars of the same species (Oliver et al., 2005; Sattler et al., 2010). Lodging has rarely been an issue for BMR cultivars in University of Kentucky forage cultivar trials for sudangrass, sorghum-sudangrass, and pearl millet (G. Olson, personal communication, 2020). However, these trials have reported periodic lodging of some, but not all, tall-type BMR sorghum cultivars.

## 2.5 The Dwarf Gene: Not Just for Snow White

A genetic improvement that has been introduced to reduce the risk of lodging is the “dwarf” trait that can be found in many commercially available cultivars of sorghum, sorghum-sudangrass, and pearl millet. Cultivars with this trait have reduced internode length, resulting in a higher leaf:stem ratio (Burton et al., 1969). Due to a greater leaf:stem ratio, the dwarf trait has been shown to result in increased digestibility, leading to increased animal performance (Burton et al., 1969). These authors reported 20% greater daily gains of steers grazing dwarf as compared to tall pearl millet. Steers rejected much less dwarf pearl millet due to reduced stem proportions in the plants, leading to increased forage utilization rates (Burton et al., 1969).

Although forage quality may be increased, some cultivars may exhibit reduced yields. Long-term data from the University of Kentucky cultivar trials have shown a 34% yield reduction in dwarf sorghums compared to tall-type commercially available cultivars (Olson et al., 2019a). However, dwarf and tall-type cultivars were planted together, resulting in potential shading of dwarf cultivars by tall-types. Burton and coworkers (1969) also showed 24% reduction in yields of dwarf pearl millet as compared to tall-type pearl millet. Although yields were reduced, the authors reported similar average daily gain (ADG) per hectare of animals grazing dwarf and tall millets. Alternatively, dwarf sudangrasses exhibited similar yields over non-dwarf counterparts (Craigmiles, 1968), and dwarf cultivars of forage sorghum in Virginia even had superior yields to tall-type cultivars (Teutsch, 2014).

## 2.6 Forage Quantity and Quality

Summer annual species are often known to be high-yielding in times when cool-season perennial pastures exhibit reduced productivity. In cultivar trails conducted from 2014-2017 in two Kentucky locations, sorghum-sudangrass averaged 11.2 Mg DM/ha, followed by pearl millet and sudangrass at 8.7 and 8.5 Mg DM/ha, respectively (Olson et al., 2017). Crabgrass yields have ranged from 8.96 – 10.08 Mg DM/ha in Kentucky, Virginia, and Arkansas (Jennings et al., 2014; Olson et al., 2019b; Teutsch et al., 2005a). Although corn is typically grazed later in the year rather than during the summer, 2020 corn silage cultivar trials in Kentucky have shown yields ranging from 10.8 to 14.5 Mg DM/ha (Kenimer et al., 2020).

Nutritive value is also an important consideration when selecting summer annual species and cultivars. Several parameters are evaluated to determine forage “quality”. The following summarizes common nutritive characteristics.

Crude protein is one of the most utilized forage quality parameters and is important when formulating livestock rations (Fisher et al., 1995). Amino acids found in protein are important for growth, maintenance, muscle development, and milk production (Cappellozza, 2019). Protein concentrations are higher in leaves versus stems, as well as younger as compared to older tissues (Buxton & Mertens, 1995). Crude protein decreases as cell walls thicken and lignify as the plant matures (Buxton & Mertens, 1995). Crude protein levels are related to available soil N, with N application generally increasing crude protein (Buxton & Mertens, 1995). Summer annuals with insufficient N fertility will likely not meet protein requirements of livestock (Ball et al., 2007).

Crude protein can reach as high as 18% in vegetative growth of warm-season annuals (McCuistion et al., 2011), but declines as plants mature. Ranges from 7-15%

have been reported in pearl millet, sorghum-sudangrass, and sudangrass in the boot growth stage (Beck et al., 2013; Beck et al., 2007a; Burton et al., 1969; Hoveland et al., 1967). Sudangrass and sorghum-sudangrass in the dough stage has been reported to have between 6 and 9% CP, which is insufficient for most classes of beef cattle (Beck et al., 2013; Hoveland et al., 1967).

Neutral detergent fiber analysis measures the amount of digestible and indigestible cell wall components which include cellulose, hemicellulose, and lignin (Ball et al., 2001). Ranges of NDF of summer annual forages are variable, but are often between 65 and 80% DM (Beck et al., 2013; Beck et al., 2007a; Hoveland et al., 1967). Neutral detergent fiber is inversely related to dry matter intake because of its relationship with gut fill (Ball et al., 2007).

Acid detergent fiber measures cellulose and lignin content in the cell wall. This parameter is negatively correlated with forage digestibility and generally increases as plants mature (Ball et al., 2007; Beck et al., 2013). Acid detergent fiber content of summer annuals is can range between 30-60% DM (Beck et al., 2013; Beck et al., 2007a; Rosser et al., 2013).

Lignin is unable to be digested in the rumen and can impede the digestion of more soluble compounds, such as protein (Ball et al., 2007), cellulose, and hemicellulose (Fisher et al., 1995) by forming cross-linkages with these compounds. Lignin content also increases as plant tissues mature. Ranges in summer annual forages can be between 3 and 12% depending on maturity and cultivar (Buxton & Mertens, 1995).

Total digestible nutrients (TDN) is a measure of the energy availability of a forage (Buxton & Mertens, 1995) and is most often the most limiting factor in animal production (Hancock et al., 2017). Crude protein and TDN are commonly used to balance rations and to determine if a forage meets the nutritional needs of livestock (Hancock et al., 2017). Summative equations are often used to determine TDN, and may include factors that contribute energy, such as crude protein, neutral detergent fiber, fat, non-fiber carbohydrates, and fiber digestibility (Hoffman, 2003). Total digestible nutrients of summer annual forages often range from around 50-60% DM (Beck et al., 2013; Beck et al., 2007a, b; Burton et al., 1969; Harmon et al., 2019; Ogden et al., 2005).

Digestibility of a forage can be inferred by many different parameters. A common method is in vitro Dry Matter Digestibility. This method involves placing a prepared forage sample in rumen fluid and measuring forage disappearance after a specified amount of time (Ball et al., 2001). Although more commonly used to provide a relative ranking of forages, Relative Feed Value is calculated based on forage digestibility and intake and is used to determine a forage’s nutritive value in relation to full-bloom alfalfa (Newman et al., 2009). As RFV uses alfalfa as a standard, it is not recommended to be used for warm-season forages (Newman et al., 2009). A better relative ranking of the nutritional value of forages is Relative Forage Quality (RFQ). The metrics used to calculate RFQ are NDF, CP, ether extract (lipids), neutral detergent fiber digestibility, ADF, and nonfibrous carbohydrates (sugars and starches; (Ball et al., 2001). Relative forage quality can be used for warm-season forages since it includes digestible fiber components in the calculation (Newman et al., 2009). Ranges of RFQ for summer annual grasses have been reported to be between 105 and 155 (Harmon et al., 2019; Salama & Zeid, 2016).

Although nutritive characteristics may give a good indication of forage quality, the best way to determine true “quality” is by evaluating animal performance (Ball et al., 2007). Table 2.1 shows results of selected studies and summarizes nutritive characteristics and animal performance of the commonly planted summer annual species in the Southeast.

Table 2.1. Nutritive characteristics (CP=crude protein, TDN=total digestible nutrients, IVTD=in vitro true digestibility, NDF=neutral detergent fiber, IVTDMD48=48h in vitro true dry matter digestibility; IVDMD=in vitro dry matter digestibility) and average daily gain (ADG) of selected summer annual forage systems of the Southeastern United States.

| Species | % CP | % TDN | Digestibility | Growth Stage | ADG (kg/day) | Calf Weight (kg) | Stocking Method | Reference |
|---|---|---|---|---|---|---|---|---|
| **Brown midrib sorghum-sudangrass** | 18.5 | | 87.3% IVTD | vegetative | 0.95 | 232 | | McCuistion et al., 2011 |
| | 8.1 | 56 | 73.8% NDF | boot | | | | Beck et al., 2013 |
| | 6 | 54.8 | 75.6% NDF | dough | | | | |
| | 7.2 | | 65.6% NDF | boot | | | | Beck et al., 2007a |
| | | | | | 1.1 | 204 | C & R | Banta et al., 2002 |
| | 17.1 | 58.3 | 78% IVTDMD48 | | 1.0 | 431 | R | Harmon et al., 2019, 2020 |
| **Sorghum-sudangrass** | 15.4 | | 57% NDF | | 0.88 | 135 | R | Tracy et al., 2010 |
| | 15.5 | | 80.3% | pre-boot | | | | Hoveland et al., 1967 |
| | 8.2 | | 70% | boot | | | | |
| | 7.4 | | 64.20% | dough | | | | |
| | 6.9 | | 70% NDF | boot | | | | Beck et al., 2007a |
| | 17.2 | 58.9 | 77% IVTDMD48 | | 0.86 | 431 | R | Harmon et al., 2019, 2020 |
| | | | | | 0.27-0.41 | yearlings | R | Dunavin, 1970 |
| **Sudan-grass** | 16.2 | | 64% NDF | | 0.94 | 135 | R | Tracy et al., 2010 |
| | 8.9 | 52.6 | 78.9% NDF | boot | | | | Beck et al., 2013 |
| | 6.3 | 50.1 | 82.5% NDF | dough | | | | |
| **Corn** | | | | vegetative | 1.2 | 277 | Strip | Practical Farmers of Iowa, 2011 |

**Abbreviations: C = continuous, R = rotational*

*Empty cells: data not stated*

Table 2.1 (continued). Nutritive characteristics (CP=crude protein, TDN=total digestible nutrients, IVTD=in vitro true digestibility, NDF=neutral detergent fiber, IVTDMD48=48h in vitro true dry matter digestibility; IVDMD=in vitro dry matter digestibility) and average daily gain (ADG) of selected summer annual forage systems of the Southeastern United States.

| Species | % CP | % TDN | Digestibility | Growth Stage | ADG (kg/day) | Calf Weight (kg) | Stocking Method | Reference |
|---|---|---|---|---|---|---|---|---|
| **Pearl Millet** | | | 36-64% IVDMD | | 0.27-1.0 | 241 | C | McCartor and Rouquette Jr, 1977 |
| | 11.2 | | 61.7% (24 hr) | pre-boot | | | | Hoveland et al., 1967 |
| | 22.79 | | 49.8% NDF | | 0.55 | 477 | R | Schmidt et al., 2013 |
| | | | | | 0.35-0.53 | yearlings | R | Dunavin, 1970 |
| | | | | | 1.6 | 270 | | Duckett et al., 2013 |
| | 18.6 | 58.3 | 78% IVTDMD48 | | 0.86 | 431 | R | Harmon et al., 2019, 2020 |
| | | | | | 0.59-0.71 | steers | R | Burton et al., 1969 |
| | 11.4 | 57.0 | | Boot | 0.35 | Dairy heifers | Hay | |
| | 13.6 | 61.4 | | boot | 0.52 | Dairy heifers | Hay | |
| **Crabgrass** | 15.6 | 62.6 | | vegetative | | | | Beck et al., 2007b |
| | 14.3 | 59.1 | | heading | | | | |
| | | | | | 0.28-1.3 | 215 | | Dalrymple, 1980 |
| | 16-21 | 56-62 | 69-75% DM disappearance | | | | | Ogden et al., 2005 |

**Abbreviations: C = continuous, R = rotational*
*Empty cells: data not stated*

Brown midrib sorghum-sudangrass in a vegetative state may support calf gains approaching 1 kg/day (McCuistion et al., 2011). Sorghum-sudangrass without the BMR trait ranged from 0.27 – 0.86 kg/day (Dunavin, 1970; Harmon et al., 2020; Tracy et al., 2010). The range of ADG on pearl millet was between 0.27-1.6 kg/day, while calves grazing corn gained 1.2 kg/day. Crabgrass provided gains of 0.28 to 1.3 kg/day for calves grazing poor quality and lush pastures, respectively (Dalrymple, 1980). The wide range of values for all parameters can be attributed to differences between species, cultivars, stage of harvest, initial calf weight, stocking method, and local weather and soil characteristics.

## 2.7 Economics of Summer Annuals

Each year inputs to summer annual systems include herbicide, seed, fertilizer and/or lime, and equipment and fuel costs. Perennial pastures incur the same costs upon establishment, but they are depreciated over multiple years (Allison et al., 2021). Due to high cost of establishment, Ball and coworkers (2007) deemed stockering on summer annuals to be “a breakeven proposition at best”.

Several studies have investigated the economic costs and returns in different summer annual systems. Comerford and colleagues (2005) found that annual forages included into perennial forage systems resulted in the lowest net returns when compared with two solely perennial pasture systems. The authors concluded that including annual species into a perennial pasture system was not economical as calf gains were no different than solely perennial systems, but extra costs were incurred, primarily due to tillage.

Tracy and colleagues (2010) determined that native warm season grass pastures were more economical than summer annual pastures when included in a cool-season pasture rotation based on variable costs in relation to returns on cattle gains. In this study, there was no difference in calf gains between the two warm-season pasture types, but initial establishment costs for the native pastures were quite high due to seed prices. However, after 3 years, annual warm-season costs exceeded those of native pastures. The authors suggested that summer annual systems could be more economical if costs were reduced, specifically field operations and nitrogen fertilizer (Tracy et al., 2010). However, it is important to recognize that some producers encounter more difficulty when establishing native warm-season pastures as compared to annuals. This can limit initial productivity of perennial warm-season pastures.

In a summary of stocker studies in Alabama, Ball and Prevatt (2009) showed that out of 37 studies including warm- and cool-season annual and perennial pasture types, annual warm-season pastures had the second highest total and variable pasture costs. Similarly, Basweti and coworkers (2009) saw little economic advantage to no-till interseeding summer annuals into established pastures because there was no resulting increase in total system productivity. However there are scenarios where annual forage incorporation are desired, especially if perennial summer production is low, as summer annual grasses can produce twice as much dry matter over this period as compared to cool-season perennial pastures (Basweti et al., 2009).

## 2.8 Botanical Diversity in Summer Annual Systems

Increasing yield potential and reducing production costs may increase attractiveness of summer annual forage systems. One potential way to accomplish these goals may be by planting multiple species together, which has been shown to increase productivity in both perennial (Minns et al., 2001; Picasso et al., 2008) and annual systems (Bybee-Finley et al., 2016; Fan et al., 2020; Naik et al., 2017). Yield potential is thought to increase with multi-species systems through several means:

- Niche differentiation/resource partitioning: species mixtures with differing morphology and physiology utilize resources more efficiently than that of a single species (Tofinga et al., 1993).
- Facilitation: the presence of one species enhances the survival or productivity of another species (i.e. the “three sisters” cropping combination of corn, beans, and squash; Callaway, 1995).

Facilitation often occurs when legumes are included into a mixture, as they may “share” fixed N with associated plants (Huston et al., 2000). This transfer occurs primarily by root and litter decomposition and by redistribution via livestock excreta (Wedin & Russelle, 2007). Other avenues for transfer occur from root and nodule excretion of nitrogenous compounds, litter leaching, and mycorrhizal transfer (Wedin & Russelle, 2007).

There is debate as to whether annual legumes can provide a significant nitrogen benefit to neighboring grasses. In comparison to perennials, annuals allocate resources to above- rather than belowground growth (Garnier, 1992). In perennial systems, N transfer tends to increase with time, with less occurring in the establishment year as compared to subsequent production years (Elgersma et al., 2000; Jørgensen et al., 1999).

Fujita and colleages (1992) and Layek and colleagues (2018) summarized results from numerous studies regarding N transfer in annual systems. Some studies found that no significant nitrogen transfer took place when legumes were included in intercropping systems, but noted that residues may provide a substantial supply of N to subsequent crops (Wahua & Miller, 1978; Izaurralde et al., 1992). Other studies observed the non-legume component contained from 25 to more than 50% N derived from neighboring legumes (Eaglesham et al., 1981; Fujita et al., 1990).

Although many studies do not directly measure N transfer, many still demonstrate increased yield or economic advantage of multi-species summer annual mixtures (Bybee-Finley et al., 2017; Emuh, 2007; Fan et al., 2020; Wandahwa et al., 2006). Osiru and Willey (1972) found 55% greater yields from a dwarf sorghum/bean mixture as compared to a sorghum monoculture, while Takele and coworkers (2017) reported a corn-common bean (Phaseolus vulgaris L.)-mung bean (Vigna radiata (L.) R. Wilczek) mixture to have a land equivalent ratio of 2.2, meaning that the mixture yielded 220% of the component species when grown in monoculture. Andrews (1972) observed an 80% increase in return per acre of intercropped sorghum/cowpea as compared to sorghum monocultures. Singh (2012) and Naik and coworkers (2017) both reported a nearly 20% increase in benefit-to-cost ratio of four corn-legume intercrops.

Although many researchers have found evidence of overyielding of mixtures, there are cases where no advantage occurs over monocultures of the highest producing species. Berkenkamp and Meeres (1987) showed that annual mixtures including legumes generally exhibited yields intermediate to, but not greater than, those from component species. Cummins (1973) observed similar or even reduced dry matter yields when intercropping soybeans into corn or sorghum as compared to  monocultures. Cardinale and colleagues (2011) also reported that only 37% of diversity experiments result in a mixture overyielding the highest producing species in monoculture.

Even in cases where summer annual mixtures do not overyield, there is the possibility to improve nutritive characteristics of mixed swards. Legumes generally have greater crude protein and digestibility as compared to grasses due to greater pectin concentration in the cell walls and the ability to fix N (Buxton & Mertens, 1995). Basaran (2017) reported greater Relative Feed Value for sudangrass-legume mixtures as compared to sudangrass monocultures. Iqbal and colleagues (2019) summarized several studies and reported an eight percent increase in crude protein and a five percent decrease in fiber. Improving summer annual nutritive characteristics would be most beneficial in livestock classes with high nutrient requirements, such as growing calves or lactating cows.

## 2.9 Nitrogen Application to Annual Grass-Legume Mixtures

Nitrogen is the most limiting nutrient in agricultural systems and is often costly to apply. Finding ways to reduce N inputs could improve economics of summer annual systems, making them more attractive to producers. Nitrogen application in mixed species systems more strongly affects the non-legume component and may even be detrimental to legume productivity (Ezumah et al., 1987; Haruna et al., 2006). Even so, N use may still result in greater productivity or economic viability of the system as a whole.

In a corn/cowpea system, Ezumah and colleagues (1987) reported a 27% decrease in cowpea grain yield when fertilized with 120 kg N ha$^{-1}$ as compared to no N, but corn grain yield increased by 62%. The increase in corn yield more than compensated for the decrease in cowpea yield, resulting in a 50% increase in total grain yield. Similarly, in a sorghum/soybean intercropping system, Haruna and colleagues (2006) reported a reduction in soybean yield and an increase in sorghum yield when fertilized with 100 kg N $ha^{-1}$ versus no N, leading to a 28% increase in gross economic margin (revenue minus variable costs) for the intercrop. Alternatively, Chowdhury and Rosario (1992) observed the greatest land equivalent ratio of corn/mung bean intercropping with only 30 kg N $ha^{-1}$ as compared to rates up to 120 kg N $ha^{-1}$. These data indicate that N response for annual grass-legume mixtures is not consistent across species, geographic location, climatic variables, or management systems.

Nutritive characteristics of summer annual grasses can also be improved by N fertilization (Fribourg, 1974). Hart and Burton (1965) reported a nearly doubling of protein concentrations and a 10% reduction in crude fiber concentration of pearl millet when increasing N application from 0 to 560 kg N $ha^{-1}$. In sorghum, Ayub and coworkers (2002) observed approximately 2.5 and 1.5 percentage unit reduction in neutral and acid detergent fibers when N was increased from 0 to 150 kg N $ha^{-1}$. Additionally, Ates and Tenikecier (2019) reported an additional 3.3, 3.7, 4.3, and 5.2 percentage units improvement of crude protein (10.89 to 14.23%), crude fiber (32.08 to 28.37%) , NDF (61.34 to 57.09%), and ADF(35.21 to 30.01%) of sorghum-sudangrass when increasing N rates from 0 to 160 kg N $ha^{-1}$.

## 2.10 Challenges in Diverse Summer Annual Forage Mixtures

Morphological and physiological differences between summer annual forages may result in some species maturing at faster rates than others (Teutsch, 2009). Grazing at the optimal time and height for one species may compromise the vigor and yield potential of another species. Livestock may also preferentially select certain species over others, particularly under continuous stocking. These actions could alter the botanical composition throughout the grazing season and potentially lead to a decrease in total yield if high-yielding species are preferentially grazed. Limited research on this topic has been conducted in summer annual systems, however, there has been somewhat more research in perennial pastures. Over a four-year grazing trial, Tracy and Faulkner (2006) observed some highly palatable species, such as alfalfa (Medicago sativa L.), declining while others increased in cool-season perennial pastures. Additionally, the authors noted that smooth bromegrass (Bromus inermis Leyss.) declined because it was grazed prior to seed head development in the spring. These examples illustrate the challenges in maintaining pasture diversity under grazing systems.

It may be a challenge to include legumes into summer annual mixtures. When planted at the same time, tall growing grasses often emerge and form a canopy before legumes. Grass roots are also more extensive and compete with legumes for resources, further reducing legume proportions (Gao et al., 2010). Shading in mixtures can limit photosynthesis, which has been suspected to be the cause of reducing nitrogen fixation and nodule activity in soybeans (Mann & Jaworski, 1970; Wahua & Miller, 1978). For this reason, Iqbal and coworkers (2017) recommend planting soybeans 18 days prior to a grass intercrop. Unfortunately, this is likely not a feasible solution for producers due to time and labor constraints.

Seed ratios can also affect productivity of mixed stands. Pal and coworkers (1993) evaluated soybean intercropped with both corn and sorghum at different seeding proportions relative to the recommended rate for monocultures of each species. The authors found the greatest land equivalent ratios with 100% grass seeding rates and 1/3 recommended seeding rate for soybean. Similarly, Basaran and coworkers (2017) also varied seeding proportions with sorghum-sudangrass mixed with either soybean or cowpea and found that soybean mixtures had greatest yield when sudangrass-soybean seed proportions were 100:100 of recommended seeding rates and when sorghum-sudangrass-cowpea mixtures were planted in a 50:100 seeding proportion.

### 2.11 Summary

Planting mixtures of summer annual forages may improve yield and/or quality as compared to grass monocultures. However, it may be a challenge to maintain functional diversity in summer annual mixtures, especially if management favors one species over another. Nitrogen fertilization recommendations for summer annual mixtures are not well established. Data is needed to establish guidelines for N application to annual mixtures with high functional diversity. In addition, little work has been evaluated animal performance on summer annual mixtures.

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# CHAPTER 3. NITROGEN FERTILIZER RATE EFFECTS ON YIELD AND BOTANICAL COMPONENTS OF SUMMER ANNUAL FORAGE MIXTURES

## Abstract

Summer annual mixed intercropping may provide supplemental grazing options for livestock during times when cool-season pastures are less productive. Nitrogen fertilizer recommendations for these complex mixtures are not well established. Inputs to these systems are often high, so optimizing N fertilizer rates is one way to increase appeal to producers. This study evaluated the effects of increasing botanical diversity and N fertilizer application on the yield and botanical composition of summer annual mixtures in four environments in Kentucky, USA. Nitrogen fertilizer rates of 0, 56, 112, 168, and 224 kg N $ha^{-1}$ were applied to a sudangrass monoculture, a three-species mixture, and an 11-species mixture. In three out of four environments, sward biomass increased as N application increased (average of 15 kg DM $ha^{-1}$ increase per kg N $ha^{-1}$; $p < 0.05$). Mixture complexity had no effect on forage DM accumulation for three out of four environments (4000, 5830, and 7280 kg DM $ha^{-1}$ averaged over mixture for three environments; $p > 0.05$). Swards were overwhelmingly dominated by sudangrass and pearl millet (73 and 24% in simple mixtures, and 62 and 22% in complex mixtures, respectively), resulting in low functional diversity. Legumes did not respond to N ($p > 0.05$), but their contribution to sward DM was <4%. Species compatibility should be a priority when utilizing multi-species mixtures. If a stronger legume component is desired, care must be taken to provide management that favors these species, such as reduced grass seeding rates to limit competition, especially during initial establishment.

## 3.1 Introduction

Summer annual forages have the potential for high production and nutritive value during the summer months when perennial cool-season pasture growth is limited by high temperatures (Moser & Hoveland, 1996). Tracy and colleagues (2010) found that summer annual pastures exhibited 61% more production and equal or greater nutritive value as compared to cool-season grass pastures during the summer months. However, annual pastures incur establishment costs every year, leading many to conclude that the enterprise is a “breakeven proposition at best” (Ball et al., 2007).

Increasing yield potential and reducing production costs may increase attractiveness of summer annual forage systems. One way to accomplish these goals may be by planting multiple species together, a practice known as intercropping. Yield potential is often increased in intercropping systems through niche differentiation, whereby species with differing morphology and physiology utilize resources more efficiently than that of a single species (Tofinga et al., 1993).

Numerous studies have documented increased land equivalent ratios or economic advantages for intercropping as compared to monocropping, but degree of benefit is dependent upon resource availability and level of interspecies competition (Lithourgidis et al., 2011). Land equivalent ratios from 1.25 to 1.94 have been reported in various grass-legume intercropping systems (Osiru & Willey, 1972; Emuh, 2007; Bybee-Finley et al., 2016; Naik et al., 2017; Fan et al., 2020). A land equivalent ratio of 2.2 was even reported in a three-species corn (Zea mays L.)/common bean (Phaseolus vulgaris L.)/mung bean (Vigna radiata (L.) R. Wilczek) mixture harvested for grain (Takele et al., 2017). In regards to economic advantage, Singh (2012) and Naik and colleagues (2017) reported nearly 20% increase in benefit-to-cost ratio of four corn-legume intercrops, while Andrews (1972) reported 80% more economic return per land unit area in intercropping as compared to sorghum [Sorghum bicolor (L.) Moench] monoculture.

The inclusion of legumes into a system is often a driver of increased productivity (Huston et al., 2000). In perennial systems, legumes will fix and “share” N with grasses during the growing season via root exudates, litter decomposition, and/or redistribution via livestock manure and urine (Paynel & Cliquet, 2003; Whitehead, 2000). It is less clear as to what degree this happens in annual cropping systems, as results are often inconsistent (Layek et al., 2012).

Fujita et al. (1992) and Layek et al. (2018) summarized results from numerous studies regarding N transfer in annual systems. Some studies found that no significant N transfer took place when legumes were included into intercropping systems but noted that residues may provide a substantial supply of N to subsequent crops (Wahua & Miller, 1978; Izaurralde et al., 1992). Other studies observed the non-legume component contained more than 50% N derived from neighboring legumes (Eaglesham et al., 1981; Fujita et al., 1990).

Due to the inconsistencies in N transfer, fertilization recommendations for summer annual grass-legume mixtures are not well established. Nitrogen fertilizer application in these systems more strongly affects the non-legume component and may even be detrimental to legume productivity, but still may result in greater productivity or economic viability of the system as a whole (Ezumah et al., 1987; Haruna et al., 2006). In a corn/cowpea (Vigna unguiculata (L.) Walp.) system, Ezumah and colleagues (1987) reported a 27% decrease in cowpea grain yield when fertilized with 120 kg N ha$^{-1}$ as compared to no N, but corn grain yield increased by 62%. The increase in corn yield more than compensated for the decrease in cowpea yield, resulting in a 50% increase in total grain yield. Similarly, in a sorghum/soybean intercropping system, Haruna and colleagues (2006) reported a reduction in soybean grain yield and an increase in sorghum grain yield when fertilized with 100 kg N ha$^{-1}$ versus no N, leading to a 28% increase in gross economic margin for the intercrop. Alternatively, Chowdhury and Rosario (1992) observed the greatest land equivalent ratio of corn/mung bean grain intercropping with only 30 kg N ha$^{-1}$ as compared to rates up to 120 kg N ha$^{-1}$.

Similar to other cropping systems, N response for annual grass-legume mixtures managed for forage are not consistent across species, geographic location, and climatic variables. This inconsistency leads to variability in N fertilizer recommendations, and presently, none are available for annual grass-legume mixtures managed for forage in Kentucky. The objective of the current experiment was to determine the impact of N fertilizer rates on total aboveground biomass production and individual species components of simple and complex mixtures of summer annual forages. It was hypothesized that more complex mixtures would result in greater biomass accumulation and exhibit reduced response to N fertilization as compared to grass monocultures or simple grass-legume mixtures.

## *3.2* Materials and Methods

### 3.2.1 Site Description

This experiment was conducted at Lexington, KY (38.128, -84.498) and Princeton, KY (37.101, -87.854) in 2018 and 2019. Soil series were a Maury silt loam (fine, mixed, active, mesic Typic Paleudalfs) and a Zanesville silt loam (fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs) (Soil Survey Staff, 2019) in Lexington and Princeton, respectively. Previous land use in Princeton for both years and in Lexington 2019 was cool-season perennial pasture. Area in Lexington 2018 was previously cropped with graminoid species. Temperature and precipitation data for each site was obtained from on-farm weather stations in the Kentucky Mesonet network (Bowling Green, KY).

### 3.2.2 Experimental Design

A randomized complete block design with four replications and a two-factor factorial treatment arrangement was utilized for this study. Field position was used as a blocking factor due to presence of very gentle slopes. Plots within blocks measured 2.7 x 6 m with 1.5 m alleys between blocks. New plot area was used each year.

Factors of interest were forage mixture complexity and N fertilizer rate. Forage mixture complexity consisted of three treatments: 1) summer annual grass monoculture (control), 2) simple mixture consisting of two summer annual grasses + one summer annual legume, and 3) complex mixture containing four summer annual grasses, four summer annual legumes, two brassicas, and one summer annual forb. Mixtures were inoculated with a peat-based multi-species inoculant (Link Cover Crop Inoculant, La Crosse Seed, La Crosse, WI). Species, cultivars, and seeding rates used can be found in Table 3.1.

Table 3.1. Forage species, cultivars, and seeding rates for each treatment.

| **Treatment** | **Species** | **Scientific Name** | **Cultivar** | **Seeding Rate†** | |
|---|---|---|---|---|---|
| | | | | Species | Total |
| | | | | (kg ha$^{-1}$) | |
| **Monoculture** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | **56** | **56** |
| **Simple** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 28 | |
| | Pearl Millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 5.6 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 28 | **61.6** |
| **Complex** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 15.7 | |
| | Pearl millet | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 4.5 | |
| | Crabgrass | *Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop. | Red River and Quick-N-Big | 1.1 | |
| | Corn | *Zea mays* L. | AgriGold 115 day | 11.2 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 11.2 | |
| | Cowpeas | *Vigna unguiculate* (L.) Walp. | Red Ripper | 11.2 | |
| | Korean lespedeza | *Kummerowia stipulacea* (Maxim) Makino | VNS | 4.5 | |
| | Sunn hemp | *Crotalaria juncea* L. | VNS | 2.2 | |
| | Forage rape | *Brassica napus* L. | T-Raptor | 1.1 | |
| | Daikon radish | *Raphanus sativus* L. | SF Select | 2.2 | |
| | Sunflower | *Helianthus annuus* L. | Peredovik | 2.2 | **67.2** |

† Pure Live Seed calculations not used because pure seed was above 98% and germination above 85% as per American Organization of Seed Certifying Agencies standards.

Nitrogen fertilizer as ammonium nitrate was hand applied in split applications for each treatment and is depicted in Table 3.2. For the 56, 112, and 168 kg N ha$^{-1}$ treatments, N was applied in 56 kg N ha$^{-1}$ increments. All three treatments received an application at planting, while the 112 and 168 kg N ha$^{-1}$ treatments received another application after the first harvest. The 168 kg N ha$^{-1}$ received an additional application following the second harvest. Forty percent (90 kg N ha$^{-1}$) of the N fertilizer rate needed for the 224 kg N ha$^{-1}$ treatment was applied each at planting and after the first harvest, with the remaining 20% (44 kg N ha$^{-1}$) applied after the second harvest. Nitrogen fertilizer was split applied in this manner as it was similar to how a producer might apply N fertilizer at different rates, with lower N fertilizer rates applied in fewer applications as compared to higher rates.

Table 3.2. Nitrogen application schedule and rates.

| **Nitrogen Treatment** | **N Applied** | | |
|---|---|---|---|
| | **At Planting** | **After 1st Harvest** | **After 2nd Harvest** |
| | kg N ha$^{-1}$ | | |
| 0 kg N ha$^{-1}$ | – | – | – |
| 56 kg N ha$^{-1}$ | 56 | – | – |
| 112 kg N ha$^{-1}$ | 56 | 56 | – |
| 168 kg N ha$^{-1}$ | 56 | 56 | 56 |
| 224 kg N ha$^{-1}$ | 90 | 90 | 44 |

### 3.2.3 Plot Management

In late May 2018 and early May 2019, plot area was sprayed with 2.3 kg glyphosate [N-(phosphonomethyl) glycine] ha$^{-1}$ twice, with approximately two weeks between applications, to control existing perennial cool-season sod. Based on soil test results (Table 3.3), plot area was then fertilized with triple superphosphate (0-45-0) and muriate of potash (0-0-60) as needed to meet warm-season forage fertility requirements in accordance with the University of Kentucky Cooperative Extension Service 2018-2019 Lime and Nutrient Recommendations (Ritchey & McGrath, 2018).

Table 3.3. Soil test results and nutrient recommendations (applied as triple superphosphate and muriate of potash) for plots in Lexington, KY and Princeton, KY in 2018 and 2019.

| **Environment** | **Soil Test Results** | | | **Amendments Applied** | | |
|---|---|---|---|---|---|---|
| | **Soil water pH** | **P** | **K** | **Lime** | **$P_2O_5$** | **$K_2O$** |
| | | —kg $ha^{-1}$— | | Mg $ha^{-1}$ | —kg $ha^{-1}$— | |
| 2018 Lexington | 7.1 | 141 | 417 | 0 | 0 | 0 |
| 2018 Princeton | 7.2 | 66 | 207 | 0 | 34 | 123 |
| 2019 Lexington | 5.4 | 353 | 136 | 4.75 | 0 | 179 |
| 2019 Princeton | 7.2 | 11 | 195 | 0 | 123 | 146 |

Conventional seedbeds were prepared by rotovating followed by field cultivating in Lexington and by disking followed by field cultivating in Princeton until soil was fine and firm. Plots were planted approximately one month following the last herbicide application using a small plot walk-behind cultipack-type seeder (Carter Manufacturing, Brookston, IN) on the following dates for each location: 27 June 2018 and 5 June 2019 at Lexington and 19 June 2018 and 11 June 2019 at Princeton.

Prior to harvest, plant height was measured with a leveling rod (SVR Series, Seco Industries, Mound City, IL). One measurement was taken at the end of each plot by estimating average height of all plants in plot. Height of tallest leaves or seed heads (if present) were recorded. Harvests were targeted to occur at a plant height of approximately 75 to 100 cm, however, some harvests were delayed resulting in greater heights. Harvest occurred on the following dates: 15 Aug 2018, 20 Sep 2018, 25 Oct

2018, 11 Jul 2019, 7 Aug 2019, and 20 Sep 2019 at Lexington and 2 Aug 2018, 7 Sep 2018, 9 Oct 2018, 19 Jul 2019, 19 Aug 2019, and 3 Oct 2019 at Princeton. A 1.5 m strip was clipped through the center of the plot using a Hege 212 small-plot forage harvester (Wintersteiger Inc., Salt Lake City, UT) leaving 20 cm residual after the first and second harvests, and 10 cm of residual after the final harvest. Entire plot area was cleared after harvest.

Fresh material was weighed upon harvest, and two 250 g subsamples were collected from each plot, one for botanical separation and one for dry matter determination. Subsamples were weighed fresh and dried in a forced air oven for 5-7 days at 55 °C until a constant weight. Percent dry matter was calculated as follows: (dry weight / fresh weight) * 100. Total yield was calculated using the following equation: kg dry matter ha$^{-1}$ = (kg fresh plot weight / 9 m2) * 10,000 m2 ha$^{-1}$ * (% dry matter / 100).

Following harvest, botanical samples were refrigerated until separations could occur. Samples were separated into each individual planted species with an additional category for weeds (anything not planted). Botanical components were then oven dried and each component's percentage of the sward on a dry matter basis was calculated using the following equation: (individual component mass / total component mass) * 100. Yield of each component was then determined by multiplying the component's proportion by the plot dry matter yield.

### 3.2.4 Data Analysis

Data were analyzed using SAS 9.4 software (SAS Institute, Cary, NC). The general linear model procedure was used to generate ANOVA tables and means were separated using Fisher's protected least significant difference post hoc test. Treatments, year, and location were considered fixed effects. Year x location interactions were observed, and data are presented by environment (year x location combination). No treatment interactions (N fertilizer rate x mixture) were observed, therefore main effects are presented. Regression models were determined using orthogonal polynomial contrasts and regression analyses were performed using the REG procedure on the appropriate contrast which was selected using the backward elimination method. A significance level of $\alpha = 0.05$ was used for all analyses.

## 3.3 Results and Discussion

Monthly temperature and precipitation averages for both Princeton and Lexington from 2018 and 2019 are compared with the most recent 30-year climate normals (1981-2010; NOAA National Centers for Environmental Information, Ashville, NC) and are shown in Figure 3.1. As the growing season for warm-season annual forages in Kentucky is typically May to October, the following weather information is summarized for that time period only. Lexington had nearly 40 cm greater rainfall in 2018 and 13 cm greater rainfall in 2019 than the 30-year average of 60 cm. For both those years, temperatures in Lexington were approximately one degree warmer than the 30-year average of 20.5 °C. Temperature and rainfall for Princeton in 2018 and 2019 were similar to the long-term average of 62 cm and 22.0 °C. Rainfall in both locations was above average in September 2018 and far below average in September 2019.

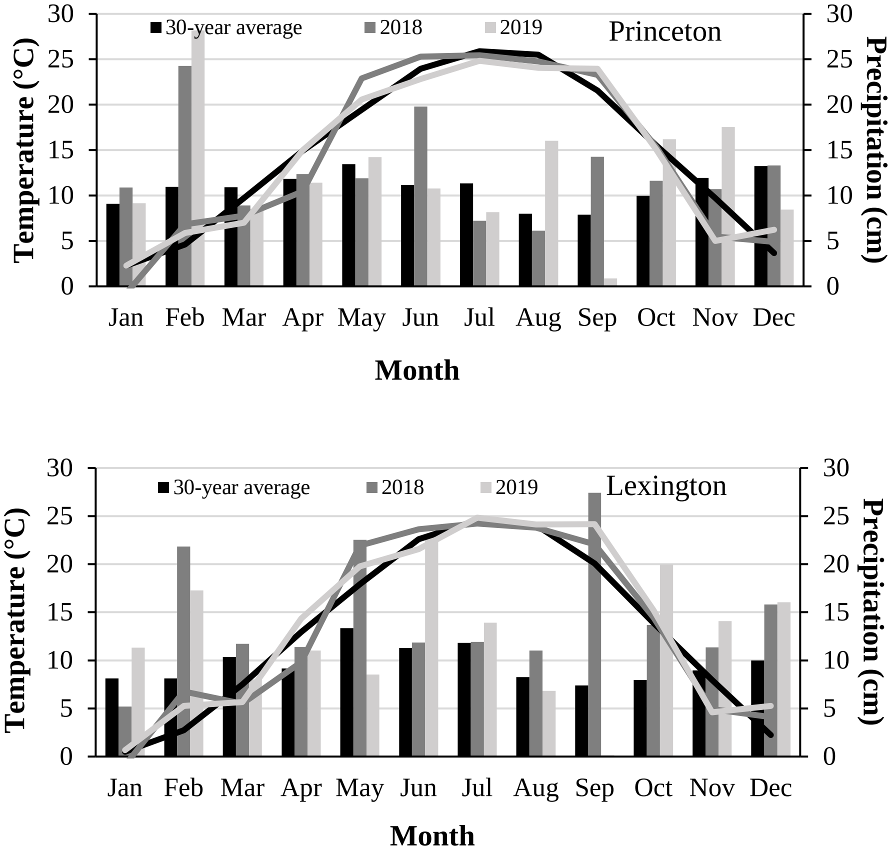


Figure 3.1. Climographs depicting monthly precipitation (bars) and temperature (lines) for 2018 and 2019 (Kentucky Mesonet, Bowling Green, KY), compared with the 30-year normals (1989-2010; NOAA National Centers for Environmental Information, Asheville, NC).

### 3.3.1 Nitrogen Fertilizer Rate Effect on Biomass Production

For all environments, N fertilizer rate significantly impacted annual forage dry matter (DM) production ($p < 0.001$). In all but Lexington 2018, annual forage DM production increased in a linear trend as N fertilizer rate increased. In Lexington 2018, annual forage DM production peaked at 112 kg N ha$^{-1}$ and then declined (Figure 3.2).

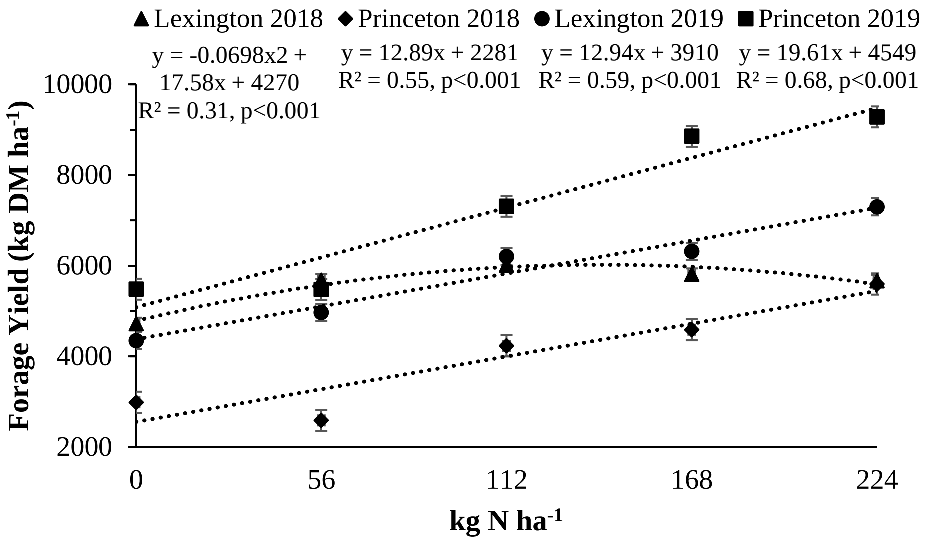


Figure 3.2. Impact of N fertilizer rate averaged over forage mixtures (no mixture x N fertilizer rate interaction) on total forage dry matter for Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019.

Nitrogen is often the most limiting factor in biomass production (Vitousek & Howarth, 1991). The positive relationship between N fertilizer rate and yield was to be expected and was similar to the results of Tofinga (1990), who concluded that N was the strongest determinant of yield and quality of grass-legume intercrops. Positive effects of N application on yield of grass-legume intercrops has also been shown in corn and ricebean [Vigna umbellata (Thunb.) Ohwi & H. Ohashi]; Rerkasem & Rerkasem, 1988), sorghum and cowpea (Patel & Rajagopal, 2003), and corn and cowpea (Asangla & Gohain, 2016).

The Lexington 2018 site did not show the same trends, however. There may have been some soil, management, or environmental properties unique to the site that was not measured but could have contributed to the limited yield response to N. For example, residual soil N or mineralizable N may have played a role in the limited yield response to N fertilizer at Lexington in 2018. Alfalfa was terminated at the Lexington 2018 site three years prior to the establishment of the current study, with subsequent cropping of graminoid species occurring. This management history was not expected to impact treatment response to N fertilizer rates as length of time since legume termination was deemed adequate in conjunction with the high yearly precipitation that results in nitrates leaching from the root zone. Alternatively, above-average rainfall amounts may have leached N from the system, although crude protein of forages in that environment was nearly double that of all other environments (16.6 vs 8.6%; unpublished data) implying that N was not limited in the system.

### 3.3.2 Diversity Effect on Biomass Production

Mixture complexity only affected annual forage DM production in Lexington 2018 ($p < 0.001$), where the simple mixture had greatest annual forage DM production (6000 kg DM $ha^{-1}$), followed by the complex mixture (5670 kg DM $ha^{-1}$), and the monoculture (5060 kg DM $ha^{-1}$). This response was most likely due to greater pearl millet biomass accumulation in mixtures in this environment as compared to other environments (see botanical composition results below). In all other environments, no differences in annual yield occurred between forage mixtures (Princeton 2018 = 4000 kg DM $ha^{-1}$; Lexington 2019 = 5830 kg DM $ha^{-1}$; and Princeton 2019 = 7280 kg DM $ha^{-1}$; $p > 0.06$) (Figure 3.3).

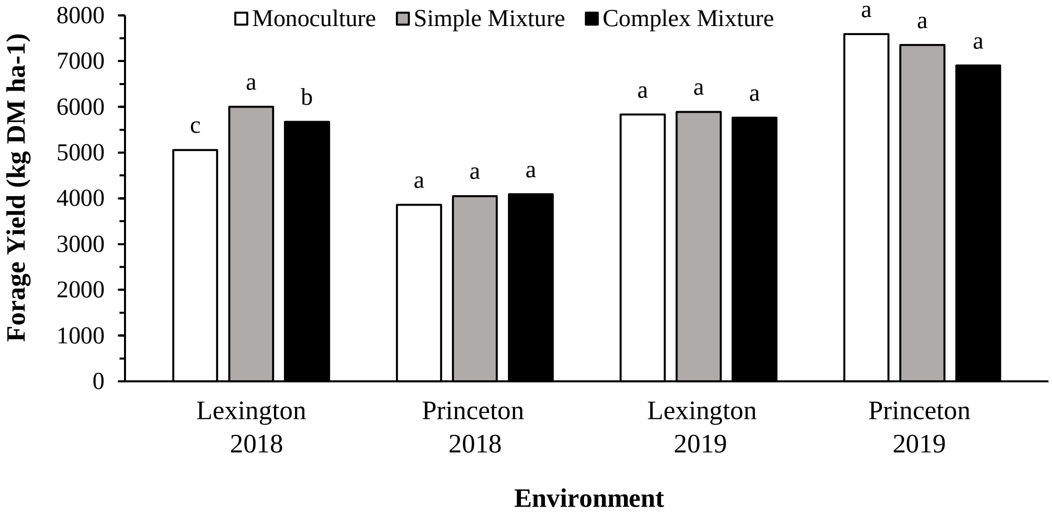


Figure 3.3. Impact of mixture complexity averaged over N fertilizer rates (no mixture x N fertilizer rate interaction) on total annual forage dry matter production for each environment (location x year interaction). Treatments within environment with the same letter are not different according to Fisher's Protected Least Significant Difference (α = 0.05).

Although generally not observed in the current study, increasing species diversity has often been linked to increased biomass production. This is often the case in native grasslands where competition for scarce resources is high and multi-species swards more efficiently utilize a variety of resources to fulfill differing niches (Minns et al., 2001). Lüscher et al. (2008) and Weigelt et al. (2009) even found this to be true in intensively managed grassland systems across Europe.

Conventional agricultural systems remain highly productive due to intensive management and competitive dominance of fast growing species, even though biodiversity is generally low (DiTommaso & Aarssen, 1989). In the current study, intensive management (P and K fertility and harvest frequency) was employed to favor summer annual grasses. Early emergence and canopy closure of grasses promoted competitive dominance over the slower development of dicotyledonous species which lead to reduced diversity of swards in both mixtures (personal observation).

Numerous researchers have also shown positive diversity-productivity relationships in simple intercropping systems around the world. For example, Azraf-ul-Haq et al. (2007) observed 2.3 and 1.5 times greater yields of higher quality forage of sorghum intercropped with both cowpea and sesbania (Sesbania sesban L.), respectively, as compared to sole sorghum. Sharma and colleagues (2009) also reported a 22% increase in dry matter yield of sudangrass [Sorghum bicolor (L.) Moench × Sorghum sudanese (P.) Stapf]/cowpea mixtures over sudangrass monocultures.

Complex assemblages of warm-season annual forages are not as common to conventional agriculture and therefore less researched than simpler mixtures. In a study conducted in North Dakota, USA, the authors observed greater biomass yield of a five species annual mixture of foxtail millet [Setaria italica (L.) P. Beauv.], forage sorghum blend, oat (Avena sativa L.), forage pea (Pisum sativum L.), and brassica hybrid-Winfred (Brassica napus L.) as compared to monocultures of sorghum-sudangrass, sorghum, foxtail millet, and pearl millet (Mozea et al., 2020). This multispecies mixture may have overyielded in comparison to monocultures due to increasing functional diversity, as both cool- and warm-season annuals were present in the mixtures.

The mixtures in the current study may not have shown improved yield with increasing species diversity due to limited species and/or functional group evenness (see botanical composition results). Similar to the current results, in three- and four-way summer annual mixtures, Bybee-Finley et al. (2016) also showed no increase in yield of intercropping systems over the highest producing monocrop in the northeastern USA.

Similar to results of the current study, their plots were also dominated by summer annual grasses with a relatively low legume component.

In contrast to the above evidence, many studies have shown positive effects of intercropping, such as increased yield, land equivalency ratios, or economic returns (Andrews, 1972; Bybee-Finley et al., 2016; Takele et al., 2017; Fan et al., 2020). Researchers in Georgia, USA, even found that including crabgrass [Digitaria sanguinalis (L.) Scop.] in a pearl millet stand increased gains for finishing cattle by 0.12 kg $d^{-1}$ over pure stands of pearl millet (Harmon et al., 2019), while Sharma and colleagues (2009) reported 27% greater benefit to cost ratio of sudangrass/cowpea intercropped hay over sole sudangrass.

Weigelt and colleagues (2009) concluded that increasing biodiversity had an even stronger effect on biomass production of perennial grassland communities as compared to increasing management (N fertilization and mowing). In contrast, results from the current study found that in three out of four environments there was no improvement in biomass yield by increasing biodiversity, and positive responses to N application were observed. This indicates that in annual agricultural systems where mixtures are dominated by grass species, N is a stronger driver of biomass production as compared to increased biodiversity.

Weigelt and colleagues (2009) also observed greater yield responses to fertilizer when excluding legumes in mixtures, presumably due to the ability of leguminous species to share nitrogen acquired from biological nitrogen fixation. As stated previously, this was not observed in the current experiment where no N fertilizer rate x mixture complexity interaction occurred, resulting in each mixture responding to N fertilizer rate similarly, regardless of legume inclusion. In order to understand why three out of four environments in this study showed no yield advantage of intercropping, individual species contributions to sward DM were documented.

### 3.3.3 Nitrogen Fertilizer Rate Effect on Botanical Composition

Species responses in each mixture to N rate are presented for each environment in Figures 3.4-3.6 due to significant N fertilizer rate x environment interactions. Only species with significant contributions to sward biomass are presented (> 200 kg DM ha$^{-1}$).

#### 3.3.3.1 Monoculture

In Lexington 2018, sudangrass DM yield showed a significant, but limited quadratic response to increasing N fertilizer rate, with a maximum yield of 5500 kg DM ha$^{-1}$ occurring around 135 kg N ha$^{-1}$ ($p < 0.01$, $R^2 = 0.48$; $y = -0.0746x2 + 17.65x + 3863$; Figure 3.4). Weeds contributed 1% of sward DM. In Princeton 2018, sudangrass DM yield showed a slight quadratic response as N fertilizer rate increased, from 2965 to 5991 kg DM ha$^{-1}$ ($p < 0.04$, $R^2 = 0.41$, $y = -0.0746x2 + 17.65x + 3863$). Weed biomass accounted for only 1% of sward DM. In Lexington 2019, sudangrass DM linearly increased as N fertilizer rate increased, with a maximum yield of 6640 kg DM ha$^{-1}$ ($p < 0.001$; $R^2 = 0.64$; $y = 14.87x + 3375$). While weed DM averaged 306 kg DM ha$^{-1}$, it only contributed 5% of sward DM. In Princeton 2019, sudangrass DM linearly increased as N fertilizer rate increased, with a maximum yield of 9790 kg DM ha$^{-1}$ ($p < 0.001$; $R^2 = 0.67$; $y = 17.19x + 4956$). Weed proportion was 2% of sward DM.

Sudangrass responses to N fertilizer rate in monoculture plantings at Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019. Weed species did not respond to N fertilizer rate ($p > 0.08$) but contributed less than 500 kg dry matter $ha^{-1}$.

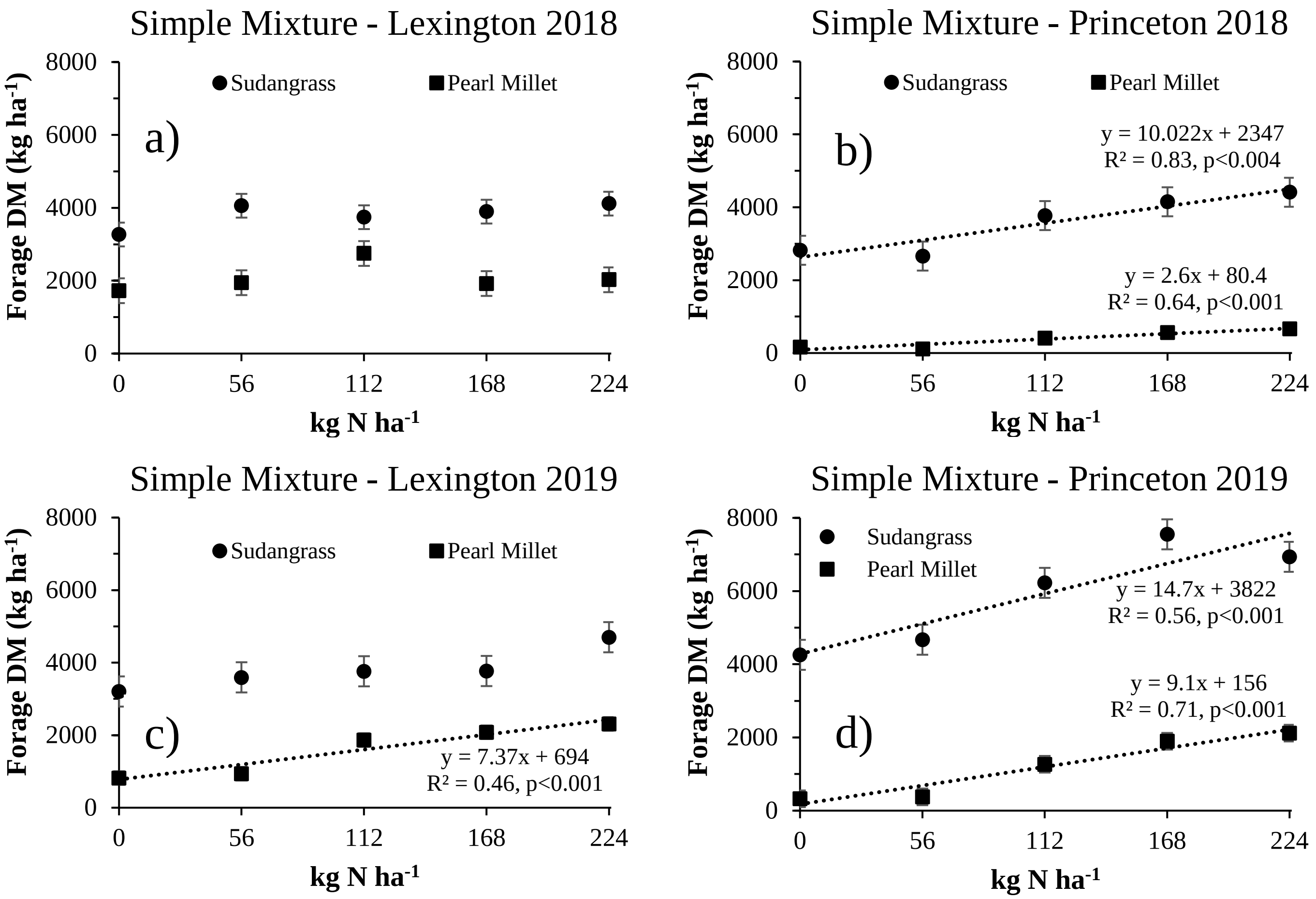
#### 3.3.3.2 Simple Mixture

In Lexington 2018, no individual species responded to increasing N fertilizer rates ($p > 0.20$). Sudangrass and pearl millet averaged 3410 and 1850 kg DM $ha^{-1}$ (Figure 3.5a). Botanical composition was as follows: sudangrass = 64%, pearl millet = 35%, and soybean and weeds = 1% each.

In Princeton 2018, sudangrass ($p < 0.004$; $R^2 = 0.83$; $y = 8.3x + 2346$) and pearl millet ($p < 0.001$; $R^2 = 0.64$; $y = 2.6x + 80.4$) DM increased with increasing N fertilization rate, with maximum DM yields of 4412 and 667 kg DM $ha^{-1}$ (Figure 3.5b). Botanical composition was as follows: sudangrass = 87%, pearl millet = 9%, soybean = 1%, and weeds = 2%.

In Lexington 2019, pearl millet was the only species to respond to N fertilizer rate, with a maximum yield of 1600 kg DM $ha^{-1}$ ($p < 0.001$; $R^2 = 0.46$; $y = 7.37x + 694$). Sudangrass and weeds averaged 3810 and 361 kg DM $ha^{-1}$, respectively (Figure 3.5c). Botanical composition was as follows: sudangrass = 65%, pearl millet = 27%, soybean = 2%, and weeds = 6%.

In Princeton 2019, sudangrass ($p < 0.001$; $R^2 = 0.56$; $y = 14.7x + 3822$) and pearl millet ($p < 0.001$; $R^2 = 0.71$; $y = 9.1x + 156$) yields increased with increasing N fertilizer rate, with maximum yields of 6940 and 2120 kg DM $ha^{-1}$, respectively (Figure 3.5d). Botanical composition was as follows: sudangrass = 75%, pearl millet = 23%, and soybean and weeds = 1% each.



Simple Mixture - Lexington 2018

Simple Mixture - Princeton 2018

Simple Mixture - Lexington 2019

Simple Mixture - Princeton 2019

Figure 3.4. Responses of individual species in simple, three-species forage mixtures to N fertilizer rates at Lexington 2018 (a), Princeton 2018 (b), Lexington 2019 (c), and Princeton 2019 (d). Soybean are not presented if they contributed < 200 kg DM ha$^{-1}$ to sward biomass. Weeds are not presented as they did not respond to N fertilizer rate. Species with no regression line did not respond to N fertilizer rate ($p > 0.05$). Lexington 2019 pearl millet error bars are not shown due to small size (185 kg DM ha$^{-1}$).

In Lexington 2018, no individual species ($p > 0.06$) responded to N fertilizer rate in Lexington 2018, but sudangrass and pearl millet averaged 3170 and 2120 kg DM ha$^{-1}$, respectively (Figure 3.6a). Botanical composition was as follows: sudangrass = 56%, pearl millet = 37%, corn = 2%, soybean, cowpea, sunflower, and daikon radish = 1% each. Weeds, crabgrass, sunn hemp, forage rape, and Korean lespedeza were not present.

In Princeton 2018, sudangrass ($p < 0.001$; $R^2 = 0.50$; $y = 11.4x + 1520$) and pearl millet ($p < 0.001$; $R^2 = 0.45$; $y = 2.1x + 146$) increased as N fertilizer rate increased, ranging from 2210 to 4960 and 190 to 690 kg DM ha$^{-1}$, respectively, from 0 to 224 kg N ha$^{-1}$ (Figure 3.6b). Botanical composition was as follows: sudangrass = 76%, pearl millet = 11, crabgrass = 6%, and soybean, weeds, corn, cowpea, sunflower, sunn hemp, and Korean lespedeza = 1% each. Daikon radish and forage rape were not present.

In Lexington 2019, sudangrass ($p < 0.01$; $R^2 = 0.42$; $y = 7.1x + 1723$) and pearl millet ($p < 0.05$; $R^2 = 0.32$; $y = 5.5x + 628$) increased with increasing N fertilizer rate (2160 - 3590 and 590 - 1960 kg DM ha$^{-1}$, respectively). Crabgrass did not respond to N fertilizer rate ($p > 0.2$) but averaged 1120 kg DM ha$^{-1}$. Crabgrass contributed >20% of the sward DM at rates of 0 to 168 kg N ha$^{-1}$, and even at 224 kg N ha$^{-1}$ contributed 11% of sward DM (Figure 3.6c). Botanical composition was as follows: sudangrass = 47%, pearl millet = 23%, crabgrass = 19%, corn = 4%, weeds = 2%, and soybean, cowpea, sunflower, and Korean lespedeza = 1% each. Sunn hemp, daikon radish, and forage rape were not present.

In Princeton 2019, sudangrass ($p < 0.001$; $R^2 = 0.52$; $y = 10.5x + 3083$) and pearl millet ($p < 0.0001$; $R^2 = 0.66$; $y = 7.2x + 373$) DM yield increased with increasing N fertilizer rate, with maximum yields of 5900 and 2030 kg DM ha$^{-1}$, respectively.

Crabgrass DM was not affected by N fertilizer rate ($p > 0.1$) but contributed 770 kg DM $ha^{-1}$ on average. Crabgrass contributed >11% sward DM in all N fertilizer rates up to 168 kg N $ha^{-1}$. At 224 kg N $ha^{-1}$, crabgrass contributed 7% of sward DM (Figure 3.6d). Botanical composition was as follows: sudangrass = 67%, pearl millet = 18%, crabgrass = 11%, and soybean, weeds, corn, cowpea, and sunn hemp = 1% each. Sunflower, daikon radish, forage rape, and Korean lespedeza were not present.

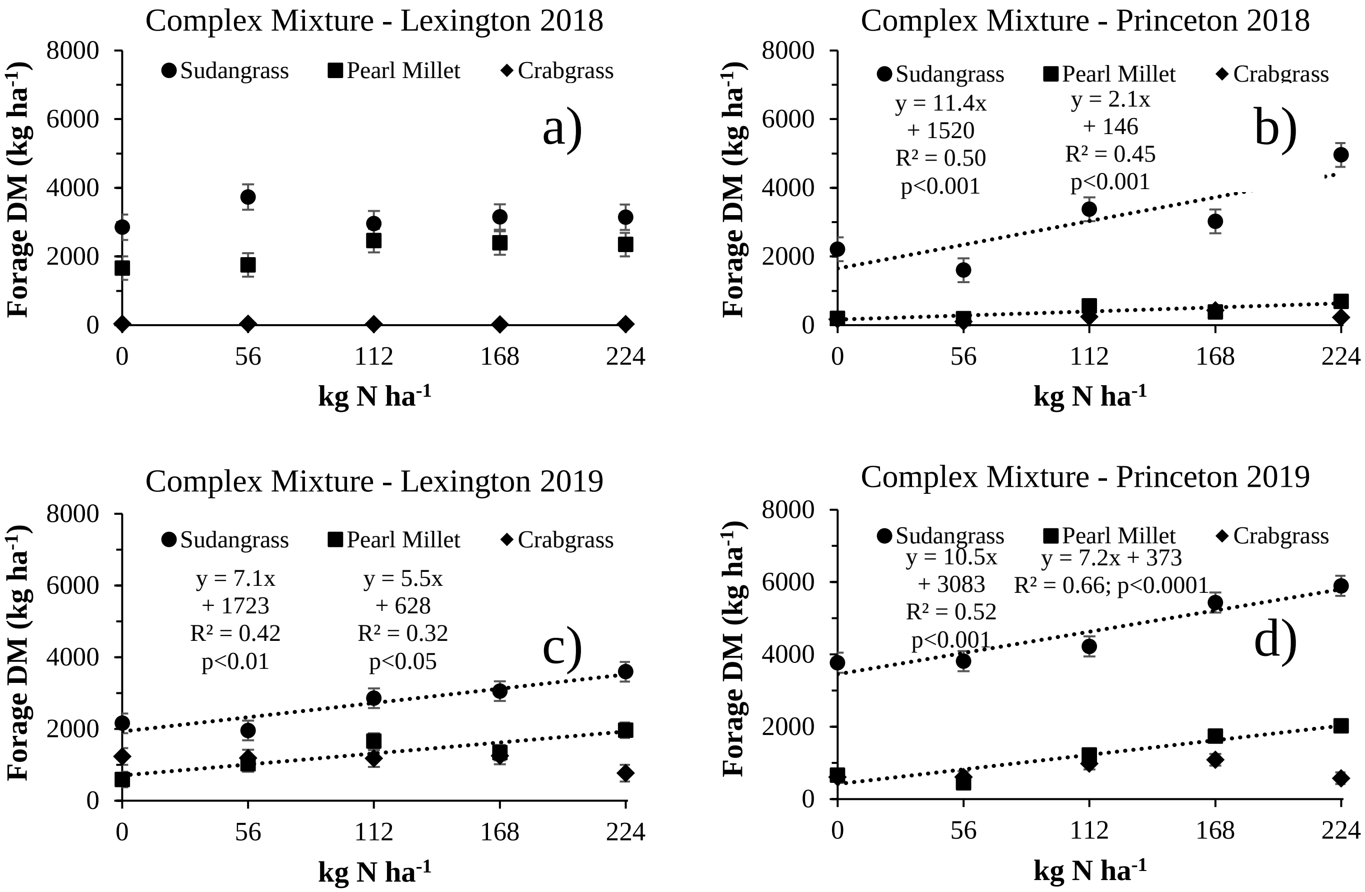


Figure 3.5. Responses of individual species in a complex, 12-species mixture to N fertilizer rate at Lexington 2018 (a), Princeton 2018 (b), Lexington 2019 (c), and Princeton 2019 (d). Weeds, soybean, corn, sunflower, sunn hemp, forage rape, daikon radish, and Korean lespedeza contributed < 200 kg DM ha$^{-1}$ to sward DM and are not presented. Species with no regression line did not respond to N fertilizer rate ($p > 0.05$). Error bars not shown due to small size are as follows: 10, 69, 69, 163, and 162 kg DM ha$^{-1}$ for Lexington 2018 crabgrass, Princeton 2018 pearl millet and crabgrass, and Princeton 2019 pearl millet and crabgrass, respectively.

### 3.3.4 Nitrogen Fertilizer Rate Effect on Grasses

For most environments and mixtures, sudangrass and pearl millet biomass responded positively to N fertilization and were most likely the driver of sward responses to N application, as most other species contributed minimally to sward biomass. Pearl millet performed moderately well in both mixtures in Lexington, even though seeds planted per hectare were 62 and 88% of that of sudangrass in simple and complex mixtures, respectively. Weed components were consistently low and did not respond to N fertilizer application. This implies that planted driver species were more competitive than weeds in acquiring N and other resources in these environments.

Sudangrass seeding rates were somewhat higher than recommended for grazing but were within recommendations for hay, as much higher seeding rates have been recommended in the southwestern USA to produce finer stemmed hay (Knowles & Ottman, 2015). These high planting populations most likely contributed to mixtures being overwhelmingly dominated by sudangrass, leading to reduced competitiveness of other component species. Osiru & Willey (1972) conducted an experiment using sorghum and common bean (Phaseolus vulgaris) mixtures in differing seeding proportions. Their results indicated that yields of components in mixtures were affected by seeding proportion of individual species. Craufurd (2000) also observed cowpea yield declining with increasing grass density, even though overall intercrop yield was still increased as compared to monocultures.

These findings, in accordance with results of the current experiment, reinforce the need for balanced seeding rates to achieve target goals (i.e. diversity, yield, etc.). Botanical separation results in the current study may have differed if seeding rates of secondary species were increased or if seeding rates of the dominant, highest yielding species were decreased. However, it is unclear as to what degree, as tillering response can increase with decreased seeding rate, leading to yield compensation (Sowiński & Szydełko, 2011).

Although crabgrass comprised a substantial proportion of sward DM in only two environments (7 and 20%), it may be useful to include in annual warm-season forage mixtures. In the current study, the low crabgrass composition was likely a result of harvest management in the current study. In order to favor higher yielding grass species, cutting height was set to 18-20 cm for the first two harvests. During the first harvest, crabgrass was minimally present, but proportions increased at each successive harvest (data not shown), likely due to increased light availability following defoliation of taller species. Crabgrass typically produces greater biomass under shorter defoliation heights, as residual plant height following mowing or grazing is recommended at 7 to 15 cm (Blount et al., 2003). A reduced cutting height may also have reduced competitive advantage of taller growing summer annuals, thereby leaving more resources available for crabgrass growth.

Although management of this experiment did not include grazing, animals have been observed lowering their heads to graze smaller statured species such as crabgrass and brassicas amid a mixed pasture including tall growing species such as sorghum-sudangrass and pearl millet (personal observation). Crabgrass also regularly “fills in” thin spots in perennial pastures and can be a good way to increase groundcover and perhaps overall pasture yield. More research is needed to evaluate diet selection, animal performance, and regrowth potential of grazed annual warm-season forage mixtures.

### 3.3.5 Nitrogen Fertilizer Rate Effect on Legumes

Nitrogen fertilizer application has been shown to reduce soybean yield of intercrops due to the increased competitiveness of associated summer annual grasses (Layek et al., 2015a, b). Unfortunately, this was not investigated in the current experiment due to low legume proportions (1 and 4% of sward DM in simple and complex mixtures, averaged across environments). It was noted that N deficiency in low N fertilizer rate treatments was more pronounced prior to second and third harvests, as compared to the first cutting (personal observation). Perhaps there was adequate residual soil N to support vigorous grass growth early in the growing season, even in 0 kg N ha$^{-1}$ treatments, leading the grasses to outcompete the legumes.

Some researchers have speculated that soybean is not compatible when grown in association with warm-season grasses due to shading from the taller statured species, resulting in loss of photosynthetic activity, nodulation, and N fixation (Wahua & Miller, 1978; Gilbert et al., 2003; Brainard et al., 2011). Reddy and colleagues (1990) also observed increases in cowpea yield when planted with dwarf rather than tall pearl millet, furthering support of claims that legumes are at a disadvantage when grown with taller grasses. Alternatively, Layek and coworkers (2012) showed soybeans to be compatible with sorghum and corn, but not pearl millet, due to its tillering nature. However, tillering sudangrass and pearl millet were specifically selected for the current study due to their regrowth potential under multi-cut management.

The multi-cut system used in this experiment also favored grasses over dicotyledonous species, reinforcing the idea that species selection should match management strategy. Results of the current study would likely have been affected by using dwarf grass varieties. Seeding legumes earlier than grasses has been shown to be a viable way of allowing the legume time to emerge before being outcompeted by grasses (Iqbal et al., 2017), as legume growth rates are typically less than those of grasses (Bybee-Finley et al., 2016). Unfortunately, this strategy may not be feasible or practical in most agricultural operations.

### 3.3.6 Pre-Harvest Height

No consistent differences were observed for height of mixtures prior to harvest (Table 3.4). In six out of twelve harvests, the complex mixture was taller than the monoculture ($p < 0.05$). In five out of the twelve harvests, the simple mixture height was also greater than the monoculture ($p < 0.05$). The remainder of the six harvests showed no difference in mixture height ($p > 0.24$).

Table 3.4. Pre-harvest height of monoculture, simple mixture, and complex mixture treatments. Means within rows sharing the same letter are not different ($p < 0.05$).

| **Environment** | **Harvest** | **Pre-Harvest Height** Mono-culture | Simple Mixture | Complex Mixture | **Standard Error** |
|---|---|---|---|---|---|
| | | m | | | |
| Lexington 2018 | 1 | 1.03 a | 0.99 a | 0.99 a | 0.02 |
| | 2 | 1.13 c | 1.33 b | 1.39 a | 0.02 |
| | 3 | 0.25 b | 0.29 a | 0.30 a | 0.01 |
| Princeton 2018 | 1 | 0.91 a | 0.91 a | 0.90 a | 0.01 |
| | 2 | 0.77 b | 0.85 a | 0.87 a | 0.02 |
| | 3 | 0.52 a | 0.53 a | 0.51 a | 0.01 |
| Lexington 2019 | 1 | 0.88 a | 0.85 a | 0.84 a | 0.02 |
| | 2 | 0.65 b | 0.78 a | 0.82 a | 0.02 |
| | 3 | 0.83 ab | 0.87 a | 0.77 b | 0.03 |
| Princeton 2019 | 1 | 0.75 a | 0.78 a | 0.73 a | 0.02 |
| | 2 | 0.91 b | 1.00 a | 0.97 a | 0.02 |
| | 3 | 1.20 a | 1.24 a | 1.24 a | 0.03 |

Plot height was measured relative to the tallest growing species in the mixture. Both simple and complex mixtures contained pearl millet, which seems to be the driver of the height responses observed. Visual observations also indicated that most legumes were considerably shorter than sudangrass and pearl millet, with the exception of sunn hemp, which was the tallest growing legume in the complex mixture.

### 3.3.7 Implications

Very few published studies have evaluated diverse mixtures of summer annual forages. However, some producers have had success with maintaining diversity in these systems (personal observation). This gap between scientific understanding of species compatibility and practical application leaves an opportunity to evaluate the agronomic, economic, and environmental benefits of diverse summer annual forage systems. Understanding species compatibility will ultimately lead to improved economics of these systems.

A prominent theory as to why low diversity swards have equal or greater biomass production as compared to higher diversity swards has been suggested by Picasso et al. (2008), Huston et al. (2000), and Sanderson et al. (2004). These authors determined that the positive relationship between species richness and biomass is mainly a reflection of a strong influence of one or two well-adapted species in a community. The authors also stated that polyculture plots including high producing forage species did not increase biomass when species diversity was increased, and that plots containing a dominant ‘driver’ species yielded similarly to the same species grown in a monoculture.

These trends were also exhibited in the current study where in three out of four environments, mixtures did not outyield monocultures and were dominated by high yielding species. The mixtures in the current study were dominated by species and cultivars that have been shown to yield well on the experimental sites. However, seeding rates of high producing species were reduced in the complex mixture in order to ‘make room’ for additional species. Seeding rates of these aggressive species could have been further reduced to allow less competitive species an opportunity to contribute more to sward biomass, although total biomass production may have been lower if seeding rates were significantly reduced.

The additional species in the complex mixture were selected to increase functional diversity, and unfortunately some species selected were not as competitive or well-adapted to experimental sites and did not contribute significantly to sward biomass.

As agriculture production relies on economic efficiency, planting less competitive species in a mixed sward would not be advised, especially if management strategies will not favor them. This could lead to an increased seed cost without a substantial production benefit.

In a multi-location trial, Barker and colleagues (2003) also found that different simple mixtures or monocultures obtained the highest yields at different locations. The authors recommend planting simple mixtures of high yielding species as opposed to monocultures as it may be hard to determine which species will yield best on specific sites or within-site microclimates. Due to the competitive dominance of fast establishing summer annual grasses, Bybee-Finley et al. (2016) also recommends matching species with similar plant heights and growth rates in intercropping systems to limit competition for sunlight. Additionally, the authors of the current study recommend reducing seeding rates of tall growing grasses or utilizing dwarf cultivars in mixtures if species diversity is to be targeted. This would allow for more resources, particularly sunlight, to be partitioned to slower, or lower growing species such as crabgrass and legumes that otherwise may not establish or compete well. Including species that are not well-suited to a management system could lead to an increased seed cost without a substantial production or diversity benefit; therefore, grass-only plantings may be more suitable under hay management regimes, as regrowth potential of annual legumes is generally less than that of grasses.

It was hypothesized that inclusion of legumes in this study would affect the mixture responses to N fertilization, and with a strong enough legume component less N fertilizer would be required to produce similar yields as monoculture sudangrass. This was not the case in the current study, as results showed similar yield trends for each mixture with increasing N fertilizer rate (no mixture x N fertilizer rate interaction). Legume content of these swards was admittedly low for the mixtures (< 5%), which most likely contributed to these results. Due to low legume content from poor establishment and competition from taller grass species, N recommendations for legume-containing summer annual forage mixtures cannot be made based on the current study. However, other research has shown that grass-legume intercrops often still respond positively up to the 100% recommended N fertilizer rate for the grass species (Layek et al., 2015a, b; Takele et al., 2017).

The current data and cited literature indicate that planting high-yielding, morphologically and developmentally compatible species in simple mixtures and fertilizing according to the grass recommendations may be advantageous in regards to economic efficiency of summer annual forage systems. However, if forage diversity is the primary goal, reducing seeding rates or using dwarf cultivars of dominant species is imperative to allow less competitive species an opportunity to establish and make significant contributions to the overall biomass production. Additionally, Tracy and Faulkner (2006) stated that "compared with pasture species richness, grazing management and climatic conditions more strongly influence grazing system productivity." In accordance with this statement, the yields in the current study were affected by environment, and no or limited yield benefits from increasing biodiversity were observed. Producers are encouraged to invest in grazing management infrastructure (fencing and water resources) for additional opportunities to increase biomass production rather than planting complex summer annual forage mixtures.

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# CHAPTER 4. NUTRITIVE CHARACTERISTICS OF LEGUME-CONTAINING SUMMER ANNUAL FORAGE MIMXTURES FERTILIZED WITH VARYING RATES OF NITROGEN

## Abstract

Nitrogen application generally improves the nutritional value of summer annual forages. However, it can have a negative effect on legume competitiveness, thereby reducing beneficial effects of planting diverse swards. This study was conducted to evaluate the effects of increasing N rate (0, 50, 100, 150, and 200 lb acre$^{-1}$) on nutritive characteristics of summer annual mixtures which included a grass monoculture (control), a simple mixture of 2 grasses and 1 legume, and a complex mixture of 4 grasses, 4 legumes, and 3 forbs. Nitrogen application up to 200 lb N acre$^{-1}$ often had a positive impact on forage quality parameters. All mixtures were overwhelmingly dominated by grasses, resulting in mixture complexity having little impact on nutritive characteristics, except in the case of lignin content. As proportions of low-lignin brown midrib (BMR) species declined with increasing mixture complexity, lignin increased. This demonstrates the importance of selecting grass species with the BMR trait that have lower lignin concentrations and increased digestibility. In this study, legume and forb species contributed minimally to sward biomass which may have been due to competition from the more aggressively establishing grasses. Care must be taken to select compatible species, appropriate seeding rates, and management to promote less well-adapted species if sward diversity is of interest, otherwise cost of additional seed may not be economical.

## 4.1 Introduction

Tracy and coworkers (2010) found that summer annual pastures produced 61% more dry matter and equal or greater nutritive value as compared to cool-season pastures during the summer months. These attributes make them an attractive alternative to grazing cool-season forages during this time. However, high annual establishment costs and high risk of stand failures in annual systems has resulted in slow adoption. Although costly to implement, summer annual forages may be a necessary component of some pasture systems. For example, they could serve as a source of emergency forage, as part of a pasture renovation sequence, or to fill the “summer slump” in cool-season pasture systems. Tracy and coworkers (2010) concluded that “finding ways to reduce…the need for N fertilizer in [annual warm-season grass] pastures seems critical to make these forage systems more economical over the long term.”

Incorporating legumes into summer annual grass swards may offer an opportunity to both reduce N fertilizer inputs and improve nutritive value due to greater crude protein and digestibility of legumes as compared to grasses (Ball et al., 2007). The greater forage quality of legumes is due to higher pectin content in the cell wall and the ability to utilize fixed atmospheric N from symbiotic relationships formed with rhizobium bacterium (Buxton & Mertens, 1995). Although N can be “shared” between legumes and associated grasses in perennial systems primarily via decomposition of plant parts and animal excreta (Wedin & Russelle, 2007), there is debate as to what extent this happens with mixtures of annual grasses and legumes, and to what degree other mechanisms may contribute to N transfer (Fujita et al., 1992; Wedin & Russelle, 2007; Layek et al., 2018).

Nitrogen application also has the potential to improve some nutritive characteristics of summer annual grasses (Fribourg, 1974). Hart and Burton (1965) reported a nearly doubling of protein concentrations and a 10% reduction in crude fiber concentration of pearl millet when increasing N application from 0 to 560 kg N ha$^{-1}$. In sorghum, Ayub and coworkers (2002) observed approximately 2.5 and 1.5 percentage unit reduction in neutral and acid detergent fibers (NDF and ADF), respectively, when N increased from 0 to 150 kg ha$^{-1}$. Additionally Ates and Tenikecier (2019) reported 3.3, 3.7, 4.3, and 5.2 percentage units improvement of crude protein, crude fiber, NDF, and ADF, respectively, of sorghum-sudangrass when increasing N rates from 0 to 160 kg N ha$^{-1}$.

While N generally has a beneficial effect on grasses, it may decrease the proportion of legumes in mixtures. Layek and coworkers (2015) reported that when soybean was intercropped with corn, sorghum, or pearl millet at the recommended N rate for the grass, root and nodule biomass and yield of soybeans were reduced as compared to no N applied. Similarly, Ofori and Stern (1987) reported reduced cowpea (Vigna unguiculata (L.) Walp.) yields when increasing N from 0 to 100 kg N ha−1 in a corn intercropping system.

Including legumes into a summer annual grass stand can improve both yield and forage quality, but nitrogen recommendations for summer annual mixtures are not well established (Layek et al., 2018). This is due to the differing effects of N on grasses versus legumes. In general, most summer annual grasses show a positive yield or forage quality response to N application (Beyaert & Roy, 2005; Broyles & Fribourg, 1959). Legumes often do not show a response to N fertilization, and may in fact show decreased productivity (Layek et al., 2015). The objective of this study was to evaluate the effects of N rate and species diversity on nutritive characteristics of summer annual forage swards.

## 4.2 Materials and Methods

This experiment was conducted at Lexington (38.128, -84.498) and Princeton, KY (37.101, -87.854) in 2018 and 2019. Soil series were a Maury silt loam (fine, mixed, active, mesic Typic Paleudalfs) and a Zanesville silt loam (fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs) (Soil Survey Staff, 2019) in Lexington and Princeton, respectively. A randomized complete block design with four replications was utilized for this study. Field position was used as a blocking factor due to presence of very gentle slopes. Plot area measured 2.7 x 6 m with 1.5 m alleys between blocks.

Factors of interest were forage mixture complexity (monoculture, simple mixture, and complex mixture) and nitrogen rate (0, 56, 112, 164, or 224 kg N ha$^{-1}$). Nitrogen treatments were hand applied as ammonium nitrate, with the higher rates being split as depicted in Table 4.1. Higher N rates were split to minimize nitrate accumulation and optimize productivity.

Forage mixture complexity consisted of three treatments: 1) summer annual grass monoculture (control), 2) simple mixture of two summer annual grasses + one summer annual legume, and 3) complex mixture of four summer annual grasses, four summer annual legumes, and three summer annual forbs. Species, cultivars, and seeding rates used can be found in Table 4.2. A multi-species inoculant (Link Cover Crop Inoculant, La Crosse Seed, La Crosse, WI) suitable for all species used in mixtures was applied to seed.

Table 4.1. Nitrogen application rates and schedule.

| **Nitrogen Treatment** | **N Applied** | | | **Total Seasonal N** |
|---|---|---|---|---|
| | At Planting | After 1st Harvest | After 2nd Harvest | |
| | kg N ha$^{-1}$ | | | |
| 1 | – | – | – | 0 |
| 2 | 56 | – | – | 56 |
| 3 | 56 | 56 | – | 112 |
| 4 | 56 | 56 | 56 | 164 |
| 5 | 90 | 90 | 44 | 224 |

Table 4.2. Forage species, cultivars, and seeding rates for the monoculture, simple mixture, and complex mixture.

| **Treatment** | **Species** | **Scientific Name** | **Cultivar** | **Seeding Rate†** | |
|---|---|---|---|---|---|
| | | | | Species | Total |
| | | | | (kg ha$^{-1}$) | |
| **Monoculture** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | **56** | **56** |
| **Simple** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 28 | |
| | Pearl Millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 5.6 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 28 | **61.6** |
| **Complex** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 15.7 | |
| | Pearl millet | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 4.5 | |
| | Crabgrass | *Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop. | Red River and Quick-N-Big | 1.1 | |
| | Corn | *Zea mays* L. | AgriGold 115 day | 11.2 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 11.2 | |
| | Cowpeas | *Vigna unguiculate* (L.) Walp. | Red Ripper | 11.2 | |
| | Korean lespedeza | *Kummerowia stipulacea* (Maxim) Makino | VNS | 4.5 | |
| | Sunn hemp | *Crotalaria juncea* L. | VNS | 2.2 | |
| | Forage rape | *Brassica napus* L. | T-Raptor | 1.1 | |
| | Daikon radish | *Raphanus sativus* L. | SF Select | 2.2 | |
| | Sunflower | *Helianthus annuus* L. | Peredovik | 2.2 | **67.2** |

† Pure Live Seed calculations not used because pure seed was above 98% and germination above 85% as per American Organization of Seed Certifying Agencies standards.

Approximately one month prior to planting, plot area was sprayed with 2.3 kg glyphosate ha$^{-1}$ twice, with approximately two weeks between applications. Lime and fertilizer (triple superphosphate and muriate of potash) were applied based on soil test results (Table 4.3) (Ritchey & McGrath, 2020).’

Table 4.3. Soil test results and nutrient recommendations for plots in Lexington, KY and Princeton, KY in 2018 and 2019.

| Environment | Soil Test Results |  |  | Amendments Applied |  |  |
|---|---|---|---|---|---|---|
|  | Soil water pH | P | K | Lime | $P_2O_5$ | $K_2O$ |
|  |  | —kg ha$^{-1}$— |  | Mg ha$^{-1}$ | —kg ha$^{-1}$— |  |
| 2018 Lexington | 7.1 | 140 | 415 | 0 | 0 | 0 |
| 2018 Princeton | 7.2 | 66 | 205 | 0 | 35 | 125 |
| 2019 Lexington | 5.4 | 355 | 135 | 4.75 | 0 | 180 |
| 2019 Princeton | 7.2 | 10 | 195 | 0 | 125 | 145 |

Conventional seedbeds were prepared by rotovating (Lexington) or disking (Princeton) followed by field cultivating until soil was fine and firm. Plots were planted on 10 July 2018 and on 5 June 2019 in Lexington and 18 June 2018 and 11 June 2019 in Princeton with a small plot walk-behind cultipack-type seeder (Carter Manufacturing, Brookston, IN).

Harvest occurred when plants reached approximately 75-100 cm (Table 4.4). A 1.5 m strip was clipped through the center of the plot using a Hege 212 small-plot forage harvester (Wintersteiger Inc., Salt Lake City, UT). Plots were clipped to a residual height of 20 cm after the first and second harvests, and 10 cm after the final harvest. Fresh plot weight was recorded, and a 250 g subsamples was collected from each plot for dry matter and nutritive value determinations.

Samples were weighed fresh, dried in a forced air oven for 5-7 days at 55°C, and weighed dry. The sample was then ground to pass through 2- and 1-mm screens sequentially using Wiley (Thomas Wiley, Philadelphia, PA) and Cyclone (Udy Corporation, Fort Collin, CO) sample mills, respectively. Nutritive characteristics were estimated using near infrared reflectance spectroscopy (Foss North America, Eden Prairie, MN) with a robust equation for hay and fresh forage (NIRS Forage and Feed Testing Consortium, Berea, KY). Forage nutritive characteristics analyzed were crude protein (CP), total digestible nutrients (TDN), acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, and 30-hour in vitro true dry matter digestibility (IVTDMD30). Total digestible nutrients were calculated as follows: TDN = 100.32 – 1.118 * ADF.

Table 4.4. Harvest dates for plots in Lexington and Princeton, KY in 2018 and 2019.

| Environment | Harvest 1 | Harvest 2 | Harvest 3 |
|---|---|---|---|
| 2018 Lexington | 15 Aug | 20 Sep | 25 Oct |
| 2018 Princeton | 2 Aug | 7 Sep | 9 Oct |
| 2019 Lexington | 11 Jul | 7 Aug | 20 Sep |
| 2019 Princeton | 19 Jul | 19 Aug | 3 Oct |

Data were analyzed using SAS 9.4 software (SAS Institute, Cary, NC). The general linear model procedure was used to generate ANOVA tables and means were separated using Fisher’s protected least significant difference post hoc test. Treatments, year, and location were considered fixed effects. Year x location interactions were observed; therefore, data are presented by environment (year x location). No treatment interactions (N rate x mixture) were observed, therefore, main effects are presented.

Regression models were determined using orthogonal polynomial contrasts and regression analyses were performed using the REG procedure on the appropriate contrast which was selected using the backward elimination method. A significance level of $\alpha = 0.05$ was used for all analyses.

## 4.3 Results and Discussion

### 4.3.1 Precipitation and Rainfall

Site averages for both Princeton and Lexington from 2018-2019 (Kentucky Mesonet, Bowling Green, KY) are compared with the most recent 30-year climate normals (1981-2010; NOAA National Centers for Environmental Information, Ashville, NC; Figure 4.1). The following data represent the months of May through October, which is the growing season for warm-season annual forages in Kentucky.

Rainfall in Lexington was nearly 40 and 13 cm greater in 2018 and 2019, respectively, than the 30-year average of 60 cm. Temperatures in Lexington were approximately one degree warmer than the 30-year average of 20.5 °C in both 2018 and 2019. Temperature and rainfall for Princeton in 2018 and 2019 were similar to the long-term average of 62 cm and 22.0 °C. both locations experienced above average rainfall in September 2018 and far below average in September 2019.

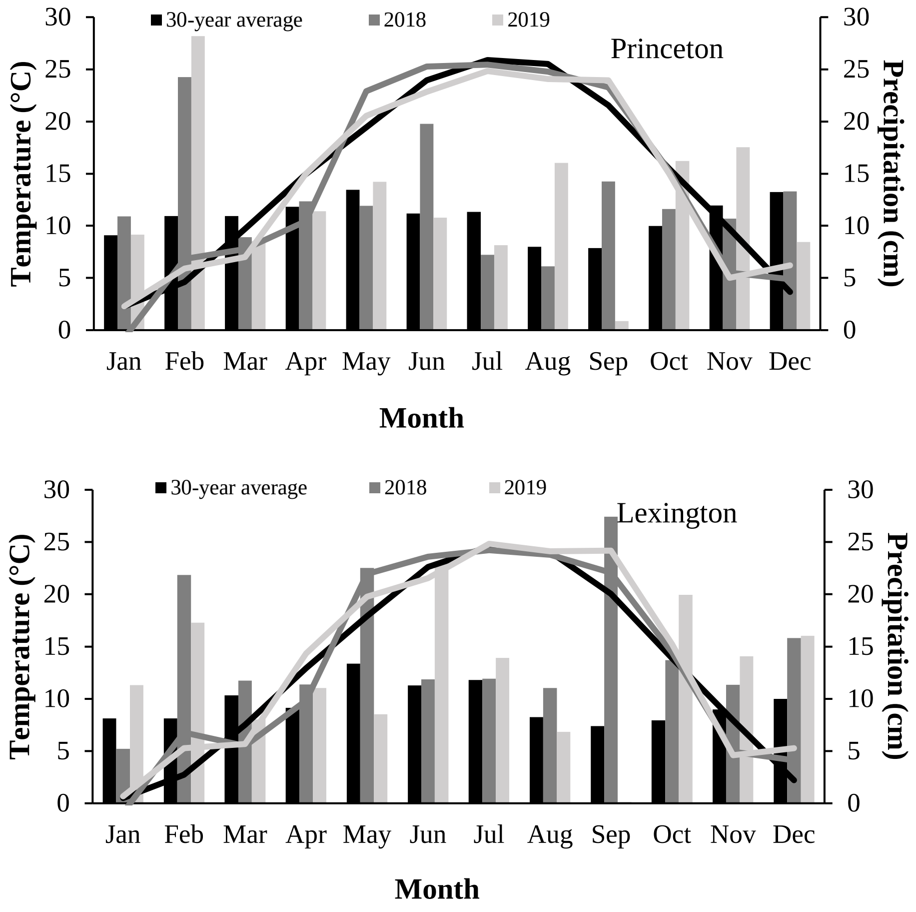

Figure 4.1. Precipitation (bars) and temperature (lines) for 2018 and 2019 (Kentucky Mesonet, Bowling Green, KY), compared with the 30-year climate normals (1989-2010; NOAA National Centers for Environmental Information, Ashville, NC) for Princeton, KY (top), and Lexington, KY (bottom).

### 4.3.2 Impact of Forage Mixture on Nutritive Characteristics

Interactions occurred between site (Lexington and Princeton) and year (2018 and 2019). Therefore, data are presented by environment (site x year combination). Environments are as follows: Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019. Emphasis was placed on total annual production rather than production of individual harvests. Therefore, nutritive value data are presented as averages weighted by harvest yields for each environment. Nutritive characteristics as affected by forage mixture complexity for each environment are reported in Table 4.5.\

Table 4.5. Impact of mixture complexity (averaged over N rate) on forage nutritive characteristics for Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019, presented as weighted averages from three harvests. Shaded boxes indicate differences observed at the α = 0.05 significance level for each environment/nutritive characteristic combination according to Tukey's post hoc test.

| **Environment** | **CP[1]** | **TDN** | **ADF** | **NDF** | **Lignin** | **IVTDMD30** |
|---|---|---|---|---|---|---|
| | % | | | | | |
| Lexington 2018 | | | | | | |
| Monoculture | 17.0 a[†] | 62.0 a | 34.2 b | 58.7 b | 3.2 b | 66.4 a |
| Simple Mixture | 16.5 a | 60.9 b | 35.3 a | 60.3 a | 4.0 a | 65.0 a |
| Complex Mixture | 16.4 a | 60.8 b | 35.4 a | 60.0 a | 3.8 a | 65.7 a |
| Princeton 2018 | | | | | | |
| Monoculture | 8.9 a | 59.0 a | 37.0 a | 63.1 a | 3.3 c | 65.1 a |
| Simple Mixture | 8.5 a | 58.8 a | 37.1 a | 62.3 a | 3.5 b | 65.2 a |
| Complex Mixture | 8.8 a | 59.0 a | 37.0 a | 62.1 b | 3.7 a | 65.6 a |
| Lexington 2019 | | | | | | |
| Monoculture | 8.9 a | 57.8 a | 38.0 a | 63.3 a | 3.9 c | 62.3 a |
| Simple Mixture | 9.1 a | 58.3 a | 37.6 a | 62.5 b | 4.1 b | 63.0 a |
| Complex Mixture | 8.9 a | 57.7 a | 38.2 a | 61.8 c | 4.4 a | 62.4 a |
| Princeton 2019 | | | | | | |
| Monoculture | 8.1 a | 57.0 ab | 38.8 ab | 64.3 a | 3.5 c | 63.9 a |
| Simple Mixture | 8.1 a | 57.2 a | 38.4 b | 63.7 a | 3.7 b | 63.9 a |
| Complex Mixture | 7.9 a | 56.7 b | 39.0 a | 63.7 a | 3.9 a | 62.8 b |

[1] Abbreviations: CP, crude protein, TDN, total digestible nutrients; ADF, acid detergent fiber; NDF, neutral detergent fiber; IVTDMD30, 30-h in *vitro* true dry matter digestibility

Within each environment, there were no differences in crude protein in response to forage mixture complexity (p > 0.09). These results are likely due to poor legume establishment (Mercier et al., 2021). Other studies have reported contradictory findings on CP responses in legume-containing intercropping systems.

Azraf-ul-Haq and colleagues (2007) observed crude protein averaging 14.5 and 15.8% for cowpea- and sesbania (Sesbania sesban (L.) Merr.)-based intercrops, as compared to 9.7% for sorghum monoculture. Without compromising dry matter production, Armstrong and coworkers (2008) saw crude protein increases of 13 and 16% of mixtures of corn grown with lablab bean [Lablab purpureus (L.) Sweet] and velvet bean [Mucuna pruriens (L.) D.C.], respectively, as compared to corn monoculture (corn: 6.1% CP, corn/lablab bean: 6.9% CP, corn/velvet bean: 7.1% CP). Herbert and colleagues (1984) found crude protein increases of 8-17% in corn intercropped with soybeans as compared to corn monoculture. In contrast, Cummins (1973) saw no significant increase in crude protein concentration when including soybean into corn or sorghum mixtures. Cowpeas have also been shown to improve crude protein concentration of corn-cowpea intercrops by up to 15% without reducing dry matter yield (Bryan & Materu, 1987).

Crude protein in Lexington 2018 was much higher than all other environments (16.6% vs. 8.6%). This may have been due to more favorable growing conditions in that environment. Additionally, only forages in Lexington 2018 would have been able to provide adequate nutrition to growing or lactating beef cattle (McCann, 2015). Total digestible nutrients in the same environment would be sufficient for lactating beef cattle, but not growing calves (McCann, 2015).

The only consistent difference between forage quality parameters was lignin increasing with increasing forage mixture complexity (Table 4.2). This may be explained by botanical composition. The sudangrass cultivar used in the current experiment contained the brown mid rib (BMR) trait, which is a phenotypic response to a genetic mutation that imparts reduced lignin content (Cherney et al., 1991). Brown midrib sudangrass proportions declined from nearly 100% in monocultures to 73 and 62% in simple and complex mixtures, respectively (Mercier et al., 2021). This reduction in BMR-containing species likely drove the responses seen here.

Differences in fiber components of grass monocultures versus grass-legume mixtures were generally between 1.5 percentage units or less in the current experiment. Other researchers have found positive effects on fiber components in mixtures as compared to monocultures. Salama and Zeid (2016) showed reduced ADF, and NDF, and increased TDN with sudangrass-cowpea mixtures as compared to sudangrass monocultures. Javanmard and colleagues (2009) also demonstrated lower ADF and NDF, while Nadeem and colleagues (2009) and Asangla and Gohain (2016) showed reduced crude fiber of corn-legume mixtures as compared to corn monocultures.

In contrast to previous work, three out of four environments in the current study showed no effect of species complexity on IVTDMD. This was also the case in a study by Contreras-Govea and colleagues (2009), where no differences of ADF or NDF were observed between sorghum and sorghum intercropped with four different legumes. In vitro true dry matter digestibility has been shown to increase in intercrops when corn or sorghum was planted with various legumes (Asangla & Gohain, 2016; Kawamoto et al., 1988). However, the Kawamoto study only showed increases of two percentage units.

While several studies have reported improved nutritive characteristics of annual grass-legume mixtures, this was not the case in the current study. Some nutritive characteristics showed statistical differences between forage mixture, but there were limited biologically important differences, as responses were always within one to two percentage units of each other. The likely driver of these results was low legume content of these mixtures. Legumes comprised less than 5% of sward dry matter for both simple and complex mixtures, leading to all treatments being dominated by grasses (Mercier et al., 2021). This likely resulted in the limited nutritive differences observed in the current study.

Altering grass and/or legume seeding rates in the current study may have improved competitiveness of legumes in the mixtures. Osiru and Willey (1972) demonstrated that component yields of sorghum and common bean (Phaseolus vulgaris) mixtures were affected by seeding proportion of individual species. Beans were more competitive when they comprised 2/3 of the mixture seeding rate as compared to 1/3. Craufurd (2000) observed cowpea yield increasing with decreasing sorghum and pearl millet densities. Tariah and Wahua (1985) also varied the seeding rates of both corn and cowpea and found that cowpea yields did not increase with decreasing corn seeding rates but did increase with increasing cowpea seeding rates. The authors suggested a corn/cowpea mixture should be planted at 33 and 50% of the monoculture rates for corn and soybean, respectively.

### 4.3.3 Impact of Nitrogen Rate on Forage Nutritive Characteristics

#### 4.3.3.1 Crude Protein

All environments resulted in increasing levels of crude protein as N rate increased ($p < 0.001$, Figure 4.2). This response was expected since N is an important component of amino acids which are the building blocks of protein. In Lexington 2018, crude protein increased from 15 to 18% as N rate increased ($p < 0.001$). Crude protein increased from 7.0 to 10.3% on average in all other environments ($p < 0.001$). The increasing trend of CP in this experiment is consistent with other studies that evaluated the effect of N application on annual warm-season forages (Ates & Tenikecier, 2019; Bahrani & Deghani-ghenateghestani, 2004; Hart & Burton, 1965; Ziki et al., 2019). Hoveland and colleagues (1967) found similar 1-2 percentage unit increases in CP of pearl millet and sorghum-sudangrass when increasing from 112 to 224 kg N ha$^{-1}$, but in a separate trial found no increase in CP with increasing N rates from 90 to 358 kg N ha$^{-1}$.

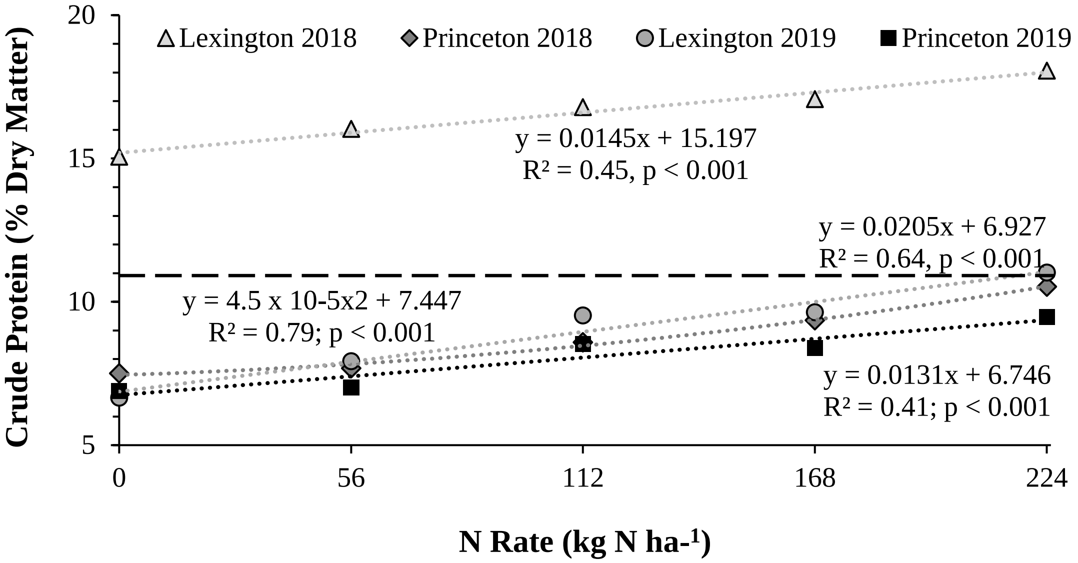

Figure 4.2. Impact of N rate on crude protein for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests. Dashed line denotes average crude protein value to support growing steers and lactating beef cows (McCann, 2015).

Interestingly, forages in Lexington 2018 were approximately 7 to 8 percentage units greater than counterparts in other environments and were the only environment that would sustain of lactating cattle (approximately 10% crude protein) at all N rate treatments (McCann, 2015). At 224 kg N ha$^{-1}$, two other environments could sustain dry and lactating cows as well as heavier weight growing animals (Figure 4.2).

The crude protein response to N mimicked yield trends in this experiment, where yield increased linearly with increasing N (Mercier et al., 2021). Linear response of yield and crude protein to N was also shown in Hart and Burton (1965) and Budakli Carpici and coworkers (2010) with pearl millet and maize, respectively. Alternatively, Beyaert and Roy (2005) observed a plateau in sorghum-sudangrass yield at 125 kg N ha$^{-1}$ when N rates were applied up to 250 kg N ha$^{-1}$. Interestingly, their findings showed that economic optimum rates were between 83 and 107 kg N ha$^{-1}$. The linear response found in the current study implies that maximum yield and crude protein concentration was not achieved. However, N rates greater than those utilized in the current experiment could result in the accumulation of toxic levels of nitrate, as seen in other summer annual grasses (Teutsch & Tilson, 2004).

Lexington 2018 may have had greater soil plant available nitrogen, although it was not measured (Mercier et al., 2021). It is unlikely that responses were due to legume content, as all forage treatments in all environments contained less than 5% legumes (Mercier et al., 2021). Plots in Lexington for the last harvest in 2018 were also considerably shorter than other environments (Mercier et al., 2021), suggesting lower leaf:stem proportions.

Alternatively, in 2018, Lexington received nearly 40 cm greater rainfall than average during the summer annual growing season (66% increase), as compared to 22% greater rainfall in 2019. Princeton received approximately average rainfall in both years of this study. Forages in Lexington in 2018 may have been less water stressed as compared to other environments, especially at the time of the final harvest. The combination of drought stress and leaf:stem proportions may explain the responses in forage quality, as periods of drought stress may accelerate maturity of annual forages, resulting in lower leaf:stem proportions and subsequently poorer forage quality (Buxton & Fales, 1994).

#### 4.3.3.2 Acid Detergent Fiber

Acid detergent fiber (ADF) decreased as N rate increased in all environments, but to varying degrees ($p < 0.001$; Figure 4.3). Both Princeton environments decreased only slightly, while Lexington environments showed a greater response to N. However, ADF responses to N for all environments were within 4 percentage units from 0 to 224 kg N ha$^{-1}$.

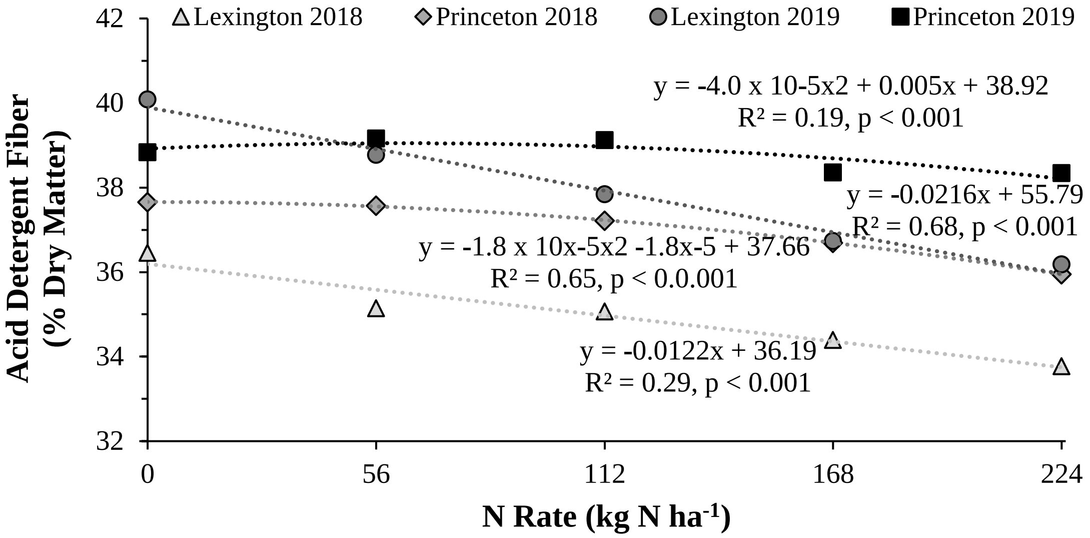

Figure 4.3. Impact of N rate on acid detergent fiber for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests.

These results are similar to Ates and Tenikecier (2019) and Ayub and colleagues (2002) who found decreasing ADF with increasing N rates in sorghum-sudangrass (35 to 30% from 0 to 160 kg N ha$^{-1}$) and sorghum (50.2 to 48.8% from 0 to 150 kg N ha$^{-1}$), respectively. In contrast, Budakli Carpici and colleagues (2010), Hazary and colleagues (2015), and Gulumser and Mut (2016) observed no effect of increasing N rate on ADF of forage maize (0 to 400 kg N ha$^{-1}$), sorghum-sudangrass (0 to 160 kg N ha$^{-1}$), and sudangrass/sorghum-sudangrass (0 to 200 kg N ha$^{-1}$), respectively.

#### 4.3.3.3 Total Digestible Nutrients

Total digestible nutrients showed trends inverse to ADF (Figure 4.4), which was expected as TDN was calculated based on ADF. None of the environments provided enough TDN to sustain growing cattle (65%+ TDN) when averaged over the growing season (McCann, 2015). All environments provided enough TDN to support dry cows (50% TDN) and three out of four environments approached the sufficiency levels for lactating cows (60% TDN) at the high N rates (McCann, 2015). Lexington 2018 showed greatest TDN values and would be sufficient for dry and lactating cows at all N rates.

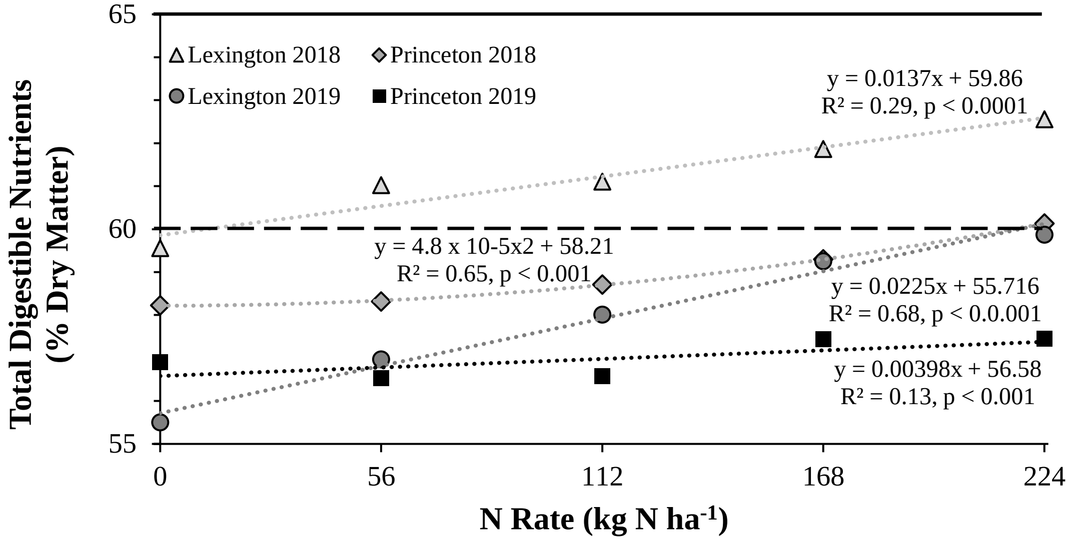

Figure 4.4. Impact of N rate on total digestible nutrients for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests. Dashed and solid lines denote suggested values to support requirement for lactating beef cows and 200 kg steers gaining 0.7 kg day$^{-1}$, respectively (McCann, 2015).

#### 4.3.3.4 Neutral Detergent Fiber

In three out of four environments, NDF declined as N application increased ($p < 0.001$; Figure 4.4). In both Lexington environments, NDF dropped approximately three percentage units from 0 to 224 kg N ha$^{-1}$ ($p < 0.001$; Figure 4.5). In Princeton 2018, NDF followed a negative quadratic response, falling from 63.2% at 0 kg N ha$^{-1}$ to 61.4% at 224 kg N ha$^{-1}$ ($p < 0.001$). No response of NDF to N rate was observed in Princeton 2019 ($p > 0.3$). As with previous parameters, Lexington 2018 was much lower than other environments and showed the most desirable NDF values.

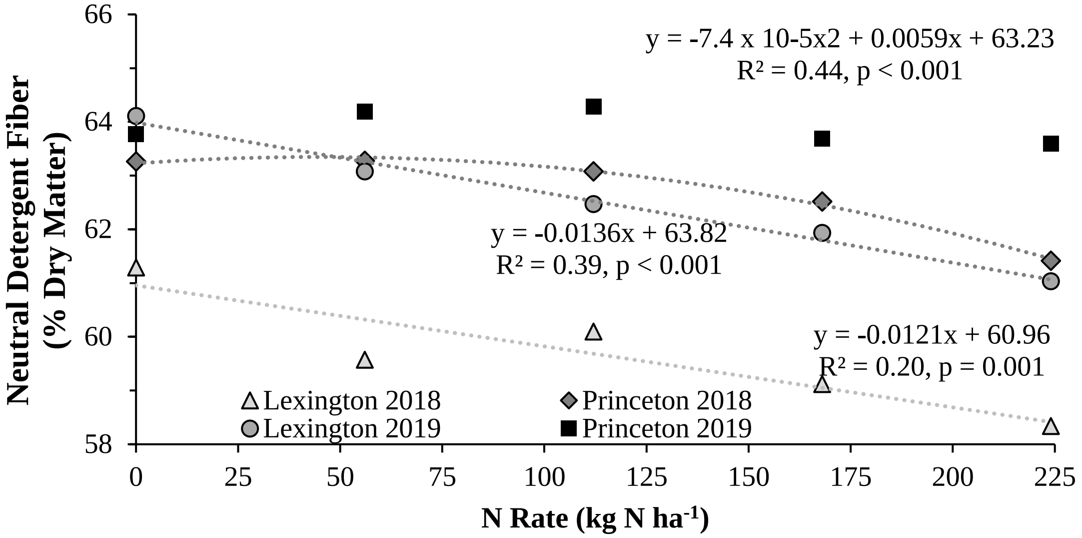

Figure 4.5. Impact of N rate on neutral detergent fiber for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests.

In general, the findings of the current experiment are in accordance with Ates and Tenikecier (2019) and Ayub and coworkers (2002) who observed a decrease in NDF with increasing N rates in sorghum-sudangrass (61.3 to 57.1 from 0 to 160 kg N $ha^{-1}$) and sorghum (66.0 to 63.6% from 0 to 150 kg N $ha^{-1}$), respectively. Conversely, Budakli Carpici and coworkers (2010) observed an increase in NDF of forage maize with increasing N rates (59.6 to 64.7% from 0 to 400 kg N $ha^{-1}$), while Hazary and colleagues (2015) and Gulumser and Mut (2016) who found no effect on increasing N on NDF of sudangrass and sorghum-sudangrass.

#### 4.3.3.5 Forage Digestibility

Unlike other parameters discussed, no consistent response of 30-h in vitro true dry matter digestibility (IVTDMD30) to N rate was observed across environments (Figure 4.6). Princeton 2018 ($p < 0.02$) and Lexington 2019 ($p < 0.007$) showed positive relationships, while Princeton 2019 ($p < 0.001$) showed a negative relationship. There was no correlation between N rate and IVTDMD30 in Lexington 2018 ($p > 0.1$). Similarly, Hart and Burton (1965) observed no effect of N on dry matter digestibility of pearl millet in rumen fistulated steers. Habib and coworkers (2007) also found no effect of N on in vitro dry matter digestibility of mechanically harvested pearl millet, sorghum, and sudangrass.

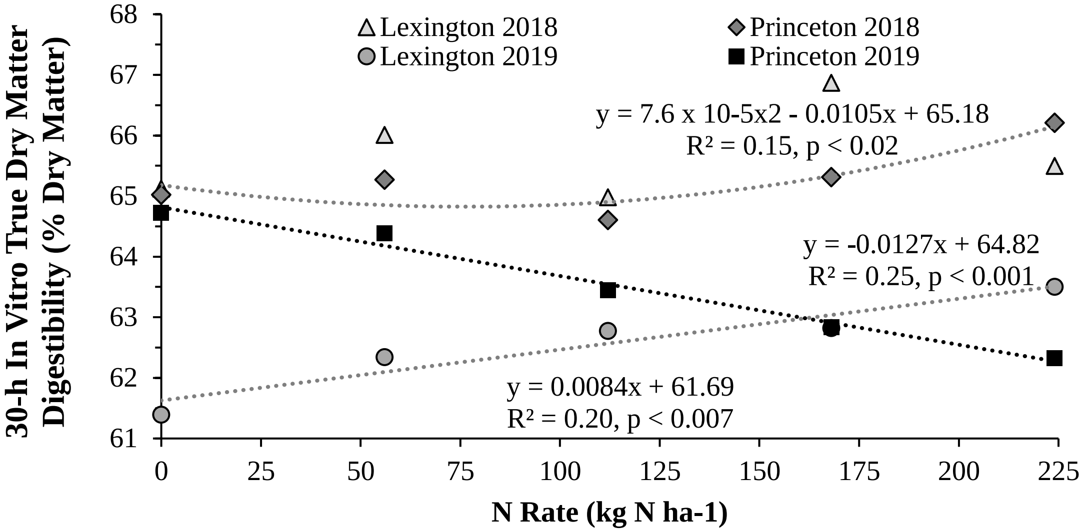

Figure 4.6. Impact of N rate on 30-h *in vitro* true dry matter digestibility for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests.

### 4.3.3.6 Lignin

Three out of four environments showed no response of lignin to N rate (Figure 4.7). Princeton 2018 was the only environment that showed a positive response ($p < 0.001$). This result may be due to all forage treatments being dominated by a low-lignin cultivar of sudangrass. However, Hoveland and colleagues (1967) observed similar findings with pearl millet and sorghum-sudangrass, where increasing N rates had no effect on lignin.

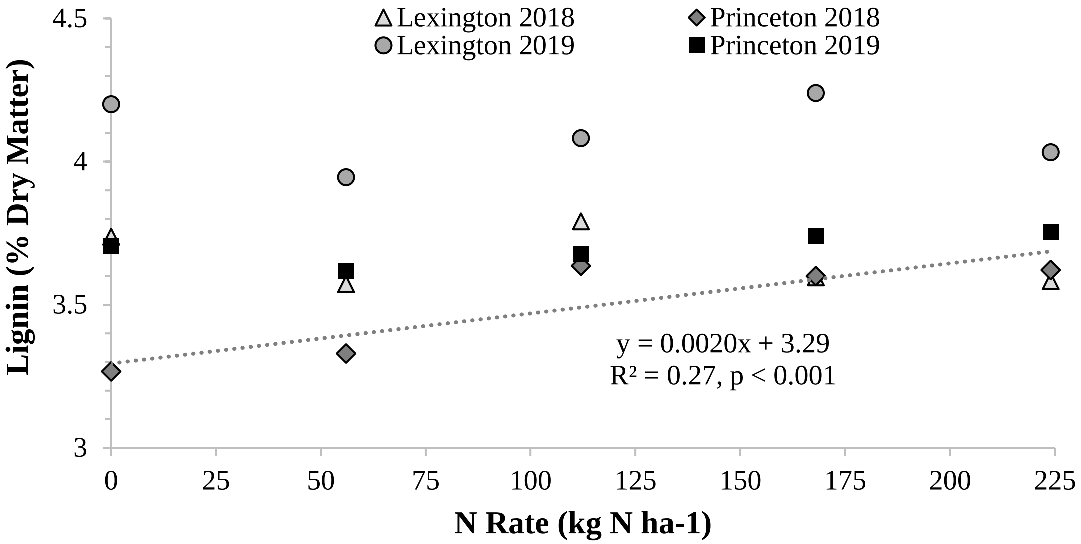

Figure 4.7. Impact of N rate on lignin for each environment averaged across forage mixtures. Data are presented as weighted averages from three harvests.

While several studies have reported improved nutritive characteristics of annual grass-legume mixtures as compared to monocultures, this was not the case in the current study. The likely driver of these results was low legume content (<5%) of these mixtures (Mercier et al., 2021). Care must be taken to select appropriate species and management strategies if sward diversity is of interest.

In general, improvements in nutritive characteristics from increasing N rate were seen for CP, ADF, and NDF, while results were mixed for in vitro true dry matter digestibility. Lignin showed no consistent response to N fertilization. Similar to responses to forage mixture complexity, differences in parameters between low and high rates of N generally occurred at a small magnitude and may not be biologically significant in some cases.

It could be argued that these forage mixtures have the potential to meet nutrient requirements of high producing livestock during some growth stages, as can be seen in numerous studies with monocultures of sorghum-sudangrass (Harmon et al., 2019; McCuistion et al., 2011; Tracy et al., 2010), sudangrass (Tracy et al., 2010), pearl millet (Burton et al., 1969; Harmon et al., 2019; Schmidt et al., 2013; Wilkinson et al., 1968), and crabgrass (Beck et al., 2007a; Bosworth et al., 1980; Ogden et al., 2005). However, results of the current study are reported as weighted averages of three harvests, rendering interpretation of nutritive characteristics more difficult in relation to animal needs. Emphasis was placed on total system productivity, rather than on individual harvest values. In a production system, the authors would advise sampling forages at each harvest to determine if nutritive value is adequate to achieve desired animal performance.

Many studies have been conducted regarding N application to crops following the Green Revolution of the mid-20th century. As N is a major component of protein, many studies have observed increases in crude protein or N content of forages with increased N application (Broyles & Fribourg, 1959; Ketterings et al., 2007; Muldoon, 1985; Rostamza et al., 2011; Tang et al., 2018). Results of the current study also followed this trend.

Similar to the current study, Kilcer and colleagues (2002) found some sudangrass forage quality parameters to be affected by N fertilization, however increases were also small and arguably not biologically significant. Alternatively, Sher and colleagues (2017) found 4 to 5 percentage units decrease in sorghum NDF when fertilized with N, which was a greater response than seen in the current study. Fribourg (1974) discussed several studies that showed limited or no response of forage digestibility to N application. The findings from the current study corroborate these results.

### 4.3.4 Implications

In addition to improving ecosystem services and stability (Tilman et al., 2006), increasing botanical diversity may improve animal performance. Animals are selective grazers and use “visual and olfactory/gustatory cues, mediated by the effects of physical and structural characteristics of vegetation” to select their diet (Hodgson et al., 1994). This may lead to animals ingesting the highest quality or most palatable forages in a mixed sward, thus improving the quality of their diet (Lesperance et al., 1960). However, once the more palatable species and/or plant parts are consumed, animals are forced to graze less palatable forages. Although not monitored in this study, future work should include grazing livestock to evaluate animal performance and effects on regrowth potential of grazed multi-species summer annual forage mixtures.

If botanical diversity is desired, care should be taken to appropriately manage seeding rates to favor slower establishing species. In the current study, grass species emerged and formed a canopy more quickly than legume seedlings (personal observation), creating an extremely competitive environment for the legumes. Iqbal and colleagues (2017) suggested planting legumes nearly three weeks prior to grasses. However, this is most likely not feasible for most producers. Work is needed to determine seeding rates that will favor non-dominant species in complex mixtures.

## 4.4 Conclusions

Low functional diversity in the current study resulted in sudangrass-dominated mixtures having nutritive characteristics similar to sudangrass monocultures. Care must be taken to select appropriate species and management strategies if sward diversity is of interest. Nitrogen application up to 224 kg N $ha^{-1}$ often had a positive impact on forage quality parameters. However, energy and protein were still relatively low and would not have been sufficient to meet nutritional demands of growing or lactating cattle when averaged across harvests. Nutritive value may be increased if summer annuals are grazed at a younger physiological state. Additionally, selecting grass species with the BMR trait is highly recommended for improved forage nutritive characteristics, since lignin is an important determinant of forage digestibility.

## 4.5 References

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# CHAPTER 5. IS THERE AN ECONOMIC ADVANTAGE TO PLANTING DIVERSE SUMMER ANNUAL FORAGE MIXTURES?

## Abstract

This study examined economic implications of planting summer annual mixtures of grasses, legumes, and forbs at varying nitrogen rates. No differences in yield occurred between the three mixtures, indicating that mixtures with lowest seed cost will be most economical. Applying N resulted in yield increases of 12.26 lb DM per lb N applied. Although yield responses to N were positive, sensitivity analyses showed that applying N resulted in positive net returns only when hay prices were high and N prices were low. When utilization rates are accounted for, enterprise budgets determined grazing to be 18% cheaper to implement than haying.

Keywords: sensitivity analysis, enterprise budget, seed cost, cost of nitrogen, hay price

## 5.1 Introduction

Utilizing summer annual forages has been described as “a breakeven proposition at best” (Ball et al., 2007, p. 232). High annual production costs may often limit the incorporation of these forages into grazing systems. In perennial forage systems these one-time expenses are depreciated over 5-10 years and risk of seeding failure only occurs once, rather than annually.

Several studies have investigated economic aspects of summer annual systems. Comerford et al. (2005) found that including annual forages into perennial systems resulted in lower net returns than perennial pasture systems. Tracy and coworkers (2010) determined that native warm season grass pastures were more economical than summer annual pastures when included in a cool-season pasture rotation. After three years, annual warm-season costs exceeded those of native pastures, even though initial establishment costs for the native pastures were quite high due to seed prices. However, some producers encounter more difficulty when establishing native warm-season grasses as compared to annual warm-season species. The authors suggested that summer annual systems could be more economical if costs were reduced, specifically field operations and nitrogen fertilizer (Tracy et al., 2010).

In a summary of 37 studies evaluating the economics of warm- and cool-season annual and perennial pasture types in Alabama, Ball & Prevatt (2009) showed that summer annual pastures ranked second highest in production costs as compared to other pasture types. Comerford et al. (2005) also concluded that including annual species into a perennial pasture system was not economical since calf gains were no different than perennial systems, but extra costs were incurred, primarily due to tillage. Similarly, Basweti and colleagues (2009) saw little benefit to no-till interseeding summer annuals into perennial pastures because there was no resulting increase in total system productivity.

In order to make these systems more attractive to producers, costs must be reduced, or returns must be increased. One way to increase returns would be to improve yield, which can often be accomplished by N fertilization, although applying N increases input costs. Viets (1950) reported a nearly doubling of sudangrass yields when fertilized with 120 lb N/ac as compared to no N. Parks et al., (1965) additionally showed 2.5x yield increases in pearl millet when fertilizing with 240 lb N/ac.

Another strategy to increase yields is by increasing species diversity. Polycultures often yield more than monocultures in grassland systems (Lüscher et al., 2008), especially when including legume species (Ashworth et al., 2018; Huston et al., 2000). In perennial systems, N can be transferred to associated grasses via root exudation, but is primarily accomplished by indirect means (root/shoot decomposition and redistribution via animal excreta) (Heichel & Henjum, 1991; Ledgard & Giller, 1995; Trannin et al., 2000). However, there is debate as to what extent, if any, this occurs in annual systems (Fujita et al., 1992; Layek et al., 2018).

Species diversity and nitrogen application interactions and their economic implications to annual grass-legume mixtures are not well understood. This study was designed to evaluate the effects of varying levels of N application on summer annual forage mixtures. Seed and N costs were evaluated in relation to yield response, and sensitivity analyses were conducted to determine optimal N rates for these mixtures at various N costs and hay prices.

## 5.2 Materials and Methods

This experiment was conducted in Lexington and Princeton, Kentucky, USA, in 2018 and 2019. A randomized complete block design with four replications and a two-factor factorial treatment arrangement was utilized. Factors of interest were nitrogen application rate (0 to 200 lb N/ac) and forage mixture complexity. Forage mixtures were as follows: 1) summer annual grass monoculture (control), 2) simple mixture consisting of two summer annual grasses + one summer annual legume, and 3) complex mixture containing four summer annual grasses, four summer annual legumes, two brassicas, and one summer annual forb. Seeds were treated with a multi-species inoculant (Link Cover Crop Inoculant, La Crosse Seed, La Crosse, WI) suitable for all legumes in mixtures. Species, cultivars, and seeding rates used can be found in Table 5.1. Nitrogen as ammonium nitrate was hand applied in split applications for each treatment, which is depicted in Table 5.2.

Table 5.1. Forage species, cultivars, and seeding rates.

| Treatment | Species | Scientific Name | Cultivar | Seeding Rate† | |
|---|---|---|---|---|---|
| | | | | Species (kg ha$^{-1}$) | Total |
| **Mono-culture** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 56 | **56** |
| **Simple Mixture** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 28 | |
| | Pearl Millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 5.6 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 28 | **61.6** |
| **Complex Mixture** | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 15.7 | |
| | Pearl millet | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9302 | 4.5 | |
| | Crabgrass | *Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop. | Red River and Quick-N-Big | 1.1 | |
| | Corn | *Zea mays* L. | AgriGold 115 day | 11.2 | |
| | Soybean | *Glycine max* (L.) Merr. | Large Lad | 11.2 | |
| | Cowpeas | *Vigna unguiculate* (L.) Walp. | Red Ripper | 11.2 | |
| | Korean lespedeza | *Kummerowia stipulacea* (Maxim) Makino | VNS | 4.5 | |
| | Sunn hemp | *Crotalaria juncea* L. | VNS | 2.2 | |
| | Forage rape | *Brassica napus* L. | T-Raptor | 1.1 | |
| | Daikon radish | *Raphanus sativus* L. | SF Select | 2.2 | |
| | Sunflower | *Helianthus annuus* L. | Peredovik | 2.2 | **67.2** |

† Pure Live Seed calculations not used because pure seed was above 98% and germination above 85% as per American Organization of Seed Certifying Agencies standards.

Table 5.2. Nitrogen application schedule and rates.

| **N Rate Treatment (lb N/ac)** | **N Applied (lb N/ac)** | | |
|---|---|---|---|
| | At Planting | After 1st Harvest | After 2nd Harvest |
| 0 | – | – | – |
| 50 | 50 | – | – |
| 100 | 50 | 50 | – |
| 150 | 50 | 50 | 50 |
| 200 | 80 | 80 | 40 |

### 5.2.1 Plot Management

Prior to planting, plot area was sprayed twice with 2 qt glyphosate/ac, with approximately two weeks between applications. Plot area was fertilized according to soil test results to meet warm-season forage fertility requirements (Ritchey & McGrath, 2018). Plots were planted into conventionally prepared seedbeds approximately one month following last herbicide application (late June 2018 and early June 2019) using a small plot walk-behind cultipack-type seeder (Carter Manufacturing, Brookston, IN).

Harvest occurred three times each year (Lexington: 15 Aug 2018, 20 Sep 2018, 25 Oct 2018, 11 Jul 2019, 7 Aug 2019, and 20 Sep 2019; Princeton: 2 Aug 2018, 7 Sep 2018, 9 Oct 2018, 19 Jul 2019, 19 Aug 2019, and 3 Oct 2019) when plants reached approximately 30-40 inches. A 5’ strip was clipped through the center of the plot using a Hege 212 small-plot forage harvester (Wintersteiger Inc., Salt Lake City, UT) leaving 7” residual after the first and second harvests, and 3” residual after the final harvest. A forage subsample was collected from each plot, weighed in a forced air oven for 7 days at 130 °F, and weighed again to determine dry matter composition.

### 5.2.2 Data Analysis

Yield data were analyzed using SAS 9.4 software (SAS Institute, Cary, NC). The General Linear Model procedure was used to generate ANOVA tables. Year x location interactions were significant; therefore, data was analyzed by “environment” (year*location combination). Terms included in the model were N rate, mixture, and N rate*mixture interaction. Means were separated using Fisher’s protected least significant difference post hoc test. Regression analyses of forage responses to N rate were performed using the REG procedure on the appropriate polynomial function (linear, quadratic, or cubic) which was selected based on the best fit (significant p-value and highest $R^2$ value). A significance level of $\alpha = 0.05$ was used for all analyses.

## 5.3 Results and Discussion

Figure 5.1 depicts climate data obtained from weather stations in the Kentucky Mesonet network (Bowling Green, KY) compared to the most recent 30-year climate normals (1981-2010; NOAA National Centers for Environmental Information, Ashville, NC). From May to October (growing season), Lexington had nearly 40 cm greater rainfall in 2018 and 13 cm greater rainfall in 2019 than the 30-year average of 60 cm. Temperatures during the growing season in Lexington were approximately one degree warmer in both years than the 30-year average of 20.5 °C. Temperature and rainfall throughout the growing season for Princeton in 2018 and 2019 were similar to the long-term average of 62 cm and 22.0 °C. Rainfall in both locations was above average in September 2018 and far below average in September 2019.

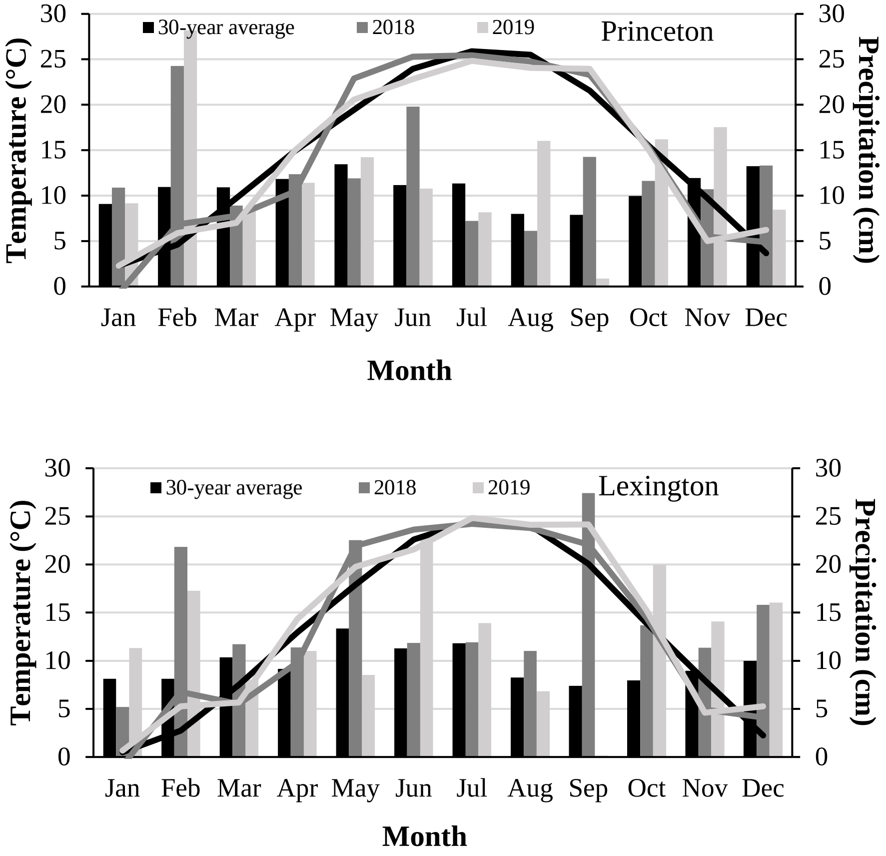

Figure 5.1These Climographs Depict Precipitation (Bars) and Temperature (Lines) for 2018 and 2019 (Kentucky Mesonet, Bowling Green, KY), Compared With the 30-Year Climate Normals (1989-2010; NOAA National Centers For Environmental Information, Ashville, NC) for Both Princeton, KY (Top), and Lexington, KY (Bottom).

### 5.3.1 Diversity Effects on Dry Matter Yield

Interactions between site and year occurred ($p < 0.05$), therefore data are presented by ‘environment’: Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019. In three out of four environments, mixture complexity did not affect annual DM production (Princeton 2018 = 3560 lb DM/ac; Lexington 2019 = 5190 lb DM/ac; and Princeton 2019 = 6490 lb DM/ac; $p > 0.06$). In Lexington 2018 ($p < 0.001$), the simple mixture had greatest annual forage DM production (5350 lb DM/ac), followed by the complex mixture (5050 lb DM/ac), and the monoculture (4510 lb DM/ac; Figure 5.2).

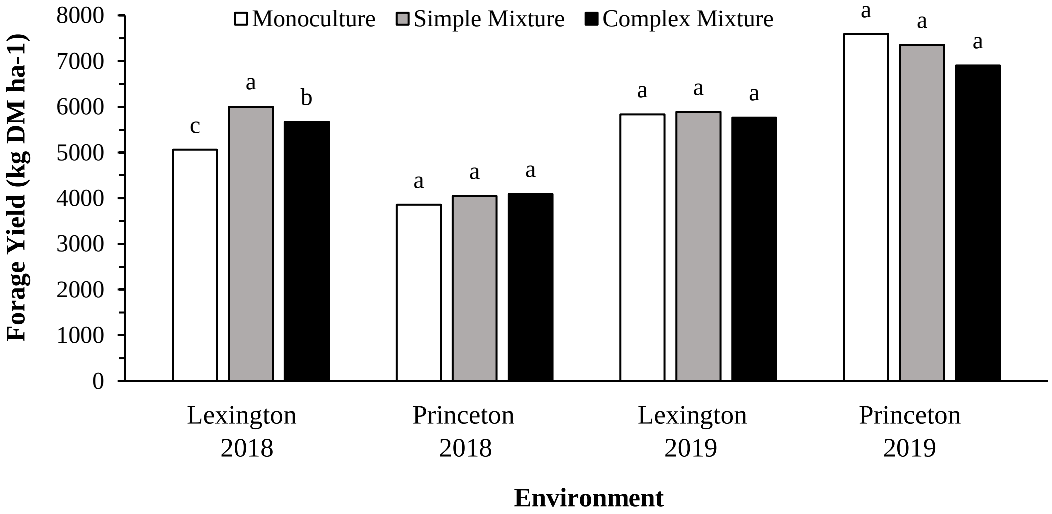

Figure 5.2. Impact of mixture complexity averaged over N rates (no mixture x N interaction) on total annual forage DM production for each environment (location x year interaction). Treatments within environment with the same letter are not different according to Fisher's Protected Least Significant Difference (α = 0.05).

### 5.3.2 Seed Cost of Mixtures

Cost of seed for forage treatments were as follows: monoculture = $99/ac, simple mixture = $90/ac, and complex mixture = $105/ac. Seed cost for the simple mixture was less than that of the monoculture because the price of pearl millet and soybean was less than that of sudangrass. Unfortunately, many species in the complex mixture did not contribute substantial amounts to sward biomass (Mercier et al., 2021). One way to improve species richness in the complex mixture would be to reduce the amount of the dominant species (primarily sudangrass, followed by pearl millet), which would also reduce seed cost.

### 5.3.3 Nitrogen Rate Effect on Dry Matter Yield

For all environments, N rate significantly impacted annual forage DM production ($p < 0.001$; Fig. 5.3). In all but Lexington 2018, annual forage DM production increased in a linear trend as N rate increased. In Lexington 2018, annual forage DM production peaked near 100 lb N/ac and then declined. Interestingly, yield increases at 50 lb N/ac were minimal in Princeton, perhaps due to some weather event or soil characteristic that resulted in a loss of N from the system early in the growing season, as N was only applied prior to planting in the 50 lb N/ac treatment and did not have subsequent applications following first and second cuttings as did the higher N treatments. Alternatively, soil reserves may have been mobilized from organic matter in the 0 lb N/ac treatment resulting in a limited impact on yield in the 50 lb N/ac treatment.

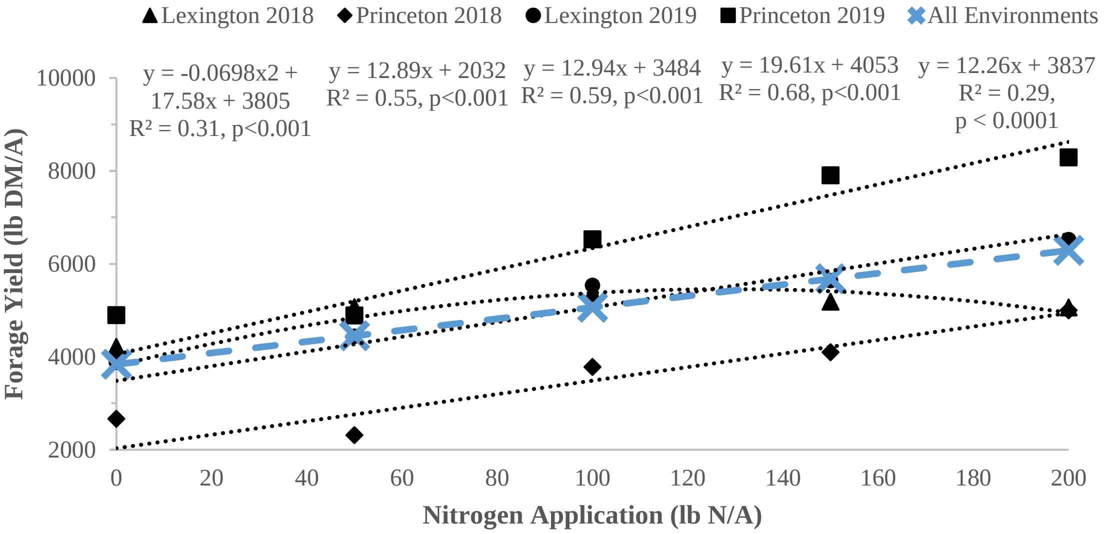

Figure 5.3. Impact of N rate on annual forage DM production for Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019. Means are averaged across forage mixtures (no mixture x N rate interaction ($p > 0.16$). Blue regression line denotes the response of pooled environments.

### 5.3.4 Cost of Inputs in Relation to Yield Response

Although a N*environment interaction occurred ($p < 0.0001$), a regression was performed on individual plot data from the entire dataset was performed to conduct these analyses ($y = 12.26x + 3837$, $R^2 = 0.29$, $p < 0.0001$; Figure 5.3). Based on results from the pooled regression, yields for N treatments are as follows: 0 lb N/ac = 3837 lb DM/ac; 50 lb N/ac = 4450 lb DM/ac; 100 lb N/ac = 5063 lb DM/ac; 150 lb N/ac = 5676 lb DM/ac; 200 lb N/ac = 6289 lb DM/ac. Even though the correlation between N and yield was low, it still provides a useful relationship to determine the impact of N price on yield.

Local fertilizer prices were obtained from Thomas Cayce Farm Supply (Princeton, KY). Throughout the course of this experiment, ammonium nitrate (33.5% N) averaged \$345/ton or \$0.5149/lb N. Therefore, costs of \$0.40, \$0.50, and \$0.60 were evaluated. Additional N application costs were added for the 100, 150, and 200 lb N/ac treatments, because of split-application of N. Phosphorus and potassium prices were \$0.30 and \$0.25 per pound of P and K, respectively. Additional P and K costs were calculated from crop removal based on yield responses for each N treatment (Eberly & Groover, 2007).

Hay prices ranging from \$60 to \$120/T were used in analyses and were based on current auction prices in Kentucky. These analyses did not include any beneficial effect N may have had on hay quality (Mercier, 2021). Results are reported on an as fed (hay) basis (15% moisture), as it is a more common metric to market hay, as opposed to on a dry matter basis. Economic advantage was calculated as (hay revenue at specific N rate – hay revenue at 0 lb N/ac) – (production costs at specific N rate – production costs at 0 lb N/ac).

Production costs include 1) N, P, and K fertilizer needed to achieve yield at a specific N rate, 2) additional fertilizer application fees for 100, 150, and 200 lb N/ac rates because they utilized split applications for N (additional $6.50/ac for 100 lb N/ac treatment and additional $13/ac for the 150 and 200 lb N/ac treatment; Halich (2020)), and 3) additional harvest costs in relation to greater yields when applying N. Table 5.3 shows these results using varying N rates when prices are $0.40, $0.50, or $0.60/lb N.

Table 5.3. Economic advantage of applying N to summer annual forages at varying hay and N prices, as compared to no N applied, calculated based on predicted yields from all environments (Figure 5.3). Scenarios resulting in a positive marginal return as compared to applying no N are bolded.

| **N Price** | **Hay Price** | | | **N Application (lb/ac)** | | |
|---|---|---|---|---|---|---|
| **$/lb N** | **$/T** | 0 | 50 | 100 | 150 | 200 |
| 0.40 | 60 | - | -$20.26 | -$47.32 | -$74.08 | -$94.64 |
| | 80 | - | -$13.05 | -$32.90 | -$52.44 | -$65.79 |
| | 100 | - | -$5.84 | -$18.47 | -$30.81 | -$36.94 |
| | 120 | - | **$1.38** | -$4.05 | -$9.17 | -$8.10 |
| | 140 | - | **$8.59** | **$10.38** | **$12.46** | **$20.75** |
| 0.50 | 60 | - | -$25.26 | -$57.32 | -$89.08 | -$114.64 |
| | 80 | - | -$18.05 | -$42.90 | -$67.44 | -$85.79 |
| | 100 | - | -$10.84 | -$28.47 | -$45.81 | -$56.94 |
| | 120 | - | -$3.62 | -$14.05 | -$24.17 | -$28.10 |
| | 140 | - | **$3.59** | **$0.38** | -$2.54 | **$0.75** |
| 0.60 | 60 | - | -$30.26 | -$67.32 | -$104.08 | -$134.64 |
| | 80 | - | -$23.05 | -$52.90 | -$82.44 | -$105.79 |
| | 100 | - | -$15.84 | -$38.47 | -$60.81 | -$76.94 |
| | 120 | - | -$8.62 | -$24.05 | -$39.17 | -$48.10 |
| | 140 | - | -$1.41 | -$9.62 | -$17.54 | -$19.25 |

*Note.* Economic advantage calculated as (hay revenue at specific N rate – hay revenue at 0 lb N/ac) –(production costs at specific N rate – production costs at 0 lb N/ac). Production costs include 1) N, P, and K fertilizer needed to achieve yield at a specific N rate, 2) additional N application fees for 100, 150, and 200 lb N/ac rates because they utilized split applications for N, and 3) additional harvest costs in relation to greater yields when applying N.

Very few scenarios result in an economic advantage of applying nitrogen to summer annual forages. The only scenario where N application is more profitable than no N is when hay prices are high ($140/T) and N prices are low. When N is $0.40/lb N, applying 200 lb N/ac results in the greatest increase in revenue as compared to 0 lb N/ac. Applying 50 lb N/ac is advantageous when N is $0.50/lb and hay is $140/T.

These results are in contrast to Beyaert and Roy (2005). These authors determined approximately 90 lb N acre$^{-1}$ to be the most economical N rate to three-cut sorghum-sudangrass in Canada. When N cost was high and crop value was low, approximately 70 lb N acre$^{-1}$ was the most economical, while when N cost was low and crop value was high, approximately 100 lb N acre$^{-1}$ was the most economical. Yield response to N differed in both experiments, likely driving differences in economic efficiency. In the current experiment, yield showed a linear increase in response to increasing N, while the response was quadratic in Beyaert and Roy (2005) with a peak near 90 lb N acre$^{-1}$. Beyaert and Roy (2005) also achieved higher annual yield, most likely improving economic efficiency of N application.

Results from this analysis contradict current agronomic recommendations for summer annual forage crops. In Kentucky, it is recommended to apply up to 220 lb N/ac in split applications to achieve highest yields. The results of this study suggest that applying recommended N rates increases yield over no N, but the cost of extra fertilizer, application fees, and harvest costs are not economical unless hay prices are high. Even in these scenarios, the relative return is very low, indicating that the risk is high. Results would likely have differed with earlier planting dates or different soil types and/or previous cropping history. More work may be needed to validate or change existing N recommendations to summer annual forage crops.

### 5.3.5 Establishment and Utilization Costs

Plot management in the current study mimicked a haying situation, however, grazing is perhaps a more common use of these forages; thus, both scenarios were evaluated. Input costs for haying and grazing sudangrass pastures are shown in Table 5.4. Assumptions used in calculations are listed in the footnotes below the table. Revenues from hay/baleage sales and increases in cattle gains are not evaluated here, as this is not a true enterprise budget.

Table 5.4. Costs of sudangrass haying and grazing.

| **HAYING** | **$/Acre** | | **GRAZING** | **$/Acre** |
|---|---|---|---|---|
| Disk-tandem | $15.50 | **Site Preparation** | Self-propelled sprayer (2x) | $15.00 |
| Field cultivator | $14.50 | | Herbicide 2x | $14.00 |
| N, P, K | $159.60 | **Fertility** | N, P, K | $111.92 |
| Application | $19.50 | | Application | $19.50 |
| Drill | $18.00 | **Planting** | No-till drill | $19.50 |
| Seed cost | $90.00 | | Seed cost | $90.00 |
| Cut, rake, bale, wrap, & moving bales | $140.15 | **Harvest** | Bush hog (2x) | $34.00 |
| | | | Cattle management | $19.13 |
| | | | Water + mineral | $54.47 |
| *Total* | *$457.25* | | *Total* | *$377.52* |
| *Per DM Ton* | *$147.50* | | *Per DM Ton* | *$121.78* |
| *Per Hay Ton* | *$125.38* | | *Per Hay Ton Equivalent* | *$103.51* |
| ***Per DM Ton Utilized*** | ***$184.38*** | | ***Per DM Ton Utilized*** | ***$202.97*** |

[1] Machinery and computed complete harvest costs of 875 lb bales derived from Halich (2020).

[2] Current fertilizer prices of $0.50/lb N, $0.30/lb P, and $0.25/lb K were obtained from Thomas Cayce Farm Supply (Princeton, KY). 200 lb N/ac was used as it resulted in the greatest economic return when hay prices are high and N is low. Phosphorus and K rates were calculated based on removal rate of forages in the hay scenario based on 3.1 T/A DM (average of all environments at 200 lb N/A) (Eberly & Groover, 2007). Soil pH was assumed to be adequate (no lime applied).

[3] Split application of N was used: one application before planting and once each after first and second harvests. Prior to planting P and K would have been blended with N.

[4] Seed cost of $90 for the simple mixture was used, as additional seed costs of other treatments did not result in increased yields.

[5] Complete hay harvest costs were computed for the entire season on a ‘875 lb per bale’ basis and converted to total costs per acre based on yield of 6289 lb DM/acre (average yield when fertilized with 200 lb N/acre).

[6] 85% DM was used to convert hay on a DM basis to a ‘hay ton’ basis.

[7] 20% storage and feeding loss was used for hay production.

[8] Soil P and K were applied at 20% of yield removal rates as most of these nutrients are returned to the soil through manure and urine deposition.

[9] Cattle management, such as labor for pasture rotation, was calculated as follows: 8.5 weeks grazing * 4.5 hours/week checking cattle and moving temporary fence (2 moves/week @ 1 hour each + 0.5 hours checking cattle on remaining 5 days) * $15/hour labor / 30 acres. It was assumed that summer annuals would be used for pasture renovation; thus fencing and water systems would be already established.

[10] Calves were assumed to be stocked for 60 days at 4.4 calves/acre (6289 lb available DM forage/acre * 60% utilization rate / 60 days grazing / 14 lb DM intake/calf (700 lb calves consuming 2% of their body weight/day).

[11] Water and mineral was calculated as follows: 4.4 calves/acre * 14 gallons water/calf/day (2 gallons water per 100 lb (Dyer et al., 2017) * 60 days * $0.01331/gallon (Caldwell County Water District, Princeton, KY) + 4.4 calves/acre * 60 days * 0.25 lb mineral/calf/day * $0.40/lb mineral.

[12] Additional cost of clipping pastures was included, to more closely reflect management of experimental plots and would have occurred following first and second grazing events in a rotational grazing system.

Grazing summer annual forages result in pasture costs of $378/acre, which is 83% of the costs associated with haying ($457/acre). When utilization rates are considered, haying costs $184/DM T utilized, while pasture costs $203/DM T utilized. Thirty-nine percent of haying costs come fertility, followed by 31% for harvesting, and 20% for seed costs. The largest costs of pasturing are fertility (35%), harvesting via livestock, including clipping after grazing (29%), and seed cost (24%).

It has been said that cattle are the most economical form of forage harvesting, but this was not the case in this analysis. In this scenario, producing sudangrass hay cost 1.2 times as much per DM ton as producing forage in a grazing system. However, when utilization rates of pasture and storage/feeding loss of bales is considered, grazing becomes less economical compared to haying. Grazing cost 10% more than the cost of making hay. However, if bales are fed on-farm, they haying scenario would incur extra expenses of water, mineral, labor, and equipment. This would result in the grazing scenario being more economical.

Others have also evaluated hay vs. grazing systems, but often with different findings. At the whole farm level, Groover (2007) determined grazing to cost approximately 74% as compared to making hay. Nyren and coworkers (2002) additionally determined grazing to provide 1.77 times greater return to land, labor, and management as compared to haying marginal, highly erodible land in North Dakota. Additional benefits from grazing summer annuals may occur when high quality feed is required in the summer for grazing dairies or for grass fed beef. Alternatively, summer annuals preserved as stored forages may be utilized during the winter when most livestock operations have a feed deficit.

Nitrogen cost in these scenarios made up a large proportion of inputs in both systems. Summer annual grasses respond very well to N and unfortunately do not produce much biomass without N fertilization. With 200 lb N/ac, plots averaged 3.14 T DM/ac, while with no N they only produced 1.9 T DM/ac. Additionally, N is a major determinant of crude protein content of forages, and the forages in this study not fertilized with N only had 7% crude protein (Chapter 4) which would not support the nutritional demands of growing or lactating cattle (McCann, 2015). Treatments fertilized with 200 lb N/ac had approximately 10% crude protein, which is in the range of adequacy for lactating cattle (Chapter 4). However, fertilizing forages with N may not be an economical form of improving protein ingestion as compared to supplementation.

Without N fertilization, yield reductions resulted in hay expenses of $68/T and $101/DM T utilized. Pasture costs on a 15% moisture basis (hay equivalent) without N fertilization and expense reductions associated with reducing yield was $56, while pasture per DM ton utilized was $110 (Table 5.5). If no N is applied, protein supplementation would likely be needed to achieve desired animal performance, as crude protein content of unfertilized summer annuals would likely be limiting.

Table 5.5. Costs of sudangrass haying and grazing with no N fertilization.

| **HAYING** | **$/Acre** | | **GRAZING** | **$/Acre** |
|---|---|---|---|---|
| Disk-tandem | $15.50 | **Site Preparation** | Self-propelled sprayer (2x) | $15.00 |
| Field cultivator | $14.50 | | Herbicide 2x | $14.00 |
| N | | **Fertility** | N | |
| P | $8.46 | | P | $1.01 |
| K | $27.30 | | K | $3.28 |
| Application | | | Application | |
| Drill | $18.00 | **Planting** | No-till drill | $19.50 |
| Seed cost | $90.00 | | Seed cost | $90.00 |
| Cut, rake, bale, wrap, & moving bales | $76.00 | **Harvest** | Bush hog (1x) | $17.00 |
| | | | Cattle management | $11.48 |
| | | | Water + mineral | $32.68 |
| *Total* | *$249.76* | | *Total* | *$203.95* |
| *Per DM Ton* | *$80.57* | | *Per DM Ton* | *$65.79* |
| *Per Hay Ton* | *$68.48* | | *Per Hay Ton Equivalent* | *$55.92* |
| ***Per DM Ton Utilized*** | ***$100.71*** | | ***Per DM Ton Utilized*** | ***$109.65*** |

[1] Applying no N resulted in 40% yield loss. P, K, and harvest costs were reduced by 40%. Fertilizer application fees were also removed.

Price of seed is also a significant cost and was 24% of total costs of production for both haying and grazing. While it may be tempting to plant the cheapest seed possible, variety trials from the University of Kentucky have shown significant differences in yields of varieties (Olson et al., 2019a). However, this study used high seeding rates that could likely be reduced with limited impact on forage yield (Sowinski and Szydelko, 2011), which would reduce costs.

Making sudangrass hay may not be economical, particularly if hay market prices are low, as this scenario resulted in a breakeven hay price of $125/T. Additionally, forage quality declines if cutting is delayed, as stage of maturity is the strongest determinant of forage quality (Nelson & Moser, 1994). Drying in a timely manner may also be difficult, as sudangrass stalks are thicker than perennial counterparts, so producing quality hay from summer annual species can be challenging in humid environments.

## 5.4 Conclusions

Results of this study indicate that planting complex species mixtures with high sudangrass seeding rates does not result in increased yields. Therefore, planting a monoculture or simple mixture of a well-adapted species may be most economical. A need exists for further research regarding compatible species in mixtures and appropriate grass seeding rates. Sensitivity analyses showed that with most hay and N prices, it is not economical to fertilize with N in the scenarios presented here, but results could vary by altering several parameters. As N fertilization has been shown to improve forage quality, N application will likely be warranted in cases where improved forage quality is desired in order to reduce costs of supplemental feeding. Grazing sudangrass pastures was not more economical than haying when forage utilization rates and storage/feeding losses were accounted for. However, grazing would likely appear more favorable if feeding costs were added to the haying scenario. Improving utilization rates of grazing land via more intensive management would also improve economic outcomes. Despite potential difficulties, annual systems may fit well in a pasture renovation sequence or as a source of emergency forage.

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# CHAPTER 6. GRAZING MIXED SUMMER ANNUAL SWARDS: FORAGE AND LIVESTOCK PERFORMANCE

## Abstract

**Objective:** The objective of this study was to determine if increasing botanical diversity improved gains of calves grazing summer annual pastures.

**Materials and Methods:** Yearling Angus-cross beef calves (329, 366, and 297 kg in 2017, 2018, and 2019, respectively) were assigned to graze one of three summer annual forage treatments without supplementation for approximately 40 days each year. Treatments included a grass monoculture with the brown midrib trait, a simple mixture (two grasses and one legume), and a complex mixture (five grasses, four legumes, and three forbs). Treatments were arranged in a randomized complete block design with three replications. Five calves grazed each experimental unit.

**Results and Discussion:** Forage yield was not different between treatments ($P > 0.85$). In 2017 and 2019, calves grazing the monoculture and simple mixture had higher average daily gain (ADG) than calves grazing the complex mixture (2017: 0.79 vs. 0.66 kg/day, $P < 0.03$; 2019: 0.59 vs. 0.43 kg/day, $P < 0.03$). In 2018, there were no differences in ADG ($P > 0.3$); however, calves only gained 0.01 kg/day, most likely due to the advanced physiological stage of forages at the onset of the study. Although several forage quality parameters were affected by mixture, none provide insight into differences observed in ADG.

**Implications and Applications**: Results indicate that the increased seed cost of mixtures is not justified. Proper management of all summer annual forages (maintaining a vegetative state) is paramount to achieving adequate gains on stockers. Forage quality should be maintained and supplement provided as needed to meet performance goals.

Keywords sorghum-sudangrass, brown midrib, forage diversity, average daily gain

## 6.1 Introduction

The cool-season perennial forages that dominate the pastures of the Mid-South may have insufficient yield and/or quality to support desired livestock performance during the summer months. Cool-season growth rates decrease at temperatures above 25°C, leading to a reduced forage availability (Moser and Hoveland, 1996). In contrast, warm-season forages have optimal growth at temperatures between 30 and 35°C (Cooper & Tainton, 1968). The greater production and nutritive value of summer annual forages may produce the quantity and quality needed to grow or finish livestock during the summer months.

Unfortunately, summer annual input costs are significant (Mercier, 2021). Incorporating legumes into swards may improve economic feasibility. Many annual grass-legume systems demonstrate increased productivity as compared to their monoculture components (Bybee-Finley et al., 2016; Fan et al., 2020; Oseni, 2010; Sharma et al., 2009). These systems may even result in greater economic efficiency when fertilized with less N due to N “sharing” between legumes and grasses (Asangla & Gohain, 2016; Takele et al., 2017).

Legume inclusion may also increase nutritive characteristics of mixed summer annual forage stands. Iqbal and colleagues (2019) summarized several experiments comparing grass-legume mixtures to grass monocultures and reported an eight percent increase in crude protein and a five percent decrease in fiber. Experiments have been conducted evaluating livestock performance when grazing summer annual grasses (Harmon et al., 2019; Schmidt et al., 2013; Tracy et al., 2010), but very limited information exists comparing animal performance on warm season grass-legume mixtures as compared to grass monocultures.

The objective of this study was to evaluate the effects of increasing summer annual forage mixture complexity on forage and livestock performance. Three forage treatments were utilized: 1) a grass monoculture, 2) a simple three-species mixture, and 3) a complex twelve-species mixture. We hypothesized that including annual legumes into these mixtures would improve forage dry matter production and nutritive characteristics, as well as livestock average daily gains.

## 6.2 Materials and Methods

### 6.2.1 Site Description

This grazing study was conducted during the summers of 2017, 2018, and 2019 at the University of Kentucky Research and Education Center located near Princeton, KY (37.1007, -87.8574). The soil series was a Crider silt loam (fine-silty, mixed, active, mesic Typic Paleudalfs; Soil Survey Staff, 2019). A randomized complete block design with three replications was used, with landscape position as a blocking factor and pasture as the experimental unit.

Nine 1.6- (2017) or 0.9-hectare (2018 and 2019) pastures were utilized for this study. Pastures were sprayed once (2019) or twice (2017 and 2018) with 2.3 kg glyphosate/ha with two weeks between applications to control existing annual (2019) or perennial (2017 and 2018) cool-season vegetation. Pastures were then fertilized according to soil test results (Table 6.1; soil test methods can be found at: http://www.rs.uky.edu/soil/tests/methods.php) with diammonium phosphate and muriate of potash as needed for summer annual forage crops (Ritchey & McGrath, 2020). Ammonium nitrate was applied in conjunction with diammonium phosphate to achieve rates of 67 or 34 kg N/ha, with the lower rate applied to treatments containing legumes.

Table 6.1. Soil test results and amendments applied.

| Year | Soil Test Results | | | Amendments Applied | | |
|---|---|---|---|---|---|---|
| | pH | P | K | Lime | $P_2O_5$ | $K_2O$ |
| | | --- kg/ha --- | | Mg/ha | --- kg/ha --- | |
| 2017 | 5.8 | 45 | 289 | 2.50 | 70 | 55 |
| 2018 | 6.1 | 53 | 329 | 2.25 | 45 | 35 |
| 2019 | 6.2 | 71 | 258 | n/a | n/a | 90 |

[1] Phosphorus and potassium were applied as diammonium phosphate and muriate of potash, respectively.

[2] Soil testing methods can be found at: http://www.rs.uky.edu/soil/tests/methods.php

Pastures were sown on June 12, 2017, July 3, 2018, and June 11, 2019, with a no-till drill. Forage treatments were a grass monoculture, a simple 3-species mixture, and a complex 12-species mixture (Table 6.2). Seeds were treated with a multi-species inoculant (Link Cover Crop Inoculant, La Crosse Seed, La Crosse, WI) suitable for all legume species present in mixtures.

Table 6.2. Forage species, cultivars, and seeding rates.

| **Mixture** | **Species** | **Scientific Name** | **Cultivar** | **Seeding Rate (kg/ha)**[1] | |
|---|---|---|---|---|---|
| | | | | **Species** | **Total** |
| **Mono-culture** | Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | 56 | 56 |
| **Simple Mixture** | Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | 28 | |
| | Pearl Millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 6 | |
| | Soybean | *Glycine max* (L.) Merr. | Big Fellow (2017); Large Lad (2018-2019) | 28 | 62 |
| **Complex Mixture** | Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | 11 | |
| | Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9301 (2017); AS9302 (2018-2019) | 4.5 | |
| | Pearl millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 4.5 | |
| | Crabgrass | *Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop. | 50:50 blend of Red River and Quick-N-Big | 1 | |
| | Corn | *Zea mays* L. | AgriGold 115 day | 11 | |
| | Soybean | *Glycine max* (L.) Merr. | Big Fellow (2017); Large Lad (2018-2019) | 11 | |
| | Cowpea | *Vigna unguiculate* (L.) Walp. | Iron Clay (2017); Red Ripper (2018, 2019) | 11 | |
| | Korean lespedeza | *Kummerowia stipulacea* (Maxim) Makino | VNS (2017 and 2019); Legend (2018) | 4.5 | |
| | Sunflower | *Helianthus annuus* L. | Peredovic (2017, 2019); VNS (2018) | 2 | |
| | Forage rape | *Brassica napus* L. | Barsica (2017, 2018); T-Raptor (2019) | 1 | |
| | Daikon radish | *Raphanus sativus* L. | Nitro (2017); SF Select (2018); Badger (2019) | 2 | |
| | Sunn hemp | *Crotalaria juncea* L. | VNS | 2 | 65.5 |

[1] High seeding rate used to ensure dense sward

### 6.2.2 Livestock Management

This study was conducted in a manner that avoided unnecessary stress or harm to animals using approved protocols (IACUC protocol 2017-2711). Commercial Angus and Angus-cross stocker calves (both heifers and steers) were utilized in this study. Calves were weighed on two consecutive days to obtain an average weight at the start and end of the study. Beginning weights were 329, 365, and 297 kg in 2017, 2018, and 2019, respectively. Calves were stratified by weight and then randomly assigned to one of three summer annual forage treatments. Calves grazed for 41, 36, and 48 days in 2017, 2018, and 2019, respectively. No supplement was fed, but calves were allowed access to ad libitum water and UK Beef IRM Cow-calf mineral (https://afs.ca.uky.edu/files/ukbeefirmmineralspecs.pdf).

Paddocks were stocked when forages reached approximately 100 cm in 2017 and 2019 and 220 cm (physiological maturity) in 2018. Grazing initiation was delayed in 2018 due to water line installation and fence construction. In 2017 and 2018 calves strip-grazed paddocks. In 2019, calves rotationally grazed paddocks that were divided in half. The first half was clipped after calves rotated to the second half. After calves had grazed both halves, tall fescue/johnsongrass hay [7.3% crude protein (CP), 53.5% total digestible nutrients (TDN; summative equation; Moore & Undersander, 2002), 5.6% lignin] was fed ad libitum for two weeks until enough forage accumulated on the first half to sustain grazing.

### 6.2.3 Forage Sampling

Biomass was determined prior to each grazing event by clipping four 1/4 m2 quadrats at random locations throughout the pasture to a residual height of 2.5 cm. A subsample for dry matter and nutritive characteristics was collected and dried for 7 days in a forced air oven at 55°C. The subsample was ground to pass through 2- and 1-mm screens sequentially using Wiley (Thomas Wiley, Philadelphia, PA) and Cyclone (Udy Corporation, Fort Collin, CO) mills, respectively.

Dry matter was determined using the following equation: % dry matter = (subsample dry weight / subsample fresh weight) * 100. Total yield was calculated using the following equation: Mg DM/ha = kg fresh weight $m^{-1}$ * 1 Mg 1000 $kg^{-1}$ * 10,000 m2 $ha^{-1}$ * (% dry matter / 100). Nutritive characteristics were estimated using near infrared reflectance spectroscopy (Foss North America, Eden Prairie, MN) with a robust equation for hay and fresh forage (NIRS Forage and Feed Testing Consortium, Berea, KY). Total digestible nutrients were calculated using an equation from Virginia Tech as follows: TDN = 100.32 – 1.118 * acid detergent fiber (ADF).

### 6.2.4 Statistical Analysis

SAS 9.4 software (SAS Institute, Cary, NC) was used to analyze data. The Generalized Linear Model procedure was used to generate ANOVA tables. Significant differences by year occurred for ADG, therefore, all forage response variables (DM yield, botanical composition, and nutritive characteristics) were analyzed by year in order to make inferences for ADG responses. When analyzed by year, the model included block and forage treatment. Means were separated using Fisher’s protected least significant difference. A significance level of $\alpha = 0.1$ was used for all analyses.

## 6.3 Results and Discussion

### 6.3.1 Environmental Conditions

Long-term climate data was obtained from the most recent 30-year climate normals (1989-2010; NOAA National Centers for Environmental Information, Ashville, NC). Weather data was collected on-site with a weather station in the Kentucky Mesonet network (Bowling Green, KY) and is presented in Figure 6.1. The site receives 130 cm of precipitation annually with an average temperature of 14.7°C. The following data represent averages from June through August, as this encompasses the time from forage establishment to grazing trial completion. The 30-year average temperature and rainfall for this period was 25.1°C and 30.5 cm. Average temperature and cumulative rainfall for the three years of the study are as follows: 24.4, 25.1, and 24.2 °C in 2017, 2018, and 24, 33, and 35 cm in 2017, 2018, and 2019, respectively. July of each year had below average rainfall.

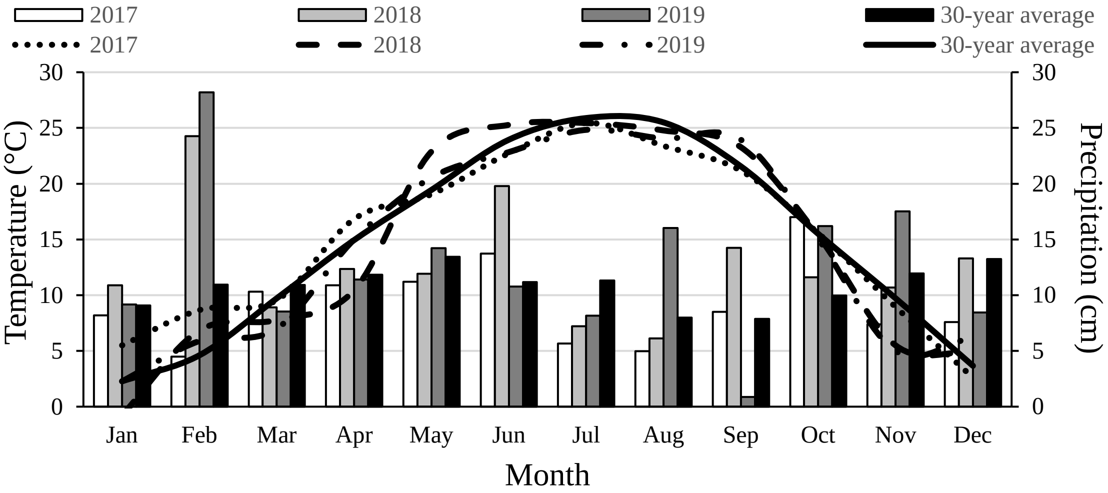

Figure 6.1. This climograph depicts temperature (lines, left axis) and precipitation (bars, right axis) for 2017 to 2019 (Kentucky Mesonet, Bowling Green, KY), compared with the 30-year climate normals (1989-2010; NOAA National Centers for Environmental Information, Ashville, NC) for Princeton, KY.

### 6.3.2 Forage Dry Matter Yield and Botanical Composition

No year x treatment interaction occurred ($p > 0.16$), and no differences in forage dry matter yield for the monoculture, simple mixture, or complex mixture were observed ($p > 0.85$). Forage yield averaged 11.89 Mg/ha. To make comparisons with ADG, data will also be presented by year. In all years, no differences in DM yield occurred for forage mixture ($p > 0.24$, $p > 0.33$, $p > 0.96$ in 2017, 2018, and 2019), and yields averaged 13.5, 15.9, and 6.3 Mg/ha (Figure 6.2).

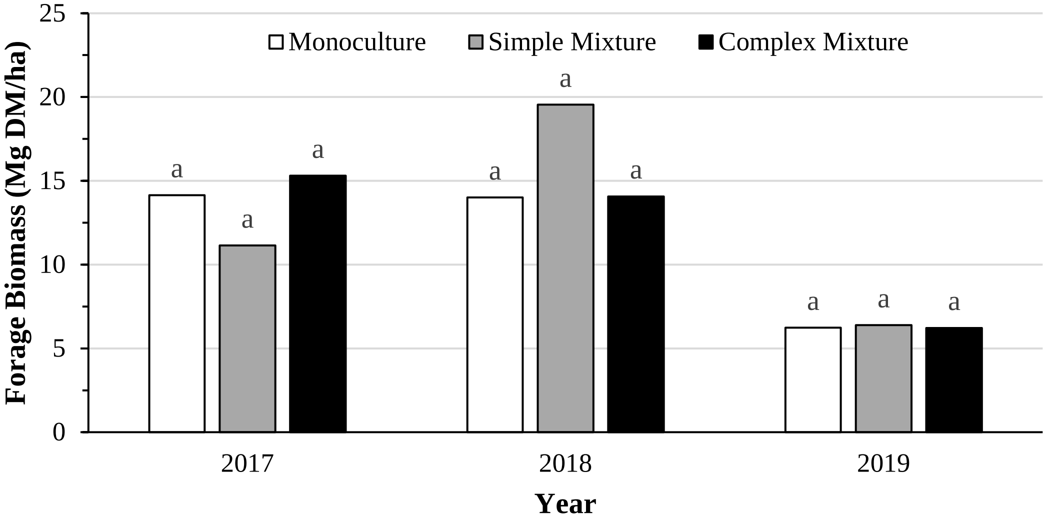

Figure 6.2. Forage biomass responses to mixture complexity: monoculture (white bar), simple mixture (grey bar) and complex mixture (black bar). Means within a year with common letters do not differ (Fisher's protected least significant difference; $\alpha = 0.1$).

Botanical components for mixtures for each year are shown in Table 6.3. Sorghum-sudangrass and sudangrass proportions are combined in the complex mixture, as it was difficult to differentiate the two species during botanical separations. Averaged across years the monoculture was comprised of 96% sorghum-sudangrass and 4% weeds.

The simple mixture had proportions of 77% sorghum-sudangrass, 8% weeds, 12% pearl millet, and 3% soybean. The complex mixture was comprised of 70% sorghum-sudangrass/sudangrass, 4% weeds, 15% pearl millet, and 5% corn. Soybean, crabgrass, cowpea, sunn hemp, sunflower, and daikon radish averaged less than 1% each. Korean lespedeza and forage rape were present in pastures to a small degree, but were not present in botanical separations.

With inclusion of additional species in both mixtures, sorghum-sudangrass proportions in the sward decreased from nearly 100% in monocultures to 77 and 70% in simple and complex mixtures. Although additional species added to mixtures generally did not have the yield potential of the sorghum-sudangrass (with the exception of corn, and pearl millet to a slightly lesser extent), biomass was not different between any of the forage treatments (Figure 6.2). This may indicate that seeding rates of monocultures could have been reduced and still achieve similar yields to the mixtures which had much lower sorghum-sudangrass seeding rates, as was shown by Sowinski and Szydełko (2011) when investigating sorghum-sudangrass yield responses to seeding rate.

Unfortunately, diversity of mixtures was low, as both simple and complex mixtures were dominated by sorghum-sudangrass, followed by pearl millet (Table 6.3). In general, legume content of swards was very low. This was most likely due to annual grasses having faster establishment and greater growth rates than legumes, leading to competitive dominance (Bybee-Finley et al., 2016). In order to improve plant species diversity, grass seeding rates should be reduced to limit shading and improve resource acquisition of other more slowly developing species (Dickson & Busby, 2009).

Table 6.3. Botanical composition of forage treatments for each year.

| Mixture & Year | | Proportion of Sward DM Biomass (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SS | W | PM | SB | CG | CN | CP | SH | KL | SF | DR | FR |
| Monoculture | 2017 | 100 | 0 | - | - | - | - | - | - | - | - | - | - |
| | 2018 | 96 | 4 | - | - | - | - | - | - | - | - | - | - |
| | 2019 | 93 | 7 | - | - | - | - | - | - | - | - | - | - |
| Simple Mixture | 2017 | 78 | 5 | 17 | 0 | - | - | - | - | - | - | - | - |
| | 2018 | 81 | 2 | 14 | 2 | - | - | - | - | - | - | - | - |
| | 2019 | 73 | 15 | 5 | 6 | - | - | - | - | - | - | - | - |
| Complex Mixture | 2017 | 74 | 4 | 18 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2018 | 72 | 0 | 19 | 0 | 0 | 6 | 1 | 2 | 0 | 0 | 0 | 0 |
| | 2019 | 64 | 9 | 10 | 1 | 2 | 6 | 1 | 3 | 0 | 4 | 1 | 0 |

[1] Abbreviations: SS = sorghum-sudangrass/sudangrass, W = weeds, PM = pearl millet, SB = soybean, CG = crabgrass, CN = corn, CP = cowpea, SH = sunn hemp, KL = Korean lespedeza, SF = sunflower, DR = daikon radish, and FR = forage rape

[2] Sorghum-sudangrass and sudangrass are combined in the complex mixture, as it was difficult differentiating the two species during botanical separations.

Interestingly, even though monocultures were fertilized with more N than both mixtures (67 vs. 34 kg N/ha), no difference in dry matter yield was detected. While some reports have shown evidence of annual legumes ‘sharing’ N with neighboring grasses, there still is uncertainty as to the extent of this sharing (Fujita et al., 1992; Layek et al., 2018). However, if N transfer occurs, it is thought to be increased with closer proximity of legumes to grasses (Fujita et al., 1990). As all seed in mixtures was blended into one lot prior to seeding in the current study, grasses and legumes would have been in close proximity and may have been more apt to share N than if they were planted in alternate rows. However, legume proportions were very low (3 and 2% of sward biomass in simple and complex mixtures) and even if N transfer occurred, it likely was minimal on a per hectare basis. The lack of yield difference may have then been due to sufficient plant available soil N.

### 6.3.3 Livestock Gains

Results are presented by year due to a year x treatment interaction ($p < 0.04$). In 2017, calves grazing the monoculture and simple mixture had higher ADG than calves grazing the complex mixture (0.79 kg/day vs. 0.66 kg/day; $P < 0.03$; Figure 6.3). In 2018, no differences in ADG were detected among treatments ($P > 0.3$). However, calves only gained 0.01 kg/day. In 2019, calves grazing the monoculture and simple mixtures again had higher ADG than calves grazing the complex mixture (0.59 kg/day vs. 0.43 kg/day, $P < 0.03$) (Figure 6.3).

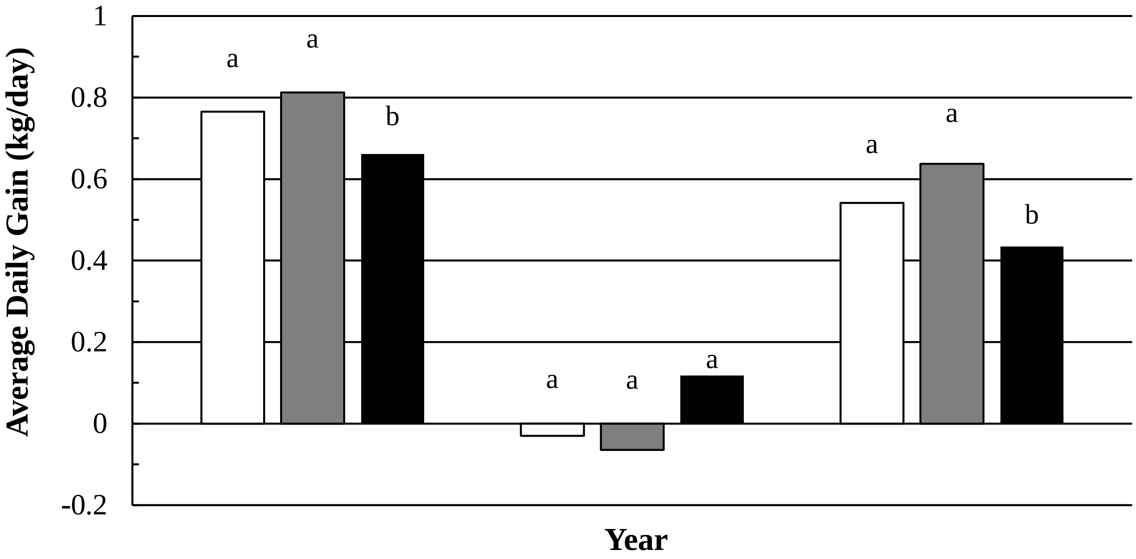

Figure 6.3. Average daily gain for stocker calves grazing a summer annual monoculture (white bar), simple mixture (grey bar) and complex mixture (black bar). Means within a year with common letters do not differ (Fisher's protected least significant difference; $\alpha = 0.1$).

Factors contributing to poor livestock gains in 2018 may have included the advanced maturity and increased plant height of forages upon grazing initiation, warmer temperatures during the grazing study, and limited visibility within the sward. Since stage of maturity is the primary determinant of forage quality (Nelson & Moser, 1994), physiologically mature forages in 2018 had lower nutritive value (see next section). Taller forages may have limited dry matter intake and/or sward utilization since calves could not reach the top of the plants. Additional heat stress may have also reduced feed intake and ADG of calves (O’Brien et al., 2010).

The top-down hypothesis states that herbivorous prey animals prefer areas with greater visibility in order to aid in predator avoidance (Riginos & Grace, 2008). Mesoherbivores (<1000 kg) in African savannas have been shown to preferentially occupy open areas as compared to areas of lower visibility, such as areas of higher tree density (le Roux et al., 2018). Domestic livestock are also affected more by visual as opposed to auditory cues (Uetake & Kudo, 1994), as can be observed when cattle balk at unfamiliar objects. Forages in 2018 were abnormally tall and calves were observed to be more flighty and agitated (K. M. Mercier, personal observation). Petherick and colleagues' (2009) work supported other studies where “cattle that [were] innately more agitated [had] poorer liveweight gains under both pasture and feedlot conditions”. Therefore, the added stress of a low-visibility environment may have contributed to poor gains in 2018.

Other reports of ADG from cattle grazing summer annual forages are often in excess of 0.95 kg/day while grazing brown midrib sorghum-sudangrass (Banta et al., 2002; Harmon et al., 2020; McCuistion, et al., 2011) and 0.85 kg/day while grazing pearl millet (Duckett et al, 2013; Harmon et al., 2020). In order to improve gain in these systems, it is recommended to maintain the forages in a vegetative state, as this generally equates to improved forage quality (Nelson & Moser, 1994).

Differences in proportions of BMR species were observed in the current study. Expression of the BMR gene imparts decreased lignin content, leading to increased forage digestibility (Miller and Stroup, 2003; Porter et al., 1978), which often results in improved ADG (McCuistion et al., 2011; Oba and Allen, 1999). In the current study, BMR forages (sorghum-sudangrass and sudangrass) in the monoculture, simple mixture, and complex mixture comprised 96, 77, and 70% of sward biomass.

Other researchers have reported similar results to the current study, where no increase in animal performance occurred when grazing diverse swards. Wedin and colleagues (1965) showed no benefit of grazing dairy cows on complex mixtures of cool-season perennial forages, as these mixtures were dominated by the same species as simple mixtures. In Georgia, including crabgrass into pearl millet swards did not result in increased steer gains, nor gains per hectare, as compared to pearl millet monoculture (Harmon et al., 2019). Swards in the current study were perhaps too botanically similar to show consistent and large differences in animal performance.

### 6.3.4 Forage Nutritive Characteristics

In order to make comparisons with ADG, forage nutritive characteristics are presented by year in Table 6.4. In 2017, ADF, neutral detergent fiber (NDF), and TDN were affected by mixture ($P < 0.1$). Acid detergent fiber was greatest in monoculture (39.3%), followed by the simple mixture (39.0%) and the complex mixture (38.4%; $P < 0.001$). Neutral detergent fiber in the monoculture (64.1%) was greater than both mixtures (average of 62.4%; $P < 0.1$). Total digestible nutrients were different for each mixture (56.4, 56.7, and 57.4% in the monoculture, simple mixture, and complex mixture; $P < 0.001$). These parameters were not affected by forage mixture: CP (9.5 %; P

$> 0.89$), lignin (3.5 %; $P > 0.82$), and 30-h in vitro total dry matter digestibility (IVTDMD30; 66.0 %; $P > 0.23$).

Table 6.4. Impact of botanical diversity on forage nutritive characteristics. Shaded cells indicate differences at α = 0.1.

| **Year** | **Nutritive Parameter[1]** (% DM) | **Forage Treatment** | | | **Mean** | **Standard Error** | **Significance[2]** |
|---|---|---|---|---|---|---|---|
| | | Monoculture | Simple Mixture | Complex Mixture | | | |
| 2017 | CP | 9.5 a | 9.7 a | 9.4 a | 9.5 | 0.92 | ns |
| | ADF | 39.3 a | 39.0 b | 38.4 c | 38.9 | 0.03 | *** |
| | NDF | 64.1 a | 62.7 b | 62.2 b | 63.0 | 0.31 | * |
| | TDN | 56.4 c | 56.7 b | 57.4 a | 56.8 | 0.04 | *** |
| | Lignin | 3.5 a | 3.5 a | 3.6 a | 3.5 | 0.10 | ns |
| | IVTDMD30 | 64.5 a | 66.0 a | 67.6 a | 66.0 | 1.06 | ns |
| 2018 | CP | 8.2 a | 7.2 a | 6.5 a | 7.3 | 0.43 | ns |
| | ADF | 40.1 a | 39.6 a | 39.8 a | 39.8 | 0.52 | ns |
| | NDF | 65.6 a | 64.0 a | 63.3 a | 64.4 | 0.70 | ns |
| | TDN | 55.5 a | 56.1 a | 55.9 a | 55.8 | 0.58 | ns |
| | Lignin | 3.6 c | 4.5 a | 4.0 b | 4.0 | 0.08 | ** |
| | IVTDMD30 | 62.3 b | 62.0 b | 64.8 a | 63.0 | 0.58 | * |
| 2019 | CP | 8.9 a | 9.5 a | 8.6 a | 9.0 | 0.69 | ns |
| | ADF | 41.2 a | 40.2 b | 40.5 b | 40.8 | 0.31 | * |
| | NDF | 65.8 a | 62.6 b | 63.0 b | 63.8 | 0.79 | * |
| | TDN | 53.9 b | 55.3 a | 55.0 a | 54.7 | 0.34 | * |
| | Lignin | 3.2 a | 3.2 a | 3.3 a | 3.2 | 0.04 | ns |
| | IVTDMD30 | 67.7 b | 71.5 a | 70.6 a | 70.0 | 0.79 | * |

[1] abbreviations: CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, TDN = total digestible nutrients, IVTDMD30 = 30 hour in vitro true dry matter digestibility

[2] ns = not significant, * = < 0.1, ** = < 0.01, *** = < 0.001

In 2018, lignin was greatest in the simple mixture (4.5%), followed by the complex mixture (4.0 %), and monoculture (3.6%; $P < 0.01$). The complex mixture had greater IVTDMD30 (64.8%) as compared to the monoculture and simple mixture (average of 62.2%; $P < 0.1$). These parameters were not affected by forage mixture: CP (7.3%; $P > 0.11$), ADF (39.8%; $P > 0.77$), NDF (64.4%; $P > 0.21$), and TDN (55.8%; $P > 0.77$).

In 2019, ADF, NDF, and TDN were affected by mixture ($P < 0.1$). Acid detergent fiber was greater in the monoculture (41.2%) as compared to both mixtures (average of 40.4%; $P < 0.1$). Neutral detergent fiber was also greater in the monoculture (65.8%) versus the mixtures (average of 62.8%; $P < 0.1$). Total digestible nutrients were lower in the monoculture (53.9%) as compared to the mixtures (average of 55.2%; $P < 0.1$). The monoculture (67.7%) also had less IVTDMD30 than the mixtures (average of 71.1%; $P < 0.1$). Crude protein (9.0%; $P > 0.65$) and lignin (3.2%; $P > 0.73$) were not affected by forage mixture.

While some of these results showed significant differences between treatments, the magnitude of the overall differences were only between 1 and 2 percentage units and may not have been biologically significant, as none of these results provided useful insight into the differences observed in ADG. Several nutritive value parameters even contradicted response seen in ADG. Mixtures sometimes had some improved nutritive characteristics over monocultures, but this was not translated into increases in ADG. Lignin concentrations were also expected to increase with mixture complexity, as each treatment had differing quantities of BMR species planted. However, that was not the case in two out of three years. These findings imply that other factors besides measured forage nutritive characteristics impacted ADG in this study.

One potential methodological fault was sampling the entire plant for forage nutritive characteristics. Although it is understood that cattle do not evenly graze the sward to the ground, entire plants were sampled to maintain consistency and to capture lower growing species in the sward. In addition, dry matter intake was not measured in this study. Although not without problems, a more accurate sampling approach may have been to mimic the grazing patterns of animals. Forage selectivity may help explain why animal performance did not reflect nutritive characteristics.

According to the Nutrient Requirements of Beef Cattle (National Research Council, 2001), in 2017, protein supplied by forages should have allowed for an ADG near 0.9 kg/day. This implies that cattle diets were energy limited, as average ADG was only 0.75 kg/day. In 2018, protein and TDN were far below suggested values for growing steers to gain a target of 0.68 kg/day. Fiber concentrations were also high (40% ADF, 64% NDF, 3.6-4.5% lignin), which likely decreased intake and digestibility (Jung & Allen, 1995). These, and previously discussed factors, most likely contributed to the poor ADG observed in 2018. In 2019, although the Ration Formulator indicated that protein and energy were relatively balanced, the lower concentrations of these components likely limited growth. Interestingly, IVTDMD30 in 2019 was four percentage units greater than in 2017, but ADG was 0.2 kg/day less.

These results indicate that crude protein and TDN estimates were fairly accurate, as they generally reflected yearly trends in animal performance. However, there were still discrepancies between forage quality and animal performance. In years that showed differences in ADG, differences were seen in ADF, NDF, and TDN with most favorable values consistently obtained in the complex mixture. Lignin was not different during those years, but was in 2018, where no differences in ADG occurred. However, in 2017 forage nutritive characteristics indicated that animal performance should have been greatest in calves grazing the complex mixture, while in 2019 forage quality indicated calves grazing the monoculture should have had lowest average daily gains. Perhaps there was some anti-quality factor(s) or reduced palatability of complex mixtures that played a stronger role in influencing intake and ADG (Ball et al., 2001), although this was not measured in the current study.

Cattle have been shown to adjust foraging preferences in diverse as compared to grass dominated swards (Wallis de Vries, 1994). However, sorghum-sudangrass and pearl millet combined comprised 89 and 86% of sward biomass in simple and complex mixtures, respectively. Therefore, both swards were grass dominated, and cattle preferences likely did not influence ADG.

It has long been understood that cattle select higher quality diets than can be predicted by forage sampling (Torell, 1954). As stated previously, forage sampling methods in the current study may not have provided accurate representation of actual livestock nutrient intake. This may have contributed to the discrepancies observed between estimated nutritive value and livestock performance.

## 6.4 Applications

The objective of this study was to determine the effects of grazing stockers on summer annual swards of increasing botanical diversity. Interestingly, forage nutritive characteristics did not reflect ADG responses, implying that whole plant and sward analysis is an inadequate metric for predicting animal performance. Increasing botanical diversity did not improve cattle performance, making the increased seed cost of mixtures difficult to justify. If diversity is a priority, producers should reduce grass seeding rates and utilize compatible species in mixtures. Although increasing mixture complexity did not improve ADG, it may offer other environmental benefits, such as providing habitat for pollinators, other macro- and micro-invertebrates, and fungi, etc. that live in the soil. Future work should consider the impact of summer annual forage diversity on nutrient cycling productivity of the entire grassland ecosystem.

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# CHAPTER 7. ECONOMIC ANALYSIS OF GRAZING BOTANICALLY DIVERSE SUMMER ANNUAL PASTURE

## Abstract

Economic analyses were performed to determine the feasibility of utilizing summer annuals to retain calves following grazing the spring flush of forages. In this study, calves grazed a monoculture, a 3-species mixture, or a 12-species mixture of summer annual forages. Average daily gain was reduced by 0.3 lbs/day in calves grazing the complex mixture in two out of three years. Under the conditions of this study, enterprise budgeting illustrated that retaining calves on summer annual forages was not economical. Sensitivity analyses indicated that this scenario would only be profitable when cattle prices are high and pasture establishment costs are low.

**Keywords**: enterprise budget, sensitivity analysis, sorghum-sudangrass, profitability, biodiversity

## 7.1 Introduction

Pastures in the upper southern United States are dominated by cool-season perennial forages. These species have a bimodal growth distribution with peaks in the spring and fall and a “summer slump” where high temperatures limit production (Moser & Hoveland, 1996). Warm-season annual forages may fill in the gap of reduced forage quantity and/or quality during the summer months. Although costly to implement, there are scenarios where summer annuals fit well into grazing systems. Examples include grazing enterprises with a high nutritional requirement (dairy grazing, heifer development, finishing beef) or for use as a smother crop in a pasture renovation sequence (Roberts & Andrae, 2004). In cases where these species are primarily used as a weed management tool, they can also provide an additional forage source during the renovation period.

When properly managed, summer annual forages have the potential for high production and quality and may be one option for improving summer performance

(Dillard et al., 2018). Tracy and colleagues (2010) found that summer annual pastures exhibited 61% more production and equal or greater nutritive value as compared to cool-season pastures during the summer months. Summer annual species have the potential to produce more than 11 Mg/ha with crude protein concentrations of over 15% (Harmon et al., 2019; Olson et al., 2017; Tracy et al., 2010). These traits are especially important for livestock that have a high plane of nutrition during the summer months.

Summer annuals are often not utilized due to high input costs and risks of stand failure. Unlike perennials, establishment costs are not depreciated over multiple years. For this reason, these systems have been deemed “a breakeven proposition at best” (Ball et al., 2007). Improving nutritive value or yield potential or reducing production costs may enhance the profitability of summer annual systems.

Increasing species diversity has been shown to have positive impacts on the production of both improved perennial and annual forage systems (Bybee-Finley et al., 2016; Picasso et al., 2008). Legume inclusion often drives the productivity of grassland systems due to their ability to acquire N from the environment via a symbiotic relationship with rhizobia bacteria (Huston et al., 2000). In perennial pastures, legume inclusion can reduce or eliminate the need for N fertilizer (Thomas, 1992). Although fixed N from annual legumes has even been found in neighboring plants (Fujita et al., 1990), the extent to which this transfer occurs is unclear.

While summer annual legumes have favorable nutritive characteristics, they generally have less yield potential than their grass counterparts (Knott et al., 2020). However, livestock grazing diverse pastures (especially with a strong legume presence) have the potential to perform better than their counterparts grazing a less diverse pasture

(Totty et al., 2013). Unfortunately, animal productivity is not always improved (Edwards et al., 2015), but grazing more diverse pastures may have other environmental benefits (Carmona-Flores et al., 2020; Edwards et al., 2015).

The objective of this experiment was to evaluate the economic feasibility of backgrounding weaned calves on summer annual forage mixtures of varying species diversity as compared to selling calves after grazing the spring flush of forages. Treatments included a grass monoculture, a simple three-species mixture, and a complex twelve-species mixture. Enterprise budgeting evaluated the cost of pasture establishment and utilization and the returns gained by backgrounding calves. A sensitivity analysis was also performed to determine profitability at various livestock market price scenarios.

## 7.2 Materials and Methods

Forage and livestock production data from Chapter 6 was used to prepare an enterprise budget and sensitivity analysis for a scenario where a producer would retain fall-born calves for 45 days after grazing the spring flush of forages. Full site description, weather data, forage establishment, livestock description, data collection methodology, and statistical analysis can be found in Chapter 6.

Three summer annual forage treatments (Table 7.1) were grazed by yearling calves without supplementation for 35-48 days during the summers of 2017, 2018, and 2019 in Princeton, KY. Forage yield and livestock performance are shown in Figures 7.1 and 7.2.

Table 7.1. Forage species, cultivars, and seeding rates.

| Mixture | Scientific Name | Cultivar | Seeding Rate (lb/A)[1] |
|---|---|---|---|
| **Monoculture** | | | |
| Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | **50** |
| **Simple** | | | |
| Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | 25 |
| Pearl Millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 5 |
| Soybean | *Glycine max* (L.) Merr. | Big Fellow (2017);<br>Large Lad (2018-2019) | 25 |
| | | **Total** | **55** |
| **Complex** | | | |
| Sorghum-sudangrass | *Sorghum bicolor var. bicolor x bicolor var. sudanenese* | AS6402 | 10 |
| Sudangrass | *Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan | AS9301 (2017);<br>AS9302 (2018-2019) | 4 |
| Pearl millet | *Pennisetum glaucum* (L.) R. Br. | Wonderleaf | 4 |
| Crabgrass | *Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop. | 50:50 blend of Red River and Quick-N-Big | 1 |
| Corn | *Zea mays* L. | AgriGold 115 day | 10 |
| Soybean | *Glycine max* (L.) Merr. | Big Fellow (2017);<br>Large Lad (2018-2019) | 10 |
| Cowpea | *Vigna unguiculate* (L.) Walp. | Iron Clay (2017); Red Ripper (2018, 2019) | 10 |
| Korean lespedeza | *Kummerowia stipulacea* (Maxim) Makino | VNS (2017 and 2019);<br>Legend (2018) | 4 |
| Sunflower | *Helianthus annuus* L. | Peredovic (2017, 2019); VNS (2018) | 2 |
| Forage rape | *Brassica napus* L. | Barsica (2017, 2018);<br>T-Raptor (2019) | 1 |
| Daikon radish | *Raphanus sativus* L. | Nitro (2017); SF Select (2018); Badger (2019) | 2 |
| Sunn hemp | *Crotalaria juncea* L. | VNS | 2 |
| | | **Total** | **60** |

[1] High seeding rate used to ensure dense sward

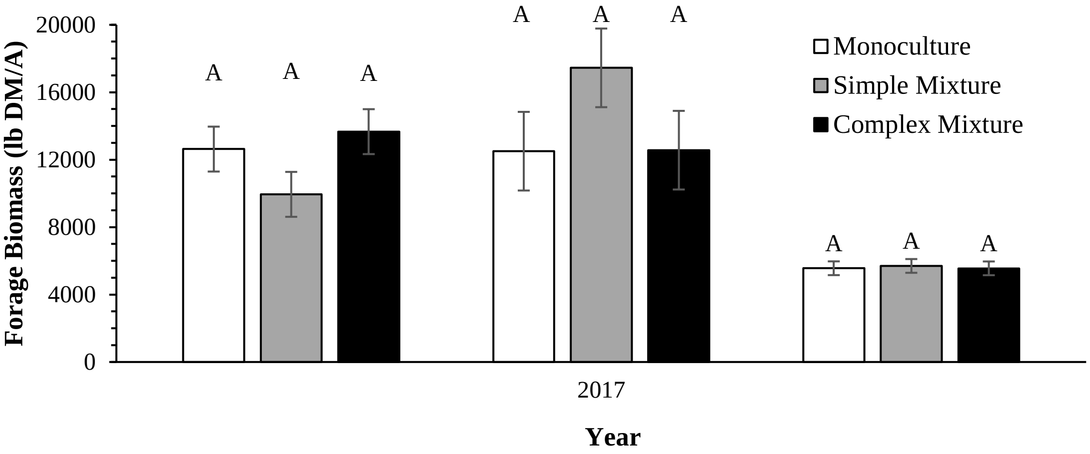


Figure 7.1. Forage biomass responses to mixture treatment: monoculture (white bar), simple mixture (grey bar), and complex mixture (black bar). Means within a year with common letters do not differ according to Fisher's protected least significant difference (α = 0.1) (Chapter 6).

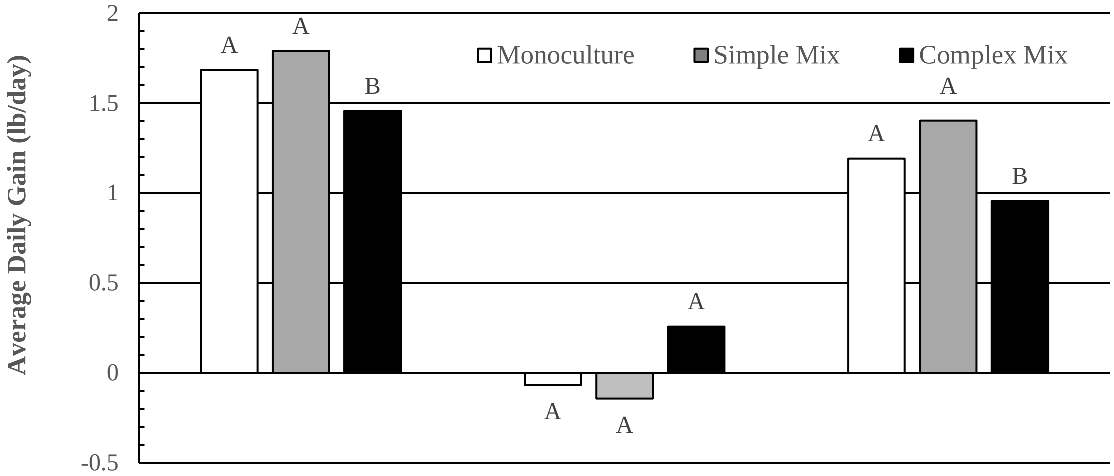


Figure 7.2. Average daily gain for stocker calves grazing a summer annual monoculture, simple mixture, and complex mixture. Means within a year with common letters do not differ according to Fisher's protected least significant difference (α = 0.1) (Chapter 6).

### 7.2.1 Costs of Summer Annual Establishment and Utilization

An enterprise budget was compiled to document expenses and returns. This scenario would represent a producer retaining fall-born calves for 45 days after grazing the spring flush of forages, rather than selling in June. This enterprise budget is not representative of costs associated with purchasing calves for backgrounding, which would include calf purchase price, commissions, antibiotics/vaccinations, and hauling in addition to those listed here.

Results from 2018 were not used in analyses, as livestock performance was atypical. Grazing was assumed to occur for 45 days (the average grazing time from 2017 and 2019). Calves weighed an average of 690 lbs at grazing initiation and were stocked at 2.2 calves/acre. Calf value per acre was calculated as calf weight * stocking rate * sale price. Price slide by weight was assumed to be $10/cwt.

Machinery costs to establish forages were obtained from Halich (2020). Fertility costs were calculated as 20% of yield removal rates (Eberly & Groover, 2007), as most nutrients are returned in grazing systems. Lime was not accounted for as pH was assumed to be adequate. Seed cost was obtained from Ramer Seed (Sharon Grove, KY) at the time of the study. Costs for burndown of remaining summer annual forage after grazing is not included, as it is assumed to be included in the establishment costs of the following crop.

Mineral was valued at $0.40/lb with consumption of 0.25 lb/calf/day. Water requirement of 2 gallons/100 lb (Dyer et al., 2017) and $0.01087/gallon was assumed based on local water price (Caldwell County Water District, Princeton, KY). Death loss for the experiment was 1%, and 4% interest on expenses plus calf value in June was included. Cattle growth implants were not used in this study and therefore not accounted for in the budget. However, many producers would opt to use them in this type of scenario.

A rotational grazing scenario was assumed with one clipping occurring with 50% probability (not all producers will clip based on their grazing management, and pastures were clipped in one out of two years in this study). Grazing infrastructure was assumed to be in place. Cattle management included labor for pasture rotation and checking livestock and was calculated as follows: 6.5 weeks grazing * 4.5 hours/week (2 rotations/week @ 1 hour each and 0.5 hours to check calves the other 5 days a week) * $15/hour labor / 20 acres (size of grazing trial area) = $21.94/acre.

Commission for cattle sales at the nearest stockyard (Kentucky-Tennessee Livestock Market, Guthrie, KY) is $3/head + 3%. Calves were assumed to weigh 755, 762, and 744 lb following grazing the monoculture, simple mixture, and complex mixture, respectively. Selling price in August was calculated by subtracting $10/cwt from June market prices to account for price differential due to weight gain.

### 7.2.2 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate profitability of grazing summer annual treatments at various livestock market prices. Market prices ranged from $100 to $200/cwt with slide ranges from $5 to $20/cwt.

## 7.3 Results

### 7.3.1 Livestock Revenue & Net Profit/Loss

Total costs for the monoculture, simple mixture, and complex mixture were $263, $253, and $270/acre, respectively (Table 7.2). Additional revenue from retaining calves is valued at $49.68, $59.02, and $34.56 per acre for the monoculture, simple mixture, and complex mixture, respectively. Breakeven sale price of calves in August would have to be $150/cwt, $148/cwt, and $152/cwt for the monoculture, simple mixture, and complex mixture, respectively, to cover costs of retaining calves on summer annual pasture and to result in a net return to land, management, and risk of $0 (Table 7.3). Average daily gain of calves grazing the monoculture and simple mixture were statistically similar, but revenues earned by grazing the simple mixture were $9/acre greater than the monoculture.

Table 7.2. Costs of producing and utilizing summer annual monocultures, simple mixtures, or complex mixtures. Shaded rows indicate cost differences between treatments.

| Expenses | Monoculture | Simple Mixture | Complex Mixture |
|---|---|---|---|
| | | $/acre | |
| Self-propelled Sprayer | 7.50 | 7.50 | 7.50 |
| Herbicide | 7.00 | 7.00 | 7.00 |
| N ($0.50/lb N) | 30.00 | 15.00 | 15.00 |
| P ($0.30/lb P) | 1.60 | 1.40 | 1.80 |
| K ($0.25/lb K) | 9.80 | 8.40 | 10.40 |
| Fertilizer Application | 6.00 | 6.00 | 6.00 |
| No-till Drill | 19.50 | 19.50 | 19.50 |
| Seed | 79.00 | 86.00 | 101.00 |
| Clipping | 8.50 | 8.50 | 8.50 |
| Labor | 21.94 | 21.94 | 21.94 |
| Mineral | 9.90 | 9.90 | 9.90 |
| Water | 25.92 | 25.92 | 25.92 |
| Death Loss (1%) | 22.44 | 22.44 | 22.44 |
| Commission | 1.54 | 1.82 | 1.08 |
| Interest | 12.15 | 12.11 | 12.19 |
| ***Total ($/acre)*** | ***262.79*** | ***253.43*** | ***270.17*** |

[1] Custom machinery rates obtained from Halich (2020).

[2] Phosphorus and potassium fertility based on 20% of yield removal rates (Eberly & Groover, 2007), and pH was assumed to be adequate.

[3] Pasture clipping occurred once per year 50% of the time.

[4] Labor for cattle management was calculated as follows: 6.5 weeks grazing * 4.5 hours/week (2 rotations/week @ 1 hour each and 0.5 hours to check calves the other 5 days a week) * $15/hour labor / 20 acres (size of grazing trial area).

[5] Calves weighed 690 in June and were stocked at 2.2 calves per acre. Final weights of calves were 755, 762, and 744 lbs for the monoculture, simple mixture, and complex mixture, respectively.

[6] Calves consumed 0.25 lb mineral ($0.40/lb) and 14 gallons of water per day (Dyer et al., 2017) ($0.01331/gallon, Caldwell County Water District, Princeton, KY).

[7] Death loss was calculated as 1% * beginning value of calves per acre.

[8] Commission was $3 + 3% (Kentucky-Tennessee Livestock Market, Guthrie, KY).

[9] 4% interest was charged on cost of calves in June plus expenses.

[10] Vet costs/vaccinations were not included, as they may not be incurred if retaining calves for an extra 45-60 days. Implants were also not used in this study.

Table 7.3. Economics of summer annual monocultures, simple mixtures, and complex mixtures.

| | **Mono-culture** | **Simple Mixture** | **Complex Mixture** |
|---|---|---|---|
| **June Calf Value Per Acre** | $2,223.57 | $2,223.57 | $2,223.57 |
| **August Calf Value Per Acre** | $2,273.24 | $2,282.59 | $2,258.13 |
| **Increase in Calf Value Per Acre** | $49.68 | $59.02 | $34.56 |
| **Cost of Production & Utilization** | $262.79 | $253.43 | $270.17 |
| **Return to Land, Management, & Risk / Acre** | -$213.11 | -$194.41 | -$235.61 |
| **August Breakeven Sale Price of Calves ($/lb)** | $1.50 | $1.48 | $1.52 |

### 7.3.2 Sensitivity Analysis

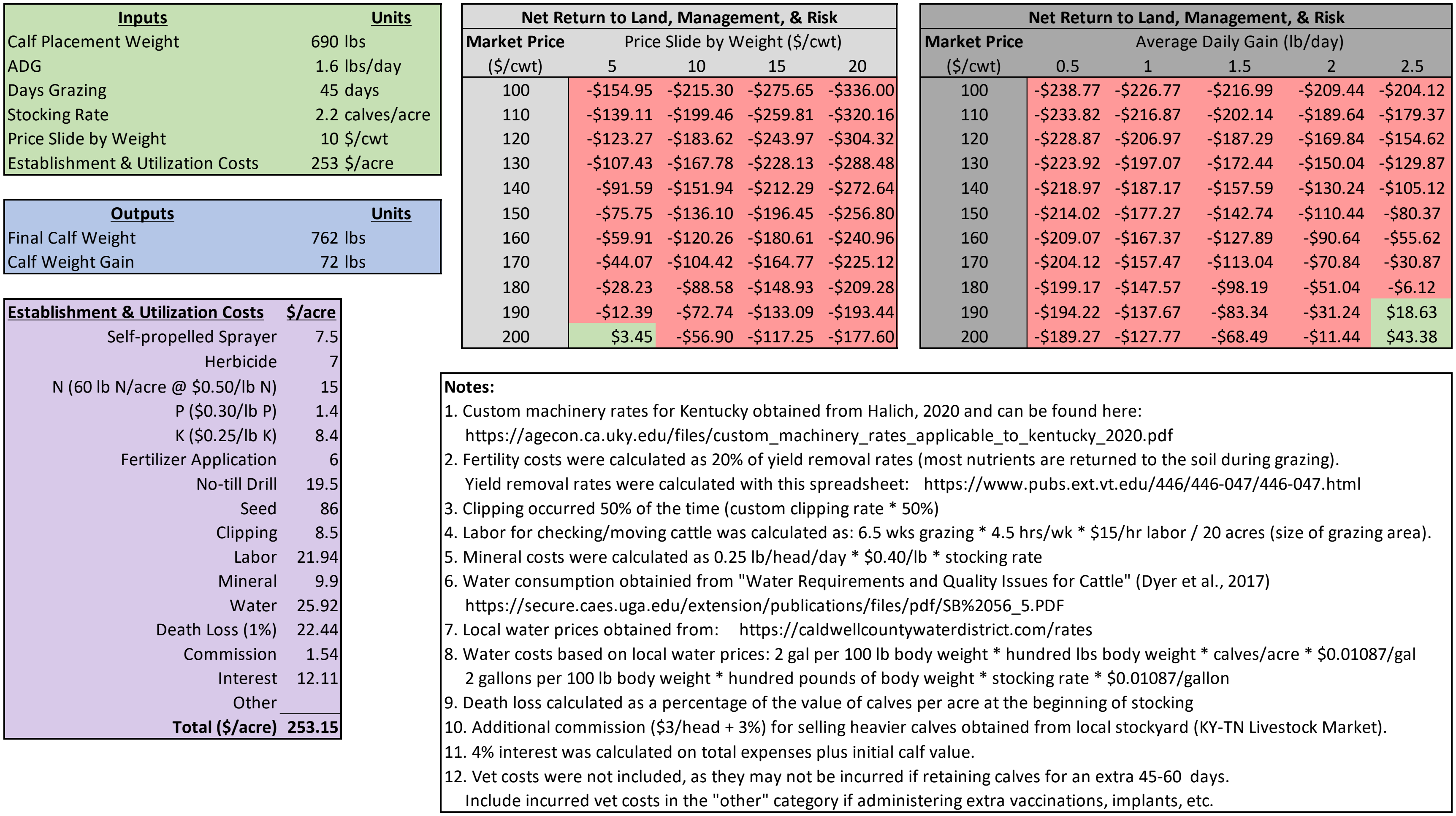
There were no scenarios resulting in positive net returns to land, management, and risk for the monoculture and complex mixture. The only positive net return ($3.45/acre) for the simple mixture occurred at $200/cwt with $5/cwt slide (Table 7.4).

Table 7.4. Return to land, management, and risk with varying market price and price slide for monocultures, simple mixtures, and complex mixtures. Bold value denotes a positive return.

| **Forage Treatment** | **Market Price** ($/cwt) | **Price Slide by Weight ($/cwt)** | | | |
|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 20 |
| Monoculture | 100 | -$173.98 | -$227.97 | -$281.95 | -$335.93 |
| | 110 | -$159.68 | -$213.67 | -$267.65 | -$321.63 |
| | 120 | -$145.38 | -$199.37 | -$253.35 | -$307.33 |
| | 130 | -$131.08 | -$185.07 | -$239.05 | -$293.03 |
| | 140 | -$116.78 | -$170.77 | -$224.75 | -$278.73 |
| | 150 | -$102.48 | -$156.47 | -$210.45 | -$264.43 |
| | 160 | -$88.18 | -$142.17 | -$196.15 | -$250.13 |
| | 170 | -$73.88 | -$127.87 | -$181.85 | -$235.83 |
| | 180 | -$59.58 | -$113.57 | -$167.55 | -$221.53 |
| | 190 | -$45.28 | -$99.27 | -$153.25 | -$207.23 |
| | 200 | -$30.98 | -$84.97 | -$138.95 | -$192.93 |
| Simple Mixture | 100 | -$154.95 | -$215.30 | -$275.65 | -$336.00 |
| | 110 | -$139.11 | -$199.46 | -$259.81 | -$320.16 |
| | 120 | -$123.27 | -$183.62 | -$243.97 | -$304.32 |
| | 130 | -$107.43 | -$167.78 | -$228.13 | -$288.48 |
| | 140 | -$91.59 | -$151.94 | -$212.29 | -$272.64 |
| | 150 | -$75.75 | -$136.10 | -$196.45 | -$256.80 |
| | 160 | -$59.91 | -$120.26 | -$180.61 | -$240.96 |
| | 170 | -$44.07 | -$104.42 | -$164.77 | -$225.12 |
| | 180 | -$28.23 | -$88.58 | -$148.93 | -$209.28 |
| | 190 | -$12.39 | -$72.74 | -$133.09 | -$193.44 |
| | 200 | **$3.45** | -$56.90 | -$117.25 | -$177.60 |
| Complex Mixture | 100 | -$195.39 | -$239.59 | -$283.78 | -$327.97 |
| | 110 | -$183.51 | -$227.71 | -$271.90 | -$316.09 |
| | 120 | -$171.63 | -$215.83 | -$260.02 | -$304.21 |
| | 130 | -$159.75 | -$203.95 | -$248.14 | -$292.33 |
| | 140 | -$147.87 | -$192.07 | -$236.26 | -$280.45 |
| | 150 | -$135.99 | -$180.19 | -$224.38 | -$268.57 |
| | 160 | -$124.11 | -$168.31 | -$212.50 | -$256.69 |
| | 170 | -$112.23 | -$156.43 | -$200.62 | -$244.81 |
| | 180 | -$100.35 | -$144.55 | -$188.74 | -$232.93 |
| | 190 | -$88.47 | -$132.67 | -$176.86 | -$221.05 |
| | 200 | -$76.59 | -$120.79 | -$164.98 | -$209.17 |

### 7.3.3 Decision Aid

An interactive spreadsheet was developed to aid producers in estimating net returns associated with retaining calves on summer annual forages after grazing the spring flush. This spreadsheet allows the user to input beginning calf weights, average daily gain, grazing period, livestock market prices, and price differential by weight (slide). Results are depicted with varying cattle market scenarios. A second output allows users to visualize net returns at different ADG levels (Figure 7.3).



| **Inputs** | **Units** |
|---|---|
| Calf Placement Weight | 690 lbs |
| ADG | 1.6 lbs/day |
| Days Grazing | 45 days |
| Stocking Rate | 2.2 calves/acre |
| Price Slide by Weight | 10 $/cwt |
| Establishment & Utilization Costs | 253 $/acre |

| **Outputs** | **Units** |
|---|---|
| Final Calf Weight | 762 lbs |
| Calf Weight Gain | 72 lbs |

| **Establishment & Utilization Costs** | **$/acre** |
|---|---|
| Self-propelled Sprayer | 7.5 |
| Herbicide | 7 |
| N (60 lb N/acre @ $0.50/lb N) | 15 |
| P ($0.30/lb P) | 1.4 |
| K ($0.25/lb K) | 8.4 |
| Fertilizer Application | 6 |
| No-till Drill | 19.5 |
| Seed | 86 |
| Clipping | 8.5 |
| Labor | 21.94 |
| Mineral | 9.9 |
| Water | 25.92 |
| Death Loss (1%) | 22.44 |
| Commission | 1.54 |
| Interest | 12.11 |
| Other | |
| **Total ($/acre)** | **253.15** |

| **Net Return to Land, Management, & Risk** | | | | |
|---|---|---|---|---|
| **Market Price** | Price Slide by Weight ($/cwt) | | | |
| ($/cwt) | 5 | 10 | 15 | 20 |
| 100 | -$154.95 | -$215.30 | -$275.65 | -$336.00 |
| 110 | -$139.11 | -$199.46 | -$259.81 | -$320.16 |
| 120 | -$123.27 | -$183.62 | -$243.97 | -$304.32 |
| 130 | -$107.43 | -$167.78 | -$228.13 | -$288.48 |
| 140 | -$91.59 | -$151.94 | -$212.29 | -$272.64 |
| 150 | -$75.75 | -$136.10 | -$196.45 | -$256.80 |
| 160 | -$59.91 | -$120.26 | -$180.61 | -$240.96 |
| 170 | -$44.07 | -$104.42 | -$164.77 | -$225.12 |
| 180 | -$28.23 | -$88.58 | -$148.93 | -$209.28 |
| 190 | -$12.39 | -$72.74 | -$133.09 | -$193.44 |
| 200 | $3.45 | -$56.90 | -$117.25 | -$177.60 |

| **Net Return to Land, Management, & Risk** | | | | | |
|---|---|---|---|---|---|
| **Market Price** | Average Daily Gain (lb/day) | | | | |
| ($/cwt) | 0.5 | 1 | 1.5 | 2 | 2.5 |
| 100 | -$238.77 | -$226.77 | -$216.99 | -$209.44 | -$204.12 |
| 110 | -$233.82 | -$216.87 | -$202.14 | -$189.64 | -$179.37 |
| 120 | -$228.87 | -$206.97 | -$187.29 | -$169.84 | -$154.62 |
| 130 | -$223.92 | -$197.07 | -$172.44 | -$150.04 | -$129.87 |
| 140 | -$218.97 | -$187.17 | -$157.59 | -$130.24 | -$105.12 |
| 150 | -$214.02 | -$177.27 | -$142.74 | -$110.44 | -$80.37 |
| 160 | -$209.07 | -$167.37 | -$127.89 | -$90.64 | -$55.62 |
| 170 | -$204.12 | -$157.47 | -$113.04 | -$70.84 | -$30.87 |
| 180 | -$199.17 | -$147.57 | -$98.19 | -$51.04 | -$6.12 |
| 190 | -$194.22 | -$137.67 | -$83.34 | -$31.24 | $18.63 |
| 200 | -$189.27 | -$127.77 | -$68.49 | -$11.44 | $43.38 |

**Notes:**

1. Custom machinery rates for Kentucky obtained from Halich, 2020 and can be found here:
https://agecon.ca.uky.edu/files/custom_machinery_rates_applicable_to_kentucky_2020.pdf
2. Fertility costs were calculated as 20% of yield removal rates (most nutrients are returned to the soil during grazing).
Yield removal rates were calculated with this spreadsheet: https://www.pubs.ext.vt.edu/446/446-047/446-047.html
3. Clipping occurred 50% of the time (custom clipping rate * 50%)
4. Labor for checking/moving cattle was calculated as: 6.5 wks grazing * 4.5 hrs/wk * $15/hr labor / 20 acres (size of grazing area).
5. Mineral costs were calculated as 0.25 lb/head/day * $0.40/lb * stocking rate
6. Water consumption obtainied from "Water Requirements and Quality Issues for Cattle" (Dyer et al., 2017)
https://secure.caes.uga.edu/extension/publications/files/pdf/SB%2056_5.PDF
7. Local water prices obtained from: https://caldwellcountywaterdistrict.com/rates
8. Water costs based on local water prices: 2 gal per 100 lb body weight * hundred lbs body weight * calves/acre * $0.01087/gal
2 gallons per 100 lb body weight * hundred pounds of body weight * stocking rate * $0.01087/gallon
9. Death loss calculated as a percentage of the value of calves per acre at the beginning of stocking
10. Additional commission ($3/head + 3%) for selling heavier calves obtained from local stockyard (KY-TN Livestock Market).
11. 4% interest was calculated on total expenses plus initial calf value.
12. Vet costs were not included, as they may not be incurred if retaining calves for an extra 45-60 days.
Include incurred vet costs in the "other" category if administering extra vaccinations, implants, etc.

Figure 7.3. Visualization of producer worksheet to evaluate net returns at customizable scenarios.
]

## 7.4 Discussion

Unfortunately, calves did not gain enough weight by grazing any of the forage treatments to offset the summer annual establishment and utilization costs. Relatively low nutritive characteristics could have contributed to these results as they would not support desired rates of gains for this class of livestock. Forages averaged 9.3% CP, 55.5% TDN, and 68% 30-h in vitro True Dry Matter Digestibility in 2017 and 2019 (Mercier, 2021). According to the University of Kentucky's Beef Ration Formulator, protein supplied by forages in 2017 should have allowed for ADG near 2 lb/day, meaning that cattle diets may have been energy limited. In 2019, although the Ration Formulator indicated that protein and energy were relatively balanced, the lower concentrations of these components likely limited growth (Mercier, 2021).

According to the decision tool, calves needed to gain 2.5 lbs/day with a market price of at least $190/cwt while grazing the simple mixture to be profitable (Figure 7.3). This level of animal performance likely would not occur without supplementation. Figure 7.4 depicts an alternate scenario with grazing extended to 60 days and varying establishment and utilization costs. If production and utilization costs could be reduced to $150/acre, the enterprise could be profitable with market prices of $160/cwt and 1.5 lb ADG, or with market prices of $140/cwt and 2 lb ADG (Figure 7.4a). Alternatively, if establishment/utilization costs were $200/acre and grazing period was 60 days, the enterprise could be profitable with 1.5 lb ADG at $180/cwt or with 2 lb ADG at $160/cwt (Figure 7.4b).

a) $150/acre establishment costs

| Market Price | Average Daily Gain (lb/day) | | | | |
|---|---|---|---|---|---|
| ($/cwt) | 0.5 | 1 | 1.5 | 2 | 2.5 |
| 100 | -$131.52 | -$117.00 | -$106.44 | -$99.84 | -$97.20 |
| 110 | -$124.92 | -$103.80 | -$86.64 | -$73.44 | -$64.20 |
| 120 | -$118.32 | -$90.60 | -$66.84 | -$47.04 | -$31.20 |
| 130 | -$111.72 | -$77.40 | -$47.04 | -$20.64 | $1.80 |
| 140 | -$105.12 | -$64.20 | -$27.24 | $5.76 | $34.80 |
| 150 | -$98.52 | -$51.00 | -$7.44 | $32.16 | $67.80 |
| 160 | -$91.92 | -$37.80 | $12.36 | $58.56 | $100.80 |
| 170 | -$85.32 | -$24.60 | $32.16 | $84.96 | $133.80 |
| 180 | -$78.72 | -$11.40 | $51.96 | $111.36 | $166.80 |
| 190 | -$72.12 | $1.80 | $71.76 | $137.76 | $199.80 |
| 200 | -$65.52 | $15.00 | $91.56 | $164.16 | $232.80 |

b) $200/acre establishment costs

| Market Price | Average Daily Gain (lb/day) | | | | |
|---|---|---|---|---|---|
| ($/cwt) | 0.5 | 1 | 1.5 | 2 | 2.5 |
| 100 | -$181.52 | -$167.00 | -$156.44 | -$149.84 | -$147.20 |
| 110 | -$174.92 | -$153.80 | -$136.64 | -$123.44 | -$114.20 |
| 120 | -$168.32 | -$140.60 | -$116.84 | -$97.04 | -$81.20 |
| 130 | -$161.72 | -$127.40 | -$97.04 | -$70.64 | -$48.20 |
| 140 | -$155.12 | -$114.20 | -$77.24 | -$44.24 | -$15.20 |
| 150 | -$148.52 | -$101.00 | -$57.44 | -$17.84 | $17.80 |
| 160 | -$141.92 | -$87.80 | -$37.64 | $8.56 | $50.80 |
| 170 | -$135.32 | -$74.60 | -$17.84 | $34.96 | $83.80 |
| 180 | -$128.72 | -$61.40 | $1.96 | $61.36 | $116.80 |
| 190 | -$122.12 | -$48.20 | $21.76 | $87.76 | $149.80 |
| 200 | -$115.52 | -$35.00 | $41.56 | $114.16 | $182.80 |

c) $250/acre establishment costs

| Market Price | Average Daily Gain (lb/day) | | | | |
|---|---|---|---|---|---|
| ($/cwt) | 0.5 | 1 | 1.5 | 2 | 2.5 |
| 100 | -$231.52 | -$217.00 | -$206.44 | -$199.84 | -$197.20 |
| 110 | -$224.92 | -$203.80 | -$186.64 | -$173.44 | -$164.20 |
| 120 | -$218.32 | -$190.60 | -$166.84 | -$147.04 | -$131.20 |
| 130 | -$211.72 | -$177.40 | -$147.04 | -$120.64 | -$98.20 |
| 140 | -$205.12 | -$164.20 | -$127.24 | -$94.24 | -$65.20 |
| 150 | -$198.52 | -$151.00 | -$107.44 | -$67.84 | -$32.20 |
| 160 | -$191.92 | -$137.80 | -$87.64 | -$41.44 | $0.80 |
| 170 | -$185.32 | -$124.60 | -$67.84 | -$15.04 | $33.80 |
| 180 | -$178.72 | -$111.40 | -$48.04 | $11.36 | $66.80 |
| 190 | -$172.12 | -$98.20 | -$28.24 | $37.76 | $99.80 |
| 200 | -$165.52 | -$85.00 | -$8.44 | $64.16 | $132.80 |

Figure 7.4. Net return to land, management, and risk when 690 lb calves stocked at 2.2 calves/acre graze for 60 days with $10/cwt price slide and varying establishment/ utilization costs (a = $150/acre, b = $200/acre, c = $250/acre). Red and green cell shading denote negative and positive returns, respectively.

The treatment that resulted in the least losses was the simple mixture, as the reduction in N fertilizer cost made up for slight increases in seed cost as compared to the monoculture, and calves had the greatest rate of gain. Seed cost could have been further reduced by decreasing grass seeding rates or by excluding species that were not competitive (soybean) with the more rapidly establishing grasses (this would result in low functional diversity). Increased N fertilizer may have improved nutritive characteristics, but it is unclear if the increased cost would have been offset by improvements in subsequent ADG.

An additional small plot experiment evaluated N rate effects on similar mixtures in comparable environments (Chapters 3-5). This study determined that 200 lb N/A resulted in the greatest yields and improved some nutritive characteristics of summer annual mixtures (Mercier et al., 2021). However, high rates of N fertilizer were only profitable when hay prices were very high and N prices were low. Similar to the current results, the mixtures of the small plot study were dominated by grasses. Results of these two studies indicate that many broadleaf species are not competitive when planted with high seeding rates of summer annual grasses.

The results of economic analyses from these two studies are in agreement with past work that has determined that summer annual systems are not an economical enterprise (Allison et al., 2021; Ball & Prevatt, 2009; Tracy et al., 2010). The authors of the current study, in agreement with the authors of the aforementioned studies, attribute the poor economic outcomes to substantial establishment costs that are not depreciated over multiple years. However, summer annual use may be warranted as part of a pasture renovation sequence or when livestock have high nutrient requirements. Potential ways to improve economic efficiency of these systems are as follows:

- Increase pasture utilization rates by rotationally stocking pastures. This may improve both forage quality and quantity (Paine et al., 1999).
- Initiate grazing at earlier growth stages. This would likely reduce total available DM but would improve forage quality and animal performance (Buxton & Fales, 1994).
- Reduce seeding rates of grasses to lessen establishment costs and promote legume establishment (Craufurd, 2000). In the current study, legumes contributed minimally to sward DM. Although seeding rates of dominant species were reduced in simple and complex mixtures, this reduction was not great enough to facilitate legume establishment.
- Utilize brown midrib cultivars. These cultivars have lower lignin content, resulting in increased forage digestibility (Miller & Stroup, 2003).
- The nutritional value of summer annual pastures needs to be determined and supplementation provided to meet desired animal performance goals.

One shortcoming of this experiment was that it did not compare summer annuals to a perennial pasture system. Therefore, these results are not intended to be used for determining whether or not to plant summer annuals, but rather to compare the impact of increasing species diversity on animal performance and subsequent profitability.

Tracy and Faulkner (2006) stated that grazing management had a stronger influence on pasture productivity than did species diversity. When utilizing summer annuals, producers are encouraged to utilize intensive management to optimize productivity and quality of fast-growing summer annual forages. This allows for less trampling/waste, and greater subsequent utilization.

Results of this study indicate that it would be most economical to plant a mixture of sorghum-sudangrass and pearl millet. As broadleaf species exhibited poor competitiveness when planted with moderately high grass seeding rates, their additional cost could not be justified. Although increasing botanical diversity did not provide economic benefit in the current study, functionally diverse summer annual pastures may contribute other ecosystem services that were not measured (Cardinale et al., 2011). If species diversity is a producer goal, then significantly reducing grass seeding rates may provide the opportunity for legumes to establish, which could lead to increased functional diversity, and perhaps increased yield and nutritive characteristics (Zhang et al., 2015). Increasing livestock performance, improving forage utilization, and reducing input costs can all contribute to more profitable summer annual grazing enterprises.

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# CHAPTER 8. SUMMARY

## 8.1 Introduction

Beef cattle production is an important facet of Kentucky's economy. In the Commonwealth, the beef industry contributes more than $1 billion in sales annually (USDA-NASS, 2019). Kentucky boasts the largest cattle herd east of the Mississippi River (Knopf & Quarles, 2018), in part due to the unique climate that produces forage throughout a large part of the year. This area is known as the "transition zone" between the temperate northern and subtropical southern U.S. where both cool- and warm-season species have favorable growing conditions (Burns & Chamblee, 1979).

While Kentucky's cool-season pasture base produces ample growth in the spring and fall, forage quantity and quality typically decline during the summer months (Moser & Hoveland, 1996). Summer annual forages could fill in this slump in yield and nutritive value during the summer months. Unfortunately, high input costs and the risk of stand failure has limited the adoption of summer annual forages.

This project was designed to investigate the potential for improving the economic feasibility of utilizing summer annuals in grazing systems. Legumes were incorporated with grasses to improve forage yield and quality and to reduce N input costs. Agronomic variables were evaluated and economic analyses were performed to compare grass monocultures, simple mixtures, and complex mixtures of summer annual forages.

## 8.2 Grazing Study

A grazing study was conducted to evaluate forage and livestock performance when stocker calves grazed mixtures of summer annual grasses and legumes. Treatments included a summer annual grass monoculture, a simple mixture of two grasses and one legume, and a complex mixture of five grasses, four legumes, and three forbs. Enterprise budgets were developed for each treatment and sensitivity analyses were conducted to determine profitability under different market price scenarios.

## 8.3 Small Plot Study

Recommendations for N fertilization rates on summer annual grass-legume mixtures are not well-established. In this study, N fertilization rates from 0 to 224 kg/ha were applied to a grass monoculture, a simple mixture of two grasses and one legume, and a complex mixture of 4 grasses, 4 legumes, and 3 forbs. Nitrogen rate effects on forage yield and quality were evaluated. Sensitivity analyses were performed to determine the economic optimum N rate when varying N and hay prices.

## 8.4 Observations & Practical Implications

Due to poor legume establishment, N recommendations for summer annual grass-legume mixtures could not be made. Grasses germinated and formed a canopy before legumes, resulting in grass-dominated swards with low functional diversity. Interestingly, forage yield was not affected by mixture in six out of seven environments (both grazing and plot trials). This occurred despite the seeding rate of the dominant grass in the mixtures being reduced to 20 to 50% of the monoculture rates.

In the plot trial, mixture complexity had a negligible effect on nutritive characteristics, except in the case of lignin content. This likely was a result of decreasing proportions of brown midrib forages as mixture complexity increased. Lignin is an anti-quality factor and an important determinant of forage digestibility. Therefore, these studies demonstrate the importance of planting brown midrib species that contain lower concentrations of lignin.

Nitrogen application up to 224 kg N $ha^{-1}$ often had a positive impact on forage quality parameters in the plot trial. However, forages in three out of four environments would not meet the nutritional demands of growing or lactating cattle throughout the entire growing season due to later physiological maturity of some harvests. This illustrates the importance of harvesting in a timely manner to maximize both forage yield and quality.

Several forage quality parameters in the grazing trial were affected by mixture. However, none provided useful insight into differences observed in livestock average daily gain. In two out of three years, calves grazing the monoculture and simple mixture had 0.15 kg higher ADG than calves grazing the complex mixture. The combination of increased seed cost and reductions in ADG of calves grazing complex mixtures made the economics of grazing summer annuals questionable at best.

Interestingly, calves only gained 0.01 kg/day in 2018. This would have resulted in substantial monetary losses in a production system as revenues from additional gain would have been essentially nonexistent. Factors contributing to poor livestock performance may have included the advanced maturity of forages upon grazing initiation, the heavier start weights of calves, warmer temperatures during the grazing study, and limited visibility within the sward.

The top-down hypothesis states that herbivorous prey animals prefer areas with greater visibility in order to aid in predator avoidance (Riginos & Grace, 2008). Forages in 2018 were abnormally tall and calves were observed to be more flighty as compared to other years where forages were not as tall upon grazing initation (K. M. Mercier, personal observation). Petherick and colleagues (2009) stated that “cattle that [were] innately more agitated [had] poorer liveweight gains under both pasture and feedlot conditions”. Therefore, the added stress of a low-visibility environment may have contributed to poor gains in 2018.

The results from 2018 illustrates an additional risk inherent to summer annual systems. Rapid growth of summer annuals may often result in advanced stages of maturity at the onset of grazing. This, in turn, reduces forage quality and subsequent animal performance, and may cause additional stress to livestock.

Although yield responses to N were positive in the plot trial, sensitivity analyses showed that applying N resulted in positive net returns only when hay prices were very high and N costs were low. Enterprise budgets determined that when utilization rates and hay storage and feeding loss were accounted for, grazing resulted in 18% fewer costs than haying. These results support the common precept that cattle are the most economic form of forage harvesting.

Enterprise budgets and sensitivity analyses for the monoculture, simple mixture, and complex mixtures in the grazing study determined the simple mixture to result in least losses.

## 8.5 Conclusions

The results of these studies reinforce several core forage tenets:

- Over-mature forages result in poor nutritive characteristics and inadequate animal performance.

- Nitrogen application improves yield and forage quality of summer annual forages.
- Grazing is a more cost-effective form of forage harvest as compared to haying.
- Utilizing cultivars with the brown midrib trait reduces lignin content.

New findings indicate that:

- Planting complex summer annual mixtures may not be economical or result in increased forage yield/quality or animal performance.
- In complex mixtures, rapidly establishing and tall growing grass species often outcompete slower establishing legumes and forbs.
- When unsupplemented, livestock ADG may not be sufficient to justify the high cost associated with utilizing summer annual forages.
- Net returns may be negative when applying N if hay prices are not high and N costs are not low.
- Seeding rates of fast-establishing and aggressively growing grasses must be reduced to encourage sward diversity. Planting compatible species at appropriate seeding rates in mixtures will impact the economic feasibility of summer annual systems.
- Results of these studies indicate that monocultures or simple mixtures of cultivars containing the brown midrib trait are most economical.

- Although results of these experiments did not favor diverse mixtures of summer annual forages, there may be environmental benefits that were not measured in these studies.

## 8.6 Future Work

As rapidly establishing grasses outcompeted other species, optimum seeding rates for summer annual grass-legume mixtures must be evaluated to encourage the growth of less aggressive species and to promote functional diversity. Once these are established, the economic optimum N rates should be determined for these diverse mixtures. Livestock may then be introduced to the system to determine the impact of summer annual mixtures with high functional diversity on livestock performance and profitability. Economic analyses is needed for various farm scenarios (spring calving cow-calf, stockering, finishing, etc.) incorporating summer annual forages under various input, performance, and market conditions.

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# APPENDICES

APPENDIX 1. Response of Botanical Components of Monocultures to Nitrogen Rates (Chapter 3)

| Environment | N Rate (kg N/ha) | Sudangrass | Weeds |
|---|---|---|---|
| | | kg DM/ha | |
| Lexington 2018 | 0 | 4332 | 25 |
| | 56 | 5102 | 49 |
| | 112 | 5448 | 45 |
| | 168 | 5442 | 30 |
| | 224 | 4927 | 12 |
| | P-value | ** | ns |
| | Regression | $y = -0.07459x^2 + 17.647x + 3863$ | – |
| | $R^2$ | 0.48 | – |
| Princeton 2018 | 0 | 2965 | 71 |
| | 56 | 2440 | 17 |
| | 112 | 3948 | 25 |
| | 168 | 4722 | 52 |
| | 224 | 5991 | 19 |
| | P-value | * | ns |
| | Regression | $y = 0.07284x^2 + 0.3144x + 2459$ | – |
| | $R^2$ | 0.78 | – |
| Lexington 2019 | 0 | 3456 | 244 |
| | 56 | 4976 | 209 |
| | 112 | 5837 | 228 |
| | 168 | 6124 | 406 |
| | 224 | 6940 | 447 |
| | P-value | *** | ns |
| | Regression | $y = 14.87x + 3375$ | – |
| | $R^2$ | 0.64 | – |
| Princeton 2019 | 0 | 6074 | 136 |
| | 56 | 5953 | 93 |
| | 112 | 7398 | 134 |
| | 168 | 8178 | 135 |
| | 224 | 9774 | 73 |
| | P-value | *** | ns |
| | Regression | $y = 17.19x + 4956$ | – |
| | $R^2$ | 0.67 | – |

[a] ns=not significant; *=significant at the 0.05 probability level; **=significant at the 0.01 probability level; ***=significant at the 0.001 probability level

APPENDIX 2. Response of Botanical Components of Simple Mixtures to Nitrogen Rates (Chapter 3).

| Environment | N Rate | Sudangrass | Weeds | Pearl Millet | Soybean |
|---|---|---|---|---|---|
| | (kg N/ha) | kg DM/ha | | | |
| Lexington 2018 | 0 | 3267 | 58 | 1724.8 | 46.2 |
| | 56 | 4056 | 43 | 1944.32 | 51.52 |
| | 112 | 3742 | 46 | 2745.96 | 61.6 |
| | 168 | 3895 | 69 | 1921.64 | 92.12 |
| | 224 | 4114 | 44 | 2024.4 | 65.8 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Princeton 2018 | 0 | 2820 | 85 | 160.16 | 54.6 |
| | 56 | 2661 | 48 | 112.28 | 115.92 |
| | 112 | 3772 | 54 | 412.16 | 40.88 |
| | 168 | 4151 | 201 | 563.64 | 50.4 |
| | 224 | 4412 | 39 | 666.96 | 29.96 |
| | P-value | ** | ns | *** | ns |
| | Regression | y = 10.022x + 2347 | – | y = 2.6x + 80.4 | – |
| | $R^2$ | 0.83 | – | 0.64 | – |
| Lexington 2019 | 0 | 3204 | 204 | 818.72 | 266.28 |
| | 56 | 3594 | 471 | 937.72 | 84.28 |
| | 112 | 3761 | 502 | 1865.36 | 102.48 |
| | 168 | 3769 | 251 | 2081.24 | 62.44 |
| | 224 | 4701 | 377 | 2310.56 | 78.96 |
| | P-value | ns | ns | *** | ns |
| | Regression | – | – | y = 7.37x + 694 | – |
| | $R^2$ | – | – | 0.46 | – |
| Princeton 2019 | 0 | 4258 | 162 | 324.24 | 110.32 |
| | 56 | 4670 | 138 | 376.32 | 61.6 |
| | 112 | 6224 | 130 | 1267.84 | 77.56 |
| | 168 | 7550 | 161 | 1896.44 | 133.56 |
| | 224 | 6936 | 89 | 2118.2 | 84.84 |
| | P-value | *** | ns | *** | ns |
| | Regression | y = 14.7x + 3822 | – | y = 9.1x + 156 | – |
| | $R^2$ | 0.56 | – | 0.71 | – |

[a] ns=not significant; *=significant at the 0.05 probability level; **=significant at the 0.01 probability level; ***=significant at the 0.001 probability level

APPENDIX 3. Response of Botanical Components of Complex Mixtures to Nitrogen Rates (Chapter 3).

| **Environment** | **N Rate** | **Sudangrass** | **Weeds** | **Pearl Millet** | **Soybean** |
|---|---|---|---|---|---|
| | (kg N/ha) | kg DM/ha | | | |
| Lexington 2018 | 0 | 2852 | 22 | 1662 | 40 |
| | 56 | 3732 | 17 | 1755 | 12 |
| | 112 | 2956 | 20 | 2462 | 22 |
| | 168 | 3151 | 13 | 2392 | 34 |
| | 224 | 3144 | 49 | 2346 | 41 |
| | P-value | ns[a] | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Princeton 2018 | 0 | 2211 | 15 | 195 | 62 |
| | 56 | 1600 | 16 | 182 | 51 |
| | 112 | 3377 | 22 | 557 | 56 |
| | 168 | 3023 | 17 | 376 | 23 |
| | 224 | 4957 | 38 | 687 | 38 |
| | P-value | *** | ns | *** | ns |
| | Regression | $y = 11.4x + 1520$ | – | $y = 2.1x + 146$ | – |
| | $R^2$ | 0.5 | – | 0.45 | – |
| Lexington 2019 | 0 | 2157 | 68 | 591 | 80 |
| | 56 | 1958 | 120 | 1023 | 48 |
| | 112 | 2857 | 126 | 1664 | 88 |
| | 168 | 3055 | 147 | 1339 | 36 |
| | 224 | 3595 | 130 | 1965 | 40 |
| | P-value | ** | ns | * | ns |
| | Regression | $y = 7.1x + 1723$ | – | $y = 5.5x + 628$ | – |
| | $R^2$ | 0.42 | – | 0.32 | – |
| Princeton 2019 | 0 | 3771 | 105 | 662 | 35 |
| | 56 | 3814 | 15 | 454 | 43 |
| | 112 | 4222 | 70 | 1223 | 45 |
| | 168 | 5435 | 56 | 1749 | 64 |
| | 224 | 5897 | 34 | 2029 | 34 |
| | P-value | *** | ns | *** | ns |
| | Regression | $y = 10.5x + 3083$ | – | $y = 7.2x + 373$ | – |
| | $R^2$ | 0.52 | – | 0.66 | – |

[a] ns=not significant; *=significant at the 0.05 probability level; **=significant at the 0.01 probability level; ***=significant at the 0.001 probability level.

APPENDIX 3 (continued). Response of Botanical Components of Complex Mixtures to Nitrogen Rates (Chapter 3).

| **Environment** | **N Rate** | **Corn** | **Crabgrass** | **Cowpea** | **Sunn Hemp** |
|---|---|---|---|---|---|
| | (kg N/ha) | | kg DM/ha | | |
| Lexington 2018 | 0 | 51 | 34 | 68 | 17 |
| | 56 | 95 | 37 | 37 | 16 |
| | 112 | 170 | 25 | 58 | 45 |
| | 168 | 219 | 19 | 47 | 35 |
| | 224 | 87 | 26 | 39 | 20 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Princeton 2018 | 0 | 10 | 170 | 52 | 45 |
| | 56 | 7 | 105 | 61 | 47 |
| | 112 | 16 | 239 | 35 | 24 |
| | 168 | 71 | 425 | 20 | 38 |
| | 224 | 0 | 221 | 68 | 51 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Lexington 2019 | 0 | 96 | 1233 | 173 | 35 |
| | 56 | 133 | 1187 | 55 | 11 |
| | 112 | 183 | 1175 | 46 | 3 |
| | 168 | 222 | 1250 | 27 | 29 |
| | 224 | 409 | 767 | 38 | 11 |
| | P-value | ns | ns | * | ns |
| | Regression | – | – | $y = 0.00265x^2 - 1.8x + 146$ | – |
| | $R^2$ | – | – | 0.50 | – |
| Princeton 2019 | 0 | 35 | 608 | 34 | 59 |
| | 56 | 37 | 608 | 52 | 49 |
| | 112 | 64 | 981 | 41 | 37 |
| | 168 | 16 | 1088 | 36 | 19 |
| | 224 | 136 | 578 | 24 | 12 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |

[a] ns=not significant; *=significant at the 0.05 probability level; **=significant at the 0.01 probability level; ***=significant at the 0.001 probability level

APPENDIX 3 (continued). Response of Botanical Components of Complex Mixtures to Nitrogen Rates (Chapter 3)

| **Environment** | **N Rate** | **Sunflower** | **Daikon Radish** | **Forage Rape** | **Korean Lespedeza** |
|---|---|---|---|---|---|
| | (kg N/ha) | kg DM/ha | | | |
| Lexington 2018 | 0 | 25 | 31 | 9 | 11 |
| | 56 | 29 | 36 | 20 | 4 |
| | 112 | 153 | 24 | 15 | 5 |
| | 168 | 24 | 22 | 7 | 8 |
| | 224 | 13 | 40 | 11 | 2 |
| | P-value | * | ns | ns | * |
| | Regression | $y = -.00723x^2 + 1.39x + 13$ | – | – | $y = -.00001x^3 + 0.003x^2 - 0.29x + 10$ |
| | $R^2$ | 0.22 | – | – | 0.45 |
| Princeton 2018 | 0 | 5 | 0 | 5 | 36 |
| | 56 | 37 | 0 | 0 | 31 |
| | 112 | 95 | 0 | 7 | 19 |
| | 168 | 12 | 0 | 0 | 21 |
| | 224 | 9 | 0 | 2 | 27 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Lexington 2019 | 0 | 0 | 5 | 13 | 118 |
| | 56 | 36 | 4 | 8 | 54 |
| | 112 | 65 | 14 | 18 | 76 |
| | 168 | 47 | 7 | 3 | 92 |
| | 224 | 23 | 19 | 0 | 48 |
| | P-value | ns | ns | ns | ns |
| | Regression | – | – | – | – |
| | $R^2$ | – | – | – | – |
| Princeton 2019 | 0 | 22 | 2 | 3 | 50 |
| | 56 | 11 | 10 | 11 | 25 |
| | 112 | 10 | 13 | 0 | 13 |
| | 168 | 10 | 16 | 1 | 34 |
| | 224 | 0 | 27 | 0 | 9 |
| | P-value | ns | ns | ** | ns |
| | Regression | – | – | $y = 0.01435x+1$ | – |
| | $R^2$ | – | – | 0.17 | – |

[a] ns=not significant; *=significant at the 0.05 probability level; **=significant at the 0.01 probability level; ***=significant at the 0.001 probability level

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# VITA

## EDUCATION

Virginia Polytechnic Institute and State University – Master of Science, 2017

University of Wisconsin-Stevens Point – Bachelor of Science, 2014

## SCHOLASTIC AND PROFESSIONAL HONORS (since 2014)

North Central Extension-Industry Soil Fertility Conference Outstanding Graduate Student Award, November 2020.

3rd Place: Integrated Plant and Soil Sciences Outstanding Continuing PhD Student, April 2020.

2nd Place: Dr. Donald L. Sparks & Dr. Bill Witt Integrated Plant and Soil Sciences Graduate Student Symposium, Lexington, KY, 14 January 2020.

Moebius Syndrome Foundation Educational Scholarship, May 2019.

1st Place: Professor Bill Witt Integrated Plant and Soil Sciences Symposium, Lexington, KY, 7 December 2018.

1st Place: Emerging Scientist Poster Competition, American Forage and Grassland Council National Meeting, Roanoke, VA, 22-24 January 2017.

Top Honors: Poster Paper Competition, 7th National Small Farm Conference, Virginia Beach, VA, 20-22 September 2016.

Virginia Forage and Grassland Council Harlan E. White Scholarship, May 2016.

Abbotsford FFA Alumni Scholarship, 2011-2016.

The Insurance Center Scholarship, June 2014.

## PROFESSIONAL PUBLICATIONS

Mercier, K., C. Teutsch, S. Smith, E. Ritchey, K. Burdine, and E. Vanzant. 2021. Nitrogen effects on DM yield and botanical components of summer annual forage mixtures. Agronomy Journal. In press.

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