2016

Combining Forage and Cover Crop Benefits from Cool-season Annuals in the Southeastern United States

Dustin John Smith
Louisiana State University and Agricultural and Mechanical College

COMBINING FORAGE AND COVER CROP BENEFITS FROM COOL-SEASON ANNUALS IN THE SOUTHEASTERN UNITED STATES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Plant,
Environmental & Soil Sciences

by
Dustin John Smith
B.A., Louisiana State University, 2009
December 2016

Acknowledgements

To thank everyone is to thank no one, and to thank no one is hubris. So in sincere gratitude to the many who have helped me along the way, I will humbly thank a few.

To my krewe d'universitaires, Paolo, Kaitlin, and Liz, whose unflagging lifelong commitment to scholarship inspired my current pursuit, I thank you.

To my major professor, Dr. Han, for taking a chance on me and providing many opportunities to grow, I thank you.

To my committee members, Dr. Pitman and Dr. Twidwell, for guidance and encouragement along the way, I think you.

To the krewe of room 242 for camaraderie and constant reminders that the rumen is half-full, I thank you.

To Dr. Tubaña for your dedication to exceptional teaching, and to your lab group for their support and compassion, I thank you.

To all the other bright, talented, hardworking, and caring students, instructors, and administrators of SPESS, for sharing your passion of learning with me, answering hundreds of my questions, and giving me endless more to ponder, I thank you.

And, to my beautiful wife, my love, my favorite, my boulder, for your strength, reassurance, and unfaltering belief in me, I thank you.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ADF – Acid-detergent fiber

ADS – Acid-detergent solubles

AR – Annual ryegrass

CC – Crimson clover

CP – Crude protein

DM – Dry Matter

DDM – Digestible dry matter

DMI – Dry matter intake

HV – Hairy vetch

IVTD – *In vitro* true digestibility

IVTDDM - *In vitro* true digestible dry matter

NDF – Neutral-detergent fiber

NDS – Neutral-detergent solubles

Rd – Radish

TDN – Total digestible nutrients

Tr – Triticale

Abstract

Cow-calf operations in the southeastern United States (U.S.) are based on warm-season perennial grass pastures. Stored forage feeding during the non-grazing season constitutes more than half of a cattle operation's annual expenses. Cool-season annuals can extend the grazing season, thereby reducing stored forage feeding. A two-year field trial was conducted to determine the forage potential of a variety of crops commonly used as winter cover crops in the southeastern U.S. The ten cover crop treatments included seven monocultures (annual ryegrass [*Lolium multiflorum*], rye [*Secale cereal*], oats [*Avena sativa*], triticale [*Triticale hexaploide*], tillage radish [*Raphanus sativus*], hairy vetch [*Vicia villosa*], crimson clover [*Trifolium incarnatum*]) and three mixtures. Harvests were made in late winter and early spring of each year. Spring harvest yielded more than twice as much dry matter (DM) as winter harvest across all treatments. Total dry matter yield per treatment ranged from 2,066 to 3,732 kg ha^{-1}. Neutral and acid detergent fiber concentrations increased about 10% from winter to spring. Crude protein decreased about 8% between harvests, however, overall crude protein concentrations were high enough to meet the nutrient requirements of lactating cows and growing calves, ranging from 17 to 25% in winter, and 11 to 22% in spring. All treatments proved to be highly digestible according to *in vitro* true digestibility analysis, ranging from 72-90% digestibility. High nutritive value across all treatments indicates feasible usage as winter forages and potential reduction of cattle production cost. Multispecies forage mixtures produced yields similar to monocultures with less risk from environmental impact and potential for a more evenly distributed yield.

Introduction

The majority (nearly 80%) of beef production in the southeastern U.S. comes from pasture based cow-calf operations (McBride and Mathews, 2011). These operations are mostly (78%) small-scale and run as part-time supplements to other enterprises, or as a retirement lifestyle (Short, 2001). The United States Department of Agriculture (USDA) considers a cow-calf operation with fewer than 100 head to be a small-scale operation (USDA-APHIS, 2011). These small-scale farms comprise about 90% of all beef cattle operations in the U.S. (NASS, 2012). This puts Louisiana right on par with the rest of the nation, having 11,237 of 12,355 farms under 100 head (Sheffield et al., 2012). Small-scale cow-calf operations are often associated with field/row crop production, and therefore can potentially benefit from grazing cover crops planted in rotation with the main cash crops.

Benefits of Cover Crops

Encouraging field/row crop producers to incorporate cover crops has been a goal of the Natural Resources Conservation Service (NRCS) since the 1930's (then, the Soil Conservation Service or SCS). The initial use of cover crops was to prevent erosion of the nation's croplands, but over the years new research has revealed many additional benefits of cover cropping such as increasing soil organic matter, providing nitrogen fixed by rhizobial nodulation on legume roots, scavenging leachable nutrients, suppressing weeds, reducing soil compaction, promoting a healthy soil microbial ecology, offering habitat for wildlife and other beneficial organisms, conserving water, and providing forage for livestock (Havlin et al. 2014; Cherr et al. 2006; Dabney et al., 2001; Heath et al., 1985). Even with all these environmental benefits that come with cover cropping, economics is still the major concern for producers (Snapp et al., 2005).

Economics of Winter Feeding

For the beef cattle owner, feed cost is the largest operating expense, with winter hay feeding constituting the largest portion of that expense. On average, feed cost is around 63% of a producer's operating budget (Miller et al., 2001). Therefore, reducing this cost is perhaps the most potent strategy to raise overall profitability. The most practical method to reduce winter feeding is to allow cattle to graze for as long as possible. The main drawback of this strategy is the time management involved, but if a producer operates a management-intensive operation within a suitable climate zone, studies show that extending the grazing season can be advantageous to their bottom line. Utley and McCormick (1978) demonstrated a boost in cow-calf profitability in Georgia by reducing conventional hay feeding with a system of overseeding annual ryegrass onto bermudagrass (*Cynodon dactylon*) pastures. Bagley et al. (1984) credited the growing popularity of using cool-season annuals for beef cattle grazing to highly nutritional quality and high potential daily gains, and found, in Louisiana, that fattening calves by winter grazing annuals, such as rye and ryegrass/clover mixtures, to be an economically sound alternative to selling calves at weaning. In 1990, Coombs et al. had similar results, showing the possibility of economically finishing cattle on forages during certain times of the year, especially those slaughtered in March through May that were fattened on cool-season annuals.

Grazing vs. Hay Feeding

In almost all cases, grazing is superior to stored food, not only economically speaking, but also nutritionally and environmentally (Ball et al., 2008). Mechanically harvested hay is wasteful, especially in relation to a cow's innate ability to harvest forage on its own with negligible nutritive or yield losses. Hay yield loss starts at cutting with leaf shatter (2%), and successive losses with raking (5%), curing (4-5%), and baling (4-6%), meaning even in fast

drying, rain free harvesting conditions there can be up to an 18% hay loss (Rotz and Muck, 1994). Hay quality loss, in terms of total digestible nutrients (TDN), also occurs during these processes: cutting (0-1.4%), raking (0.6-1.2%), curing (1.5-1.8%), and baling (1-4%), again, meaning even in ideal harvesting conditions there can be more than an 8% loss in TDN (Rotz and Muck, 1994). Leaching of nutrients from hay continues during the curing process and while the hay is stored (Perry, 1980). Proper storage of hay requires laborious transportation and expensive sheltered facilities. Hay is lost during the transportation to feeding sites, and during feeding from trampling, refusal, and spillage. Moreover, feeding hay creates a centralized location for cattle to congregate which can result in ruts, soil compaction, and a concentration of manure around the feeding area (Flores and Tracy, 2012). Up to 60% of the hay fed can be wasted instead of consumed (Sheffield et al., 2012).

In contrast to hay feeding, grazing allows cattle to benefit from the full nutritional value of forages while bearing all the transportation work for the producer, eliminates the need for large storage facilities, and more evenly distributes manure over the entire pasture (White et al., 2001). Harvested hay represents nutrients permanently removed from the soil system of a field, whereas grazing promotes nutrient cycling and a redistribution of most ingested nutrients except those which the plants obtain from the atmosphere, i.e. carbon, hydrogen, and oxygen (Haynes and Williams, 1993). Even with all shortcomings considered, hay is still the typical feedstock utilized during winter because of its wide availability and convenient employment.

Year-round Grazing

In suitable climates, where extending the grazing season is a viable option, planting cool-season annuals to reduce hay feeding has been a proven method used in the U.S. since at least as early as the 1900's (Bagley et al., 1984). In Louisiana, cow-calf operations are based on

bermudagrass or bahiagrass (*Paspalum notatum*) permanent pastures. Both species are warm-season perennial grasses that produce the majority of their biomass during early summer months. They quickly lose forage quality with the heat and drought stresses of late summer and autumn, and are dormant from approximately November to April (Henderson and Robinson, 1982). This leaves a 5 to 6-month period for cool-season growth or hay feeding in the southeast (Hoveland, 1992). With Louisiana's mild winters, it is possible to have nearly year-round grazing, if proper management practices are implemented.

Over the past 60 years, numerous studies have been performed to optimize year-round grazing practices for cow-calf operations in the southern U.S., prompted mostly by improvements made to the seed drill (Dudley and Wise, 1953). In 1978, Hoveland et al. prolonged the grazing season for 3 extra months and nearly doubled calf gain per ha by overseeding bermudagrass pastures with rye and clovers in Alabama. In another study, Hill et al. (1985) reduced hay consumption (21% on bahiagrass pastures and 28% on bermudagrass pastures) by pasturing calves on sod-seeded annual ryegrass in Georgia. This reduction, coupled with higher stocking rates, offset the extra seed and fertilizer expenses. In Florida, an eight-year cow-calf study on bahiagrass pastures showed that sod-seeding rye or wheat (*Triticum aestivum*) with crimson clover and arrowleaf clover (*Trifolium vesiculosum*) decreased hay consumption by 30%, increased calf weaning weight, and increased cow weight (DeRouen et al., 1991). Gunter et al. (2002) conducted a limit-grazing study in Arkansas using sod-seeded wheat, rye, and annual ryegrass mixtures to successfully reduce hay consumption by 12-14%. In Louisiana, Scaglia et al. (2014) were able to forage-finish steers on a bermudagrass and annual ryegrass system with only 55 days of hay feeding while maintaining an annual average daily gain of 0.67 kg and garnering over $700 per steer return on expenses.

While sod-seeded cool-season annuals have had favorable outcomes and have proven to be economically viable, there are still some concerns as to establishment success and timing. Han et al. (2012) found there to be a general unreliability with sod-seeding clovers in Louisiana bermudagrass pastures; although when established successfully, crimson clover increased subsequent bermudagrass dry matter yield to the level of plots fertilized with 112 and 225 kg ha^{-1} nitrogen. Other studies have shown similar results of varying establishment success (Bertrand and Dunavin, 1973; Burris et al., 1979; Faé et al., 2009). Establishment timing is important when trying to extend the grazing season, as is the concern of sod-seeded cool-season annuals inhibiting the growth of the perennial warm-season crops if left on the field.

Conventional tillage methods can lead to earlier establishment, thereby earlier grazing than sod-seeding, which is crucial to successfully reducing hay feeding (Coffey et al., 2002). With conventional seedbed preparation, there is also the potential to maximize forage biomass accumulation, as well as forage nutritive quality. Therefore, while costlier, planting cool-season annuals in prepared seedbeds may be justified, especially on croplands where growing animals could benefit most from grazing highly nutritious forages (Ball et al, 2015). A Louisiana study (Bagley et al., 1987) showed the effectiveness of incorporating a portion of cultivated land (17%) with warm- and cool-season annuals to increase net returns of a cow-calf operation. A Georgia study (Utley et al., 1976) found that cool-season annuals planted in prepared seedbeds offered twice as many grazing days per ha as did sod-seeded pastures. Bagley et al. (1990) reported that, while cool-season annuals planted on prepared seedbeds in Louisiana had the highest costs (per ha grazing days) when compared with sod-seeded annuals and perennial pastures, these higher costs were offset by the higher quality forage resulting in greater daily gains (at least 0.9 kg d^{-1}).

Animal Performance

Reducing winter hay feeding can only be effective if animal performance is maintained or improved when using the supplement. Therefore, most studies of extending the grazing season have been systems trials in which direct measurements of animal performance were taken, i.e. daily gain, weaning rate, calving interval, etc. from herds fed different feedstock and/or under different grazing management. For example, Bertrand and Dunavin (1973) conducted a study in Florida, comparing sod-seeded small grain monocultures (wheat, oats, triticale, and rye), ryegrass, and clover mixtures on beef calf daily weight gain. They found that even though forage biomass production varied from year to year, calf daily gain was nearly 1 kg across all treatments. When good stands of cool-season annuals are established, body weight gains of calves grazing cool-season annuals can well exceed those fed hay. Even in a year of poor crop growth, grazing calves can still gain an equal amount of body weight as those fed hay (Coffey et al., 2002). It is, however, necessary to use appropriate forages for a region, as Allen et al. (2000) demonstrated the importance of site-specific optimization in grazing systems. The tested system in Virginia showed that rye did not yield the winter feed requirements, while other studies (Bertrand and Dunavin, 1973; Bagley et al., 1984; Edmisten et al., 1998) demonstrated rye's ability to provide sufficient winter forage to supplement hay feeding.

Animal performance can be influenced by weather conditions affecting the growth of certain forage species (Allen et al., 1992), and just as forage stands vary from year to year, the complexities with animal trials are compounded by the necessity to adjust for grazing intensity, stocking rate, cattle breed, etc. (Blaser et al., 1986). A cow-calf systems study in Louisiana demonstrated the inability of 0.4 ha of land to maintain a cow-calf unit year-round (Coombs et al., 1983). In this study, bermudagrass pastures were sod-seeded with clovers, ryegrass, or a

mixture of the two. None of the systems proved to be profitable. Bransby (1989) demonstrated that the dynamics of grazing intensity can drastically affect the results of a grazing trial.

Nutrient requirements of beef cattle are affected by many factors, including age, season, and environmental stresses. The most physically demanding period for beef cows is during lactation, when nutrient requirements can be more than 20% higher than for non-lactating cows (NRC, 2000). To maximize efficiency and profits, a cow-calf enterprise should schedule a calving season rather than have year-round calving (Gadberry et al., 2016). A herd that is on an autumn calving schedule can potentially benefit from reduced environmental stresses and the nutritive boost from grazing cool-season annuals which may also impact future productivity (Moore et al., 2009). The goal of any forage program should be to align the energy and nutrient requirements of the herd with the quality of usable forages. This means, not only knowing the nutritional demands of cattle, but also being able to predict the nutritive value of forages that will become available.

Forage Nutritive Value

Evaluation of forage nutritive value pertains to the relationship between laboratory analyses of forage composition and their estimations of animal performance based on known correlations (Allen et al., 2011). Animal performance is the definitive valuation of a forage, however, feeding trials are often laborious, time consuming, and costly. Thus, more practical procedures are used to determine forage composition so that animal performance can be predicted (Perry, 1984). These procedures involve gravimetrically quantitative, wet-chemistry analyses designed to estimate digestibility, potential animal intake, and metabolizable energy of a forage as related to the composite makeup of the plant cells (Van Soest, 1994).

Cells of forage biomass can be divided into two general parts: cellular contents and cell walls. Cell contents, consisting mostly of lipids, protein, soluble carbohydrates, and organic acids, are generally available to ruminant animals (Perry, 1980). Cell walls, on the other hand, are composed mostly of partially/non-digestible structural carbohydrates: cellulose, hemicellulose, and lignin (Ball et al., 2001). Cellulose, the most abundant carbohydrate, is the primary component of cell walls that can be hydrolyzed by ruminants for energy (Van Soest, 1994). Hemicellulose is a polysaccharide that binds to cellulose within the primary cell wall (Gibson, 2012), and is nearly 50% digestible by ruminants (Hespell, 1988). Lignin is an indigestible structural substance with no nutritive value. The ratio of cell wall components is a major contributing factor to forage nutritive value, as they constitute the portion of fermentable carbohydrates that are necessary to maintain a healthy rumen (Perry et al., 1999). These proportions are highly variable, depending on plant species and plant maturity (Van Soest, 1967).

Many factors contribute to varying forage quality, including species, phenotypic traits, soil fertility, and environmental conditions; however, the generalized hierarchy of forage quality is: young > mature, fresh > stored, annual > perennial, cool-season > warm-season, legumes > grasses, and leaf > stem (Ball et al, 2015). The most important factor influencing the forage quality of a species is the maturity of the plant, meaning the developmental growth stage, not necessarily the age of the plant nor the date of harvest. The general developmental stages of plants include vegetative, boot, flowering, and seed production (Van Soest, 1994). Plants are at their peak digestibility during the vegetative stage when meristematic plant cells are flush with highly digestible soluble carbohydrates (Edmisten et al., 1998). Then, as the plant matures past the boot stage, forage quality decreases. Holloway et al. (1979) showed that both, dams and their weaning calves, gained 18 kg more bodyweight (at 240-day weaning) when grazing younger,

higher quality pastures (tall fescue [*Festuca arundinacea*]-legume) than those on more mature, lower quality pastures. The difference between the pastures in this study was that one was clipped regularly to maintain a vegetative state while the other was allowed to mature.

The time it takes for a plant to mature can be influenced by many factors, including species, cultivar, harvest dates, and environment (Helsel and Thomas, 1987). As the plant matures it accumulates biomass, therefore a tradeoff between a smaller amount of young, higher quality biomass, and a greater amount of mature, lower quality biomass should be accounted for in any grazing program (Blaser et al., 1986). Careful management practices are necessary to maximize pasture use efficiency by balancing forage yield and forage quality.

As plants mature, there are multiple causes for decreasing digestibility, but is mostly affected by the chemical composition of the cell wall. Development of secondary cell walls contributes to rumen microbial degradation resistance. Cell walls are composed of structural carbohydrates that are necessary to lend rigidity and protection to the growing plant (Taiz et al., 2015). This process involves the lignification of both primary and secondary cell walls. Lignin is both an almost completely indigestible substance, and also a hindrance to the microbial degradation of cellulose, hemicellulose, and other polysaccharides to which it is attached (Moore and Jung, 2001). Consequently, an increase in plant lignin necessarily results in a decrease in total ruminant digestibility. Also, no amount of lignin is shown to contribute to ruminant products such as milk or meat (Minson, 1990). The steady decrease in plant digestibility corresponds with the plant's leaf to stem ratio decreasing as it reaches higher levels of maturity. Stems, generally but not always, contain a greater concentration of lignin-filled xylem tissue than leaves, making them more resistant to chemical breakdown (Jung, 2012). Also, ruminants have more difficulty chewing stems, resulting in larger fragments that are more difficult to physically

break down (Minson, 1990). Then, with the onset of seed development, sugars and starches are translocated to, and concentrated in the seed heads, further reducing the overall digestibility of the plant's leaves and stems (Taiz et al., 2015).

Forage Nutritive Value Analysis

Because of the intricacies of plant cellular structure, multiple chemical analyses are necessary to determine the constitution of a forage, and thereby obtain a somewhat standardized prediction of animal performance (Van Soest, 1967). The first step in chemical analysis is the neutral-detergent fiber (NDF) procedure which uses a boiling neutral-detergent solution (pH=7) and a heat stable α-amylase rinse to solubilize cell contents (Robertson and Van Soest, 1981). The soluble cellular contents, or neutral detergent solubles (NDS), are stripped from the cell, and the remainder constitutes the approximate non-readily available cell wall portion that relies on the symbiotic microbial fermentation within the rumen before it can be digested by the animal (Goering and Van Soest, 1970). This fibrous mass accumulates in the rumen causing the animal to feel physically full, resulting in lower dry matter intake (DMI). Thus, because NDF is negatively correlated with dry matter digestibility, it has a strong correlation with DMI (Lalman, 2004). A higher NDF concentration results in a smaller proportion of nutritious cell content and larger proportion of partially/non-digestible fiber; therefore, as NDF increases, digestibility decreases, digestion slows, passage through the animal slows, and DMI decreases (Rohweder et al., 1978). Dry matter intake is one of the most important indicators of potential animal performance, because the amount an animal eats is highly correlated to body weight gain, and ultimately is the primary limiting factor of ruminant production (Lippke, 1980). However, NDF is only an estimation of intake because of factors such as forage palatability and animal preference that vary across species (Abrams et al., 1987; Van Soest, 1994).

Acid-detergent fiber (ADF), typically used to estimate the digestible energy of a forage, is determined by boiling a forage sample in a 1.0 normality sulfuric acid-detergent solution (Van Soest, 1963). In addition to removing cell contents, the acid-detergent solution also dislodges hemicellulose from the cell walls. In all, the soluble portion is known as acid detergent solubles (ADS). The remaining portion represents the mostly non-digestible lignified cell wall material, while the ADS portion represents the readily available energy sources (Goering and Van Soest, 1970). As the proportion of ADF increases, ruminants are less able to utilize the nutrients contained in the forage. Hemicellulose content can be calculated by subtracting the ADF value from NDF. However, this calculation is only an estimation due to some lignin and cell wall protein losses during the NDF procedure (Jung, 2012), and incomplete hemicellulose removal and some lignin loss during the ADF procedure (Van Soest and McQueen, 1973). Acid detergent fiber has a high correlation with digestible dry matter (DDM) and is therefore used as a satisfactory estimation of the energy value of a forage, even without a foundation in cellular biology or rumen chemistry (Van Soest, 1991).

Because of lignin's near total indigestibility, it is regarded as an anti-quality component, and is a limiting factor of forage digestibility (Moore and Jung, 2001). Lignin content can be determined by washing the acid-detergent insoluble fiber, mostly cellulose, lignin, and ash left from the ADF procedure, in 72% sulfuric acid (Goering and Van Soest, 1970). Cellulose is removed, leaving only lignin and acid-insoluble ash to remain. While too much lignified fiber makes forages unpalatable and difficult to digest, some amount is necessary for both healthy plants and healthy rumination. If a particular forage has a low fiber concentration and a high soluble nutrient concentration, it will quickly pass through the digestive tract, limiting microbial fermentation and fiber degradation in the rumen that is dependent on energy from cellulosic

digestion (Van Soest, 1994). Ruminants feeding heavily on low fiber forages, i.e. grains or pure legume stands, may develop acidosis from the disruption of the normal rumen pH of 6.0-6.7 (Heath et al., 1985). Thus forage quality ultimately relies on a balance between palatability, digestibility, and available energy (Raymond, 1969).

Wet chemistry analyses use uniform specimen and standardized procedures to provide a cellular constituent breakdown of forage samples. While this allows for useful inter-forage observations, chemical analyses of forages are limited by the exclusion of animal physiology from their evaluations. In an attempt to account for rumen biology, the *in vitro* true digestibility (IVTD) procedure involves the fermentation of forage samples within a replicated rumen environment (Tilley and Terry, 1963). The IVTD procedure is an alternative to apparent digestion tests that involve measuring fecal output against animal intake. Both are predictors of *in vivo* digestibility, however IVTD is corrected for endogenous losses such as mucins, epithelial cells, and digestive enzymes (Van Soest et al., 1966). Although the IVTD method is rapid and relatively reproducible, the output is restricted to a singular value representative of digestibility, thus lacking information on factors limiting digestion and degradation kinetics which influence the digestive efficiency of the ruminant (Mould, 2003).

Aside from digestible energy, the next most important nutritional quality of a forage is its protein content. Protein is used by ruminants for growth, tissue development, and maintenance, as well as needed by rumen microorganisms to maintain efficient fiber degradation (Perry et al., 1999). Protein is usually the main limiting nutrient for growing or lactating ruminants, requiring between 7 and 12% of their DDM consumption to be protein (Ball et al., 2015). When protein constitutes less than 7% of total digestible nutrients in a forage there is drop in voluntary intake (Moore et al., 1999a). This is a result of the rumen microbes’ need to acquire nitrogen from

ingested protein, and when their requirement is not met there is an overall suppression of the ruminal digestion system (Coleman and Moore, 2003). Concentration of protein within forages is affected by species, climate, and management factors comparable to digestibility. The generalized hierarchy for forage protein content is: legumes > grasses, temperate grasses > tropical grasses, leaves > stems, young > mature (Minson, 1990). Maturity is the most influential factor determining protein concentration of a forage species. After boot stage, protein content quickly begins to drop, along with NDS, ADS, and IVTD (Edmisten et al., 1998). Bermudagrass and bahiagrass pastures can sufficiently fulfill summer protein demand when actively growing and kept at the vegetative stage, however, hay produced from these grasses is usually harvested at a more mature stage and is typically of too low quality to provide sufficient protein during winter feeding (Moore et al., 1999b). Cool-season annuals, on the other hand, generally exceed the nutrient requirements of livestock, and therefore can better match forage nutritive value to animal needs (Evers, 2008).

Cover Crops and Forages

A cover crop is essentially any plant growth that is not harvested as a cash crop, nor considered to be a weed (SARE, 2010). A forage is any plant growth used to feed an animal via grazing or harvesting (Allen et al., 2011). The two naturally coincide as all forages serve as ground cover, and most cover crop species planted in rotation with cash crops make nutritious feedstock for animals (Heath et al., 1985). The goal of cover crops, to maintain constant ground cover, may share the goal of forage producers, to have continuous forage production throughout the year. Incorporating winter crops traditionally used as cover crops into a grazing program helps to minimize the forage deficit periods in the southeastern U.S. from early autumn to late spring (Ball et al., 2015).

In the southern U.S., specifically zone A as distinguished by Ball et al. (2015), cool-season annuals are planted due to the lack of persistence of cool-season perennials such as tall fescue and alfalfa (*Medicago sativa*). The typical cover crops planted in autumn are annual ryegrass, small grains, clovers, hairy vetch, and brassicas. Cool-season annuals can be seeded as early as September 1st, depending on species and seedbed preparation (Twidwell et al., 2015), but sporadic autumn rains can delay planting until after October when the threat of drought has passed. Seeding into cultivated land can typically be done earlier than overseeding into sod due to the lack of competition with the previous crop's residue (Ball et al., 2015). Most species establish root growth in autumn and produce only a small amount of biomass during the short winter, but some may provide enough growth for grazing in November and December (Bertrand and Dunavin, 1973; Coombs et al., 1990). Depending on temperature and precipitation, rapid growth can occur in late winter or early spring when the bulk of biomass is produced. Small grains and brassicas will senesce with the lengthening days of early spring, while clovers, vetch, and ryegrass may continue to grow until the end of spring.

Many of the soils across the Southeast are highly weathered and contain a relatively low percentage of organic matter, creating a susceptibility to erosion (SARE, 2010). Winter cover crops can alleviate this susceptibility by adding organic matter from the decomposition of plant biomass, and establishing ground cover to protect against sediment loss from wind and water (Havlin et al. 2014). Louisiana's particularly wet winters create conditions for nitrate leaching on fallow fields. Winter cover crops can capture some of the residual fertilizer nitrogen from the summer cash crop, and having growing plants on the field also reduces the amount of water that will permeate passed the root zone, thus further reducing nutrient loss. The breakdown of above and below ground cover crop biomass improves soil tilth, increases organic matter, and supports

soil biological activity. However, if left on the field, plant residue may interfere with subsequent crop growth due to nitrogen immobilization if the cover crop has a high carbon to nitrogen ratio (SARE, 2010), or physically impede growth if a thick thatch is present (Bollera and Bulluck, 1994). This is less of a concern when cattle are used to remove the plant biomass from the field, leaving behind manure which is more readily converted to plant available nutrients (Havlin et al. 2014).

Annuals complete their life cycle in one growing season, limiting the amount of energy the plant spends developing secondary cell walls, which are less digestible. Cool-season plants are C_3 plants which thrive in cool, moist conditions. The cell walls of C_3 plants tend to be thin, and their cellular structure tends to make them more readily digestible for ruminants than the thick-walled bundle sheath cells of C_4 plants (Sage and Monson, 1990). Both, their short life cycle and cellular arrangement, contribute to the high digestibility of cool-season annual herbage.

When used for forage in the south, cool-season annuals can be harvested for silage or high quality hay production, but are most often used for pasture grazing due to unfavorable weather conditions for forage preservation. Because of the high forage quality of cool-season annuals, creep-grazing, or limit-grazing for a few hours per day is recommended for maximum pasture use efficiency (Blaser et al., 1986), and to prevent animal health disorders such as bloat or rumen acidosis which can result from a low fiber diet (Perry, 1980). Cows that fatten too much from unrestricted access to high quality forage may also experience lower calving and breeding performance (Beck et al., 2013).

Annual Ryegrass

Annual ryegrass (AR), also known as Italian ryegrass, is the most common winter pasture crop grown in the lower South where cool-season perennials do not persist (Ball et al., 2015). It is a fast-growing, upright, non-spreading bunch grass with dark, smooth leaves, growing to 30 cm or taller. Annual ryegrass can be established by broadcast seeding or drill seeding, and if planted early enough on a prepared seedbed has potential for fall grazing, producing copious amounts of palatable DM, 2,200-13,500 kg ha^{-1} yr^{-1} (SARE, 2010; Twidwell et al., 2015). If not grazed too heavily (below 7.5 cm), AR regrows well and can be harvested multiple times throughout the season. Cattle grazing on AR benefit from its high protein content (over 20% of dry matter), and can achieve average daily gains of nearly 1 kg (Ball et al., 2001).

Annual ryegrass can tolerate moderate to low soil fertility, and can grow in a wide range of edaphic conditions. Not only does it perform well in wet conditions, but AR also produces dense clusters of fibrous roots which lend strength to soil structure, reducing erosion from high rainfall and preventing rutting and compaction from livestock. These roots excel at nutrient scavenging, particularly nitrogen, because of their high moisture usage, which mitigates leaching (Shipley et al., 1992).

Annual ryegrass is often planted as part of a mixture, either with small grains or legumes. Because of AR’s early and vigorous growth, it serves well as a weed suppressor, but can also be detrimental to the establishment of a companion crop. Therefore, the proportion of AR in the seed mixture should be reduced to ensure good stands of both crops.

Seed cost is relatively low at less than $1 per 0.5 kg and, after all costs are considered, can be established for between $27 and $46 per ha (Fae et al., 2009; Beck et al., 2008). Depending on planting method and whether or not it is part of a mixture, the recommended

seeding rate for AR rate is between 22 and 34 kg ha^{-1} (Twidwell et al., 2015). Higher seeding rates can increase early season biomass yields, but may not necessarily be beneficial to a cow-calf operation on a spring calving schedule (Venuto et al., 2004).

Reliability, biomass production, animal performance, and cost combine to make AR the standard winter forage of the lower South (Heath et al., 1985), however, AR has a potent reseeding ability, which is beneficial in dedicated pasture situations, but can cause weediness in field/row crops. For all its many strengths, unwanted AR can inhibit the growth of a cash crop, therefore may not be the ideal choice for rotations on non-dedicated pasture fields.

Small Grains

The small grains used in this study were oats, rye, and triticale. All three are fast-growing, high biomass producing bunch grasses that can grow over 1 m tall. Small grains can be sod-seeded over perennial pastures or broadcast seeded on cultivated land, although drill seeding is recommended for faster germination to reduce root rot in moist soils (SARE, 2010). Seeding usually occurs in September or October, and due to their fast rate of germination and height, small grains act well as weed suppressors. The deep growing, fibrous roots of small grains are generally good at scavenging leachable nutrients and preventing topsoil erosion. As a forage, small grains can provide abundant feedstock to grazing animals during the winter, leading to over 1 kg average daily gains (Daniels et al., 2004). However, small grains are quick to mature in the spring, which significantly lowers forage quality during late spring grazing. Legumes are often planted with small grains to help extend their grazing period and improve nutritive value (Ball et al., 2015).

For non-forage cover crop purposes, rye is the most commonly used small grain in the U.S. Of all the small grains, rye is the hardiest, the tallest, and the fastest growing. Rye can be

relatively inexpensive to establish with seed cost of $5-8 per ha (Kaiser, 2014), and a recommended seeding rate of 56-100 kg ha^{-1} (Twidwell et al., 2015). After all costs, including seed, fertilizer, seedbed preparation, etc., are considered, rye can be planted for about $46 per ha (Beck et al., 2008). Rye tolerates low soil fertility and can grow in a wide range of edaphic conditions, producing between 3,400-11,000 kg ha^{-1} yr^{-1} DM. Moreover, rye is more cold tolerant and more drought tolerant than other small grains (SARE, 2010). This means that rye can be planted later in autumn than other small grains and still produce good stands. For these reasons, rye fits well into most crop rotations to work as a nutrient catch crop, weed suppressor, and/or erosion control, however, rye is quick to mature in spring, making it less palatable to grazing cattle. The lower palatability of rye is not necessarily a concern when grazing options are limited to only rye, and can be ameliorated with the incorporation of a legume companion plant.

In contrast to rye, oats are the least cold and drought tolerant of the small grains. Oats tend to perform better in warmer climates than rye, making them more suitable for warm, wet southern winters. Oats can be broadcast or drill seeded with recommended rates of 67-112 kg ha^{-1}, and in Louisiana can produce more than 9,000 kg ha^{-1} yr^{-1} DM (Twidwell et al., 2015). The seed cost of planting oats is between $10-13 per ha (SARE, 2010). As a forage, oats are typically more palatable than rye, and some breeding work is being conducted to further improve palatability of forage-types, as well as grazing tolerance (Kim et al., 2014). Oats can provide high quality forage, rich in protein and energy, from late fall through spring (Mackowiak et al., 2011). Oats have potential to be dual purposed as a grazed crop in autumn and winter, and as a grain crop with spring regrowth under proper management practices.

Triticale, a hybrid of rye and wheat, is mostly grown for forage purposes in the U.S., either for hay, silage, or grazing. Triticale tends to have more of the hardiness of rye combined

with the higher palatability of wheat. While DM yield is less than rye or wheat, between 3,000-7,000 kg ha^{-1} yr^{-1} (Redmon et al., 1998a; Vigil and Poss, 2016), triticale generally provides a longer grazing period because it is slower to mature than other small grains (Schwarte et al., 2005). Recommended seeding rates are 100-135 kg ha^{-1} (Blount et al., 2014), with seed costs of about $7 per ha (Miller et al., 2003). Because a pure stand of triticale typically does not provide sufficient biomass production for winter grazing, most work with triticale has been done with mixtures of other grasses or legumes to optimize biomass production and forage quality. Triticale combined with legumes decreases overall DM yield, but has a greater crude protein concentration (Karadag and Buyukburc, 2004). Annual ryegrass can be mixed with triticale as a companion plant to add forage quality without reducing yield (Drake and Orloff, 2002).

Annual Legumes

Annual legumes, unlike grasses, are broadleaf dicots with shallow tap root systems. While legumes serve to prevent soil erosion and suppress weeds through aboveground biomass production, they are not as efficient at nutrient scavenging as grasses or brassicas (Shipley et al., 1992). Their major contribution as a cover crop is their ability to biologically fix atmospheric nitrogen. Rhizobium bacteria live symbiotically within nodules on the root systems of legumes where the bacteria convert nitrogen gas into plant available ammonium (Havlin et al., 2014). This process can significantly reduce nitrogen fertilization requirements of subsequent crops (Hargrove, 1986) and can provide 50-70% of the required nitrogen to companion plants, depending on the legume species (Havlin et al., 2014). Proper inoculation of legume seeds with the appropriate rhizobia can help ensure maximum nitrogen fixation (Twidwell et al., 2015). While most legumes can tolerate many types of soil conditions, rhizobium nodulation can be inhibited by acidic soils (Havlin et al., 2014).

As a forage, legumes are highly nutritious and highly digestible. In the South, cool-season legumes will establish in autumn and overwinter well, but most biomass production occurs in spring. When grown as a companion plant, their late growth can complement grasses, particularly small grains, which are maturing in spring and losing forage quality. Grazing pure stands of legumes is not necessarily the best use of pasture, as there will be limited biomass production compared to grasses, and the low fiber concentration of some legumes can lead to bloat (Van Soest, 1994). Combining cool-season legumes with cool-season grasses can increase the protein and lower NDF of the overall mixture more than monoculture grasses fertilized with 76 kg ha^{-1} nitrogen (Han et al., 2013). It is possible that the legume, through competition with the grass, can reduce overall yield, however, the high concentration of protein in legumes will increase the overall protein content (Lithourgidis et al., 2006). The majority of legume nitrogen is located in the above ground plant portion, therefore grazing can reduce the amount of residual soil nitrogen available to subsequent crops (Decker et al., 1994; Caddel et al., 2012).

Crimson clover is an upright, rapidly growing legume with relatively early spring growth. Crimson clover is adapted to well-drained soils but can thrive on clay soils with moderate acidity and in a wide range of climatic conditions (Heath et al., 1985). As a residual nitrogen scavenger, crimson clover only recovers about 10% (Shipley et al., 1992), however, it can fix, on average, between 78-168 kg ha^{-1} atmospheric nitrogen (SARE, 2010). Crimson clover is a protein rich forage capable of accumulating between 4,000-6,000 kg ha^{-1} DM (SARE, 2010). Biomass can be harvested for hay, but also tolerates grazing, and will regrow well if not heavily grazed. Crimson clover will not typically reseed, so planting must be done each autumn at a rate of 13-34 kg ha^{-1}, costing between \$11-16 per ha (Twidwell et al. 2015; SARE, 2010). Seeding rates are dependent

on seedbed preparation, planting method, and whether planted as a monoculture or as part of a mixture. Crimson clover works well as a companion plant, typically with AR in the South.

Hairy vetch is a vining cool-season legume that is perhaps the most commonly used cool-season annual legume cover crop. Hairy vetch has very limited growth in autumn and winter, but produces vigorously sprawling biomass in the spring that can suppress spring weeds in subsequent crops and provide protein rich forage for ruminants. Hairy vetch is tolerant to a wide range of edaphic and climatic conditions, and has relatively low soil fertility requirements, but total biomass yields are less than other winter cover crops, averaging between 1,960-6,950 kg ha^{-1} yr^{-1} (Heath at al., 1985). Hairy vetch has a recommended seeding rate of 17-45 kg ha^{-1} at a cost of $14-26 per ha, and can fix an abundant amount of nitrogen, between 100-225 kg ha^{-1} (SARE, 2010). Hairy vetch has poor nutrient scavenging ability with its short taproot, recovering only about 11% residual nitrogen fertilizer (Shipley et al., 1992), but works well as a companion to deep rooted small grains. Hairy vetch can also complement the growth patterns of faster maturing small grains, adding a boost to late spring forage quality (Ranells and Wagger, 1997). Grazing should not begin until plants reach about 15 cm, and close grazing should be avoided to ensure regrowth (Hoveland and Webster, 1963). As with all legumes, hairy vetch accumulates most of its nitrogen in aboveground plant tissue (90%), therefore, removing biomass by grazing will lessen the amount of nitrogen contributed to the soil (Shipley et al., 1992). Even with the removal of top biomass, hairy vetch can still contribute 10-22 kg N ha^{-1} from root degradation (Kuo and Jellum, 2002).

Radish

Radish is a fast growing cool-season annual that produces tall, leafy top growth and a large, edible taproot. This large taproot has the ability to scavenge nutrients deep within the soil

profile that would otherwise be unavailable. In addition to nutrient capturing, the taproot can ameliorate soil compaction by penetrating hardpans and creating deep, porous channels when the root decays. Radishes can be established by broadcast seeding with 11-22 kg ha^{-1} at a seed cost of $9-13 per ha, and should typically be planted earlier than small grains (SARE, 2010). Radishes do not tolerate poorly drained soils and generally require nitrogen fertilization for a strong stand (Ball et al., 2015). Radishes produce high amounts of biomass, up to 9,000 kg ha^{-1}, that is palatable and highly nutritious. However, because of its high moisture content and low fiber, livestock should not graze radish exclusively as this may lead to health disorders such as bloat (Van Soest, 1994). Radishes can tolerate grazing and, if not grazed to the bulbous aboveground portion of the taproot, can have good regrowth (Ball et al., 2015).

Forage Mixtures

The primary benefit of planting multiple species on one pasture is to insure against crop failures due to climatic extremes (Soder er al., 2007). Mixtures increase the success of establishment with varying weather conditions, as different species will thrive in different conditions. Forage mixtures will also increase the nutrient use efficiency of a pasture, and while overall biomass production may not increase, forage yield distribution can expand the grazing season due to the varying maturation rates of different species. Competition between species for light and nutrients may contribute to an overall decline in total biomass yield, however, forage quality will generally be higher (Deak et al, 2007). The increase in forage quality is determinant on the species composition, not the complexity of the mixture, thereby making it necessary to select the right species at the right seeding rates to maximize forage production (Brink et al., 2015). Therefore, laboratory analyses of individual cool-season annuals can help determine the

forage potential of species mixtures, if not how competition between species will affect overall forage quality.

Objective

The goal of this study was to determine the forage potential of cool-season annual cover crops, based on dry matter yield and nutritive value, for the purpose of extending the grazing season of the southeastern U.S into winter and spring. This study examined ten cover crops at two harvests, one in late winter, then one in early spring to determine the regrowth potential of the cover crop treatments. Prepared seed beds were used under the assumption that cover crops would be planted on cultivated cash crop fields. The assumed method of harvest would be ruminant grazing for the first harvest, followed by a second grazing period or the potential use of the cover crop as a green manure for the subsequent cash crop.

Materials and Methods

A two-year field trial was conducted at the LSU AgCenter Ben Hur Research Station in Baton Rouge, LA. Winter cover crop treatments were planted on November 4, 2014, and December 9, 2015. Seven monoculture cover crops and three mixtures were planted in 1.8 m by 4.3 m end-trimmed prepared seedbeds. Plots were seeded with a 7-row plot drill set at 18 cm row spacing (Table 1 and Table 2). Each treatment plot alternated with a border plot of oats to reduce border effect (Peterson, 1994).

Table 1. Seeding rates of cool-season annual cover crop monocultures.

Cover Crop Species	Seeding Rate (kg ha^{-1})
Annual Ryegrass (*Lolium multiflorum*)	57.7
Oats (*Avena sativa*)	233.2
Rye (*Secale cereale*)	260.6
Triticale (*Triticum secale*)	261.2
Crimson Clover (*Trifolium incarnatum*)	71.7
Hairy Vetch (*Vicia villosa*)	142.9
Radish *(Raphanus sativus*)	22.4

Table 2. Seeding rates and ratios of cool-season annual cover crop mixtures.

Forage Mixture	Seeding Rate (kg ha^{-1})	Approx. Seed Ratio by Weight	Count
Radish, Annual Ryegrass, & Crimson Clover	62.8	7:36:7	1:21:3
Radish, Oats	132.3	1:9	11:39
Radish, Triticale, Crimson Clover	215.8	7:85:8	9:52:39

Soil type at the planting site was Cancienne silt loam. There were no soil fertility limiting factors based on LSU AgCenter Soil Testing Laboratory analysis. Soil pH was 6.16. First year treatments were fertilized with 18-52-67-11 kg N-P-K-S ha^{-1} on November 12, 2014, then top

dressed with 101 kg N ha^{-1} in mid-February. Second year treatments were pre-plant fertilized with 18-52-67-11 kg N-P-K-S ha^{-1}, then received 13.6 kg urea ha^{-1} (46-0-0, N-P-K) in early February, and then top dressed with 40.8 kg N ha^{-1} in late February.

Two harvests were made, one in late winter and one in early spring. The late winter harvest was made after all treatments had accumulated sufficient biomass and were all in a vegetative stage. The early spring harvest was made after all treatments had developed sufficient regrowth and were mostly beyond the vegetative stage. The first year harvests were made on February 16 and April 9, 2015. The second year harvests were made on March 7 and April 6, 2016. Harvests were made with a push lawnmower with a 76 cm cutting width and blades set 8 cm from the ground. An attached mulching bag was used to collect the herbage. A single center strip was collected from the entire length of each treatment plot. Therefore, the dimensions 76 cm by 4.27 m were used to estimate forage yield per ha (.76 m x 4.27 m = 3.25 m^2). The mulching bag was tared before each cut, then weighed after forage collection. A grab sample of the herbage was taken from the mulching bag, placed into a paper bag, weighed and dried. The grab samples were dried for three days at 55º C in a forced-air drying oven, then reweighed. The estimated DM yield per ha of each treatment was calculated as:

DM Yield Per ha = Fresh Weight x Percent DM x Plot-to-ha Conversion Factor,

where

Percentage Dry Matter = Dry Sample Weight / Wet Sample Weight,

and

Plot-to-ha Conversion Factor = 10,000 m^2 / 3.25 m^2 = 3,076.92.

Dried samples were ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm sieve, the size shown to be critical for legume and grass particle passage through

the rumen (Poppi et al., 1980). A 1-gram subsample was used to determine absolute dry matter by crucible drying in a 105º C oven for three hours.

Wet chemistry methods were used to determine nutritive quality. Acid detergent fiber and neutral detergent fiber contents were determined, non-sequentially, using an Ankom® 2000 automated fiber analyzer (Methods 12 and 13, respectively, ANKOM Technology Corp., Macedon, NY) based on standard methods set by Robertson and Van Soest (1981). Acid detergent lignin was analyzed by washing post-ADF sample bags with 72% H_2SO_4 for 3 hours, according to ANKOM method 8. Crude protein (CP) was determined by combustion method (Dumas, 1831) using LECO® FP-528 nitrogen determinator (Method 3942, LECO Corp, St. Joseph, MI). Because most proteins contain roughly 16% nitrogen, protein content was estimated by multiplying the total nitrogen times 6.25. This calculation assumes all nitrogen is incorporated into protein, i.e. not free amino acids, and includes all forms of protein (Minson, 1990).

In vitro true digestibility (IVTD) test was performed based on the Tilley and Terry (1963) method, modified with an additional third step (NDF) by Goering and Van Soest (1970). Rumen fluid was collected from a fistulated Holstein cow (*Bos taurus*) fed an alfalfa diet. Rumen fluid was kept warm during transportation in a sealed thermos. In the laboratory, rumen fluid was flushed with CO_2 to maintain an anaerobic environment. Samples and reagents were prepared according to ANKOM method 3, and the samples were incubated for 48 hours using the ANKOM DAISY^{II} incubator. After the incubation period, samples were sequentially run through the NDF procedure (ANKOM method 13) to remove any rumen-digestible residue, then weighed to determine IVTD DM disappearance. IVTD on a DM basis was calculated as:

IVTD (DM) = ((Final Bag Weight – (Bag Tare Weight x Bag Correction)) / Sample Weight,

where

Bag Correction = Final Blank Bag Weight / Original Blank Bag Weight.

The forage yield of each treatment was multiplied with its corresponding IVTD percentage to determine *in vitro* true digestible dry matter (IVTDDM) yield.

Statistical Analysis

The experimental design was a randomized complete block. Data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, 2004). Year was considered as a random effect because all treatments were annuals that were replanted each year in different plot locations. Replication within year was also treated as a random effect. Cover crop treatment and harvest date were treated as fixed effects.

Results and Discussion

Response variables were DM yield, NDF, ADF, ADL, CP, IVTD, and IVTDDM. Mean separations were deemed significant at $P < 0.05$ (Table 3).

Table 3. Significance of fixed effects from analysis of variance for dry matter (DM) yield, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP), *in vitro* true digestibility (IVTD), and *in vitro* true digestible dry matter (IVTDDM) by treatment and harvest.

	DM Yield (kg ha^{-1})	NDF ---	ADF ---	ADL g kg^{-1}	CP ---	IVTD ---	IVTDM (kg ha^{-1})
Treatment (T)	NS†	***	*	*	***	**	*
Harvest (H)	***	***	***	NS	***	***	***
T x H	NS	***	*	NS	***	***	NS

† NS, not significant; *, significant at $P < 0.05$; **, significant at $P < 0.01$; ***, significant at $P < 0.001$.

Dry Matter Yield

Each year, all plots were successfully established in autumn, overwintered, then brought to physiological maturity in spring. No observable insect, fungal, or viral damage was noticeable in either growing season. However, DM yield was confounded by unusual weather events occurring in south Louisiana during autumn of 2015 and spring of 2016.

The 2-year average early spring harvest yielded more than twice as much biomass (103%) than late winter harvest on average across all treatments (P<0.001). Yield distribution between late winter and early spring harvests varied among treatments with oats and radish/oats treatments being the most consistent, and crimson clover, triticale, and AR treatments being the least consistent (Table 4). Treatment x harvest interaction was not significant in forage production (P=0.4373).

Table 4. Cool-season annual cover crop dry matter yield (Mg ha^{-1}) per harvest, mean of 2 years.

Cover Crop	First Harvest†	Second Harvest†	Total
Annual Ryegrass	0.77	2.17	2.94
Rye	1.06	2.28	3.34
Oats	1.45	2.03	3.48
Triticale	0.86	2.43	3.30
Crimson Clover	0.52	1.54	2.07
Hairy Vetch	0.65	1.48	2.14
Radish	0.91	1.67	2.58
Radish/Oats	1.75	1.99	3.73
Radish/Annual Ryegrass/Crimson Clover	1.09	2.15	3.24
Radish/Triticale/Crimson Clover	0.83	2.32	3.15

SE=0.51

† Not significantly different (P=0.44).

No treatment effect was detected in forage production (*P*=0.0816). However, numerically, oats out yielded other small grains, oats/radish treatment out yielded other mixtures, and legume and radish monocultures produced the least amount of biomass. Hairy vetch did not reach anthesis by the time of the early spring harvest of 2016, and regrowth continued accumulating biomass for a potential third harvest in late May.

The range of DM yield on average per harvest was from 1031 kg ha^{-1} (crimson clover) to 1866 kg ha^{-1} (radish/oats). Although DM yield comparisons are difficult to make between studies as many factors contribute to varying forage production, including regional climate, soil characteristics, cultivar, planting dates, harvest, number of harvests, etc. (Heath et al, 1985), average annual DM yield for all treatments was lower than the production ranges of other cover crop studies (SARE, 2010). Twidwell et al. (2015) reported that AR produced more than 11 Mg ha^{-1} annual DM yield in Louisiana, which is 274% more biomass than produced by this study. Oats monoculture was particularly low compared to their potential annual production in

Louisiana of nearly 9 Mg ha^{-1} (Allen et al., 1978). Soil fertility was not the limiting factor for biomass production as all levels were within sufficiency ranges (based on LSU AgCenter soils laboratory analyses) and nitrogen fertilizer was applied in sufficient amounts (in accordance with LSU AgCenter recommended rates).

With year considered a random variable, weather variations between years influenced the variance of cover crop biomass in 2016 and resulted in a lack of detectable treatment mean difference. Unusually high rainfall in October and November of 2015 (more than twice the 30-year average) postponed planting by one month (Figure 1). Delayed establishment in 2016 had no noticeable impact on the forage yield of the late winter harvest when compared to 2015, however, high rainfall occurred again in March of 2016 (81% higher than the 30-year average), resulting in waterlogging of the heavy silt loam soil and a diminished early spring harvest (Figure 2). While this study did not aim to compare forage production between years, it is important to highlight the substantial differences. Across all treatments, biomass accumulation at early spring of 2016 was only 36% of that in 2015. Among the treatments, rye showed the greatest biomass decrease (81%). Some single-harvest forage studies show similar rye and crimson clover DM yield results due to unfavorable weather conditions in some years and favorable weather conditions in others (Mitchell and Teel, 1977; Ranells and Wagger, 1996). Fluctuating weather conditions in Maryland resulted in fewer significant treatment responses, showing unexpectedly similar average DM yields among hairy vetch (3.4 Mg ha^{-1}), crimson clover (3.7 Mg ha^{-1}), and wheat (3.4 Mg ha^{-1}) (Decker et al., 1994).

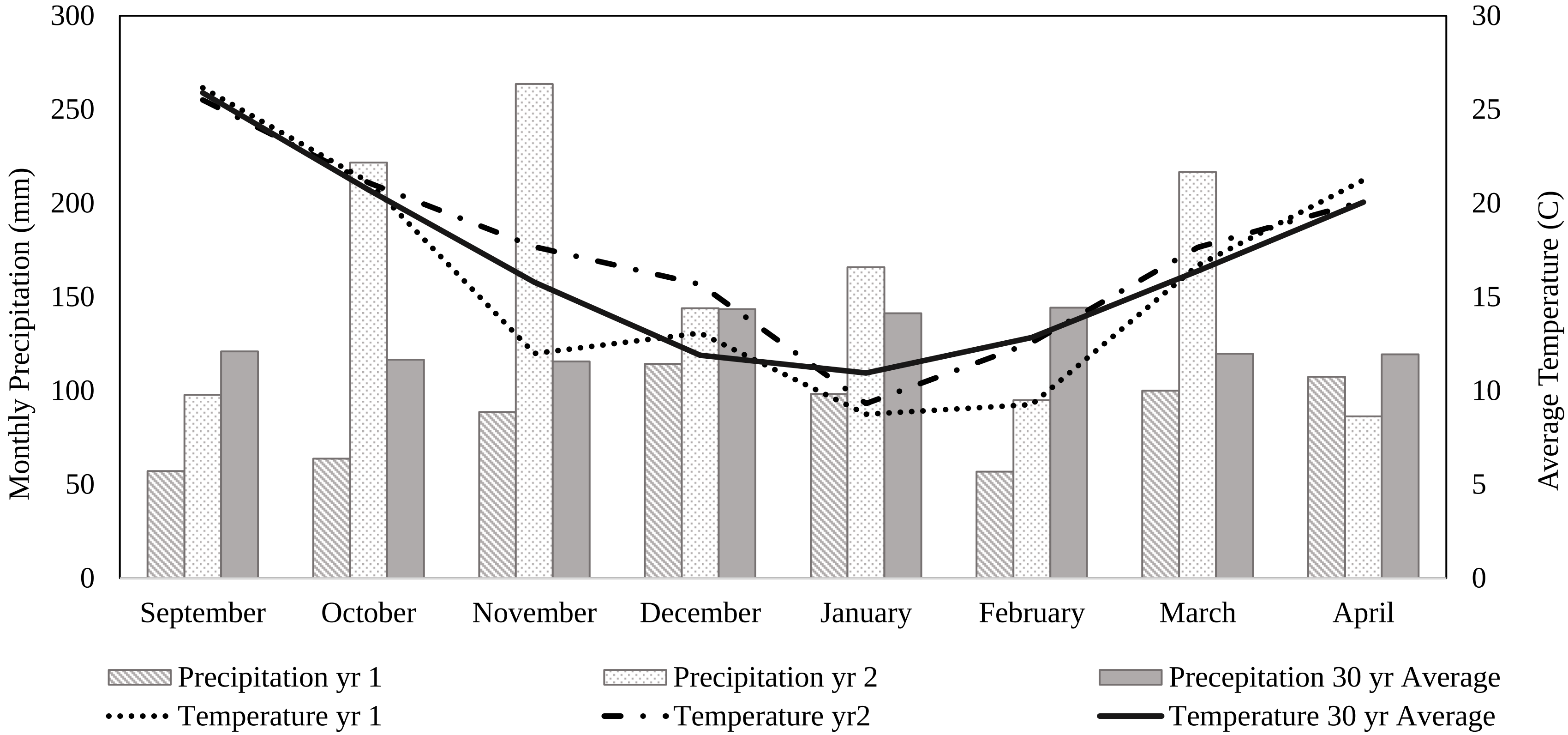
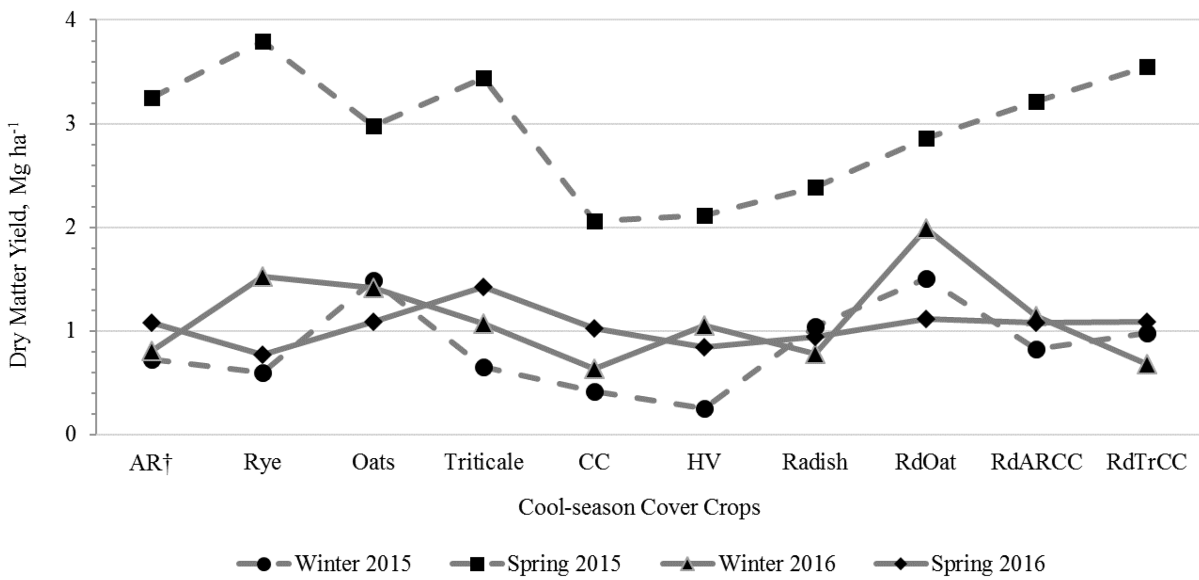


Figure 1. Weather data for Louisiana State University AgCenter Ben Hur Research Station in Baton Rouge, LA for 2015, 2016, and 30-year average.



† AR, annual ryegrass; CC, crimson clover; HV, hairy vetch; Rd, radish; Tr, triticale.

Figure 2. Dry matter yield of cool-season annual cover crops at winter and spring harvests of 2015 and 2016.

The extended period of saturated heavy silt loam soil during March of 2016 probably resulted in anaerobic soil conditions. These conditions are known to restrict root growth in grasses and legumes, which in turn reduce above ground biomass (Cannell et al., 1985; Gibbered et al., 2001). Legume rhizobial nodulation is also impeded by waterlogged soils which inhibits their atmospheric nitrogen fixation capacity (Pugh et al., 1995). The reduction in cover crop growth, especially legumes, allowed for an incursion of weeds, mostly annual bluegrass (*Poa annua*) (Figure 3). Both, reduced cover crop growth and increased weed competition, caused a large error term (SE=470), resulting in a lack of statistical power to detect treatment effects in dry matter yield (kg ha^{-1}).

Figure 3. Crimson clover monoculture plot with weed incursion. *Photo taken March 30, 2016.*

Neutral Detergent Fiber

Differences in NDF were highly significant among cover crop treatments (*P*<0.001). There was a highly significant treatment x harvest interaction in NDF (*P*<0.001). Neutral detergent fiber increased nearly 10% across all treatments between late winter harvest and early spring harvest (*P*<0.001). Crimson clover had the most consistent NDF, maintaining around 420 g kg^{-1} for both harvests. Triticale and radish/triticale/crimson clover treatments had the greatest increases in NDF between harvests at more than 18% each (Table 5). The lowest NDF concentration was detected at the late winter harvest of radish (332 g kg^{-1}), while the highest NDF concentration was found in triticale at the early spring harvest (582 g kg^{-1}).

Neutral detergent fiber represents the fibrous mass of a forage that requires rumen microbial digestion before passing through a ruminant, contributing to ruminal fill. A lower NDF facilitates faster passage of forage through the ruminant, thus increasing the animal’s ability to intake more forage (Van Soest, 1994). A lower NDF typically means a forage will be more

Table 5. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) as a percentage of dry matter of cool-season annual cover crops at winter and spring harvests, mean of 2 years.

	NDF		ADF		ADL‡	
Cover Crop	Winter	Spring	Winter	Spring	Winter	Spring
Annual Ryegrass	44.5^{ef†}	50.2^{cd}	31.5^{efg}	35.8^{bcd}	12.3	10.1
Rye	41.5^{fg}	52.0^{bcd}	26.2^{h}	35.4^{cde}	11.4	12.7
Oats	38.4^{gh}	49.8^{cd}	26.8^{h}	37.8^{bc}	6.6	12.6
Triticale	39.6^{gh}	58.2^{a}	27.7^{gh}	42.3^{a}	9.4	10.8
Crimson Clover	41.6^{fg}	42.7^{fg}	28.1^{gh}	33.3^{def}	10.8	12.6
Hairy Vetch	36.7^{hi}	39.3^{gh}	26.2^{h}	33.5^{def}	9.3	11.1
Radish	33.2^{i}	47.5^{de}	28.0^{gh}	39.8^{ab}	13.5	16.2
Radish/Oats	39.5^{gh}	52.3^{bc}	27.7^{gh}	38.3^{abc}	6.3	9.1
Radish/Annual Ryegrass/Crimson Clover	38.8^{gh}	48.0^{cde}	28.1^{gh}	35.4^{cde}	10.4	9.9
Radish/Triticale/Crimson Clover	37.1^{hi}	55.5^{ab}	29.6^{fgh}	38.4^{abc}	11.8	10.3
	SE=2.3		SE=1.6		SE=2.2	

† Values with different letters within NDF and ADF columns differ at $P<0.05$.
‡ Not significantly different (P=0.49).

palatable, ruminants will intake more of it, and weight gains will be higher (Lippke, 1980). All NDF concentrations in this study were within a range that would be considered relatively low, being below 600 g kg^{-1} where NDF begins to negatively affect forage DMI of ruminants (Van Soest and Wine, 1967). Therefore, these NDF levels indicate potentially high animal intake, although animal preference must also be accounted for.

On average, legume and radish monoculture treatments contained about 7% less NDF than the grass monocultures. Legumes and radishes typically contain less NDF than grasses, mostly due to differing amounts of fiber accumulation in the stems (Ball et al., 2015). A lower NDF means legumes contain more soluble cellular contents which results in their generally higher digestibility, however the NDF portion of grasses has been found to be more digestible than that of legumes (Buxton and Redfearn, 1997).

Acid Detergent Fiber

There was about a 9% increase in ADF concentration between late winter and early spring harvests on average across all treatments ($P<0.001$). The increase of ADF between harvests would be expected, same as NDF, due to fiber accumulation as plants mature. Differences among treatments were detected ($P=0.0130$) and there was a significant treatment x harvest interaction in ADF (P=0.0354). Triticale had the highest ADF concentration, averaging 350 g kg^{-1} per harvest. Hairy vetch had the lowest ADF concentration, averaging less than 298 g kg^{-1} per harvest. Annual ryegrass had the most consistent ADF concentration between harvests, increasing only 4.3%, whereas triticale increased the most (14.6%). On average, legume monocultures contained about 3% less ADF than grass monocultures.

Acid detergent fiber is negatively correlated with the digestibility of a forage (Van Soest, 1963). The ADF range in this study, 262 to 423 g kg^{-1}, would be considered relatively low,

predicting high ruminant digestibility and a high energy availability. However, it is an approximate estimation of digestibility based on regression equations, not the biological or chemical composition of the extracted fiber (Van Soest, 1994). The main use of the ADF method in the study was to fractionate the cell wall portion of forages into its component parts.

Cellular Fractionation

Cellulose, hemicellulose, and lignin make up the majority of the cell wall portion of a forage, represented as a whole by NDF. Fractionation of these components can help predict digestibility within a ruminant (Van Soest, 1994) (Appendix). Lignin, and its association with other cell wall portions, is almost completely indigestible and therefore its concentration has the greatest influence on forage digestibility (Moore and Jung, 2001). Changes in lignin content between harvests were very small except for the 6% increase in the oats treatment. Differences in ADL levels were detected among cover crop treatments (P=0.0201). No differences were found between harvests in ADL (P=0.0845), nor was there a treatment x harvest interaction (P=0.4901). Average ADL concentrations of grass and legume monocultures were around 110 g kg^{-1}. Radish monoculture was slightly higher at 148 g kg^{-1} ADL.

Although lignin is not considered fiber, it is a major component of extracted NDF and ADF, and contributes to the indigestible portion of a forage. While the proportion of ADL within treatments had no significant increase with plant maturity, the decrease in digestibility (predicted by ADF) may reflect a greater association between lignin and cell wall constituents (Van Soest, 1994). It is because the NDF portion of legumes is more lignified that causes it to be less digestible than grass fiber (Buxton and Redfearn, 1997). However, the lack of ADL increase is unusual as lignin levels increase as soluble cell contents decrease (Moore and Jung, 2001). The similar lignin levels between harvests may have been influenced by the sequential ADF-ADL

method, where the ADF method is known to remove a fraction of lignin (up to 50%), thus reducing ADL extracted lignin in proportion with their concentrations (Hatfield and Fukushima, 2005).

Hemicellulose was determined by subtracting ADF from NDF. Differences in hemicellulose levels were detected among treatments ($P<0.001$). There was a highly significant treatment x harvest interaction in hemicellulose ($P<0.001$). There was only a 1.6% increase in hemicellulose between harvests across all treatments ($P=0.0147$). All treatments increased hemicellulose concentration between late winter and early spring harvests except crimson clover and hairy vetch monocultures which decreased by 4.2% and 4.7%, respectively. This concentration decrease was due to the legumes' unchanging soluble cellular contents while accumulating cellulose. Triticale had the highest increase among the grass treatments at 4.1%. The lowest hemicellulose concentration was 52 g kg^{-1} in radish at late winter harvest, and the highest was 172 g kg^{-1} in radish/triticale/crimson clover mixture at early spring harvest.

Because changes in hemicellulose were also minimal, the largest cell wall composition change, resulting from an increase in the cell-wall:cell-content ratio, was the increase in cellulose content. The digestibility of cellulose in ruminants, depending on lignification, is about 58% and hemicellulose is about 49% (Hespell, 1988). As expected, cellulose represented the largest fraction of cell wall content of all treatments (Van Soest, 1994).

Cellulose was calculated by subtracting ADL from ADF. Differences in cellulose levels were detected among treatments ($P<0.001$). There was a significant treatment x harvest interaction ($P=0.0394$). There was a 7.7% increase in cellulose between harvests across all treatments ($P<0.001$). The lowest cellulose composition was 14.5% in radish at late winter harvest, and the highest was 31.5% in triticale at early spring harvest. Triticale had the largest

increase (14.1%) in cellulose between harvests. Grasses averaged 2.8% more cellulose than legumes or radish.

As with yield, forage nutritive value comparisons are difficult to make between studies. Due to the ever-increasing cell-wall components of maturing plants, the date of harvest influences the nutritive value of a forage (Helsel and Thomas, 1987). Nutritive value can also be affected by seedbed preparation, temperature, length of day, precipitation, harvesting, etc. (Heath et al, 1985). The unpredictability of soil and climatic conditions makes the nutritive value analysis of one harvest a poor predictor of the nutritive value of any subsequent harvests (Van Soest et al., 1978). This study assumed grazing would be the primary method of forage harvesting, therefore the two harvest dates are meant to give a brief appraisal of forage quality across the late winter grazing period, as well as demonstrate the regrowth ability of each treatment to provide forage for the early spring grazing period.

Cellular composition of a forage species also assumes a pure stand at harvest. Due to copious rainfall during the second year, weed growth was present in the treatment plots. Weeds were collected along with forage treatments, as this study focused on ‘as is’ conditions to simulate an actual pasture environment. Reduced growth of cover crop treatments, combined with weed contamination, affected the yield and composition analysis of this study.

Crude Protein

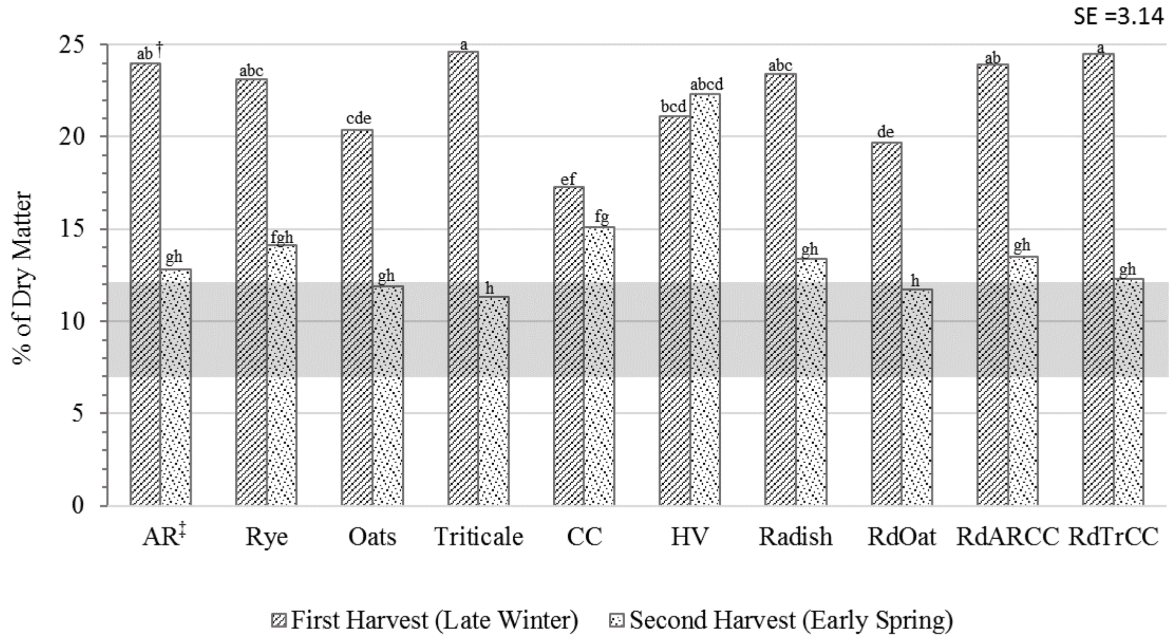
Differences in CP concentrations were detected among treatments ($P<0.001$) as well as a highly significant treatment x harvest interaction ($P<0.001$). There was an 8.4% decrease in CP concentration from late winter harvest to early spring harvest across all treatments ($P<0.001$). Beck et al. (2008) found a similar decrease (8.25% average) between February and April

harvests of annual ryegrass and rye. In this study, hairy vetch had the highest CP, averaging 21.7% per harvest.

As expected from maturing plants, protein concentrations decreased between the two harvests (Edmisten et al., 1998), with the exception of hairy vetch. Hairy vetch took longer to reach physiological maturity than the other treatments, remaining in a vegetative stage at early spring harvests. Hairy vetch was the only treatment that increased CP (1.2%) between harvests. Redmon et al. (1998b) reported a 4.85% CP decrease in hairy vetch from March to April in Oklahoma. Triticale fluctuated the most, dropping from the highest CP (246 g kg^{-1}) at late winter harvest to the lowest CP (113 g kg^{-1}) at early spring harvest. Hairy vetch and triticale CP concentrations in this study were slightly higher than the average 182 g kg^{-1} and 81.0 g kg^{-1} CP, respectively (harvested at early heading stage), reported by Karadag and Buyukburc (2004). A Michigan study showed a smaller CP percentage decrease of maturing small grains with rye decreasing 7% and oats only decreasing 3.4% on average (Helsel and Thomas, 1987).

All treatments contained high amounts of protein throughout the growing season as would be predicted from cool-season annuals (Figure 4). All treatments, at both harvests, were well within or well above the required 7-12% protein levels for lactating cows and growing calves for optimal performance (Ball et al., 2015). This range represents the stages in ruminant animal development that requires the highest levels of protein, and the level of crude protein below which ruminal fermentation may be limited (Buxton et al., 1995).

Winter protein levels in legumes were unexpectedly lower than all the grasses (Redmon et al., 1998b), except oats. Legumes typically have higher CP concentrations than grasses, but these treatments may have been affected by restricted nodulation from anaerobic soil



† Columns with different letters differ at *P*<0.05.
‡ AR, annual ryegrass; CC, crimson clover; HV, hairy vetch; Rd, radish; Tr, triticale.

Figure 4. Crude protein content of cool-season annual cover crops at winter and spring harvests, mean of 2 years. *Shaded area indicates protein requirement of lactating cows and growing calves*.

conditions impeding plant uptake of nitrogen (Taiz et al., 2015). Because of their low CP levels, the addition of crimson clover to the radish/annual ryegrass and radish/triticale mixtures did not appear to increase overall CP concentrations.

In Vitro True Digestibility

Again, as expected from cool-season annuals, all cover crop treatments were highly digestible (Wilman and Altimimi, 1984), even after decreasing in digestibility as they matured (Table 6). Differences in IVTD were detected among treatments (*P*=0.0035). A highly significant treatment x harvest interaction was found in IVTD (*P*<0.001). There was an 11.5% decrease in IVTD between harvests across all treatments (*P*<0.001).

Table 6. *In vitro* true digestibility (IVTD) and *in vitro* true digestible dry matter (IVTDDM) yield of cool-season annual cover crops at winter and spring harvests, mean of 2 years.

	IVTD (%)		IVTDDM (Mg ha^{-1})‡		
Cover Crop	Winter	Spring	Winter	Spring	Total
Annual Ryegrass	87.7^{ab}†	79.8^{de}	0.67	1.73	2.41
Rye	88.8^{ab}	79.5^{de}	0.93	1.80	2.73
Oats	89.9^{ab}	74.6^{fgh}	1.31	1.55	2.86
Triticale	90.5^{a}	73.9^{gh}	0.78	1.76	2.54
Crimson Clover	81.9^{cd}	75.9^{efgh}	0.43	1.18	1.61
Hairy Vetch	86.0^{bc}	82.2^{cd}	0.57	1.23	1.80
Radish	88.0^{ab}	72.4^{h}	0.80	1.22	2.02
Radish/Oats	90.0^{ab}	76.5^{efg}	1.57	1.52	3.10
Radish/Annual Ryegrass/Crimson Clover	89.9^{ab}	78.4^{def}	0.97	1.70	2.68
Radish/Triticale/Crimson Clover	90.5^{a}	75.0^{fgh}	0.75	1.69	2.43
	SE=1.5		SE=0.38		

† Values with different letters within IVTD columns differ at $P<0.05$.
‡ Not significantly different (P=0.35).

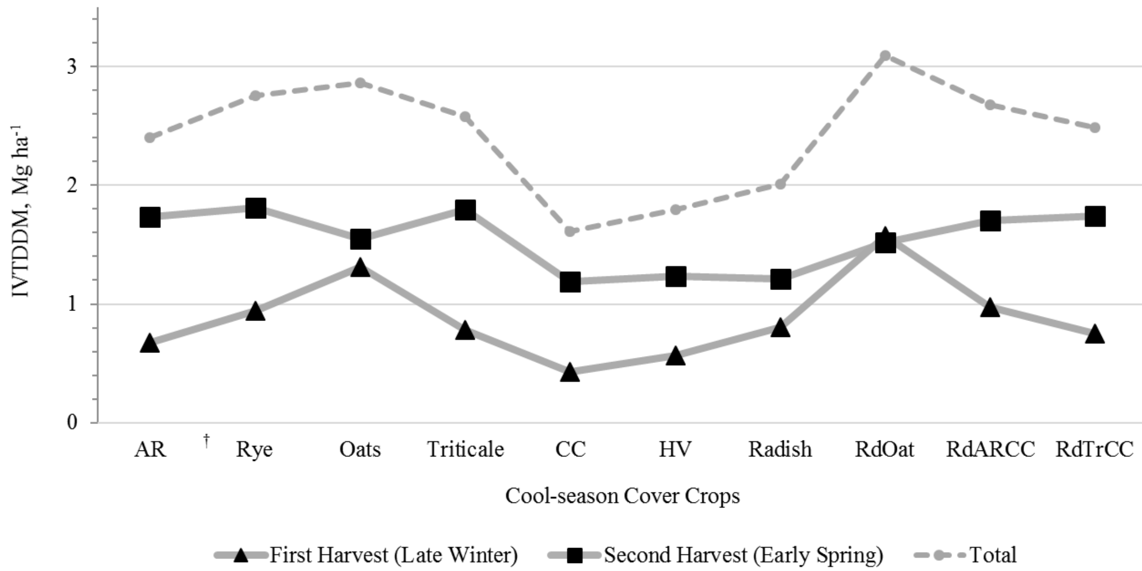
In vitro true digestibility is a biological analysis of forage degradation that is dependent on the microbial population collected with the rumen fluid, and will therefore vary with the ruminant physiology (Tilley and Terry, 1963; Van Soest et al., 1966). As an estimation of digestibility, treatments in this study exceeded the digestibility of bermudagrass (50-60%), tall fescue (53-72%), and alfalfa (57-69%) which often serve as the basis of many forage programs (Ball et al., 2015). The highest IVTD levels were in triticale and radish/triticale/crimson clover treatments (905 g kg^{-1}) at late winter harvest. The lowest IVTD level was in radish (724 g kg^{-1}) at early spring harvest. Hoveland et al. (1986) reported IVTD ranges for rye and hairy vetch to be 70-79% and 77-82%, respectively, from vegetative to mature stages, which were numerically higher than this study but reflected similar percentage decreases. Oats, triticale, and radish had the greatest decrease in IVTD between harvests of the monocultures. This was reflected in their

NDF increase (negatively correlated with IVTD), resulting in a reduction of soluble cellular contents (Bertrand and Dunavin, 1975). Legume monocultures were less digestible than the grasses and radish at late winter harvest. However, their digestibility decrease was not as great, resulting in hairy vetch having the numerically highest digestibility of the early spring harvest. Hairy vetch only decreased 3.8% IVTD, again, due to the fact that it had not yet reached anthesis at the time of the early spring harvest.

In Vitro True Digestible Dry Matter

In vitro true digestible DM was calculated by multiplying the treatment DM yield (kg ha^{-1}) times its corresponding IVTD %. Differences in IVTDDM between harvests were highly significant ($P<0.001$). Differences between treatments were also detected ($P=0.0485$). No treatment x harvest interaction was detected ($P=0.3502$). Even with the 11.5% decrease in IVTD, there was a 75% IVTDDM yield increase across all treatments between late winter and early spring harvests due to the much higher dry matter yield. Radish/oats mixture had the numerically highest IVTDDM yield average at 1547 kg ha^{-1} per harvest. Crimson clover, hairy vetch, and radish had the lowest IVTDDM at 807, 898, and 1010 kg ha^{-1}, respectively.

While statistically similar, the numerical differences in the treatment x harvest interaction in IVTDDM illustrate potential consistency between harvests (Figure 5). Oats and radish/oats treatments maintained relatively high IVTDDM yields at both harvests. Annual ryegrass and triticale were particularly inconsistent, with low winter yields followed by abundant spring growth. Inconsistent IVTDDM distribution can severely limit the grazing options available to cattle producers. Studies have shown that multispecies mixtures may provide more consistent, if not more abundant, biomass production (Tilman et al., 1996; Deak et al., 2009; Bonin and Tracy, 2012; Pollnac et al., 2014).



† AR, annual ryegrass; CC, crimson clover; HV, hairy vetch; Rd, radish; Tr, triticale.

Figure 5. *In vitro* true digestible dry matter (IVTDDM) yield of cool-season annual cover crops at winter and spring harvests, mean of 2 years.

Summary and Conclusions

The cool-season annuals tested in this study proved to be highly digestible, nutritious, and productive. This suggests their feasible usage as late winter/early spring forages while, under proper management practices, maintaining their additional value as cover crops. All treatments, except for crimson clover, demonstrated excellent regrowth, indicating a potential for substantially extending the grazing season in the southeastern U.S. The three forage mixtures outperformed the radish and crimson clover monocultures, but not their respective grass component monocultures.

Oats and radish/oats mixture were the superior treatments in terms of consistent digestible dry matter production from late winter to early spring. For forage purposes, an oats or oats mixture cover crop may be the preferred cover crop choice. Annual ryegrass and radish/annual ryegrass/crimson clover mixture did not show consistent biomass production between harvests, however, annual ryegrass's thick sod may be preferred for better grazability. Rye had satisfactory biomass production and only minor nutritive variation between harvests, however, rye is known to be less palatable to ruminants and, therefore, forage utilization should be made before its flowering stage. Triticale's and radish/triticale/crimson clover mixture's less vigorous winter production, followed by a precipitous drop in nutritive value between harvests, make them less attractive as a forage option.

Legume monocultures can be highly beneficial as cover crops in terms of nitrogen contribution, however, the low biomass production from crimson clover and hairy vetch monocultures during late winter and early spring indicates some site-specific limitations to their usage. Crimson clover showed difficulty establishing in heavy, waterlogged soils, making it less competitive in mixtures with tall growing radishes and grasses. Hairy vetch may perform better

in a grass mixture with its climbing and later maturing growth habits. Hairy vetch also provided higher CP concentrations and a slightly more consistent digestible dry matter production across harvests than crimson clover. Tillage radish produced modest amounts of highly nutritious biomass, and showed no production nor nutritional benefit, nor drawback, to the forage mixtures.

Due to the statistically similar yield results between monocultures and mixtures, as well as the high digestibility across all treatments, other factors may contribute more to deciding which cover crop would best fit a particular forage program. Agronomic factors include site-specific climate and soil conditions, and maintaining consistent forage availability. Economic factors include seed prices and the reduction of winter feeding by extending the grazing season. Diverse forage mixtures can provide a longer grazing period than monocultures due to the developmental differences among species. Forage mixtures should be optimized for soil conditions, forage availability, and crop rotation schedules.

Literature Cited

Abrams, S.M., H.W. Harpster, P.J. Wangsness, J.S. Shenk, E. Keck, and J.L. Rosenberger. 1987. Use of a standard forage to reduce effects of animal variation on estimates of mean voluntary intake. J. Dairy Sci. 70:1235-1240.

Allen, M., P.E. Schilling, H.D. Ellzey, and O.D. Curtis. 1978. A summary of nitrogen studies with forage crops at the southeast Louisiana dairy and pasture experiment station. Louisiana Agr. Exp. Sta. Bull. 712.

Allen, V.G., C. Batello, E.J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters, and M. Sanderson. 2011. An international terminology for grazing lands and grazing animals. Grass Forage Sci. 66:2-28.

Allen, V.G., J.P. Fontenot, and R.A. Brock. 2000. Forage systems for production of stocker steers in the upper south. J. Anim. Sci. 78:1973-1982.

Allen, V.G., J.P. Fontenot, D.R. Notter, and R.C. Hammes, Jr. 1992. Forage systems for beef production from conception to slaughter: I. Cow-calf production. J. Anim. Sci. 70:576-587.

ANKOM Technology. 2005. Method 3: In vitro true digestibility using the DAISY^{II} incubator. Ankom Technology Corp., Macedon, NY. Available online: https://www.ankom.com/sites/default/files/document-files/Method_3_Invitro_0805_D200_D200I.pdf (Accessed October 25, 2016).

ANKOM Technology. 2016. Method 8: Determining acid detergent lignin in beakers. Ankom Technology Corp., Macedon, NY. Available online: https://www.ankom.com/sites/default/files/document-files/Method_8_Lignin_in_beakers.pdf (Accessed October 25, 2016).

ANKOM Technology. 2016. Method 12: Acid detergent fiber in feeds – filter bag technique (for A2000 and A20001). Ankom Technology Corp., Macedon, NY. Available online: https://www.ankom.com/sites/default/files/document-files/Method_12_ADF_A2000.pdf (Accessed October 25, 2016).

ANKOM Technology. 2016. Method 13: Neutral detergent fiber in feeds – filter bag technique (for A2000 and A20001) Ankom Technology Corp., Macedon, NY. Available online: https://www.ankom.com/sites/default/files/document-files/Method_13_NDF_A2000.pdf (Accessed October 25, 2016).

Bagley, C.P., J.C. Carpenter, Jr., J.I. Feazel, F.G. Hembry, D.C. Huffman, and K.L. Koonce. 1987. Effects of forage system on beef cow-calf productivity. J. Anim. Sci. 64:678-686.

Bagley, C.P., J.I. Feazel, J.C. Carpenter, Jr., H.E. Harris, and K.L. Koonce. 1984. Performance of steers grazing cool-season annual forage mixtures. Louisiana Agr. Exp. Sta. Bull. 759.

Bagley, C.P., G.M. Hill, J.W. Knox, D.F. Coombs, W.M. Oliver, A.F. Loyacano, W.E. Wyatt, D.C. Huffman, K.W. McMillin, T.D. Bidner, and A.M. Saxton. 1990. Year-round production of beef using maximum levels of forages. I. Stocker Phase. Appl. Agric. Res. 5:309-314.

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 2015. *Southern Forages*. 5th Ed. International Plant Nutrition Institute (IPNI), Peachtree Corners, GA.

Ball, D.M., E.N. Ballard, M.L. Kennedy, G.D. Lacefield, and D.J. Undersander. 2008. Extending grazing and reducing stored feed needs, in: G.L.C.I. Pub. (ed.), Bryan, TX.

Ball, D.M., M. Collins, G.D. Lacefield, N.P. Martin, D.A. Mertens, K.E. Olson, D.H. Putnam, D.J. Undersander, and M.W. Wolf. 2001. Understanding forage quality. American Farm Bureau Federation Publication 1-01, Park Ridge, IL.

Beck, P., S. Gadberry, and J. Jennings. 2013. Using cool-season annual grasses for grazing livestock. University of Arkansas, FSA 3064- PD-12-13RV. Available online: http://www.uaex.edu/publications/PDF/FSA-3064 (Accessed July 13, 2016).

Beck, P.A., S.A. Gunter, K.S. Lusby, C.P. West, K.B. Watkins, and D.S. Hubbell, III. 2008. Animal performance and economic comparison of novel and toxic endophyte tall fescues to cool-season annuals. J. Anim. Sci. 86:2043-2055.

Bertrand, J.E. and L.S. Dunavin. 1973. Small grain crops, alone and in mixtures with ryegrass and clover, for growing beef calves. Jay, Fla., ARC Rep. 73-1.

Bertrand, J.E. and L.S. Dunavin. 1975. Certain characteristics of cool-season annual forages and their relationships to performance by growing beef calves. J. Anim. Sci. 41:1206-1211.

Blaser, R. E., R. C. Hammes, Jr., J. P. Fontenot, H. T. Bryant, C. E. Polan, D. D. Wolf, F. S. McClaughery, R. G. Kline, and J. S. Moore. 1986. Forage-animal management systems. Virginia Agr. Exp. Stn. Bull. 86–7, Virginia Polytechnic Inst. State Univ., Blacksburg.

Blount, A.R., J.M.B. Vendramini, J.C.B. Dubeux, A. Babar, K.E. Kenworthy, P.R. Munoz, and K.H. Quesenberry. 2014. Cool-season forage variety recommendations for Florida. University of Florida/The Institute of Food and Agricultural Sciences Extension Service Publication SS-ARG-84.

Bollero, G.A. and D.G. Bullock. 1994. Cover cropping systems for the central corn belt. J. Prod. Agric. 7:55-58.

Bonin, C.L. and B.F. Tracy. 2012. Diversity influences forage yield and stability in perennial prairie plant mixtures. Agr. Ecosyst. Environ. 162:1-7.

Bransby, D.I. 1989. Justification for grazing intensity experiments: economic analysis. J. Range Manage. 42:425-430.

Brink, G.E., M.A. Sanderson, and M.D. Casler. 2015. Grass and legume effects on nutritive value of complex forage mixtures. Crop Sci. 55:1329-1337.

Burris, W.R., C.H. Hovermale, and W.E. Brown. 1979. Wheat, rye or oats with ryegrass and crimson clover for winter grazing steer calves. Miss. Agric. Forestry Exp. Sta. Res. Highlights 5:1-4.

Buxton, D.R. and D.D. Redfearn. 1997. Plant limitations to fiber digestion and utilization. J. Nutr. 127:814s-818s.

Buxton, D.R., D.R. Mertens, and K.J. Moore. 1995. Forage quality for ruminants: plant and animal considerations. Prof. Anim. Sci. 11:121-131.

Caddel, J., D. Redfearn, H. Zhang, J. Edwards, and S. Deng. 2012. Forage legumes and nitrogen production. Oklahoma Cooperative Extension Fact Sheets PSS-2590. Division of Agricultural Sciences and Natural Resources, Oklahoma State University. Available online: http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-3101/PSS-2590web%20color.pdf (Accessed September 5, 2016).

Cannell, R.Q., R.K. Belford, P.S. Blackwell, G. Govi, and R.J. Thomson. 1985. Effects of waterlogging on soil aeration and on root and shoot growth and yield of winter oats (*Avena sativa* L.). Plant Soil 85:361-373.

Cherr, C.M., J.M.S. Scholberg, and R. McSorley. 2006. Green manure approaches to crop production: a synthesis. Agron. J. 98:302-312.

Coffey, K.P., W.K. Coblentz, T.G. Montgomery, J.D. Shockey, K.J. Bryant, P.B. Francis, C.F. Rosenkrans, Jr., and S.A. Gunter. 2002. Growth performance of stocker calves backgrounded on sod-seeded cool-season annuals or hay and grain. J. Anim. Sci. 80:926-932.

Coleman, S.W. and J.E. Moore. 2003. Feed quality and animal performance. Field Crop. Res. 84:17-29.

Coombs, D.F, C.P. Bagley, G.M. Hill, J.W. Knox, A.F. Loyacano, W.M. Oliver, W.E. Wyatt, D.C. Huffman, K.W. McMillin, T.D. Bidner, and A.M. Saxton. 1990. Year-round production of beef using maximum levels of forages. II. Finishing Phase. Appl. Agric. Res. 5:315-320.

Coombs, D.F., S.A. Phillips, J.L. Bartleson, K.L. Koonce, and D.C. Huffman. 1983. Pasture management systems for cow-calf production at two locations in northeast Louisiana. Louisiana Agr. Exp. Stn. Bull. 744.

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221-1250.

Daniels, L.B., K.F. Harrison, D.S. Hubbell, III, E.B. Kegley, D. Hellwig, and Z.B. Johnson. 2004. Evaluation of small grain forage crops and cultivars of soft red winter wheat for stocker cattle. University of Arkansas. Arkansas Agricultural Experiment Station Report 973. Available online: http://arkansasagnews.uark.edu/973.pdf (Accessed September 1, 2016).

Deak, A., M.H. Hall, and M.A. Sanderson. 2009. Grazing schedule effect on forage production and nutritive value of diverse forage mixtures. Agron J. 101:408-414.

Deak, A., M.H. Hall, M.A. Sanderson, and D.D. Archibald. 2007. Production and nutritive value of grazed simple and complex forage mixtures. Agron. J. 99:814-821.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86:126-135.

DeRouen, S.M, D.L. Prichard, F.S. Baker, Jr., and R.L. Stanley, Jr. 1991. Cool-season annuals for supplementing perennial pasture on beef cow-calf productivity. J. Prod. Agric. 4:481-485.

Drake, D.J. and S.B. Orloff. 2002. Using triticale and annual ryegrass in cool-season perennial grass grazing systems. Western Alfalfa and Forage Conference. Available online: https://www.csuchico.edu/grassfedbeef/research/documents/Using%20Triticale%20and%20Ann Ann.pdf (Accessed September 1, 2016).

Dudley, R.F. and L.N. Wise. 1953. Seeding in permanent pasture for supplementary winter grazing. Miss. Agr. Exp. Sta. Bull. 505.

Dumas, J.B.A. 1831. Procedes de l'analyse organique. Ann. Chim. Phys. 247:198–213.

Edmisten, K.L., J.T. Green, Jr., J.P. Mueller, and J.C. Burns. 1998. Cool-season annual small grain forage potential. II. Quantifications of nutritive characteristics of four small grain species at six growth stages. Commun. Soil Sci. Plant Anal. 29:881-899.

Evers, G.W. 2008. Forage systems to reduce the winter feeding period. In: Proc. Adjusting to High Fuel and Fertilizer Prices. Tech. Rep. 2008-01. Tex. A&M Univ., College Station. p. 59-68.

Faé, G.S., R.M. Sulc, D.J. Barker, R.P. Dick, M.L. Eastridge, and N. Lorenz. 2009. Integrating cool-season annual forages into a no-till corn silage system. Agron. J. 101:1286-1296.

Flores, J.P. and B. Tracy. 2012. Impacts of winter hay feeding on pasture soils and plants. Agr. Ecosyst. Environ. 149:30-36.

Gadberry, S., J. Jennings, H. Ward, P. Beck, B. Kutz, and T. Troxel. 2016. Beef cattle production. University of Arkansas Cooperative Extension. Pub. MP184-PD-2-2016RV.

Gibberd, M.R., J.D. Gray, P.S. Cocks, and T.D. Colmer. 2001. Waterlogging tolerance among a diverse range of *Trifolium* accessions is related to root porosity, lateral root formation and ‘aerotropic rooting.’ Ann. Bot.-London 88:579-589.

Gibson, L.J. 2012. The hierarchical structure and mechanics of plant materials. J. R. Soc. Interface. 9:2749-2766.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Agr. Handbook No. 379, U.S. Department of Agriculture, Agricultural Research Service.

Gunter, S.A., K.A. Cassida, P.A. Beck, and J.M. Phillips. 2002. Winter-annual pasture as a supplement for beef cows. J. Anim. Sci. 80:1157–1165.

Han, K.J., M.W. Alison, Jr., W.D. Pitman, and M.E. McCormick. 2012. Contributions of overseeded clovers to bermudagrass pastures in several environments. Crop Sci. 52:431-441.

Han, K.J., M.W. Alison, W.D. Pitman, and M.E. McCormick. 2013. Contribution of field pea to winter forage production and nutritive value in the south-central United States. Crop Sci. 53:315-321.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agron. J. 78:70-74.

Hatfield, R. and R.S. Fukushima. 2005. Can lignin be accurately measured? Crop Sci. 45:832-839.

Havlin, J.L., S.L. Tisdale, W.L. Nelson, and J.D. Beaton. 2014. *Soil Fertility and Nutrient Management: An Introduction to Nutrient Management*. 8th Edition. 505 p. Pearson, Upper Saddle River, NJ.

Haynes, R.J. and P.H. Williams. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Adv. Agron. 49:119-199.

Heath, M.E., R.F. Barnes, and D.S. Metcalfe. 1985. *Forages: The Science of Grassland Agriculture*. 4th ed. Iowa State Univ. Press. Ames, IA.

Helsel, Z.R. and J.W. Thomas. 1987. Small grains for forage. J. Dairy Sci. 70:2330-2338.

Henderson, M.S. and D.L. Robinson. 1982. Environmental influences on fiber component concentrations of warm-season grasses. Agron. J. 74:573-579.

Hespell, R.B. 1988. Microbial digestion of hemicelluloses in the rumen. Microbiol. Sci. 5:362-365.

Hill, G.M., P.R. Utley, and W.C. McCormick. 1985. Evaluation of cow-calf systems using ryegrass sod-seeded in perennial pastures. J. Anim. Sci. 61:1088-1094.

Holloway, J.W., W.T. Butts, Jr., J.D. Beaty, J.T. Hopper, and N.S. Hall. 1979. Forage intake and performance of lactating beef cows grazing high or low quality pastures. J. Anim. Sci. 48:692-700.

Hoveland, C.S. 1992. Grazing systems for humid regions. J. Prod. Agric. 5:23-27.

Hoveland, C.S. and H.L. Webster. 1963. Growth of warrior vetch as influenced by clipping management. Crop Sci. 3:274-275.

Hoveland, C.S., G.A. Buchanan, S.C. Bosworth, and I.J. Bailey. 1986. Forage nutritive quality of weeds in Alabama. Alabama Agr. Exp. Stn. Bull. 577.

Hoveland, C.S., W.B. Anthony, J.A. McGuire, and J.G. Starling. 1978. Beef cow-calf performance on Coastal bermudagrass overseeded with cool-season annual clovers and grasses. Agron. J. 70:418-420.

Jung, H. 2012. Forage digestibility: the intersection of cell wall lignification and plant tissue anatomy. Int. Adv. Rumin Nut. Res. 162–174.

Kaiser, J. 2014. Cover crop basics for southeast Missouri. NRCS Plant Materials Program. Pub. 12100. Available online: http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/mopmsbr12100.pdf (Accessed August 31, 2016).

Karadag, Y. and U. Buyukburc. 2004. Forage qualities, forage yields and seed yields of some legume-triticale mixtures under rainfed conditions. Soil and Plant Sci. 54:140-148.

Kim, K., N.A. Tinker, and M.A. Newell. 2014. Improvement of oat as a winter forage crop in the southern United States. Crop Sci. 54:1336-1346.

Kuo, S. and E.J. Jellum. 2002. Influence of winter cover crop and residue management on soil nitrogen availability and corn. Agron. J. 94:501-508.

Lalman, D. 2004. E-974. Nutrient Requirements of Beef Cattle. Oklahoma Cooperative Extension Service. Stillwater, OK.

Lippke, H. 1980. Forage characteristics related to intake, digestibility and gain by ruminants. J. Anim. Sci. 50:952-961.

Lithourgidis, A.S., L.B. Vasilakoglou, K.V. Dhima, C.A. Dordas, and M.D. Yiakoulaki. 2006. Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios. Field Crops Res. 99:106-113.

Mackowiak, C.L., R.O. Myer, A.R. Blount, J.L. Foster, and R.D. Barnett. 2011. Yield and mineral concentrations of Southeastern United States oat cultivars used for forage. J. Plant Nutr. 34:1828-1842.

McBride, W.D. and K. Mathews, Jr. 2011. The Diverse Structure and Organization of U.S. Beef Cow-Calf Farms. EIB-73. Economic Research Service, USDA.

Miller, A.J., D.B. Faulkner, R.K. Knipe, D.R. Strohbehn, D.F. Parrett, and L.L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17:295-302.

Miller, M., J. Kliebenstein, and L. Gibson. 2003. Triticale enterprise budgets: the economic cost and return of growing winter triticale in Iowa. Department of Economics, Iowa State University. Available online: http://www.agmrc.org/media/cms/enterprise_budget_7CF2926139811.pdf (Accessed September 1, 2016).

Minson, D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, NY.

Mitchell, W.H. and M.R. Teel. 1977. Winter-annual cover crops for no-tillage corn production. Agron. J. 69:569-573.

Moore, A.D., L.W. Bell, and D.K. Revell. 2009. Feed gaps in mixed-farming systems: insights from the Grain & Graze program. Anim. Prod. Sci. 49:736-748.

Moore, J.E., M.H. Brant, W.E. Kunkle, and D.I. Hopkins. 1999a. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77:122-135 (Suppl. 2).

Moore, J.E., W.E. Kunkle, and W.F. Brown. 1999b. Forage quality and the need for protein and energy supplements. 40th Annual Florida Beef Cattle Short Course Proc., University of Florida, Gainesville, FL. 1-3 May 1999. UF/IFAS Extension (University of Florida/Institute of Food and Agricultural Sciences Extension), Gainesville, FL.

Moore, K.J. and H.G. Jung. 2001. Lignin and fiber digestion. J. Range Manage. 54:420-430.

Mould, F.L. 2003. Predicting feed quality – chemical analysis and in vitro evaluation. Field Crop. Res. 84:31-44.

National Agricultural Statistics Service (NASS). 2012. Census of Agriculture. USDA.

National Research Council (NRC). 2000. *Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000*. Washington, DC: The National Academies Press.

Perry, T.W. 1980. *Beef Cattle Feeding and Nutrition*. Academic Press, Inc., NY.

Perry, T.W. 1984. *Animal Life-cycle Feeding and Nutrition*. Academic Press, Inc., Orlando.

Perry, T.W., A.E. Cullison, and R.S. Lowrey. 1999. *Feeds and Feeding*. 5th ed. Prentice Hall, Upper Saddle River, NJ.

Petersen, R.G. 1994. *Agricultural Field Experiments: Design and Analysis*. Marcel Dekker, NY.

Pollnac, F.W., R.G. Smith, and N.D. Warren. 2014. Cultivar diversity as a means of ecologically intensifying dry matter production in a perennial forage stand. Ecosphere 5:1-12.

Poppi, D.P., B.W. Norton, D.J. Minson, and R.E. Hendrickson. 1980. The validity of the critical size theory for particles leaving the rumen. J. Agric. Sci. 94:275-280.

Pugh, R., J.F. Witty, L.R. Mytton, and F.R. Minchin. 1995. The effect of waterlogging on nitrogen fixation and nodule morphology in soil-grown white clover (*Trifolium repens* L.). J. Exp. Bot. 46:285-290.

Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88:777-782.

Ranells, N.N. and M.G. Wagger. 1997. Grass-legume bicultures as cool-season annual cover crops. Agron. J. 89:659-665.

Raymond, W.F. 1969. Nutritive value of forage crops. Adv. in Agron. 21:1-108.

Redmon, L.A., J.L. Baker, and E.G. Krenzer, Jr. 1998a. Cool-season annual forage grasses. OSU Extension Facts F-2571. Oklahoma Cooperative Extension Service, DASNR, Oklahoma State Univeristy, Stillwater, OK.

Redmon, L.A., G.W. Horn, and C. Lunsford. 1998b. Cool-season annual legume effects on wheat forage nutritive value. J. Plant Nutr. 21:805-813.

Robertson, J.B. and P.J. Van Soest. 1981. The detergent system of analysis. In: James, W.P.T., Theander, O. (Eds.), *The Analysis of Dietary Fibre in Food*. Marcel Dekker, NY, Chapter 9, pp. 123-158.

Rohweder, D.A., R.F. Barnes, and N. Jorgensen. 1978. Proposed hay grading standards based on laboratory analyses for evaluating quality. J. Anim. Sci. 47:747-759.

Rotz, C.A. and R.E. Muck. 1994. Changes in forage quality during harvest and storage. In: *Forage Quality, Evaluation, and Utilization*, Eds. G.C. Fahey, Jr. et al. Am. Soc. Agron., Madison, WI. pp. 828-868.

Sage, R.F. and R.K. Monson. 1990. *C4 Plant Biology*. Academic Press. San Diego, California.

SAS Institute. 2004. SAS/STAT user's guide (Ver. 9.1.3 Service Pack 4). SAS Institute Inc., Cary, NC.

Scaglia, G., J. Rodriguez, J. Gillespie, B. Bhandari, J.J. Wang, and K.W. McMillin. 2014. Performance and economic analysis of year-round forage systems for forage-fed beef production in the Gulf Coast. J. Anim. Sci. 92:5704-5715.

Schwarte, A.J., L.R. Gibson, D.L. Karlen, M. Liebman, and J.L. Jannink. 2005. Planting date effects on winter triticale dry matter and nitrogen accumulation. Agron. J. 97:1333-1341.

Sheffield, R.E., K. Harborth, G. Scaglia, B.D. LeBlanc, K. Nix, and K. Pope. 2012. Sustainable best management practices for beef production. LSU AgCenter, Pub. 2884. Available online: http://www.lsuagcenter.com/NR/rdonlyres/58A1684A-740F-4A35-B314-0F01CCC9288A/87569/pub2884beefbmppubLOWRES.pdf (Accessed June 21, 2016).

Shipley, P.R., J.J. Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84:869-876.

Short, S.D. 2001. Characteristics and production costs of U.S. cow-calf operations. Electronic report for the economic research service. USDA. Statistical Bulletin Number 974-3.

Snapp, S.S., S.M. Swinton, R. Labarta, D. Mutch, J.R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron. J. 97:322-332.

Soder, K.J., A.J. Rook, M.A. Sanderson, and S.C. Goslee. 2007. Interaction of plant species diversity on grazing behavior and performance of livestock grazing temperate region pastures. Crop Sci. 47:416-425.

Sustainable Agriculture Research & Education (SARE). 2010. Managing cover crops profitably. Handbook Series Book 9. National Institute of Food and Agriculture, USDA.

Taiz, L., E. Zeiger, I.M. Møller, and A. Murphy. 2015. *Plant Physiology and Development*. 6th ed. Sinauer Associates, Inc. Sunderland, MA.

Tilley, J. M. A. and R.A. Terry. 1963. A two-stage technique for the *in vitro* digestion of forage crops. Grass Forage Sci. 18:104–111.

Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379:718-720.

Twidwell, E., M.W. Alison, K.J. Han, T.D. Martin, G. Williams, S. Laird, J. Simmons, and H.P. Viator. 2015. Cool-season pasture and forage varieties. Louisiana State University Agricultural Center Pub. 2334. Available online: http://www.lsuagcenter.com/~/media/system/f/5/4/4/f5447f5a8bf9eee4e8feddd2ada7f5e2/pub2323coolseasonpastureandforagevarieties20152016.pdf (Accessed August 8, 2016).

United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS). 2011. Small-Scale U.S. Cow-calf Operations. USDA-APHIS-VS, CEAH. Fort Collins, CO. Available online: www.aphis.usda.gov/animal_health/nahms/smallscale/downloads/Small_scale_beef.pdf (Accessed June 21, 2016).

Utley, P.R. and W.C. McCormick. 1978. Evaluation of cow-calf management systems using sod-seeded ryegrass pastures. J. Anim. Sci. 47:1219-1224.

Utley, P.R., W.H. Marchant, and W.C. McCormick. 1976. Evaluation of annual grass forages in prepared seedbeds and overseeded into perennial sods. J. Anim. Sci. 42:16-20.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analysis and its application to forages. J. Anim. Sci. 26:119-128.

Van Soest, P. J. 1994. *Nutritional Ecology of the Ruminant*. 2nd ed. Comstock Pub. Ithaca, NY.

Van Soest, P.J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Off. Ana. Chem. 46:829-835.

Van Soest, P.J. and R.H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. J. Assoc. Off. Ana. Chem. 50:50-55.

Van Soest, P.J. and R.W. McQueen. 1973. The chemistry and estimation of fibre. Proc. Nutr. Soc. 32:123-130.

Van Soest, P.J., D.R. Mertens, and B. Deinum. 1978. Preharvest factors influencing quality of conserved forage. J. Anim. Sci. 47:712-720.

Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Van Soest, P.J., R.H. Wine, and L.A. Moore. 1966. Estimation of the true digestibility of forages by the in vitro digestion of cell walls. In: 10th International Grassland Congress Proceedings, Helsinki. 438-441.

Venuto, B.C., D.D. Redfearn, W.D. Pitman, and M.W. Alison. 2004. Impact of seeding rate on annual ryegrass performance. Grass Forage Sci. 59:8-14.

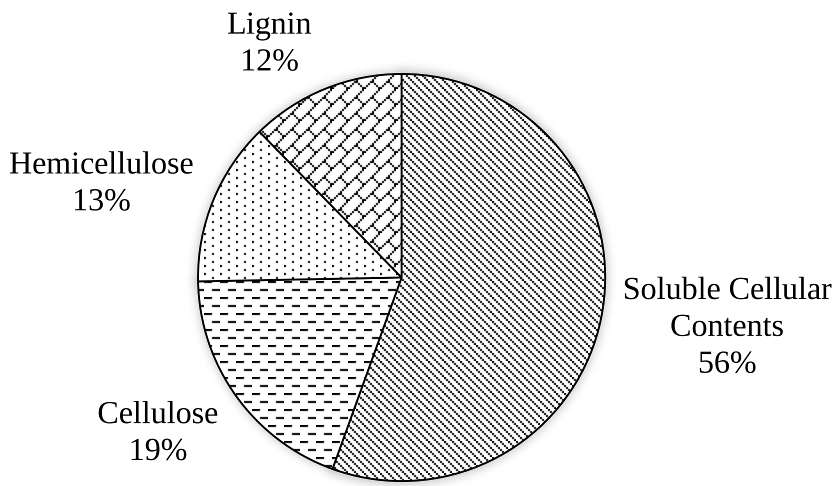
Vigil, M.F. and D.J. Poss. 2016. N response of no-till dryland winter triticale forage. Commun. Soil Sci. Plan. 47:1117-1127.

White, S.L., R.E. Sheffield, S.P. Washburn, L.D. King, and J.T. Green, Jr. 2001. Spatial and time distribution of dairy cattle excreta in an intensive pasture system. J. Environ. Qual. 30:2180-2187.

Wilman, D. and M.A.K. Altimimi. 1984. The in-vitro digestibility and chemical composition of plant parts in white clover, red clover, and lucerne during primary growth. J. Sci. Food Agric. 35:133-138.

Appendix

Cellular Composition of Annual Ryegrass Dry Matter (Winter Harvest)



Cellular Composition of Annual Ryegrass Dry Matter (Spring Harvest)

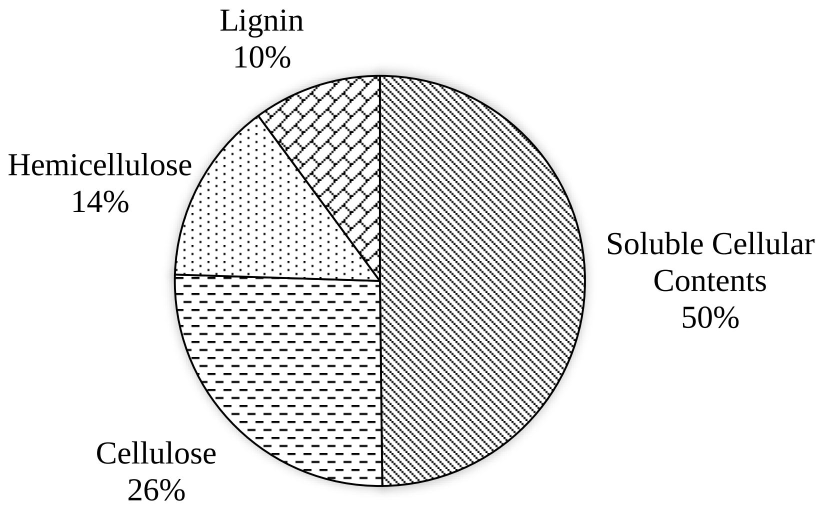
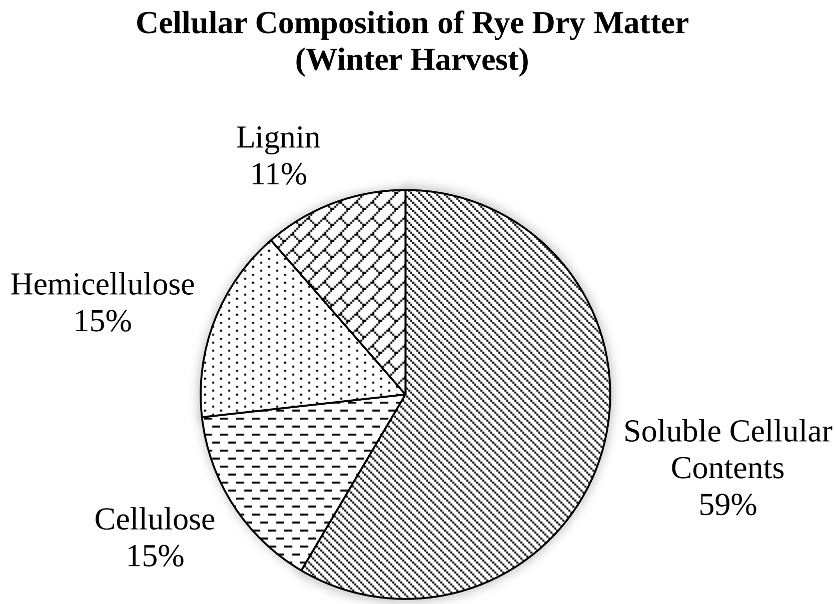


Figure A.1 Changes in cellular composition between winter and spring harvests of annual ryegrass dry matter.



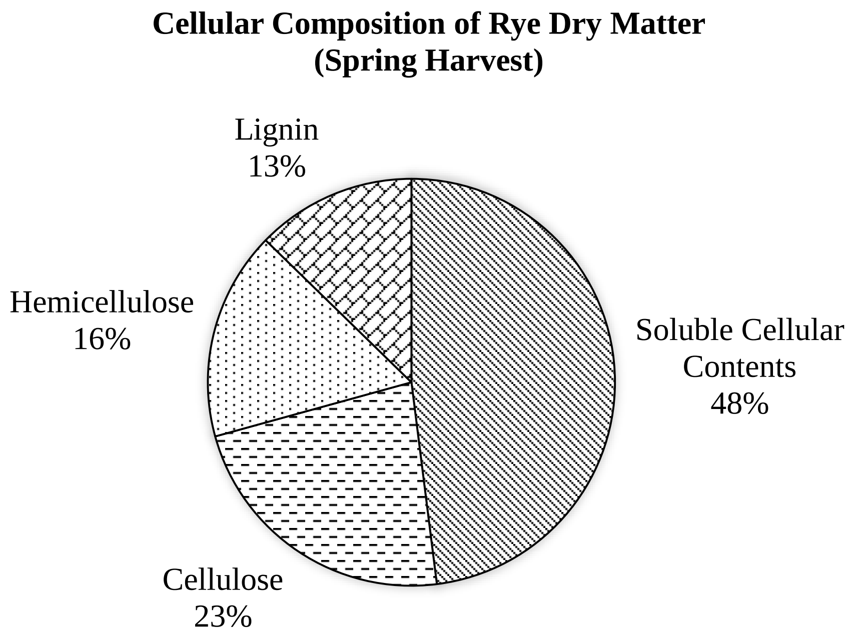
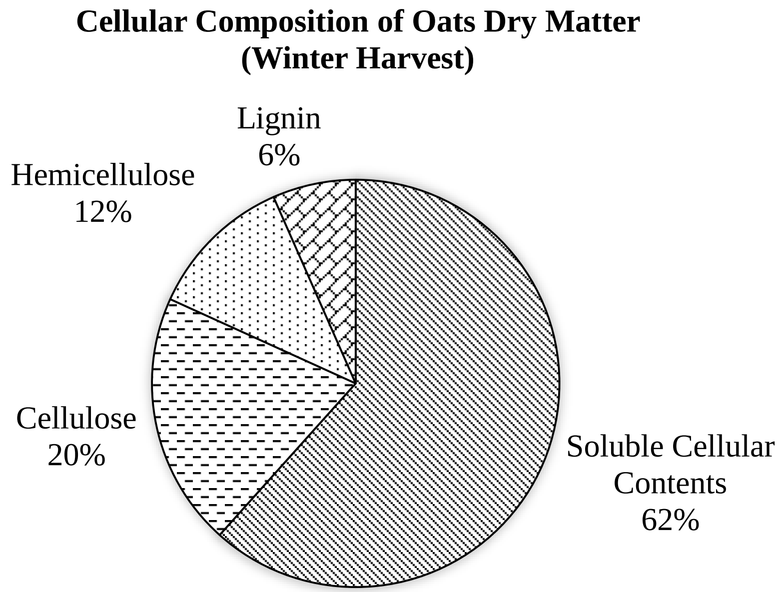


Figure A.2 Changes in cellular composition between winter and spring harvests of rye dry matter.



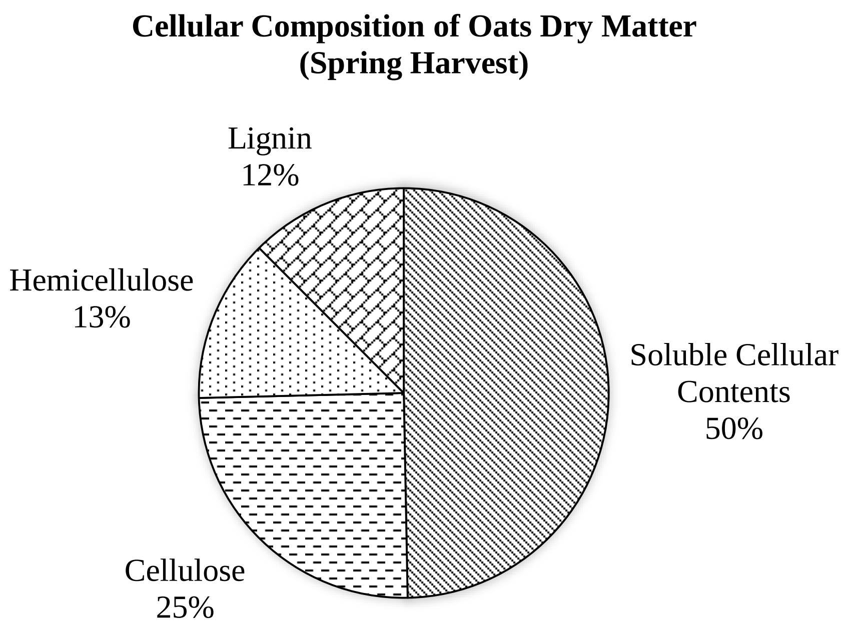
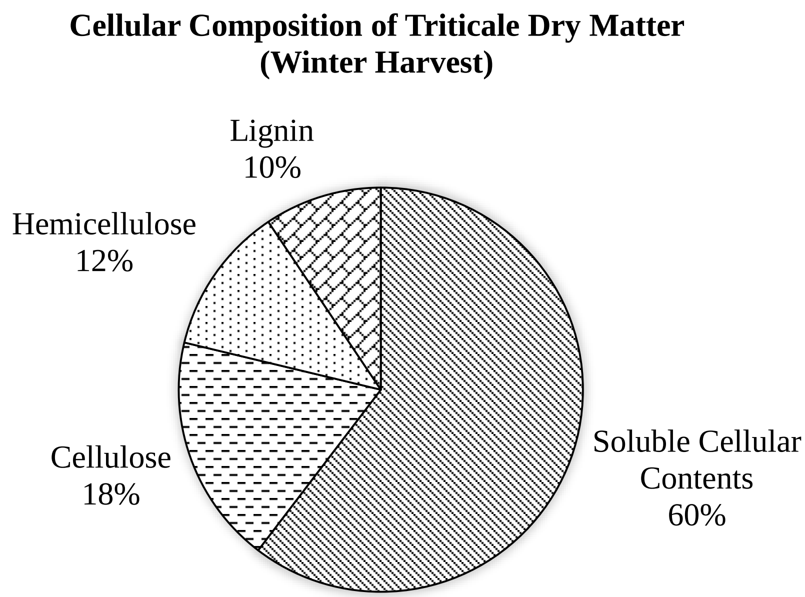


Figure A.3 Changes in cellular composition between winter and spring harvests of oats dry matter.



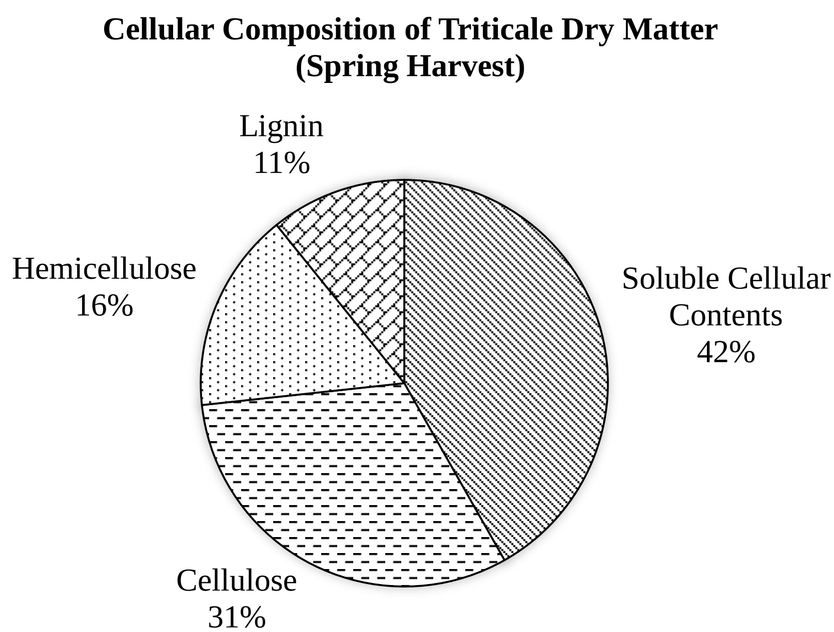
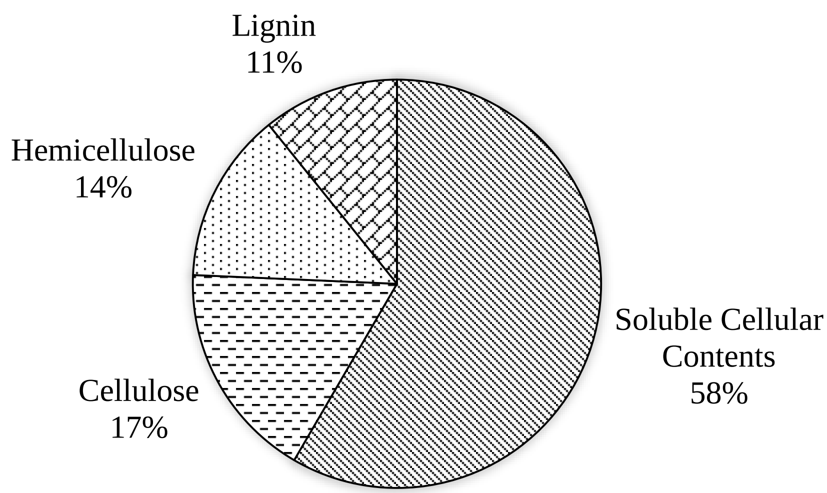


Figure A.4 Changes in cellular composition between winter and spring harvests of triticale dry matter.

Cellular Composition of Crimson Clover Dry Matter (Winter Harvest)



Cellular Composition of Crimson Clover Dry Matter (Spring Harvest)

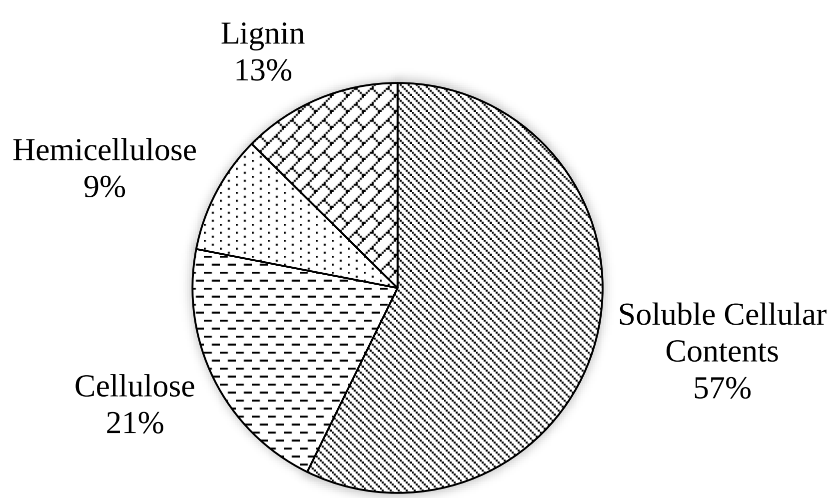
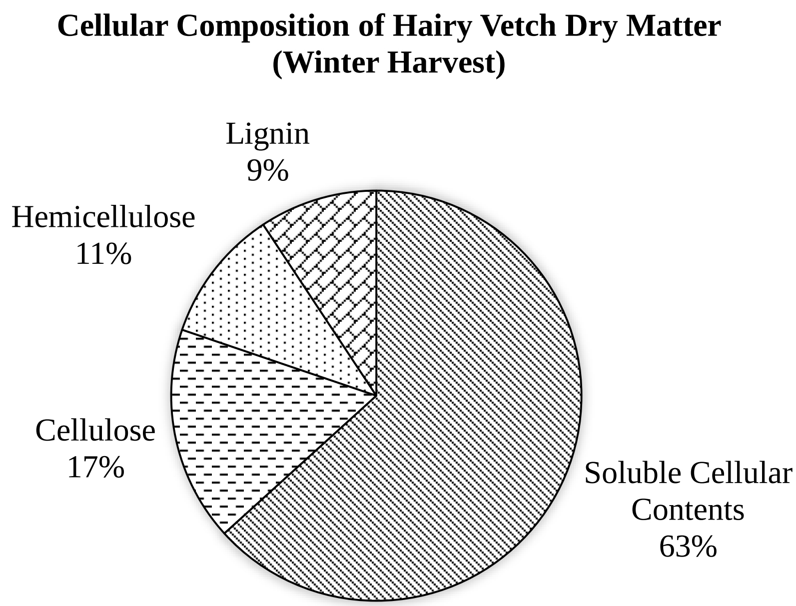


Figure A.5 Changes in cellular composition between winter and spring harvests of crimson clover dry matter.



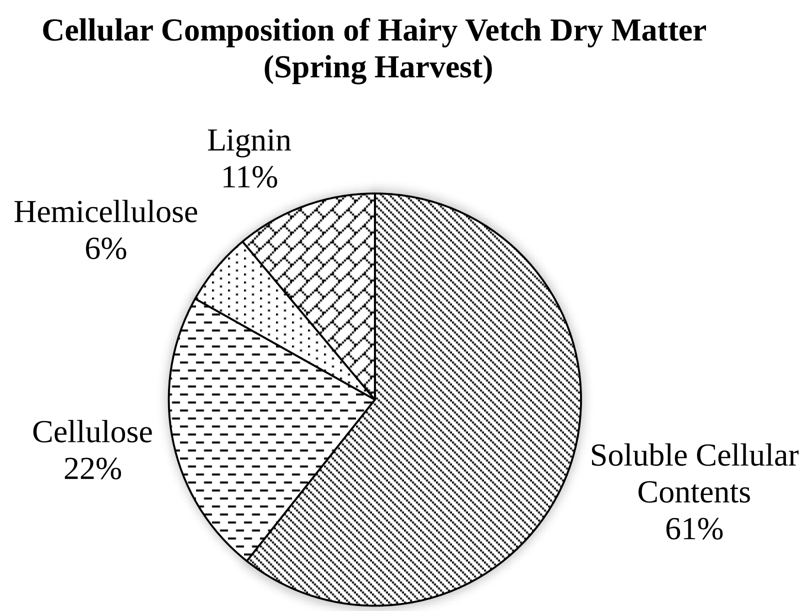
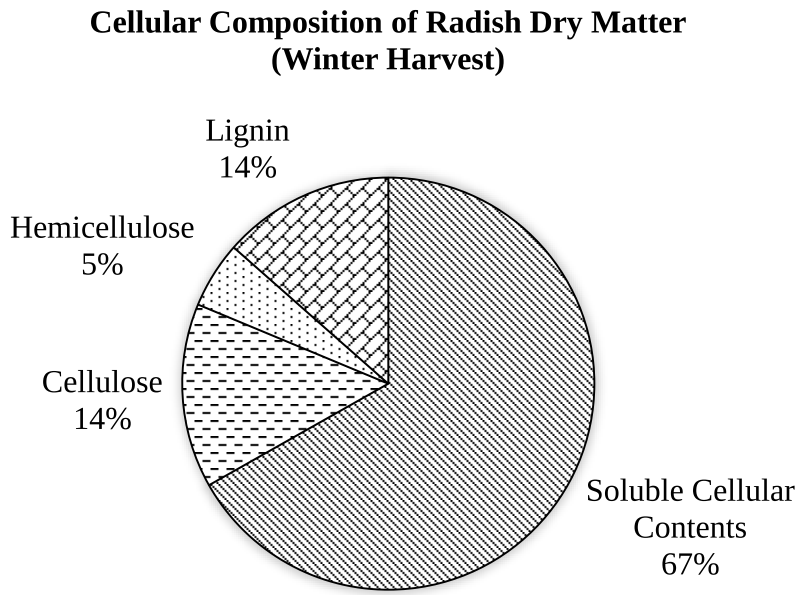


Figure A.6 Changes in cellular composition between winter and spring harvests of hairy vetch dry matter.



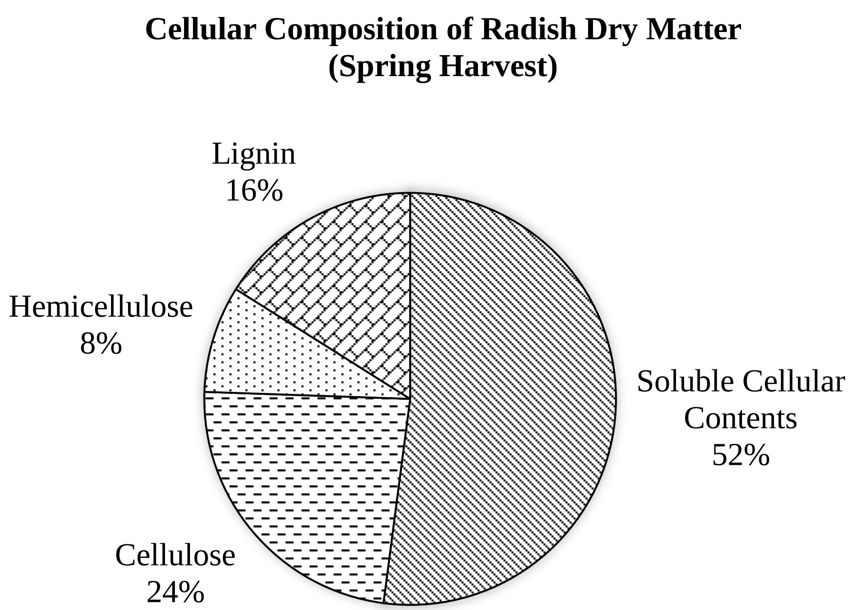


Figure A.7 Changes in cellular composition between winter and spring harvests of radish dry matter.

Vita

Dustin Smith is a native of Baton Rouge, Louisiana, U.S. He received a Bachelor of Arts in creative writing with a minor in philosophy from Louisiana State University in 2009. He hopes to earn his Master of Science degree in forage agronomy from Louisiana State University in December of 2016. Upon graduation, Dustin will seek a career in which he can best employ his knowledge of forages while further expanding his understanding of sustainable agriculture.