

Cool-season annual cover crop species and dual-use forage cover crops
in no-till Tennessee production systems

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Abstract

The benefits of including a cover crop within corn and soybean production systems has been well-documented. However, there are many cover crop species which have not been examined for their suitability to Tennessee production systems. The objectives of this study were to 1) compare regional adaptability and impact on soil attributes and cash crop effects of select cover crop species and, 2) evaluate the forage quality and impact on soil attributes, and cash crop effects of using these cover crops as a spring forage. Sixteen cool-season annual species including legumes, cereals, and brassicas were evaluated for two seasons at three University of Tennessee AgResearch centers: East Tennessee Research and Education Center (ETREC), Middle Tennessee Research and Education Center (MTREC), Research and Education Center at Milan (RECM). Two cash crop rotations were used to represent common production systems in the Mid-South: soybean / cover crop / corn (S/cc/C) and soybean / cover crop / soybean (C/cc/S). Two management systems were included in this study: dual-use (cover crop harvested prior to cash crop planting) and single-use (cover crop chemically terminated before cash crop planting). Forage plots were only included at ETREC and MTREC. Cover crops were established at two different times in the fall and were evaluated for cover crop performance (ground cover, biomass at termination), forage value (yield, quality), soil attributes (nutrients, pH, cation exchange capacity, moisture), and cash crop value (yield, quality). Cereals were a better fit in the S/cc/C rotation, as these species produced greater season-long ground cover and biomass at termination than the no-cover control. All species had good forage nutritive values in either crop rotation but covers in soybean/corn did not produce as much biomass as C/cc/S covers. The species produced 1936 to 3880 kg ha⁻¹ of biomass and could be used as a spring forage in the C/cc/S rotation. No significant soil attribute or cash crop effects were observed.

Through these studies, cover crop species were identified that are adapted to Tennessee corn/soybean and soybean/corn rotation systems and dual-use cover cropping was determined to provide high-quality forage without reducing short-term ecological benefits of cover cropping.

Table of Contents

List of Tables	vii
List of Figures	viii
Introduction.....	1
Ecological Benefits	1
Cover Crop Species.....	3
Regional Adaptation.....	5
Cost of Cover Crop Utilization	5
Dual-use Cover Crop.....	6
References	8
Chapter 1: Cover Crop Species Adaptation	10
Abstract	11
Introduction	12
Objective	15
Materials and Methods	16
Statistical Analysis	20
Results	21
Cover Crop Growth and Biomass.....	21
Soil Attributes and Cash Crop	23
Discussion	24
Tables and Figures	27
References	38
Chapter 2: Dual-use Forage Cover Crops.....	40
Abstract	41
Introduction	42
Objective	45
Materials and Methods	46
Statistical Analysis	49
Results	50
Forage Yield and Nutritive Value	50
Soil Attributes and Cash Crop	52
Discussion	53
Tables and Figures	57

References	68
Conclusions.....	70
References	72
Vita.....	76

List of Tables

Table 1-1: Cover crop variety and seeding rate information.	27
Table 1-2: Plot establishment, sampling, and termination dates.	28
Table 1-3: Cover crop burndown applications by crop rotation, year, and location.	29
Table 1-4: P values for ground cover, biomass, and C:N according to Fisher's protected LSD...	30
Table 1-5: P values for soil health attributes according to Fisher's protected LSD.....	35
Table 1-6: P values for cash crop yield and quality according to Fisher's protected LSD.	37
Table 2-1: Cover crop variety and seeding rate information.	57
Table 2-2: Plot establishment, harvest, and termination dates.....	58
Table 2-3: P values for forage yield and nutritive values according to Fisher's protected LSD..	59
Table 2-4: Mean percent Ca, P, K, Mg, and ash in the S/cc/C rotation based on 100% dry matter.	61
Table 2-5: Mean ADF, NDF, K, and ash concentrations in the S/cc/C rotation.	62
Table 2-6: Mean percent Ca, P, K, Mg, and ash in the C/cc/S rotation based on 100% dry matter.	65
Table 2-7: Soil attribute P values according to Fisher's protected LSD.	66
Table 2-8: Cash crop yield and quality P values according to Fisher's protected LSD.	67

List of Figures

Figure 1-1: Mean digital image analysis (DIA) of percent cover crop ground cover in December within S/cc/C rotation.	30
Figure 1-2: Mean digital image analysis (DIA) of percent cover crop ground cover in February within S/cc/C rotation.	31
Figure 1-3: Mean digital image analysis (DIA) of percent cover crop ground cover at termination within S/cc/C rotation.	31
Figure 1-4: Cover crop biomass at termination in S/cc/C rotation.	32
Figure 1-5: Mean digital image analysis (DIA) of percent cover crop ground cover in December within C/cc/S rotation.	32
Figure 1-6: Mean digital image analysis (DIA) of percent cover crop ground cover in February within C/cc/S rotation.	33
Figure 1-7: Mean digital image analysis (DIA) of percent cover crop ground cover at termination within C/cc/S rotation.	33
Figure 1-8: Cover crop biomass at termination in C/cc/S rotation.	34
Figure 1-9: Mean C:N ratios from cover crop biomass in the C/cc/S rotation.	34
Figure 1-10: Mean water-extractable organic N from the soil after cover crops in the C/cc/S rotation sequences.	36
Figure 1-11: Mean soil Mn after cover crops in the C/cc/S rotation sequence.	36
Figure 2-1: Mean percent CP in dual-use cover crops in the S/cc/C rotation based on 100% dry matter.	60
Figure 2-2: Mean forage yield by species in C/cc/S rotation.	63

Figure 2-3: Mean percent CP in dual-use cover crops in the C/cc/S rotation based on 100% dry matter.	63
Figure 2-4: Mean percent ADF in dual-use cover crops in the C/cc/S rotation based on 100% dry matter.	64
Figure 2-5: Mean percent NDF in dual-use cover crops in the C/cc/S rotation based on 100% dry matter.	64

Introduction

Cover crops provide many beneficial ecosystem services such as reduced soil erosion (Fageria et al., 2005; De Baets et al., 2011; Kaspar and Bakker, 2015), reduced nitrate leaching (Fraser et al., 2013), carbon sequestration (Poeplau and Don, 2015), nitrogen fixation (Snapp et al., 2005), soil moisture conservation (Fageria et al., 2005), and weed suppression (Fageria et al., 2005; Baraibar et al., 2018). Cover crops are traditionally incorporated into the soil with tillage or terminated and left in the field as ground cover before cash crop planting. While cover crops have been studied a great deal, little research has been conducted on the full ecological impact and adaptation of these cover crop species in the Mid-South. Utilizing cover crops as forage could provide an additional benefit in the form of providing high-quality forage without negatively affecting cash crop performance for integrated crop/livestock producers in the Mid-South, (Sulc and Franzluebbers, 2014; Franzluebbers and Stuedemann, 2015). Further research is needed to examine whether this type of system would result in reduced ecological benefits. The goal of this study is to evaluate a variety of cover crop species for their value as a winter cover crop and potential as a dual-use cover crop/forage crop in the Mid-South.

Ecological Benefits

The benefits of cover crop use has been well-documented (Schipanski et al., 2014; Baraibar et al., 2018). Cover crops can affect erosion, nutrient management, water management, weed suppression, and other ecological processes. While each of these benefits can affect soil attributes and cash crop quality, some of these benefits are interrelated.

Erosion reduction

Erosion occurs when wind or rain gradually removes the topsoil. Cover crops alleviate erosion by providing ground cover during the months when cash crops are not in the field.

Erosion caused by rainfall can also lead to a decrease in water infiltration and an increase in nutrient runoff (Fageria et al., 2005). While aboveground biomass can reduce rain and wind erosion, cover crop roots also help reduce erosion, specifically species with finer root systems such as many of the cereals (De Baets et al., 2011).

Soil nutrition

Legume cover crops fix atmospheric nitrogen (N) through symbiotic relationships with rhizobia soil bacteria which can then be utilized by crop grown in conjunction or after the legume cover crops. Increased N from legumes can offset the amount of fertilizer N needed, which can reduce costs to producers (Snapp et al., 2005). However, this benefit may not be seen immediately (Kaye and Quemada, 2017). Residues from cereal cover crops can increase soil organic carbon (C) but may immobilize N (Reberg-Horton et al., 2012). After several years of cover crop use, soil organic C stocks in no-till corn and soybean systems has been shown to increase in some environments (Olson et al., 2014). Loss of soil organic C negatively effects soil properties such as water infiltration, soil aggregation, and soil microbe activity (Ruis and Blanco-Canqui, 2017).

Water management

Cover crops prevent nutrient leaching by reducing erosion and through scavenging of excess nutrients. This is beneficial to the environment because these nutrients are prevented from moving into groundwater and in turn contaminating streams, rivers, and lakes (Reberg-

Horton et al., 2012). Studies have shown that cover crops increase infiltration rate and soil moisture, thereby potentially reducing future drought stress (Dunn et al., 2016).

Weed suppression

Cover crops also help to reduce weed occurrence by competing for nutrients and light (Hartwig and Ammon, 2002; Baraibar et al., 2018). Reduction in the occurrence of weeds can reduce costs by decreasing pesticide applications (Snapp et al., 2005; Schipanski et al., 2014).

Biogeochemical processes

Cover crops are capable of sequestering soil organic carbon, which can compensate for as much as 8% of greenhouse gases directly from agricultural emissions (Poeplau and Don, 2015). Cover crops can potentially contribute to local temperature increases during winter months when snow covers the ground (Lombardozzi et al., 2018). Leafy cover crops shade out portions of the field, causing heat from the sun to be absorbed rather than reflected by the snow, causing an increase in local temperature by as much as 3°C. This local warming can increase soil temperature, making earlier planting in the spring possible.

Cover Crop Species

Not all cover crops are the same. Therefore, it is important to consider which types of cover crops give which benefits, and the associated disadvantages. Commonly used cover crops can be grouped into cereals, legumes, or brassicas. Each of these groups differ physiologically and have different advantages/disadvantages for cropping systems. Cereals are commonly planted as cover crops and many are used as a forage crop as well, as they are relatively inexpensive, cold tolerant, and produce high biomass (Kaspar and Bakker, 2015). Cereal cover crops can also be harvested or grazed as a forage crop (Sulc and Franzluebbers, 2014). Cereals

have been used as cover crops to reduce nutrient leaching and erosion, such as NO_3^- (Fageria et al., 2005). However, cereals grown before other grass-family crops (such as corn) can be a source of pathogens which can affect corn seedling germination and growth (Schenck et al., 2017).

Legumes are commonly used as cover crops due to their ability to provide N through a symbiotic relationship with N-fixing rhizobia bacteria in the soil. Results have varied as to whether legume cover crops provide an increase of N availability to cash crops (Coombs et al., 2017); however, many studies have shown that leguminous cover crops increase available soil N (Snapp et al., 2005; Ketterings et al., 2015). It has been reported that the potential of legume cover crops to increase available N depends on environmental factors, such as climate and soil type, and its effect on biomass accumulation rather than species (Coombs et al., 2017). Legume seed is typically more expensive than other types of cover crops, but with the potential decrease in the amount of mineral N required, these species could offset this disadvantage. Legumes also should typically be inoculated with the correct N fixing bacteria, which is an additional expense (Fageria et al., 2005).

Brassicas produce a taproot which can break up the subsoil, increasing soil aeration and allowing water and nutrients to be more readily available in the soil (Chen et al., 2014). Brassicas are beneficial in no-till systems because they may mitigate some of the negative effects of compaction, thereby benefiting successive cash crops. Brassicas could potentially increase available N in the soil by scavenging and retaining the N (Dean and Weil, 2009; Gieske et al., 2016). However, it must be noted that N will gradually become available as the cover crop residue decomposes, which could lead to the N not being readily available when the cash crop needs it most. (Gieske et al., 2016). Brassicas can contain allelopathic compounds which are

toxic to some weeds, insects, and nematodes (Haramoto and Gallandt, 2004). Some brassicas, such as radish, do not have very high cold tolerance, and decomposition is more rapid in colder temperatures, thereby reducing the amount of N that may have been scavenged (Thorup-Kristensen, 1994; Gieske et al., 2016).

Regional Adaptation

The most common cover crop species currently in use in the Mid-South are annual ryegrass (*Lolium multiflorum*), cereal rye (*Secale cereale*), wheat (*Triticum aestivum*), and crimson clover (*Trifolium incarnatum*) (Sulc and Franzluebbbers, 2014). Of these, cereal rye, wheat, and crimson clover are generally very successful (Franzluebbbers and Stuedemann, 2015). However, there are many more species in use as cover crops in other regions of the U.S. which could prove to be suitable to the Mid-south (Kaspar and Bakker, 2015; Appelgate et al., 2017).

Cost of Cover Crop Utilization

Although cover crops have the potential to decrease production costs by reducing herbicide or mineral nutrient application, cover crop establishment costs can still be high (Hartwig and Ammon, 2002; Coombs et al., 2017). These costs can be broken down into direct and indirect costs. The main direct cost of cover crops is establishment. Some cover crops cost more than others due to the physiological attributes of the crop, such as legumes (Snapp et al., 2005). Cost of establishing cover crops also include the equipment necessary to plant these crops, fertilization, tillage, and irrigation should the cover crops require these inputs.

Indirect costs of utilizing cover crops pertain to cash crop establishment and growth. Cover crops could potentially limit the establishment of cash crops in some circumstances, such as reduced N availability, issues with cover crop persistence, and delayed soil warming (Snapp et al., 2005). Nitrogen within cover crop residues will gradually become available as the residues

decompose and the C/N ratio decreases, so the N may not be available to the cash crop within the first two months after termination (Snapp and Borden, 2005). Some cover crops have been shown to shade the soil, hindering soil warming, and can negatively affect the germination of spring-planted cash crops (Snapp et al., 2005). Cover crop persistence and re-emergence can create issues with establishing cash crops along with additional economic costs to terminate the cover crops (Snapp et al., 2005).

Another cost associated with utilizing cover crops is the risk of disease. Cover crops can be a reservoir of inoculum that can affect subsequent cash crops. In corn, pathogens which affect seedlings can over-winter in cereal cover crops and carry over to corn if planted after cereal rye (Robertson et al., 2017). Soybean can also be affected by pathogens which over-winter in legume cover crops (Robertson et al., 2017). However, it was observed that cover crops can reduce the incidence of stalk rot in corn and white mold in soybean (Robertson et al., 2017).

Dual-use Cover Crop

While cover crops provide benefits to cash crop production systems, they also cost money to establish, and these benefits may not be observable in the short-term. However, there is potential to mitigate some of this through use of cover crops as dual-use forage crops. Cover crops present a viable option to integrated crop/livestock producers in the Mid-South due to the suitability for winter forage growth in the region (Franzluebbers, 2007; Sulc and Franzluebbers, 2014). Franzluebbers and Studemann found that grazing winter cover crops, specifically cereal rye and hairy vetch, in the Southeastern United States had no significant effect on soil microbial C and N mineralization while also exhibiting a positive effect on soil microbial biomass C in a no-till system after three years. Forage yields from this grazing study ranged from 2197 to 6007 kg ha⁻¹ for cereal rye and 2701 to 5705 kg ha⁻¹ for hairy vetch (2015). Studies in other regions of

the Midwest showed that species such as oats (*Avena sativa*) and forage radish (*Raphanus sativus*) planted as monocultures are a good quality late season forage (Hansen et al., 2013).

Cover crops can provide many benefits to producers and the environment. However, not all cover crops provide the same benefits. Cereals, legumes, and brassicas all have advantages and disadvantages unique to each group, and it is important to know what benefits will be gained by using each type of cover crop functional group as well as which species are regionally adapted within each group. It is also important to know the cost of using cover crops, such as establishment cost and potential negative effects to production systems such as reemergence. There is a potential to offset costs of using cover crops in integrated crop and livestock operations, as some cover crops have been found to produce high forage yields. Evaluating a range of cover group functional groups and species within those groups for regional adaptation, ecological benefits, costs associated with using cover crops, and alternative uses like harvesting as a forage will aid in developing recommendations that help producers maximize cover crop benefits within Mid-South corn and soybean production systems.

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Chapter 1: Cover Crop Species Adaptation

Abstract

Many cool-season annuals could be suitable for use as cover crops in no-till corn and soybean production systems in the Mid-South; however, a limited number have been evaluated in these systems. Suitability may also be dependent on the cover crop growing season, which varies in length based on the preceding/succeeding cash crop. Sixteen cool-season cereal, legume, and brassica species were evaluated at three Tennessee locations (Knoxville, Spring Hill, Milan), across two growing seasons (2017-2018, 2018-2019), and repeated under two rotations: soybean/cover crop/corn (S/cc/C) and corn/cover crop/soybean (C/cc/S). Treatments were arranged in randomized complete block design with three replications. Cover crops were evaluated for percent ground cover (Dec, Feb., at termination), biomass (termination), and carbon and nitrogen content (termination). Soil samples, taken two months after cash crop establishment, were analyzed for water-extractable organic nitrogen (WEON), water-extractable organic carbon, macro and micro-nutrients, pH, organic matter, and cation exchange capacity. Cash crops were evaluated for yield, oil, protein, and starch. In the S/cc/C rotation, triticale, wheat, oat, and barley had higher season-long ground cover and biomass at termination than the control. In the C/cc/S rotation, woolypod vetch, crimson clover, wheat, and triticale had higher season-long ground cover and biomass at termination than the control. Nitrogen content and WEON differed among cover crop species only in the C/cc/S rotation. Species did not differ by cash crop yield or quality in either rotation. These results will aid producers in selecting species best adapted to cash crop rotations in the Mid-South.

Introduction

Cover crops provide many benefits to corn and soybean production systems, including reduced soil erosion, better nutrient and moisture retention, increased nitrogen (N), sequestration of carbon (C), reduced soil compaction, and weed suppression (Snapp et al., 2005; Schipanski et al., 2014; Baraibar et al., 2018). Cover crops have been integrated into some no-till production systems throughout Tennessee for several decades. However, the number of species which are widely used is relatively limited. Several species are commonly used as cool-season cover crops in the Mid-South (Sulc and Franzluebbbers, 2014; Franzluebbbers and Stuedemann, 2015); however, there are many more species used in other parts of the country which could be suitable for Mid-South production systems (Kaspar and Bakker, 2015; Appelgate et al., 2017). The most common cover crop species currently in use in the Mid-South are *Lolium multiflorum* (annual ryegrass), (*Secale cereale*), wheat (*Triticum aestivum*), and crimson clover (*Trifolium incarnatum*)(Sulc and Franzluebbbers, 2014; Franzluebbbers and Stuedemann, 2015).

Cover crops typically are from one of three functional groups: cereal, legume, or brassica. Each group has advantages and disadvantages, so knowing what to expect from these groups is important in evaluating cover crops for their usefulness in crop production systems. Cereals are commonly planted as cover crops as they are cheap, cold tolerant, and produce a lot of biomass (Kaspar and Bakker, 2015). Cereals can also reduce erosion and nutrient leaching such as NO_3^- (Fageria et al., 2005). Cereals grown before corn can be a source of pathogens which can effect corn seedling germination and growth (Schenck et al., 2017).

Legumes are commonly used as cover crops due to their relationship with N-fixing rhizobia bacteria which live in the soil. Results have varied as to whether legume cover crops provide an increase of N availability to cash crops (Coombs et al., 2017); however, many studies

have shown that leguminous cover crops increase available soil N (Snapp et al., 2005; Ketterings et al., 2015). It was found that the potential of legume cover crops to increase available N depended on environmental factors, such as climate and soil type, rather than species (Coombs et al., 2017). Legumes can also be more expensive than other types of cover crops, but with the potential decrease in the amount of mineral N required, these species could offset this disadvantage. Legumes also should be inoculated with the correct N fixing bacteria, which is an additional expense and requires time before planting (Fageria et al., 2005).

Brassicas produce a taproot which can break up the subsoil, increasing soil aeration and allowing water and nutrients to be more readily available in the soil (Chen et al., 2014). Brassicas are beneficial in no-till systems because they may mitigate some of the negative effects of compaction, thereby benefiting successive cash crops. Brassicas could potentially increase available N in the soil by scavenging and retaining the N (Dean and Weil, 2009; Gieske et al., 2016). However, it must be noted that N will gradually become available as the cover crop residue decomposes, which could lead to the N not being readily available when the cash crop needs it most. (Gieske et al., 2016). Brassicas can contain allelopathic compounds which are toxic to some weeds, insects, and nematodes (Haramoto and Gallandt, 2004). Some brassicas, such as radish, do not have very high cold tolerance, and decomposition is more rapid in colder temperatures, thereby reducing the amount of N that may have been scavenged (Thorup-Kristensen, 1994; Gieske et al., 2016).

The dominant two cash crops in the Mid-South are corn and soybean, and these crops are commonly rotated with each other. These crops have different planting and harvesting timing. Corn is typically planted in early to mid spring and harvested around early to mid fall. Soybean, on the other hand, is typically planted in late spring-early summer and harvested in mid to late

fall. Because of these different timings, there are differences in the growing season for cover crops. If cover crops are going in after corn, then there will be about a month and half of additional growing time compared to cover crops going in after soybean. Likewise, if cover crops are terminated prior to soybean, they will have several weeks additional growing time in the Spring compared with termination prior to corn.

By having access to multiple species, farmers could select species which better fit their crop rotation and site environmental conditions. For a species to work well as a cover crop in a given region, the species must be capable of producing enough biomass to provide the benefits associated with cover crops. These species must also be able to survive through the winter and have adequate biomass and ground cover throughout the cover crop growing season to be a functional cover crop. Additionally, potential changes to soil health and cash crop yield and quality are factors in determining if a species is a good cover crop. The objective of this study is to determine the regional adaptation of several cool-season cereals, legumes, and brassicas and their suitability to no-till corn / cover crop / soybean and soybean / cover crop / corn production systems.

Objective

Compare regional adaptation, impact on cash crop yield and quality, and ecological impacts among sixteen cool-season annual cover crop monocultures under two crop rotation systems (corn/cover crop/soybean and soybean/cover crop/corn).

Materials and Methods

Plots were established at three locations in Tennessee: the Plant Sciences Unit of the East Tennessee Research and Education Center (ETREC) in Knoxville, TN (35.892495, -83.959613), Middle Tennessee Research and Education Center (MTREC) in Spring Hill, TN (35.721164, -86.964894), and the Research and Education Center at Milan (RECM) in Milan, TN (35.933423, -88.706431). Soil types differed between all three locations: Sequatchie loam (fine-loamy, siliceous, semiactive, thermic Humic Hapludult) at ETREC, Maury silt loam (fine, mixed, active, mesic Typic Paleudalf) at MTREC, and Lexington silt loam (fine-silty, mixed, active, thermic Ultic Hapludalf) at RECM. Plots were no-till drilled at each location with a row spacing of 19-cm (Table 1-1). Plots were planted 3.05×9.14 m at ETREC and MTREC and 3.66×9.14 m at RECM. After emergence, the ETREC plots were trimmed to 7.62 m long and MTREC plots were trimmed to 8.23-m long.

Treatments included sixteen cool-season annual or biennial cover crop species species evaluated under two crop rotation systems: soybean / cover crop / corn (S/cc/C) and corn / cover crop /soybean (C/cc/S) over two season (2017-2018, 2018-2019). Plots which were S/cc/C in year one were C/cc/S in year two and vice versa. Species which were evaluated included wheat (*Triticum aestivum*), cereal rye (*Secale cereale*), barley (*Hordeum vulgare*), oat (*Avena sativa*), triticale (*Triticosecale*), crimson clover (*Trifolium incarnatum*), arrowleaf clover (*T. vesiculosum*), berseem clover (*T. alexandrinum*), red clover (*T. pratense*), common vetch (*Vicia sativa*), hairy vetch (*V. villosa*), woolypod vetch (*V. villosa* Roth ssp. *dasycarpa*), Austrian winter pea (*Pisum sativum* subsp. *arvense*), canola (*Brassica napus*), forage radish (*Raphanus sativus* var. *oleiformis*), and purple-top turnip (*B. rapa* subsp. *Rapa*). Additionally, a no cover crop treatment was included as the control. Seeding rates followed the University of Tennessee

recommendations (Bates, et al., 2016) (Table 1-1). Cover crop termination occurred in March for the S/cc/C rotation and in April for the C/cc/S rotation (Table 1-2).

Three time periods were selected to represent cover crop growth throughout the season: December for fall growth, February for winter growth, and termination for spring growth. At each time point, photographs of a randomly selected 0.09 m² area of each plot were taken and analyzed for percent green ground cover using the Canopeo software developed at Oklahoma State University. Prior to termination, cover crop biomass from a randomly selected 0.09 m² area of each plot was trimmed and collected in paper bags. These biomass samples were weighed, dried at 65°C for 72 hours, then weighed again to calculate dry matter. Subsamples from the dried biomass were taken and ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) using a 1-mm screen. The ground samples were processed using a dry combustion C:N analyzer (Flash EA1112, CE Cleantech, NJ, USA) to determine C, N, and C:N ratio within the aboveground cover crop biomass. Berseem clover and no cover control plots were excluded from this as these plots were composed of only weeds.

All plots were sprayed with a non-selective herbicide 3-5 weeks prior to cash crop planting (Table 1-3). Cover crops were terminated in mid-April for the S/cc/C rotation, and in late April for the C/cc/S rotation (Table 1-2). Cash crops were planted in 76.2 cm rows using a four-row no-till planter. Corn (Terrel REV 23HR55) was planted at a seeding rate of 84,000 seeds per hectare in late April to early May, and soybeans (Terrel 45L57) were planted at a rate of 347,000 seeds per hectare from mid to late May (Table 1-2). The soybean variety used the first year was unavailable the second, so a new variety (Credenz 4548 LL) was used in year two. The corn and soybean used were both Liberty Link, which confers tolerance to the herbicide glufosinate [2-amino-4-(hydroxy[methyl]phosphoryl)butanoic acid]. Corn and soybean plots

were fertilized with P and K according to soil tests taken from fallow plots. All corn plots were fertilized with 89.67 kg ha⁻¹ N soon at planting. A side dressed application of N at a rate of 179 kg ha⁻¹ was applied in the corn 5 to 6 weeks after planting. A post-emergent herbicide (glufosinate and S-metolachlor) was applied 3 to 5 weeks after planting.

Two months after cash crop planting, ten 15-cm deep soil core samples per plot were collected and sent to Brookside Laboratories (New Bremen, OH, USA) for analysis. Soil characteristics measured included water extractable organic carbon (WEOC), water extractable organic nitrogen (WEON), C/N ratio, total exchange capacity (CEC), pH, organic matter (OM), estimated N release, and macro and micronutrients. Soil samples were air dried, ground, then sieved for <2mm particles. Samples for WEON and WEOC weighing 2 g were extracted with 20 ml of deionized water and shaken for 10 minutes. These samples were then filtered through Whatman 2 filter paper and the water extract was analyzed using a Teledyne-Tekmar Torch C:N analyzer (Teledyne-Tekmar, Mason, OH, USA). Samples for N-P-K and micronutrients were extracted with 40 ml of H₃A, shaken for 10 minutes, then filtered with Whatman 2 filter paper. The extract was then analyzed for NO₃, NH₄, and PO₄ using a FIAlyzer-1000 flow injection analyzer (FIALab, Seattle, WA, USA). The extract was also analyzed for P, K, S, Mg, Ca, B, Na, Zn, Fe, Mn, Cu, and Al using a Thermo Scientific ICP-OES (Thermo Fisher Scientific, Waltham, MA, USA).

Corn harvest occurred from early September to early October, and soybean harvest occurred from early to late October (Table 1-1). Total plot weight and moisture were taken at harvest. Plot weights were adjusted to standard crop moisture (corn: 15.5%, soybean: 13%) and converted to a per ac value. A grain sample weighing approximately 0.45 kg was collected from each plot at harvest. Near-infrared spectroscopy (NIRS) using an Infratec 1229 grain analyzer

(Foss North America, Eden Prairie, MN) was used to assess soybean oil and protein and corn oil, protein, and starch content.

Statistical Analysis

An analysis of variance was performed using the glimmix procedure in SAS 9.4 (Cary, NC). Fisher's Protected LSD was used to find mean separations. A P-value of less than 0.05 was used to determine statistical significance. Analysis were performed separately for each rotation (C/cc/S and S/cc/C). Independent variables were analyzed separately and included cover crop ground cover (December, February, termination), cover crop biomass (termination), soil health attributes, and cash crop yield and quality. Species was the only fixed effect. Random effects for this model were year, location, and replication.

Results

Cover Crop Growth and Biomass

Soybean / cover crop / corn

Within the S/cc/C rotation, significant differences among species were observed at each of the three time points for percent ground cover and final biomass; however, N, and C:N at termination were not significant (Table 1-4). Mean ground cover percentages ranged from 0 to 23% in Dec. (Figure 1-1), 0 to 29% in Feb. (Figure 1-2), and 0 to 57% at termination (Figure 1-3). All cereal species provided ground cover greater than the control at each of the three timepoints (Dec., Feb., termination) (Figure 1-1, Figure 1-2, Figure 1-3). None of the legume and brassica species provided significant ground cover in Dec. (Figure 1-1) or Feb. (Figure 1-2). However, by spring termination, crimson clover, hairy vetch, woolypod vetch, and winter pea exceeded the no cover control (Figure 1-3). None of the brassica species exceeded percent cover of the control at any time point.

Cover crop biomass in the S/cc/C rotation was taken in late and ranged from 355 to 2182 kg ha⁻¹ (Figure 4). Wheat (2108 kg ha⁻¹), oat (1596 kg ha⁻¹), crimson clover (1453 kg ha⁻¹), barley (1425 kg ha⁻¹), and triticale (1383 kg ha⁻¹) produced significantly higher biomass than the no-cover control (419 kg ha⁻¹). Biomass from all other species were not significantly different from the control.

Corn / cover crop / soybean

Within the C/cc/S rotation, cover crop species differed significantly for percent ground cover at each of the three time points (Dec., Feb., termination) and for biomass, N, and C:N at termination (Table 1-4). Mean ground cover percentages ranged from 0 to 61% in Dec. (Figure 1-5), 0 to 49% in Feb. (Figure 1-6), and 0 to 91% at termination (Figure 1-7). All cereal species

exceeded percent ground cover in the no cover control in Dec. (Figure 1-5). Of the legumes, only crimson clover and woolypod vetch also exceeded the control at that time point. Forage radish was the only brassicas to exceed the control (Figure 1-5). Most of the cereals (wheat, triticale, cereal rye) and some legumes (crimson clover, hairy vetch, woolypod vetch) continued to provide ground cover greater than the control into Feb., while the brassica species dropped back due to winter kill (Figure 1-6). By spring termination, most legume species exceeded the no cover control and had produced considerable ground cover (45 to 91% cover). These include crimson cover, hairy vetch, woolypod vetch, winter pea, and arrowleaf clover. However, the brassicas continued to perform poorly. Triticale, wheat, and oat were the only cereals to provide cover greater than the control at termination (Figure 1-7).

Biomass within the C/cc/S rotation was taken in mid-April and ranged from 592 to 3197 kg ha⁻¹ (Figure 1-8). Some species from within each functional group exhibited significantly higher biomass than the no cover control. These included crimson clover (3197 kg ha⁻¹), hairy vetch (3187 kg ha⁻¹), woolypod vetch (3004 kg ha⁻¹), and winter pea (2577 kg ha⁻¹) within the legumes, wheat (3101 kg ha⁻¹), triticale (2851 kg ha⁻¹), oat (2679 kg ha⁻¹), and cereal rye (2336 kg ha⁻¹) within the cereals, and canola (2579 kg ha⁻¹) within the brassicas. Biomass from all other species were not significantly different from the control, which consisted of winter weeds (460 kg ha⁻¹). Berseem clover plots were composed of only weeds; therefore, those plots were excluded from further analysis.

Cover crop biomass C:N ratio differed significantly by species ranging from 11.8 to 38.5 (Figure 1-9). Legumes generally had lower C:N ratios (11.8 to 18.0), cereals generally had lower higher C:N ratios (23.5 to 38.5), and brassicas were generally intermediate statistically between legumes and cereals in C:N ratio (17.4 to 26.7).

Soil Attributes and Cash Crop

No significant differences among species were observed in the soil attributes or cash crop yield and quality within the S/cc/C rotation. In the C/cc/S rotation, WEON and Mn did exhibit significant differences among species (Table 1-5). While no species increased soil WEON relative to the control, oat and cereal rye did exhibit a significant decrease (Figure 1-10). Mn was significantly different among some of the species which generally produced more biomass (Figure 1-11). While a select few of species were significantly higher in Mn than the control, most species were not significantly different from one another. No other measured soil health characteristics, cash crop yield or quality characteristics were found to differ significantly among species (Table 1-6).

Discussion

It is important to select a cover crop species which will provide adequate ground cover throughout the growing season and produce adequate biomass to act as a mulch and/or nutrient source during the early stages of cash crop growth. Optimum cover crop species selection was dependent on the cash crop rotation with which it was grown. Cover crop species which provided significantly more ground cover than the no cover control throughout the S/cc/C cover crop growing season were triticale, wheat, cereal rye, and oat, while in the C/cc/S rotation, these were woolypod vetch, crimson clover, and triticale.

Although several legume species provided significant cover by termination in the S/cc/C rotation, none provided significant biomass at termination, which would limit the N credit gained in the succeeding corn crop. More legume species were adapted to the early planting and later termination of a C/cc/S system, however, an N credit in this rotation is less beneficial. These results suggest a need to screen a larger number of legume species and genotypes within species for adaptation to Mid-South S/cc/C rotations.

Cover crop species did differ in terms of C:N ratio from the cover crop biomass within both rotations, illustrating the importance of cover crop growth stage in determining appropriate cash crop nutrient management after a cover crop, as well as species selection. Cover crops in the S/cc/C rotation were in late vegetative stages and cover crops in the C/cc/S rotation were in early bloom or early reproductive stages. The C:N ratio will increase as cover crops mature into reproductive stages and begin producing seed heads or flowers. This aligns with previous research which concluded that later termination of cover crops reduced available N and in turn increases the C:N ratio (Wayman et al., 2015).

Soil attributes were not different in the S/cc/C rotation but did differ in the C/cc/S rotation. This is likely because of the longer cover crop growing season under the C/cc/S rotation, which allowed greater cover crop biomass accumulation. In the C/cc/S rotation, oat and cereal rye reduced WEON compared to the no cover control. While this did not hurt yields since these cover crops preceded a nitrogen-fixing cash crop, this could be problematic for non-legume cash crops in a similar rotation timing. This study examined soil attributes two months after cash crop planting; however, past research has shown that peak nutrient availability is seen approximately 2 to 6 weeks after termination (Wyland et al., 1996; Hu et al., 1997; Parr et al., 2014). Expanding this study to include more soil sampling dates between termination and two months after cash crop planting could give a clearer picture of differences in nutrient release between these two rotations.

It was not surprising to find no significant differences in cash crop yield, as previous short-term studies show similar results (Reddy, 2001; Ruffo et al., 2004). Corn plots were fertilized with the same N rate across all treatments, assuming no nitrogen credit, in order to provide an even playing field. As a result, N was not a limiting factor and is likely the reason no yield advantage from legumes was observed. This is contrast to previous research which concluded that corn yields increased after cover crop use in 2 of 3 years (Andraski and Bundy, 2005; Miguez and Bollero, 2005). However, this difference may be due to differences in cover crop growing season length, as these studies examined cover crops established in August and terminated in early May, giving the legume cover crops more time to establish before the winter and a longer period to grow in the spring.

Results from this study will help producers select cover crop species that are best adapted to their specific growing region and cash crop production system. These results also aid in better

understanding short term impacts of these species on nutrient dynamics under cash crop rotations that differ in cover crop planting/termination timing. Many of the species evaluated, such as cereal rye, oat, triticale, crimson clover, hairy vetch, and woolypod vetch, were well-suited for use within no-till C/cc/S rotations in the Mid-South. However, fewer species were found that offered both full season ground cover and adequate biomass at termination in the S/cc/C rotation. Future research to identify legume species and genotypes with greater cold hardiness could be beneficial to developing more diverse cover crop mixes that provide better nutrient benefits for Mid-South S/cc/C cash crop systems.

Tables and Figures

Table 1-1: Cover crop variety and seeding rate information.

Cover crop	Seeding rate (kg ha ⁻¹)	Planting depth (cm)	Variety	
			2017-2018	2018-2019
Clover, arrowleaf	11.21	1.27	Yucchi	VNS
Clover, berseem	13.45	1.27	VNS	VNS
Clover, crimson	28.03	1.27	Dixie	Dixie
Clover, red	11.21	1.27	VNS	VNS
Vetch, common	33.63	5.08	VNS	VNS
Vetch, hairy	33.63	5.08	VNS	VNS
Vetch, woolypod	33.63	5.08	Lana	Lana
Winter pea	56.05	5.08	VNS	VNS
Barley	168.15	5.08	Bob Winter	Bob Winter
Oat	168.15	5.08	Arivat	Secretaret
Triticale	168.15	5.08	Fridge	Fridge
Cereal rye	168.15	5.08	VNS	VNS
Wheat	201.78	5.08	Arthur	VNS
Canola	8.97	1.27	Edimax CL	Edimax CL
Forage radish	16.82	1.27	Torpedo	Torpedo
Turnip	6.73	1.27	Purple top white globe	Purple top white globe

Table 1-2: Plot establishment, sampling, and termination dates.

Year	Location	Growing season	Cover crops					Cash crops		
			Establishment	Dec. sample	Feb. sample	Term. sample	Termination	Planting	Harvest	Crop
2017-2018	ETREC	S/cc/C	10/27/17	1/7/18	3/6/18	4/11/18	4/18/18	5/7/18*	10/3/18	Corn
	MTREC		10/25/17	1/4/18	3/1/18	4/4/18	4/11/18	4/30/18	9/11/18	
	RECM		10/26/17	1/2/18	3/2/18	3/27/18	4/9/18	5/1/18	9/5/18	
	ETREC	C/cc/S	9/25/17	1/7/18	3/6/18	4/20/18	4/30/18	5/24/18	10/9/18	Soybean
	MTREC		9/25/17	1/4/18	3/1/18	4/18/18	4/27/18	5/11/18	10/22/18	
	RECM		9/26/17	1/2/18	3/2/18	4/23/18	4/30/18	5/1/18	10/3/18	
2018-2019	ETREC	S/cc/C	10/31/18	1/7/19	3/6/19	4/1/19	4/11/19	5/16/19*	9/18/19	Corn
	MTREC		10/24/18	1/3/19	3/1/19	3/28/19	4/2/19	4/18/19	9/19/19	
	RECM		10/30/18	1/4/19	3/2/19	3/28/19	3/29/19	4/17/19	9/5/19	
	ETREC	C/cc/S	10/12/18	1/7/19	3/6/19	4/15/19	4/24/19	5/9/19	10/2/19	Soybean
	MTREC		10/5/18	1/3/19	3/1/19	4/11/19	4/18/19	5/8/19	9/25/19	
	RECM		9/21/18	1/4/19	3/2/19	4/12/19	4/19/19	5/7/19	10/24/19	

Table 1-3: Cover crop burndown applications by crop rotation, year, and location.

Soybean/cover crop/Corn				Corn/cover crop/Soybean			
2018				2018			
Location	Active ingredient	Chemical	Rate liter ha ⁻¹	Location	Active ingredient	Chemical	Rate liter ha ⁻¹
ETREC	glyphosate	N-(Phosphonomethyl)glycine	1.7	ETREC	glyphosate	N-(Phosphonomethyl)glycine	1.7
	2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2		2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2
MTREC	glyphosate	N-(Phosphonomethyl)glycine	2.9	MTREC	glyphosate	N-(Phosphonomethyl)glycine	2.9
	2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2		2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2
RECM	glyphosate	N-(Phosphonomethyl)glycine	2.9	RECM	glyphosate	N-(Phosphonomethyl)glycine	2.9
	dicamba	3,6-dichloro-2-methoxybenzoic acid	1.2		glufosinate	2-amino-4-(hydroxy[methyl]phosphoryl)butanoic acid	2.3
2019				2019			
Location	Active ingredient	Chemical	Rate liter ha ⁻¹	Location	Active ingredient	Chemical	Rate liter ha ⁻¹
ETREC	glyphosate	N-(Phosphonomethyl)glycine	2.9	ETREC	glyphosate	N-(Phosphonomethyl)glycine	2.9
MTREC	glyphosate	N-(Phosphonomethyl)glycine	3.5	MTREC	glyphosate	N-(Phosphonomethyl)glycine	3.5
	2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2		2, 4-D	2,4-Dichlorophenoxyacetic acid	1.2
RECM	glyphosate	N-(Phosphonomethyl)glycine	2.9	RECM	N/A	N/A	N/A
	dicamba	3,6-dichloro-2-methoxybenzoic acid	1.2				

Table 1-4: P values for ground cover, biomass, and C:N ratio according to Fisher's protected LSD. P values less than 0.05 are significant.

Soybean/cover crop/Corn		Corn/cover crop/Soybean	
Variable	P value	Variable	P value
Dec. cover	0.000	Dec. cover	0.005
Feb. cover	0.000	Feb. cover	0.011
Term. cover	0.000	Term. cover	0.002
Biomass	1.024	Biomass	0.002
C:N ratio	0.065	C:N ratio	0.001

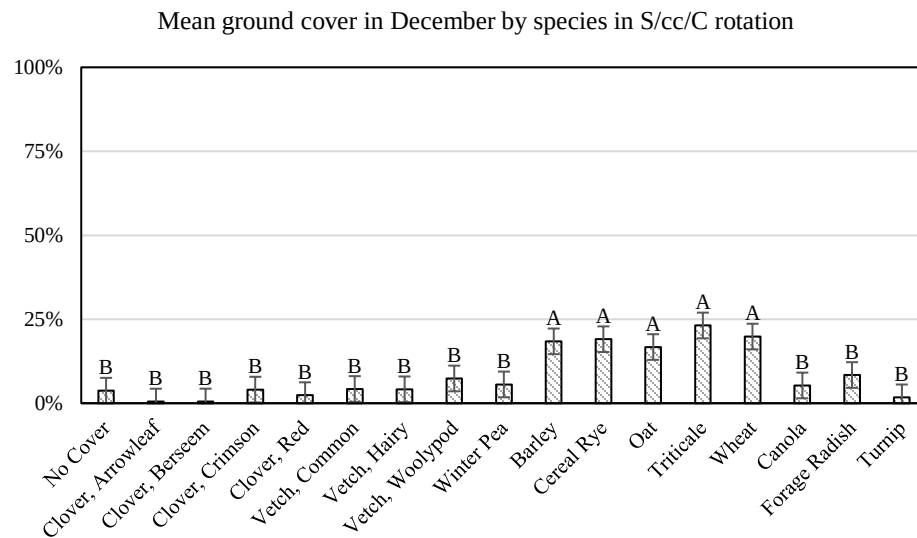


Figure 1-1: Mean digital image analysis (DIA) of percent cover crop ground cover in December within S/cc/C rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

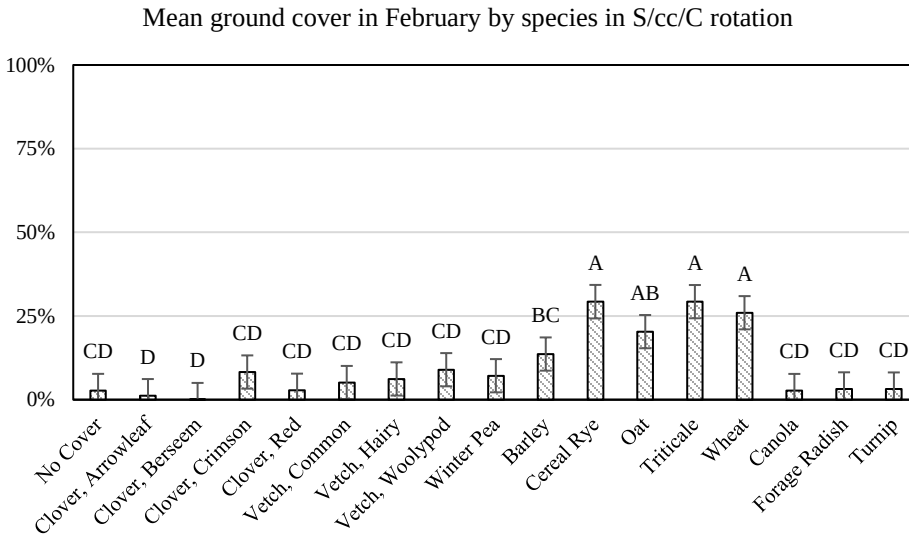


Figure 1-2: Mean digital image analysis (DIA) of percent cover crop ground cover in February within S/cc/C rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

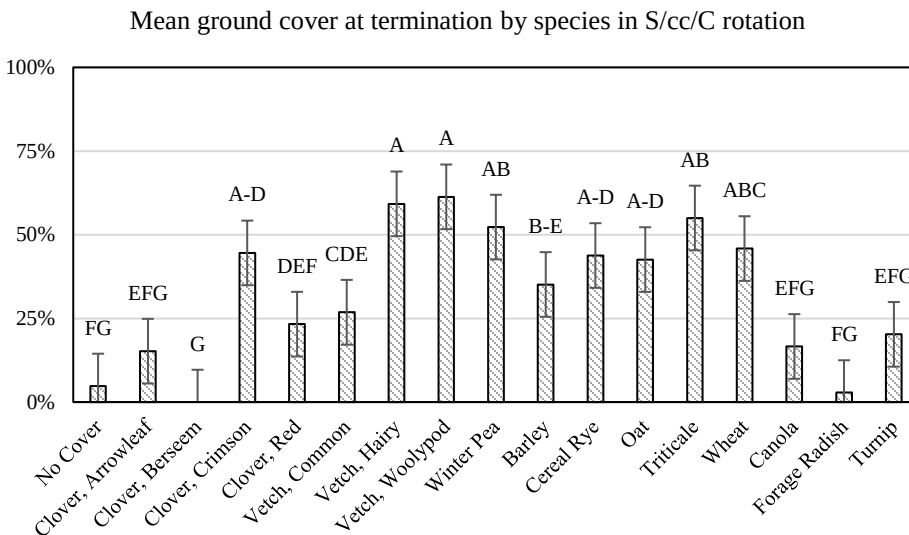


Figure 1-3: Mean digital image analysis (DIA) of percent cover crop ground cover at termination within S/cc/C rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

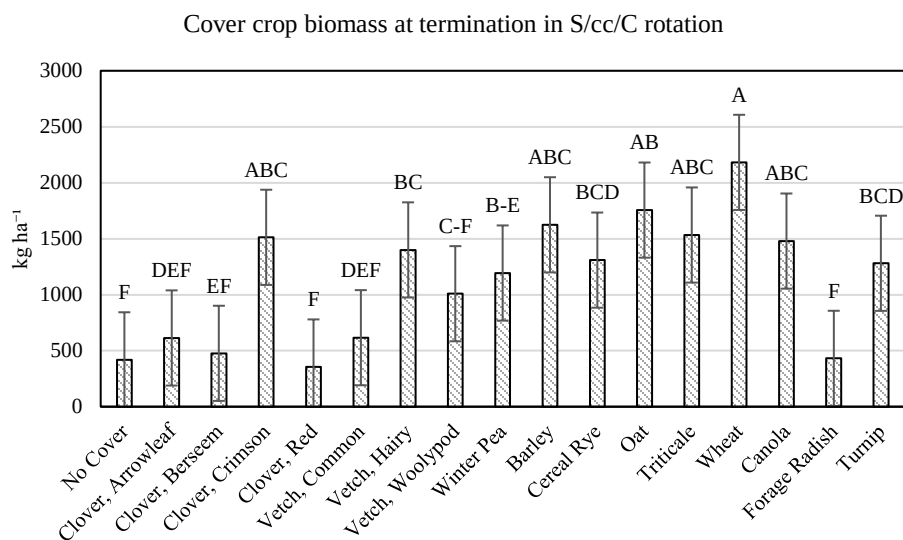


Figure 1-4: Cover crop biomass at termination in S/cc/C rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

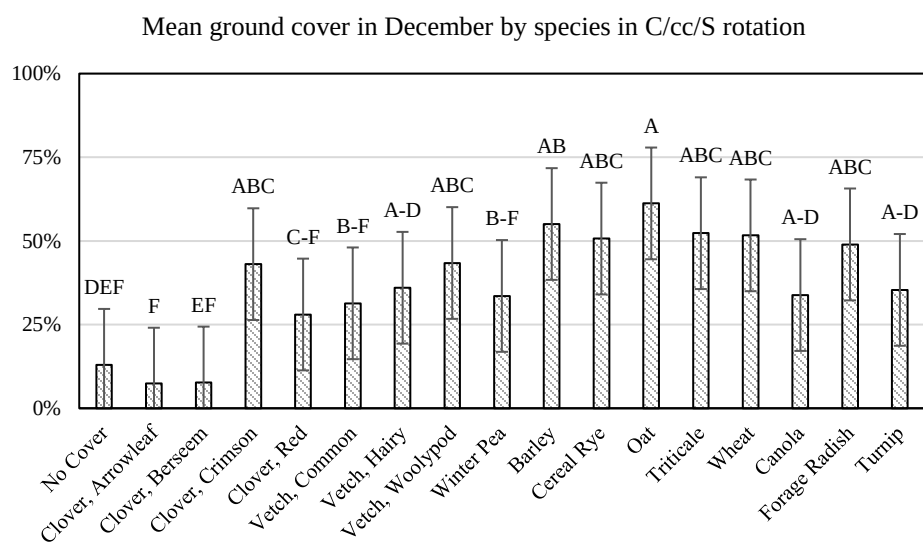


Figure 1-5: Mean digital image analysis (DIA) of percent cover crop ground cover in December within C/cc/S rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

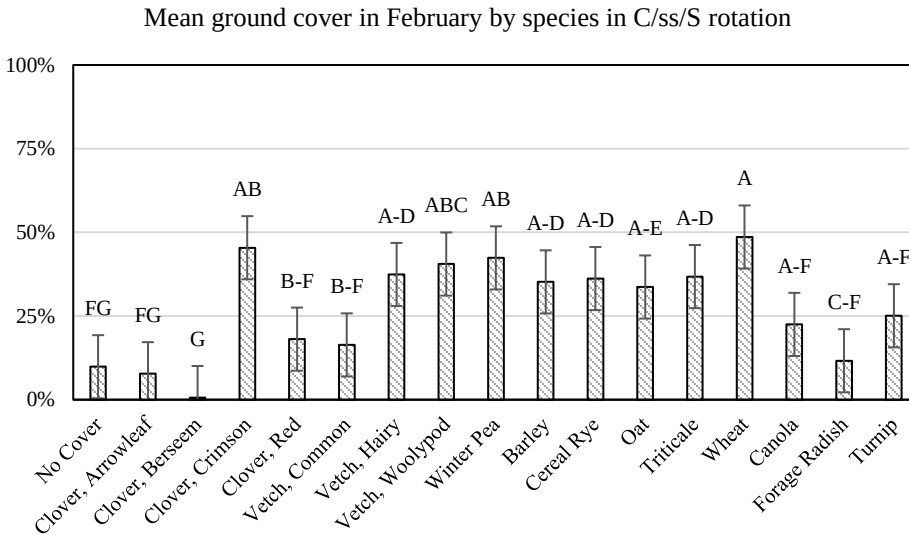


Figure 1-6: Mean digital image analysis (DIA) of percent cover crop ground cover in February within C/cc/S rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

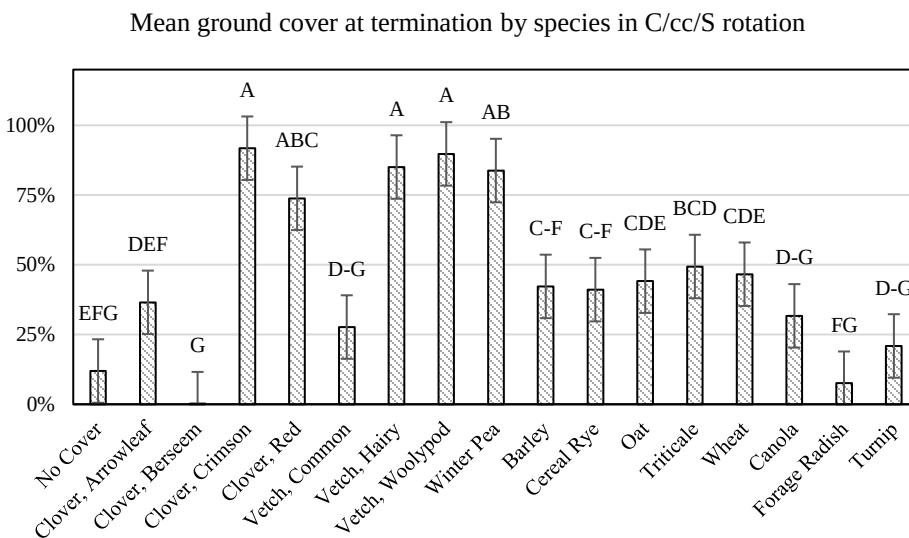


Figure 1-7: Mean digital image analysis (DIA) of percent cover crop ground cover at termination within C/cc/S rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

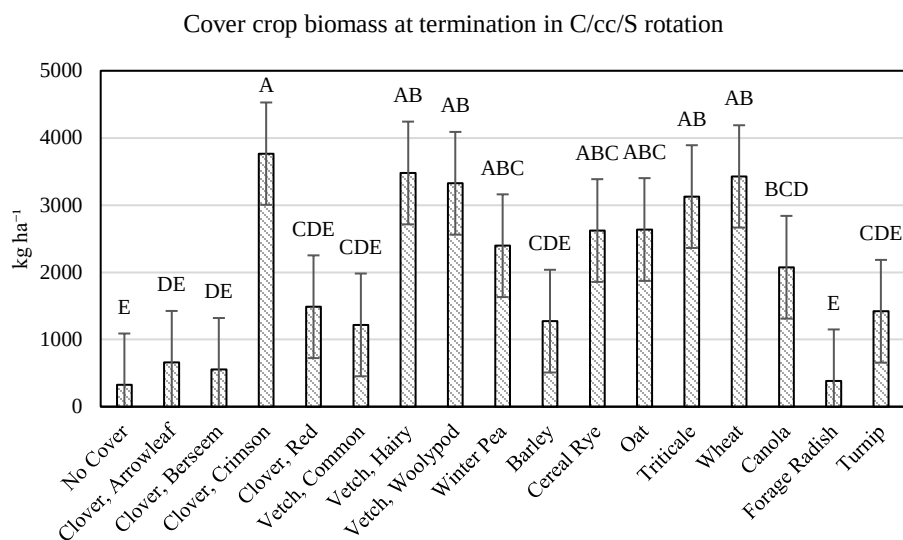


Figure 1-8: Cover crop biomass at termination in C/cc/S rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

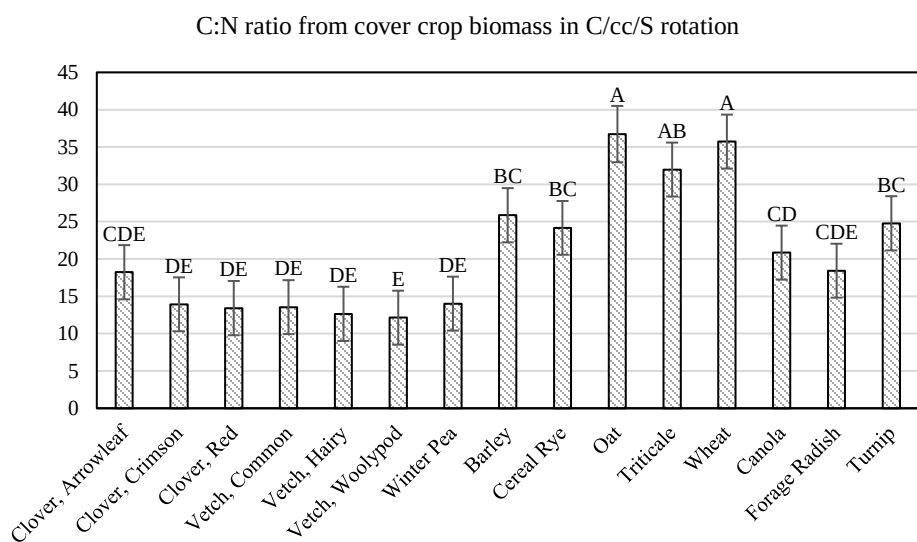


Figure 1-9: Mean C:N ratios from cover crop biomass in the C/cc/S rotation. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Table 1-5: P values for soil health attributes according to Fisher's protected LSD. P values less than 0.05 are significant.

Soybean/cover crop/Corn		Corn/cover crop/Soybean	
Variable	<i>F</i> value	Variable	<i>F</i> value
WEOC	0.592	WEOC	0.839
WEON	0.837	WEON	0.034
C:N ratio	0.868	C:N ratio	0.334
P	0.749	P	0.875
Ca	0.897	Ca	0.663
Mg	0.756	Mg	0.615
K	0.759	K	0.633
Na	0.872	Na	0.898
S	0.505	S	0.272
B	0.988	B	0.400
Mn	0.704	Mn	0.036
Cu	0.681	Cu	0.566
Zn	0.766	Zn	0.560
Al	0.984	Al	0.802
Fe	0.399	Fe	0.434
TEC	0.986	TEC	0.726
pH	0.538	pH	0.148
OM	0.976	OM	0.725
N release	0.936	N release	0.568

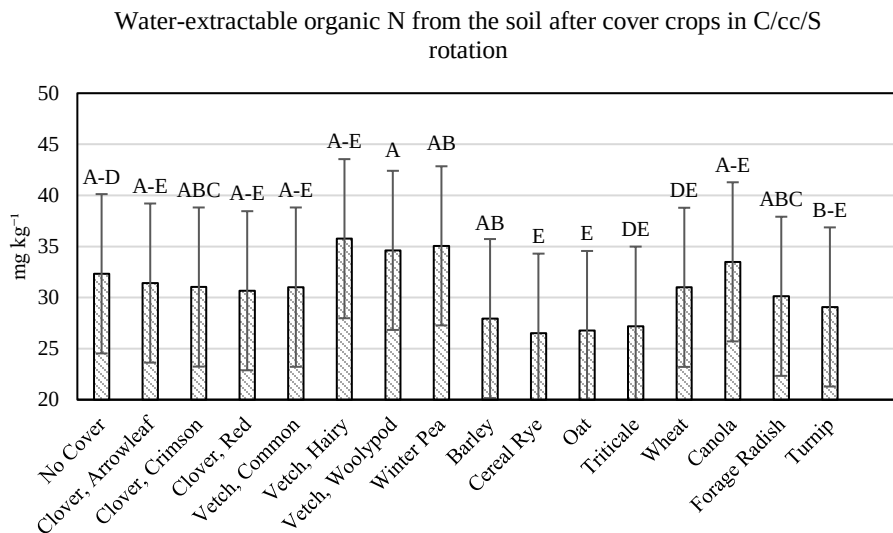


Figure 1-10: Mean water-extractable organic N from the soil after cover crops in the C/cc/S rotation sequences. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

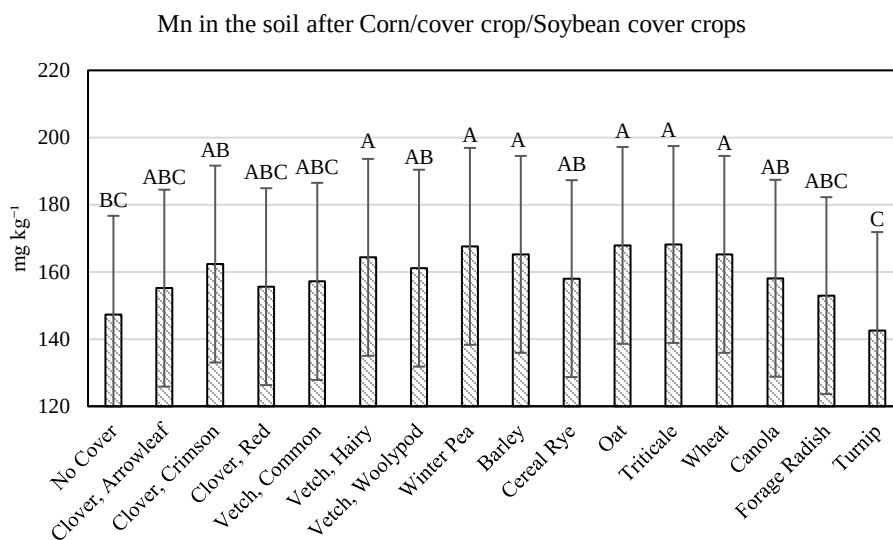


Figure 1-11: Mean soil Mn after cover crops in the C/cc/S rotation sequence. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Table 1-6: P values for cash crop yield and quality according to Fisher's protected LSD. P values less than 0.05 are significant.

Soybean/cover crop/Corn		Corn/cover crop/Soybean	
Variable	<i>F</i> value	Variable	<i>F</i> value
Yield	0.880	Yield	0.650
Oil	0.802	Oil	0.715
Starch	0.688	Starch	n/a
Protein	0.555	Protein	0.710

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Chapter 2: Dual-use Forage Cover Crops

Abstract

Cover crops provide many ecological benefits to agricultural production systems. Utilizing cover crops as forage for livestock could offer additional economic benefit though information on implementation and ecological impact is limited. Fifteen cool-season species were evaluated in a dual-use (harvested for forage then chemically terminated) and single-use (terminated before cash crop planting) management systems. This was repeated under a soybean/cover crop/corn (S/cc/C) and corn/cover crop/soybean (C/cc/S) rotation. Data were analyzed by rotation using a mixed model ANOVA (SAS 9.4). Means were separated using Fisher's Protected LSD ($P < 0.05$). Forage yield, nutritive value (FNV) (crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), Ca, P, K, Mg, and ash), soil attributes (water extractable organic C and N [WEOC and WEON], micronutrients, pH, and cation exchange capacity), and cash crop yield and quality (oil, protein, starch) were measured. Forage yields were not significantly different in the S/cc/C rotation but ranged from 453 to 2440 kg ha⁻¹. Most species in the C/cc/S rotation were significantly higher than the control (1936 to 3880 kg ha⁻¹). Generally, legumes had the highest CP, Ca, K, P, and Mg. Cereals had higher ADF and NDF, and brassicas had higher NDF. No differences in soil attributes or cash crop yield and quality were observed, except slightly higher pH (+0.1) in the single-use system within the C/cc/S rotation. If appropriate species are selected, dual-use cover crop system within either rotation can provide 1859 to 3880 kg ha⁻¹ of quality forage, without reducing short term ecological benefits.

Introduction

Cover crops provide many ecological benefits to production systems, such as reduction of soil erosion (Kaspar and Bakker, 2015) and nutrient losses (Fraser et al., 2013), increased moisture retention in the soil (Fageria et al., 2005), weed suppression (Baraibar et al., 2018), carbon sequestration, and green manure source for nitrogen (N) and carbon (C) (Snapp et al., 2005; Schipanski et al., 2014). Several species which are suited for use as cover crops have also been used as forage crops (Hansen et al., 2013); however, many of these have not been evaluated for their suitability as a dual-use forage cover crop in the Mid-South.

Several species of cool-season cereal cover crops could fit well into a Mid-South dual-use cover cropping system, as they are typically cheap, easily obtainable, and provide a good amount of biomass (Kaspar and Bakker, 2015; Appelgate et al., 2017). Cereal rye (*Secale cereale*) is likely the most common cereal cover crop; however, other species, such as wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), could be suited for use as dual-use cover crops, as they are commonly already found in the Mid-South as grain crops and may be of higher forage quality than cereal rye. Legumes, such as vetches and clovers, could also fit well into this system, as legumes generally have high forage nutritive value, fix atmospheric N, and, depending on species, can produce an adequate amount of biomass (Ketterings et al., 2015). Crimson clover (*Trifolium incarnatum*) is a common cover crop legume that produces a high amount of biomass and can attract pollinators if allowed to flower in the spring. Brassicas are also being encouraged for incorporation in cover crop systems. Brassicas produce a taproot and can scavenge N, but vary in cold tolerance (Gieske et al., 2016). While few studies have examined brassica species for adaptation to the Mid-South, turnip (*Brassica rapa*) and canola (*B. napus*) have been used as

cover crops in Midwestern U.S. (Appelgate et al., 2017), and may be suited for use in the Mid-South as winters are generally more mild than winters in the Midwest.

Important forage nutritive value characteristics are relatively high dry matter content, crude protein, and total digestible nutrients. Cellulose, hemicellulose, and lignin, on the other hand, should be relatively low, as these components will decrease digestibility. The prime quality standard of grass or legume hay is characterized by 190 g kg⁻¹ or higher crude protein (CP), 310 g kg⁻¹ or less acid detergent fiber (ADF), and 400 g kg⁻¹ or less neutral detergent fiber (NDF) (Ball et al., 2015). Prime forage should include levels of CP, ADF, and NDF within or as close to these ranges as possible. It is possible to get nutritive values in these ranges from spring grazed or harvested dual-use cover crops. For example, August sown oat in the Northern U.S. produced 180 g kg⁻¹ CP and 521 g kg⁻¹ NDF (Contreras-Govea and Albrecht, 2006; Sulc and Franzluebbers, 2014). September sown rye + oat in the Midwest produced 390 g kg⁻¹ NDF and 837 g kg⁻¹ *in vitro* neutral digestible fiber (IVNDF) (Faé et al., 2009; Sulc and Franzluebbers, 2014). October sown legumes, such as crimson clover and hairy vetch (*Vicia villosa*), in Spain produced averages of 195 g kg⁻¹ CP (Iglesias and Lloveras, 1998). Since forage nutritive value is dependent on growth stage and environment, it is important to evaluate cover crop species in the Mid-South under common cash crop rotations that will dictate cover crop planting and harvest timing.

Harvest timing affects forage nutritive value due to physiological changes in plant biomass. The optimal time to harvest or graze forages is early bloom in legumes and early boot stage in cereals. As forages mature, fiber increases and protein decreases, resulting in an overall decrease of forage nutritive value. Iglesias and Lloveras (1998) found that CP decreased by 44 g kg⁻¹, ADF increased by 46 g kg⁻¹, and *in vitro* true organic matter digestibility decreased by 49 g

kg⁻¹ between April and May cool-season legume harvests. These harvest timings are important to the Mid-South since the two most common crops grown in this area are corn (planted in April) and soybean (planted in May). The growing season of corn and soybean are different lengths, so having two rotation timings or sequences is important to understand which cover crop species perform best as a dual-use cover crop in these cash crop production systems.

Objective

The objective of this study is to compare economic (cash crop yield and quality, forage yield and nutritive value) and ecological (soil nutrients, pH, soil moisture) impacts of seventeen cover crop species under two crop rotations (soybean/ cover crop/corn, corn/cover crop/soybean) and two cover crop management systems (single-use and dual-use).

Materials and Methods

Plots were established at two University of Tennessee AgResearch centers: Plant Sciences Unit of the East Tennessee AgResearch and Education Center (ETREC) in Knoxville, TN (35.892495, -83.959613) and Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN (35.721164, -86.964894). Soil types differed between locations: Sequatchie loam (fine-loamy, siliceous, semiactive, thermic Humic Hapludult) at ETREC and Maury silt loam (fine, mixed, active, mesic Typic Paleudalf) at MTREC. Treatments were a factorial design with fifteen cover crop species and a no cover control evaluated under two management systems: single-use (cover crop chemically terminated and left as residue before cash crop planting) and dual-use (cover crop residue mechanically harvested then chemically terminated prior to cash crop planting). This was repeated under two different cover crop planting/harvesting times resulting from different cash crop rotations: corn / cover crop / soybean (C/cc/S) and soybean / cover crop / corn (S/cc/C) and was repeated over two growing seasons (Fall 2017 through Spring 2019). Cover crops were seeded at rates recommended by University of Tennessee Extension for forage production (Bates et al., 2016) (Table 2-1).

Plot establishment and termination dates were the same as the previous chapter with the addition of a forage harvest (Table 2-2). Cover crop plots in the S/cc/C were established in late October of each year. Forage harvest occurred in late March to early April and plots were terminated shortly after. Corn was planted in mid-April to early May and harvested in mid-September to early October. Cover crop plots in the C/cc/S rotation were established in late September to early October. Forage harvest occurred in mid- to late April and plots were terminated shortly after. Soybean was planted in early to late May and harvested in late September to late October. Plots were arranged in a randomized complete block design with

three replicates at each location. Plots were planted 3.1-m x 9.1-m and were trimmed to 7.5-m at ETREC and 8.2-m at MTREC.

Cover crop biomass from one randomly selected 0.9-m² area of each plot was sampled at a height of 5-cm and weeds were separated from cover crop biomass. Samples were dried at 55°C for 72 hours and reweighed to determine dry cover crop biomass. Forage nutritive value was assessed using harvested biomass from a 0.9-m² area of each dual-use plot. The biomass was ground using a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) and an Udy (Udy One Corporation, Fort Collins, CO, USA) cyclone type grinder to get particle diameters of 1-mm or less. Once ground, the samples were dried again before analysis. Samples were scanned using a Foss DS2500 (Foss North America, Eden Prairie, MN, USA) NIRS analyzer to estimate crude protein (CP), acid-detergent fiber (ADF), neutral-detergent fiber (NDF), calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg). Samples were scanned by species composition using the 2020 grass hay calibration for cereals, 2020 legume hay calibration, and the 2020 mixed hay calibration for brassicas. These calibrations were provided by the NIRS Consortium (Hillsboro, WI, USA). Analysis of forage nutritive value was done to compare among species, so the no cover control was excluded. Soil attributes and cash crop yield and quality were determined using the same method as the previous chapter. In brief, ten, 15-cm soil samples were taken from each plot two months after cover crop termination. These samples were sent to Brookside Laboratories (New Brennan, OH USA) for analysis of WEOC (water-extractable organic carbon), WEON (water-extractable organic N), pH, N release, TEC (total exchange capacity), P, K, Mg, Ca, S, Mn, B, Zn, Fe, Al, Cu, and Na. Soil samples were dried and ground, then sieved for <2mm particles. WEON and WEOC was determined using samples weighing 2 g which were extracted with 20 ml of deionized water and shaken for 10 minutes.

Samples were then filtered through Whatman 2 filter paper the water extract was analyzed with a Teledyne-Tekmar Torch C:N analyzer (Teledyne-Tekmar, Mason, OH, USA). Samples for N-P-K and micronutrients were extracted with 40 ml of H₃A, shaken for 10 minutes, then filtered with Whatman 2 filter paper. This extract was also analyzed for NO₃, NH₄, and PO₄ using a FIAlyzer-1000 flow injection analyzer (FIALab, Seattle, WA, USA). Analysis for P, K, S, Mg, Ca, B, Na, Zn, Fe, Mn, Cu, and Al was conducted the same extract from the N-P-K samples and was conducted using a Thermo Scientific ICP-OES (Thermo Fisher Scientific, Waltham, MA, USA).

Cash crops were harvested with a small plot combine which recorded total plot weight and moisture. Yields were adjusted to a per ha basis and converted to standard crop moistures (15.5% for corn and 13% for soybean). Samples weighing approximately 0.45 kg were analyzed for protein, oil, and starch analysis using a Foss Tecator Infratec 1229 grain analyzer (Foss North America, Eden Prairie, MN, USA).

Statistical analysis of the data was performed using SAS 9.4. Proc Glimmix was used for analysis of variance. Fisher's Protected LSD was used to find mean separations. A P value of less than 0.05 was used to determine statistical significance. Two models were used in this study. Model one included species as the only fixed effect. Model two included species and management system as fixed effects. In both models, random effects were location, replication, and year. Model one independent variables were analyzed separately and include cover crop forage yield and nutritive values. Model two independent variables were analyzed separately and included soil attributes, cash crop yield, and quality. Rotations were analyzed separately for each independent variable.

Statistical Analysis

Statistical analysis of the data was performed using SAS 9.4. Proc Glimmix was used for analysis of variance. Fisher's Protected LSD was used to find mean separations. A P value of less than 0.05 was used to determine statistical significance. Two models were used in this study. Model one included species as the only fixed effect. Model two included species and management system as fixed effects. In both models, random effects were location, replication, and year. Model one independent variables were analyzed separately and include cover crop forage yield and nutritive values. Model two independent variables were analyzed separately and included soil attributes, cash crop yield, and quality. Rotations were analyzed separately for each independent variable.

Results

Forage Yield and Nutritive Value

Soybean/ cover crop/ corn rotation

Crude protein, Ca, P, and Mg were significantly different among species (Table 2-3). Forage yields were significantly different, however yields ranged from 454 to 2440 kg ha⁻¹. Across all species, crude protein ranged from 121 to 227 g kg⁻¹ (Figure 2-1). Legumes generally had the highest percentages of CP, ranging from 136 to 227 g kg⁻¹. Cereals were lowest in CP and ranged from 121 to 139 g kg⁻¹. Brassicas were intermediate, ranging from 140 to 168 g kg⁻¹. Like crude protein, calcium, phosphorus, and magnesium values tended to cluster by functional group: legumes, cereals, brassicas. Calcium values tended to be similar among the legumes and brassicas, ranging from 10.8 to 15.3 g kg⁻¹, while values for cereals ranged from 4.9 to 6.5 g kg⁻¹ (Table 2-4). Phosphorus ranged from 2.7 to 3.9 g kg⁻¹ (Table 2-4). Phosphorus values were similar in the legumes and brassicas, ranging from 3.0 to 3.9 g kg⁻¹ and lower in cereals, ranging from 2.7 to 3.0 g kg⁻¹. Magnesium values were also similar in legumes and brassicas, ranging from 2.2 g kg⁻¹ to 3.0 g kg⁻¹, and lower in cereals, ranging from 1.7 to 2.1 g kg⁻¹ (Table 2-4). While ADF, NDF, and K were not significantly different among species, these values tended to be similar among the broader functional groups of cereals, legumes, and brassicas (Table 2-5). Acid detergent fiber ranged from 257 to 376 g kg⁻¹, NDF ranged from 328 to 471 g kg⁻¹, and K ranged from 18 to 24 g kg⁻¹.

Corn/ cover crop/ soybean rotation

Forage yield, CP, ADF, NDF, Ca, P, K, and Mg differed significantly among species (Table 2-3). Forage yields tended to be higher compared with the S/cc/C rotation, ranging from 460 to 3880 kg ha⁻¹ (Figure 2-2). Unlike the S/cc/C rotation, where cereals dominated in terms

of forage yields, in the C/cc/S rotation, a larger number of species representing each functional group were significantly higher than the no-cover control. Within the legumes, this included crimson clover (3880 kg ha⁻¹), woollypod vetch (3291 kg ha⁻¹), winter pea (3023 kg ha⁻¹), and hairy vetch (2558 kg ha⁻¹). Within the cereals, wheat (2623 kg ha⁻¹), oat (2155 kg ha⁻¹), cereal rye (2018 kg ha⁻¹), and triticale (1936 kg ha⁻¹) were significantly higher. Canola (1979 kg ha⁻¹) was the only brassica with a yield significantly higher than the control; however, fewer brassica species were evaluated compared with the other two functional groups.

Across all species, crude protein ranged from 92 to 254 g kg⁻¹ (Figure 2-3). Compared to the S/cc/C rotation, CP from legumes was higher while CP from cereals and brassicas was lower. Values for CP still tended to cluster by functional group and, similar to S/cc/C rotation, legumes had higher CP (ranging from 191 to 254 g kg⁻¹), brassicas were intermediate (129 to 145 g kg⁻¹), and cereals had the lowest concentrations (92 to 111 kg ha⁻¹). Acid detergent fiber values were like those within the S/cc/C rotation and ranged from 269 to 360 g kg⁻¹; however, no distinct species grouping was observed (Figure 2-4). Neutral detergent fiber also clustered by species families and ranged from 353 to 562 g kg⁻¹ (Figure 2-5). Compared to the S/cc/C rotation, legume NDF decreased and cereal and brassica NDF increased. Species grouping of values was observed with legumes being lowest (353 to 416 g kg⁻¹), brassicas intermediate (434 to 470 g kg⁻¹), and cereals highest (474 to 562 g kg⁻¹).

Calcium ranged from 3.5 to 16.5 g kg⁻¹ (Table 2-1). Similar to the S/cc/C rotation, legumes and brassicas had higher calcium concentrations (12.0 to 16.5 g kg⁻¹) than the cereals (3.5 to 4.4 g kg⁻¹). Phosphorus values in the legumes were highest (3.3 to 4.0 g kg⁻¹), intermediate in brassicas (2.3 to 3.1 g kg⁻¹), and lowest in cereals (2.0 to 2.4 g kg⁻¹) (Table 2-1). Unlike the S/cc/C rotation, species grouping of phosphorus values was different between

legumes, brassicas, and cereals. Potassium values were similar in legumes and brassicas, ranging from 17.5 to 28.9 g kg⁻¹, while cereals were lower, ranging from 14.7 to 2.07 g kg⁻¹ (Table 2-6). Like the S/cc/C rotation, Mg values were similar in legumes and brassicas, ranging from 2.2 to 3.2 g kg⁻¹, and cereals were lowest, ranging from 1.4 to 1.7 g kg⁻¹ (Table 2-6).

Soil Attributes and Cash Crop

No soil attribute or cash crop differences were observed among species or between management system in either crop rotation, apart from soil pH between management systems in the C/cc/S rotation (Table 2-7, Table 2-8). Soil pH was statistically higher in the single-use plots by 0.1; however, this is not a very drastic change and would likely not have an immediate effect on cash crop productivity. No other differences were observed in soil health or cash crop.

Discussion

Cash crop rotation impacted which species were best suited to a dual-use cover crop/forage system as well as the biomass potential of those species. In the S/cc/C rotation, no species was significantly higher than the no-cover control, possibly due to the large amount of variation. Forage yields in this rotation ranged from 453 to 2440 kg ha⁻¹. A greater range of species provided significant amounts of biomass in the C/cc/S rotation, including crimson clover, woolypod vetch, hairy vetch, winter pea, wheat, triticale, oat, cereal rye, and canola. With yields from species significantly higher than the no-cover control ranging from 1936 to 3880 kg ha⁻¹ before spring soybean planting (C/cc/S rotation), any of these species would be good choices for spring grazing before cash crop planting. Previous research by Faé et al. (2009) showed oat + rye and annual ryegrass yields from two grazings to be 4763 kg ha⁻¹ and 3449 kg ha⁻¹ respectively with average daily weight gain (ADG) of livestock in the spring of 0.76 to 0.86 kg day⁻¹. Similar ADG could be obtained from the higher yielding cover crops in this study, depending on nutritive value.

Yields of the most of the cereal species in the S/cc/C rotation were similar in the C/cc/S rotation, however cereal rye and wheat were slightly higher (+159 and +183 kg ha⁻¹) and oat and triticale were lower (- 113 and - 413 kg ha⁻¹) than in the S/cc/C rotation. A greater increase in biomass was expected from the longer growing season; however, this may not have been observed in the cereals due to nutrient deficiencies as none of the cover crops were fertilized. While fertilizing cover crops is not currently a typical practice, these results suggest application of a N fertilizer or mixing cereal cover crops with N-fixing legumes could help to maximize yield potential in cereals utilized as dual-use cover/forage crops. Legumes, which were able to fix atmospheric N and were not N limited, exhibited a large increase in biomass from pre-corn

(S/cc/C) to pre-soybean (C/cc/S). For example, major increases were observed in hairy vetch (+1205 kg ha⁻¹), winter pea (+1765 kg ha⁻¹), woolypod vetch (+2128 kg ha⁻¹), and crimson clover (+2179 kg ha⁻¹). Most of these legume species more than doubled in biomass between the two crop rotations. While these results indicate producers can maximize biomass/forage production by selecting best-suited species to their specific cash crop rotation, very little research has examined within species variation for most of these cover crops. Most species that were evaluated were not of specified genetic composition (i.e., “variety not stated”), which is how many of the available cover crop species are sold. As breeders work to develop adapted varieties within some of these species, more options may become available both across and within species with better adaptation to Mid-South dual-use cover/forage systems.

Most of the species in either crop rotation had adequate forage nutritive value (FNV) for stocker grazing; however, some generalizations can be made about differences of values in each rotation. According to the quality standards by Ball et al. (2015), any CP value above 190 g kg⁻¹, any ADF value below 310 g kg⁻¹, and any NDF value below 400 g kg⁻¹ are considered prime quality for high-quality forages. Most of the legumes in both rotations had close to or higher than 190 g kg⁻¹ CP apart from arrowleaf clover, red clover, and common vetch in the S/cc/C rotation. Generally, CP in the legumes were higher in the C/cc/S rotation, indicating that CP will be higher during early bloom than in the late vegetative growth stage. In the cereals and brassicas, CP slightly decreased from late vegetative to the early boot growth stage. Crude protein in cereals and brassicas was lower than 190 g kg⁻¹ in both rotations but was generally above 100 g kg⁻¹. Acid detergent fiber was below or close to 310 g kg⁻¹ in both rotations for most of the species. Neutral detergent fiber within the legumes close to or below 400 g kg⁻¹ in both rotations, while mostly higher than 400 g kg⁻¹ in cereals and brassicas. These values are similar

to those from oat + rye and ryegrass forage cover crops in previous research (Contreras-Govea and Albrecht, 2006; McCormick et al., 2006; Faé et al., 2009). Concentrations of Ca, P, K, and Mg were generally higher in the legumes and brassicas; however, the concentrations of these macronutrients in all of the species were adequate to meet the mineral needs of finishing beef cattle weighing approximately 544 kg (Gill et al., 2004).

No differences among species and management system were observed in soil and cash crop analysis, indicating that the removal of cover crop biomass had no short-term negative effect on soil attributes, cash crop yield, and quality. This is not surprising, as previous studies dealing with soil attribute changes after cover crops concluded that changes will not be seen after short-term use of cover crops (Richter et al., 2007; Boyer et al., 2018) and any N increases would be seen in a period of time between 2 and 6 weeks after termination (Wyland et al., 1996; Hu et al., 1997; Parr et al., 2014). Earlier soil sampling could have elaborated further on soil N changes due to management. Cash crop yield and quality also exhibited no differences, which is consistent with previous studies (Reddy, 2001; Ruffo et al., 2004; Bracey et al., 2020). Because the cash crops in this study were equally fertilized, any yield benefits from additional N were not seen. Also, since the cover crop biomass was removed, any aboveground N was not returned to the soil for the cash crops to use. These conclusions align with previous research that concluded the removal of cover crop biomass had no effect on cash crop yields and would be could be a good practical source of forage (Butler et al., 2016).

In addition to examining long-term impacts of this system, further research under grazing could be beneficial in determining best management practices to maximize economic benefits to producers implementing a dual-use/cover crop system. Grazing cover crops could benefit integrated crop-livestock producers by reducing feed costs and generating income after two years

of grazing (Cartwright, 2015). Grazing cover crops rather than harvesting as forage could be a better management decision as the yields of the top-performing cover crops may not be enough to justify equipment operation costs. Grazing cover crops also returns nutrients to the soil from manure and urine that livestock deposit (Franzluebbers, 2007). However, compaction and soil penetration resistance could be an issue in grazing (Franzluebbers and Stuedemann, 2008; de Faccio Carvalho et al., 2010). Additional research into the ecological and economic differences between mechanical harvesting and grazing cover crops in this region would be useful.

Results from this study indicate utilizing cover crops as a spring forage before cash crop planting could be beneficial to integrated crop/livestock producers in the Mid-South. However, the utility of this system is dependent on selecting species best suited for specific timings dictated by the cash crops with which covers are grown in rotation. For a shorter growing season (S/cc/C rotation) wheat, triticale, oat, and cereal rye are good choices. For a longer growing season (C/cc/S rotation) crimson clover, woolypod vetch, winter pea, wheat, hairy vetch, oat, cereal rye, canola, and triticale are all good choices. Species adaptation to these Mid-South production systems should continue to be monitored as new cover crop varieties are developed and released. While this study provides support for harvesting cover crops as a forage crop, further examination of long-term environmental impacts on soil and cash crop attributes, as well as examination under grazing, would help to better define environmental impacts of dual-use cover/forage systems. Yield and quality estimates suggest this type of system would add additional economic value; however, a full economic analysis of costs and benefits would further aid producers in determining if a dual-use cover/forage system is an appropriate fit for their cropping system.

Tables and Figures

Table 2-1: Cover crop variety and seeding rate information.

Cover crop	Seeding rate (kg ha ⁻¹)	Planting depth (cm)	Variety	
			2017-2018	2018-2019
Clover, arrowleaf	11.21	1.27	Yucchi	VNS
Clover, crimson	28.03	1.27	Dixie	Dixie
Clover, red	11.21	1.27	VNS	VNS
Vetch, common	33.63	5.08	VNS	VNS
Vetch, hairy	33.63	5.08	VNS	VNS
Vetch, woolypod	33.63	5.08	Lana	Lana
Winter pea	56.05	5.08	VNS	VNS
Barley	168.15	5.08	Bob Winter	Bob Winter
Oat	168.15	5.08	Arivat	Secretaret
Triticale	168.15	5.08	Fridge	Fridge
Cereal rye	168.15	5.08	VNS	VNS
Wheat	201.78	5.08	Arthur	VNS
Canola	8.97	1.27	Edimax CL	Edimax CL
Forage radish	16.82	1.27	Torpedo	Torpedo
Turnip	6.73	1.27	Purple top white globe	Purple top white globe

Table 2-2: Plot establishment, harvest, and termination dates.

Year	Location	Growing season	Cover crops			Cash crops		
			Establishment	Forage harvest	Termination	Planting	Harvest	Crop
2017-2018	ETREC	S/cc/C	10/27/17	4/11/18	4/18/18	5/7/18*	10/3/18	Corn
	MTREC		10/25/17	4/4/18	4/11/18	4/30/18	9/11/18	
	ETREC	C/cc/S	9/25/17	4/20/18	4/30/18	5/24/18	10/9/18	Soybean
	MTREC		9/25/17	4/18/18	4/27/18	5/11/18	10/22/18	
2018-2019	ETREC	S/cc/C	10/31/18	4/1/19	4/11/19	5/16/19*	9/18/19	Corn
	MTREC		10/24/18	3/28/19	4/2/19	4/18/19	9/19/19	
	ETREC	C/cc/S	10/12/18	4/15/19	4/24/19	5/9/19	10/2/19	Soybean
	MTREC		10/5/18	4/11/19	4/18/19	5/8/19	9/25/19	

Table 2-3: P values for forage yield and nutritive values according to Fisher's protected LSD.

Variables with an P value less than 0.05 are significant.

Soybean/cover crop/Corn		Corn/cover crop/Soybean	
Variable	P value	Variable	P value
Forage yield	0.051	Forage yield	0.000
CP	0.003	CP	0.000
ADF	0.090	ADF	0.028
NDF	0.112	NDF	0.007
Ca	0.000	Ca	0.000
P	0.008	P	0.000
K	0.835	K	0.000
Mg	0.000	Mg	0.000
Ash	0.146	Ash	0.066

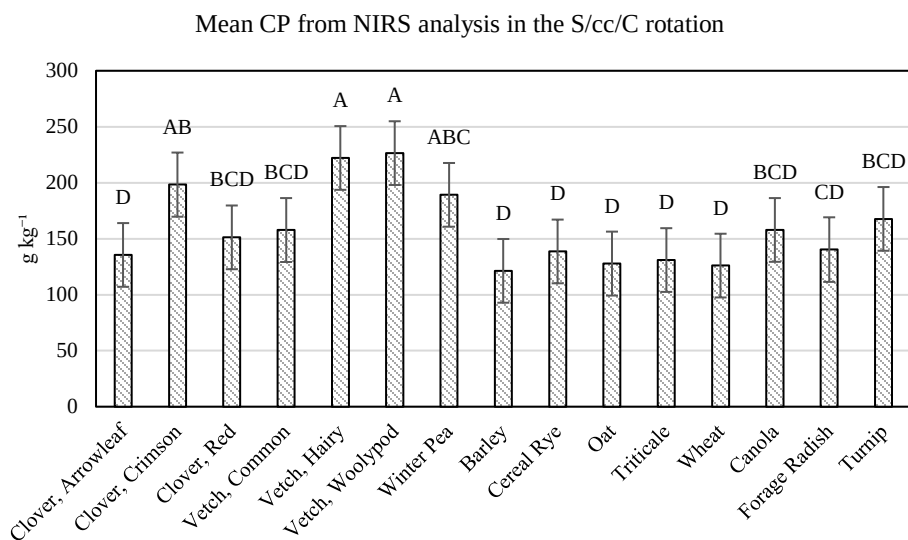


Figure 2-1: Mean percent CP in dual-use cover crops in the S/cc/C rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Table 2-4: Mean percent Ca, P, K, Mg, and ash in the S/cc/C rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Species	Calcium		Phosphorus		Magnesium	
	g kg ⁻¹	MS	g kg ⁻¹	MS	g kg ⁻¹	MS
Clover, Arrowleaf	10.8	CD	3.0	CDE	2.9	A
Clover, Crimson	13.5	ABCD	3.2	BCDE	2.6	AB
Clover, Red	12.1	ABCD	3.2	BCDE	2.8	A
Vetch, Common	10.2	DE	3.3	BCD	2.7	A
Vetch, Hairy	13.4	ABCD	3.7	AB	2.8	A
Vetch, Woolypod	14.9	AB	3.9	A	2.9	A
Winter Pea	11.4	BCD	3.5	ABC	2.2	BC
Barley	6.5	EF	3.0	CDE	2.1	C
Cereal Rye	6.1	F	2.7	E	2.1	C
Oat	5.1	F	2.8	DE	1.8	C
Triticale	5.3	F	2.7	E	1.9	C
Wheat	4.9	F	2.7	E	1.8	C
Canola	15.2	A	3.0	CDE	3.0	A
Forage Radish	14.5	ABC	3.0	CDE	3.0	A
Turnip	15.3	A	3.1	CDE	3.0	A

Table 7: Mean ADF, NDF, K, and ash concentrations in the S/cc/C rotation. These values did not differ significantly by species according to Fisher's protected LSD when tested at the 0.05 level of probability.

Species	ADF g kg ⁻¹	NDF g kg ⁻¹	K g kg ⁻¹	Ash g kg ⁻¹
Clover, Arrowleaf	376	453	17.9	13.0
Clover, Crimson	271	328	22.2	10.7
Clover, Red	347	412	18.7	12.7
Vetch, Common	331	411	20.5	10.9
Vetch, Hairy	277	349	19.6	10.7
Vetch, Woolypod	264	341	23.7	10.0
Winter Pea	289	385	21.4	10.1
Barley	292	450	21.9	10.6
Cereal Rye	257	429	19.3	8.2
Oat	267	453	22.8	8.8
Triticale	277	452	21.6	8.6
Wheat	283	471	22.1	9.0
Canola	307	411	21.8	9.1
Forage Radish	321	421	21.9	9.2
Turnip	285	380	22.4	10.1

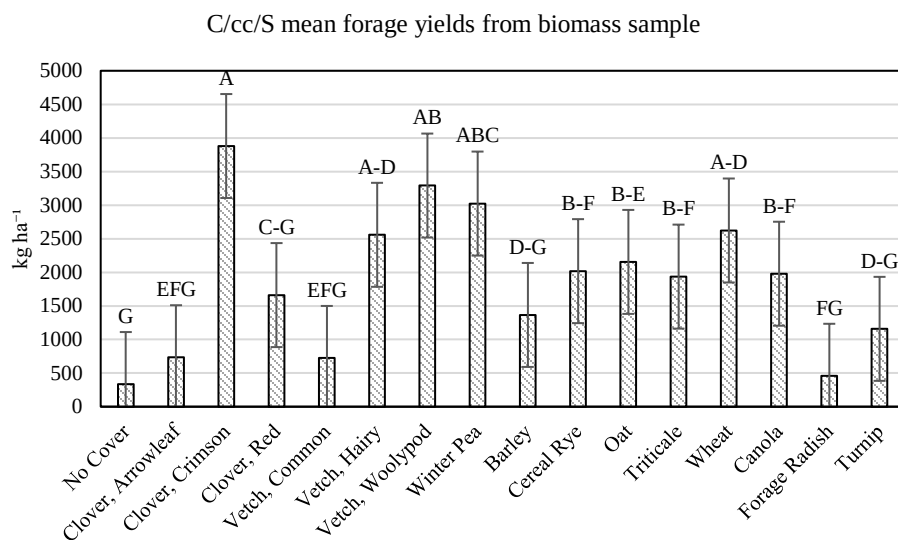


Figure 122-2: Mean forage yield by species in C/cc/S rotation. Species with an MS letter in common are not significantly according to Fisher's protected LSD when testes at the 0.05 level of probability.

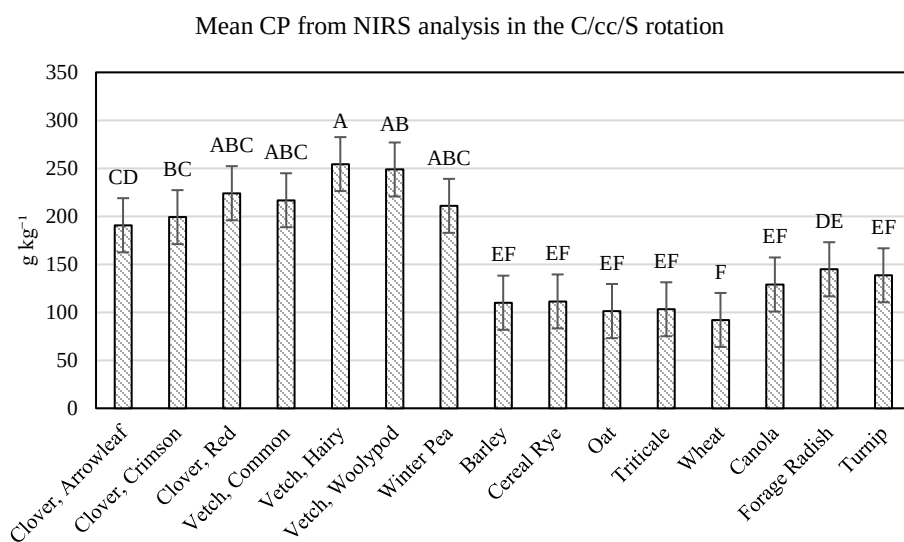


Figure 13: Mean percent CP in dual-use cover crops in the C/cc/S rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

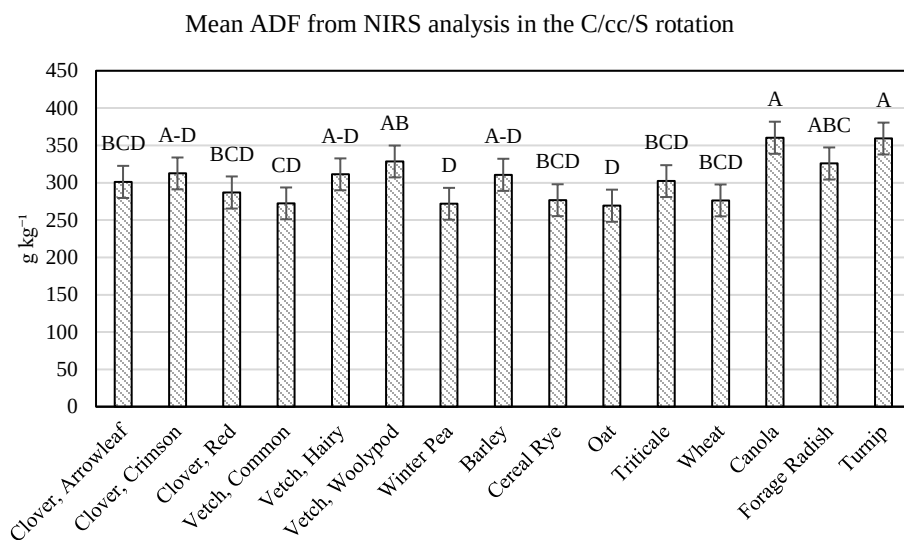


Figure 142-4: Mean percent ADF in dual-use cover crops in the C/cc/S rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

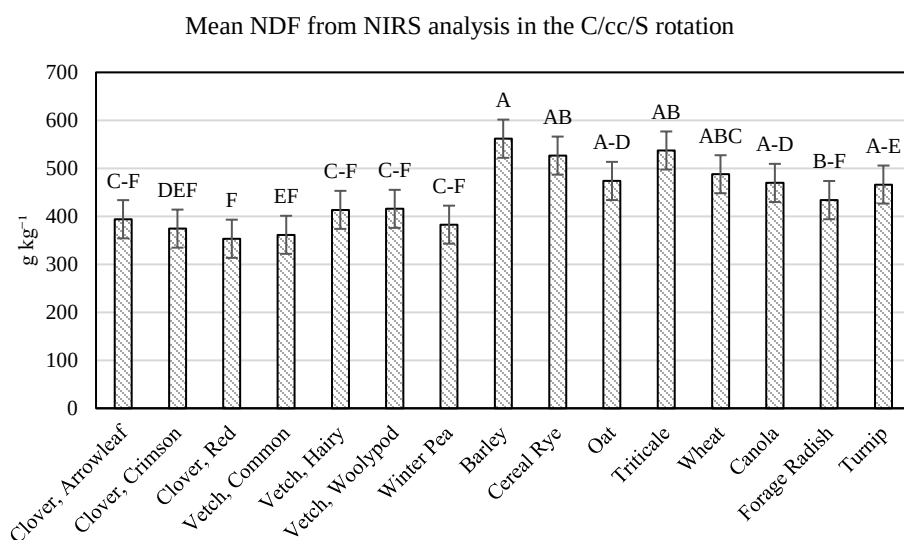


Figure 152-5: Mean percent NDF in dual-use cover crops in the C/cc/S rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Table 2-6: Mean percent Ca, P, K, Mg, and ash in the C/cc/S rotation based on 100% dry matter. Species with an MS letter in common are not significantly different according to Fisher's protected LSD when tested at the 0.05 level of probability.

Species	Calcium		Phosphorus		Potassium		Magnesium	
	g kg ⁻¹	MS	g kg ⁻¹	MS	g kg ⁻¹	MS	g kg ⁻¹	MS
Clover, Arrowleaf	13.6	AB	3.4	BC	17.5	FG	2.8	ABC
Clover, Crimson	14.2	AB	3.4	BC	25.1	ABC	2.6	BCD
Clover, Red	16.5	A	3.7	AB	25.5	ABC	2.8	ABC
Vetch, Common	12.7	AB	3.6	AB	24.9	ABCD	3.2	A
Vetch, Hairy	15.1	AB	3.9	A	26.7	ABC	2.9	ABC
Vetch, Woolypod	15.8	AB	4.0	A	28.9	A	2.9	ABC
Winter Pea	12.2	AB	3.3	BC	27.0	AB	1.8	EFG
Barley	3.5	C	2.4	DE	18.7	EFG	1.7	FG
Cereal Rye	3.5	C	2.4	DE	17.0	FG	1.6	FG
Oat	4.4	C	2.2	DE	17.5	FG	1.5	G
Triticale	3.7	C	2.4	DE	20.7	DEF	1.5	G
Wheat	4.0	C	2.0	E	14.7	G	1.4	G
Canola	12.0	B	2.3	DE	22.6	CDE	2.2	DEF
Forage Radish	14.9	AB	3.0	C	22.4	CDE	3.0	AB
Turnip	14.3	AB	2.5	D	23.9	BCD	2.4	CDE

Table 2-7: Soil attribute P values according to Fisher's protected LSD. A P value less than 0.05 is significant.

Soybean/cover crop/Corn				Corn/cover crop/Soybean			
Variable	Species	Harvest	Species × harvest	Variable	Species	Harvest	Species × harvest
WEOC	0.940	0.571	0.230	WEOC	0.811	0.887	0.852
WEON	0.888	0.633	0.526	WEON	0.124	0.383	0.806
C:N ratio	0.900	0.811	0.411	C:N ratio	0.308	0.410	0.710
P	0.745	0.718	0.771	P	0.718	0.448	0.787
Ca	0.611	0.383	0.073	Ca	0.152	0.727	0.727
Mg	0.601	0.985	0.948	Mg	0.337	0.764	0.829
K	0.836	0.807	0.655	K	0.742	0.199	0.621
Na	0.809	0.483	0.610	Na	0.849	0.909	0.594
S	0.694	0.842	0.331	S	0.386	0.790	0.659
B	0.952	0.574	0.966	B	0.846	0.606	0.543
Mn	0.620	0.695	0.761	Mn	0.129	0.999	0.318
Cu	0.678	0.704	0.907	Cu	0.764	0.831	0.522
Zn	0.636	0.464	0.490	Zn	0.691	0.355	0.624
Al	0.998	0.656	0.916	Al	0.754	0.718	0.722
Fe	0.789	0.292	0.528	Fe	0.739	0.850	0.370
TEC	0.835	0.942	0.823	TEC	0.488	0.520	0.861
pH	0.638	0.558	0.630	pH	0.216	0.039	0.839
OM	0.974	0.836	0.799	OM	0.706	0.597	0.367
N release	0.976	0.897	0.681	N release	0.769	0.640	0.156

Table 2-8: Cash crop yield and quality P values according to Fisher's protected LSD. A P value less than 0.05 is significant.

Soybean/cover crop/Corn				Corn/cover crop/Soybean			
Variable	Species	Harvest	Species × harvest	Variable	Species	Harvest	Species × harvest
Yield	0.981	0.603	0.649	Yield	0.848	0.520	0.811
Oil	0.994	0.953	0.677	Oil	0.444	0.518	0.362
Starch	0.613	0.300	0.635	Starch	n/a	n/a	n/a
Protein	0.145	0.515	0.954	Protein	0.752	0.293	0.993

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Conclusions

There are many species evaluated in this study which were suited to no-till corn and soybean production systems in the Mid-South. However, it is important to choose the best-suited species depending on which cash crops will precede and succeed the cover crop. Cover crops which performed well when grown in between soybean harvest in the fall and corn planting in the spring, providing ground cover throughout the cover crop growing season and biomass at termination that were significantly higher than a no-cover control, were barley, cereal rye, oat, triticale, wheat, woolypod vetch, hairy vetch, and winter pea. Cover crops which performed well when grown in between corn harvest in the fall and soybean planting in the spring were hairy vetch, woolypod vetch, crimson clover, winter pea, red clover, and triticale, as they provided good spring ground cover and biomass. No negative effects to soil attributes or cash crop yield and quality were observed in this short-term study. Utilizing some of these species as a dual-use forage cover crop is a viable option, producing up to 3880 kg ha⁻¹ of high quality forage for integrated crop and livestock producers if grown after corn and before soybean, without any negative effects to soil attributes or cash crop yield and quality. Crimson clover, woolypod vetch, winter pea, hairy vetch, wheat, oat, cereal rye, triticale, and canola grown in the corn/soybean rotation all produced significantly higher forage yields (1979 to 3880 g kg⁻¹) than the no cover control and had good forage nutritive value. Fewer species were suited to use in as a dual-use cover crop within the soybean/corn rotation, and while there were not significant differences in species in this rotation, however wheat, triticale, oat, and cereal rye produced the good forage yields (1859 to 2440 g kg⁻¹) and would be good choices for dual-use cover crops in a shorter growing season. Additional research on insects, diseases, allelopathic properties, and economic costs of establishment and management should be conducted in order to gain an even

better understanding about the application of these cover crop species in Mid-South no-till corn and soybean production systems. A longer-term study may also reveal further effects to soil attributes and cash crop yield and quality after years of utilizing these species as a dual-use forage cover crop.

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Vita

Education

Weston Bracey began his college education in 2014 at Austin Peay State University where he majored in Agriculture Science and was member of Delta Tau Alpha National Honor Society. While still a student, he was fortunate to work at the University of Tennessee Highland Rim Research and Education Center in Springfield, Tennessee during the summer of 2016 and the University of Kentucky Western Kentucky Research and Education Center in Princeton, Kentucky during the summer of 2017. After graduating from Austin Peay State University in December 2017, he began work on his Master of Science degree in Plant Sciences at the University of Tennessee, Knoxville. During this time, he worked on his thesis project while also working as a member of the Official Variety Testing and Agroecology laboratory under Dr. Virginia R. Sykes. During his time at the University of Tennessee, he assisted with variety trial field research, cover crop research, extension publications, presented at three national and international society meetings, various extension in-service trainings and field days, submitted two manuscripts to Agronomy Journal for review, and was a member of Gamma Sigma Delta National Honor Society. After completing his field research and writing, he accepted a position at the University of Tennessee AgResearch and Education Center at Milan working as a Research Associate.