EVALUATING THE IMPACT OF FORAGE BRASSICAS IN A COOL SEASON MIX ON STOCKER CATTLE PERFORMANCE AND SOIL HEALTH CONDITIONS

by

LAUREN SMITH POWELL

(Under the Direction of R. Lawton Stewart Jr. and Janine Sherrier)

ABSTRACT

The objectives of this study were to examine the inclusion of forage *Brassica* in a winter annual mixture on forage productivity, animal performance, and soil characteristics in the southeastern United States. A three-year grazing trial was conducted to compare performance on two treatments including control (CONT) of annual ryegrass, cereal rye, and crimson clover compared with this same mixture with the addition of the forage-type rape-turnip hybrid. Steers weights, forage samples, and soil samples were collected throughout the grazing period each year. Forage yield was similar early in the grazing season, greater for CONT in midseason, and greater for BRAS in late season. Forage nutritive was similar for both treatments. Steer average daily gains were generally greater for the CONT mixture in the first half but tended to be greater for the BRAS mixture at the end of the season. Soil health results showed little practical significance between treatments.

INDEX WORDS: Forage *Brassica*, turnips, kale, swedes, forage yield, forage nutritive value, CP, TDN, dNDF30, lignin, cool-season annuals, beef cattle, grazing

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INTRODUCTION

On many livestock operations one of the highest expenses is supplemental feeding throughout the late fall and winter when forage production typically declines. However, extending the grazing season has proven to reduce the high cost of supplemental feeding. In some cases, grazing winter annual crops has been shown to increase the number of grazing days by as much as 80 days (Stewart et al., 2013). Feeding stored feeds is usually two to three times more expensive than grazing forages (Ball, et al., 2008). Extending the grazing season decreases the need for adding stored feeds in livestock diets, therefore, cutting cost of stored feeds and labor cost associated with those stored feeds.

Forage Production in Georgia

Like much of the southeastern United States, Georgia's mild climate and high rainfall are ideal conditions for nearly year-round forage production (Hancock et al., 2011). This allows Georgia producers to take advantage of both warm-season and cool-season forages to extend the grazing season and reduce the usage of conserved forages or other supplements. Georgia producers utilize warm-season perennial grasses because of their potential to grow during late spring, summer and early autumn (Ball et al, 2015; Figure 1.1). These producers can also utilize cool-season forages during late winter and early spring and often will inter seed cool-season annuals into their warm-season pastures to provide highly nutritious grazing when warm-season grasses are dormant (Hancock et al., 2011). However, there are minimal species that fill the gap between October and December when neither cool nor warm-season forages are growing in Georgia and the southeastern United States.

Potential for Forage Brassicas in Georgia

Forage *Brassicas* spp. (turnips[*Brassica rapa]*, kale[*Brassica oleracea*], canola[*Brassica napus]*, swedes[*Brassica napobrassica]*, etc.) are cool-season non-leguminous forbs that are commonly used in other parts of the world such as New Zealand and Australia. Some forage brassica species are known to establish rapidly and produce approximately 4000 kg dry matter ha^{-1} in late fall or early winter in locations with mild winters (Table 1.1; Figure 1.1; Lemus et al., 2014). Forage brassicas can be grown in the southeastern United States and have the potential to provide highly nutritious forage for grazing animals (Ball et al, 2015). Forage brassicas have an observed crude protein of 200 to 250 g kg^{-1}, an approximate neutral detergent and acid detergent fiber of 19.8 and 16.8, respectively, and *in vitro* digestible dry matter of 650 to 800 g kg^{-1} (Table 1.2; Smart et al., 2004).

Forage brassicas have the potential to fill the gap in late autumn and early winter with a forage that meets the nutrient requirements of all stages of livestock production when supplementation is often needed. This strategy could be beneficial to livestock producers by decreasing the cost of hay production and achieving high animal production, such as average daily gains on stocker cattle above 1 kg d^{-1} (Ingram et al., 2018). The high forage quality of brassicas could be advantageous during fall calving season or increasing daily gains on stocker cattle when nutrient requirements are high (Stewart et al., 2013).

Potential for Improvement of Soil Health in Georgia by Forage Brassicas

Improving soils with high compaction levels and low soil organic matter content is critical to achieving high forage mass in both forage and crop systems. Compaction and lack of organic matter are two of the major factors contributing to poor soil health in Georgia. Soil compaction is often a product of heavy equipment traffic or hoof damage. Soils with high compaction have a reduced ability to infiltrate and drain water. Plant growth and root development are greatly affected by compaction because the roots are less able to penetrate that soil, as shallow root systems can cause issues with moisture stress and nutrient uptake (Hanna et al., 2009).

Having an adequate amount of organic matter is one of the most important components in soil health, as it plays a vital role as a nutrient source, reduction of soil compaction and water holding capacity (Hancock et al., 2014). Adequate amounts of organic matter depend on soil type and there are limited accepted guidelines for sufficient organic matter content in particular agricultural soils (Magdoff and van Es, 2012). Fine-texture soils tend to have naturally greater amounts of soil organic matter when compared to coarse-textured sands or sandy loams (Magdoff and van Es, 2012). Greater amounts of soil organic matter improve the soils ability to reduce leaching by increasing its water holding capacity (Gaskin et al., 2014). In Georgia, sand and sandy loam soils, are prone to have high runoff and low infiltration.

The use of cover crops to improve soil health in agricultural systems is a common practice. Cover crops help with weed control and make it easier to practice no-till or conservation tillage methods that further improve soil health. The practice of using cover crops could be of benefit to Georgia producers because of their effect on building organic matter and reducing soil compaction (Boudreau et al., 2017).

Brassicas used as a cover crop have been associated to improve root health and disease suppression (Snapp, 2006). The disease suppression property is related to the large amounts of glucosinolates with in the brassica tissue (Snapp, 2006). The large taproot of brassicas allows for soil compaction restoration, phosphorus uptake, and for following crop roots to grow in their channels after decomposition. Brassicas are also known for their low C:N ratios (Salon). Low

C:N ratios will allow nitrogen to be more available to the soil microbial biomass, which will then decompose residue more quickly and allow nutrients to be more readily available (USDA, 2011).

Purpose of the Experiment

There has been research that focused on potential forage mass of brassicas in the southeastern United States (Lemus and White, 2014; Ingram et al., 2018). Research has also been conducted on the planting date and land preparation methods on yield and forage quality of forage brassicas in Georgia (Denman, 2018). Forage brassicas used in a grazing system is a common practice in other countries however, little research has been conducted on the use of brassicas in a forage mixture in the southeastern United States, especially in Georgia.

Using winter cover crops to improve soil health is a popular practice in the southeastern United States. Limited research has been conducted on the impact of grazing cover crops on soil organic matter, compaction and water holding capacity. Franzluebbers and Stuedemann (2008) conducted research looking at the soil physical response to cattle grazing cover crop under conventional and non-tillage in the southern piedmont USA. It was observed that grazing cover crops had little effect on soil compaction (Franzluebbers and Stuedemann 2008). Likewise, Tollner et al. (1990) observed no difference in soil compaction with or without grazing of a rye cover crop in Georgia. However, previous research does not asses the effects of stockers grazing a forage mixture including a tap-rooted crop such as forage brassicas on soil health.

Therefore, the objectives of this study are to 1) compare stocker cattle weight gains, stocking rates, and grazing periods on September-planted rye, annual ryegrass, and crimson clover with or without forage brassicas and 2) compare the changes in OM, compaction, and water holding capacity of soil from before and after production of rye, annual ryegrass, and crimson clover with or without forage brassicas on paddocks that are grazed and exclusion areas within those paddocks where no grazing has occurred. This study provides information to Georgia cattle producers about the potential of forage brassicas in a winter annual grazing mixture as compared to a mixture without brassicas.

Expected Results

It is hypothesized that when planted in September, the addition of forage brassicas to a mixture of cereal rye, annual ryegrass, and crimson clover can economically sustain average daily gains of 1.13 – 1.25 kg per day for stocker beef cattle. Also, it is hypothesized that the addition of forage brassicas to a mixture of cereal rye, annual ryegrass, and crimson clover will extend the grazing season. Moreover, it is hypothesized that grazing a winter annual forage mixture with forage brassicas can improve soil health by increasing soil OM, reducing compaction, and increasing soil water holding capacity.

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Tables and Figures

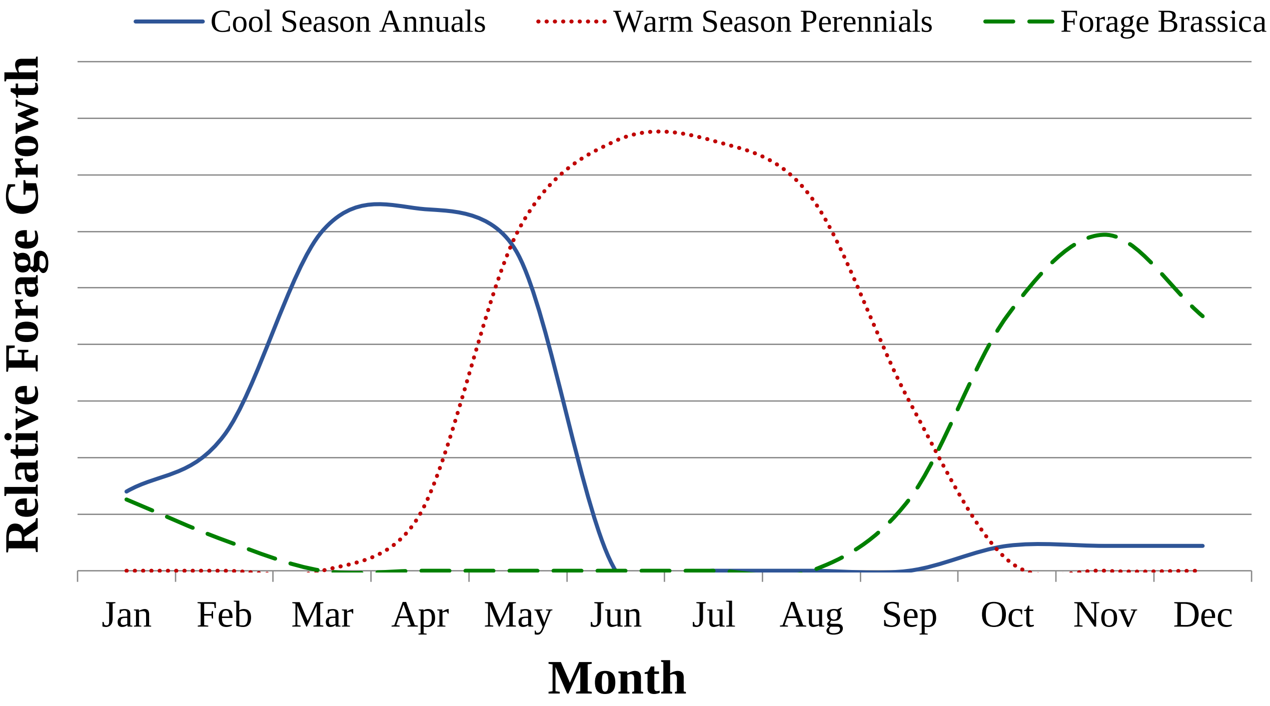

Figure 1.1. Estimated growth curves of cool season annual and warm season perennial forages grown in the southeastern United States. Adapted from Ball et al. (2008). Estimated forage brassica growth curve adapted from Denman (2018).

CHAPTER 2

LITERATURE REVIEW

Forage *Brassicas* spp. are a cool season annual crop that have the potential to provide high quality and high yield forage during the time period that perennial forage crops have limited production in the southeastern United States. Forage brassicas can be grazed 80 to 150 days after planting, depending on species (Hall and Jung, 2008). The four main species of brassicas that are often used for forage are, kale (*Brassica oleracea*), rape, also known as canola (*Brassica napus*), swede (*Brassica napobrassica*), turnip (*Brassica rapa*) and turnip hybrids, all of which have their own distinctive features.

Species

Kale (*Brassica oleracea*):

Kale is known for its winter hardiness, surviving temperatures as low as -12°C, allowing it to be grazed in late autumn. It is highly digestible and has high crude protein levels around 150 -170 g kg^{-1}. Saha et al. (2017) define crude protein content of forage as the total nitrogen (N) in the diet, which includes not only true protein but also non-protein nitrogen (e.g., urea and ammonia in a feed; nitrate is not included in non-protein nitrogen). Jung et al. (1986) observed *In Vitro* Dry Matter Digestibility (IVDMD) values for kale ranging from 821 to 836 g kg^{-1}. There are two varieties used for forage: narrow stem and stemless. Varieties that produce a stem require 150 to 180 days to achieve maximum forage production and can grow up to 152 cm tall with 5.08-cm stems (Lemus and White, 2014). Stemless varieties reach heights of 63.5 cm and mature at 90 days; this allows for a second harvest. (Lemus and White, 2014; Hall et al., 2008). Kale provides 150-180 days of grazing and has dry matter forage mass from 13450 -20175 kg kg ha^{-1}

making it ideal for beef cattle (*Bos taurus*) late-season grazing. To optimize grazing management on kale, use rotational grazing or strip grazing (Lemus and White, 2014).

Rape (*Brassica napus):*

Rape is a multi-stemmed plant with fibrous roots. Stem height, diameter, maturity, and preference by livestock vary with differing varieties (Lemus and White, 2014; Hall et al., 2008). Rape can be grazed 60 to 120 days after establishment and is more easily managed for multiple grazings compared to other brassica species. Most hybrids produce greatest biomass at 60 days after planting (DAP) and then given 30 days to regrow before a second grazing; it is best to leave a 25.4-cm stubble height to allow for rapid regrowth (Lemus and White, 2014). There are two types of forage rape: a giant, leafy type and a dwarf type. The giant varieties are best suited for cattle grazing as they often prefer these varieties over the dwarf types (Lemus and White, 2014). Rape provides 70-110 days of grazing and has biomass from 8966.81-13450.2 kg per hectare (Lemus and White, 2014).

Swede (*Brassica napobrassica*):

Swede produces a large edible root, providing both aboveground and root forage. Swede yields greater biomass than turnip but has a slower growth rate and requires 150 to 180 days to reach maximum forage production. Swedes usually produce short stems but can have stems that reach up to 0.76 m tall when grown with tall crops like cereal rye (*Secale cereal)* (Lemus and White, 2014). Some varieties of swede are cold hardy, making it ideal for stocking piling or late fall grazing (Hall et al., 2008). In general, all swede varieties are recommended for late fall grazing (Lemus and White, 2014; Hall et al., 2008). Swede provides 150-180 days of grazing and has dry matter biomass ranging from 20,175 to 22,417 kg ha^{-1} (Lemus and White, 2014).

Turnip (*Brassica rapa*) and turnip hybrids:

Turnips are short-season root brassicas that produce bulbs, stems, and leaves (Lemus and White, 2014). Turnips grow rapidly and can reach maximum forage production around 80 to 90 days after planting (Lemus and White, 2014; Hall et al., 2008). Proportion of tops and roots varies depending on variety; turnip crops can vary from 90 percent tops/10 percent roots to 15 percent tops/85 percent roots. Crude protein concentration can range from 150 – 240 g kg $^{-1}$ in the tops and 80-150 g kg $^{-1}$ in the bulbs (Lemus and White, 2014). Crude Protein concentrations in turnip bulbs are approximately one-half of that of turnip tops; therefore, turnips with greater root production often reduce the crude protein yield of the total crop (Hall et al., 2008). When multiple grazings are desired, only the turnip tops should be grazed during the first grazing, leaving the bulbs unharmed. Turnip regrowth is initiated at the top of the bulb and if damaged, it will inhibit regrowth (Lemus and White, 2014). To optimize grazing management on turnips and turnip hybrids it is best to use rotational or strip grazing (Lemus and White, 2014; Hall et al., 2008). Turnips provide 60-180 days of grazing and has forage mass from 6,725- 11,205 kg ha^{-1} (Lemus and White, 2014).

Forage Yield by Planting Date of Forage Brassicas

Forage brassicas have the capability to produce substantial dry matter (DM) biomass during the transition period of warm-season and cool-season forages. However, research has shown that despite this ability, the overall yield of forage brassicas is reliant on soil temperature and moisture content (Rao and Horn, 1986).

Research has supported that planting date has a significant effect on DM biomass of forage brassica (Kalmbacher et al., 1982; Denman, 2018). A study conducted in Southern Florida showed that DM biomass of turnip, swede, rape and kale were all decreased by a later planting date (Kalmbacher et al., 1982). Mean total biomass of 4040 kg ha^{-1} were observed for the

October-planted brassica and consistently decreased in the following November and January planting dates (2820 kg ha^{-1} and 1550 kg ha^{-1}, respectively) and a decrease in the overall growing season (150 days, 130 days, and 110 days respectively). These authors suggest that lower mean temperatures result in lower overall DM biomass and shorter growing seasons for forage brassicas (Kalmbacher et al., 1982).

Likewise, a study was conducted in Northeast Georgia observing the effect of planting date (September 1st, September 15th, October 1st, and October 15th) and land preparation method (conventional till, no till-burn, no till-mow, and no-till with residue) on overall yield of forage brassicas (Denman, 2018). The results of this study indicated that the earlier planting dates (S1 and S15) resulted in higher overall forage biomass (4669 and 2254 kg DM ha^{-1}, respectively; $P < 0.05$) compared to the later planting dates (O1 and O15; 1431 and 1610 kg DM ha^{-1}, respectively; $P < 0.05$). It was also observed that greater forage biomass were achieved with conventional tillage and no till-burn (4669 and 2147 kg DM ha^{-1}, respectively; $P < 0.05$) land preparation methods as compared to no till-mow and no-till with residue (116 and 27 kg DM ha^{-1}, respectively; $P < 0.05$; Denman, 2018). It can be concluded that the higher temperatures during the earlier planting dates had a positive effect on biomass of forage brassica.

Planting forage brassicas during late summer (September 1st – September 15th respectively) in the southeast has the potential to provide higher biomass compared to later planting dates during the transition time between warm and cool season forage crop production. The higher biomass associated with earlier planting dates could be beneficial during a time when forage production is low and supplemental feeding is high.

Forage Yield Potential Among the Varieties and Species of Brassicas

Significant differences have been observed in growth rates early in the season and total DM yield among the varieties and species of brassicas. Horn and Rao (1986) observed that shoot

DM production was highest at 85 to 95 days after planting for turnips and turnip hybrids. The greatest total DM yield was produced by 'Cyclon' in the fall and 'Purpletop' in the spring (5680 and 5130 kg ha^{-1}, respectively). The hybrid variety 'Tyfon' produced the highest forage biomass (6450 kg ha^{-1}) compared to either Cyclon or Purpletop, however, 'Tyfon' didn't reach maximum yield until 95 DAP. The higher forage yield of 'Tyfon' is likely the result of greater partitioning of photosynthate to foliage production instead of root production as compared to Purpletop and Cyclon turnip varieties. In the same study, the authors observed that in early harvest, DM biomass of kale were less than those observed by rape, however after 90 days of growth, biomass were similar. Therefore, kale is thought to have a slower maturity than the turnip and turnip hybrid. However, Horn and Rao (1986) observed kale to have a greater overall herbage yield due to its ability to grow longer into the fall compared to rape. Harper and Compton (1980) had similar observations, confirming that regardless of the slower DM accumulation rate, kale is more winter hardy allowing it to grow later in the season and produce more overall forage yield compared to rape. Comparably, Kalmbacher et al. (1982) stated that rape or turnips required 100 to 120 days to reach maximum forage yield while kale required 150 to 180 days. It was also noted that kale produced maximum DM biomass (6220 kg ha $^{-1}$) when planted in October and allowed to stockpile.

Kalmbacher et al. (1982) found that kale produced the highest DM biomass with a single cutting (6220 kg ha^{-1}), as forage biomass significantly decreased with multiple cuttings (2250 kg ha^{-1}; $P < 0.05$). Alternatively, rape provided the greatest biomass (4630 kg ha^{-1}) when subject to multiple cuttings as compared to a single cutting (1250 kg ha^{-1}). This suggests that rape is able to recover quickly from cutting allowing the overall forage yield to increase with each harvest. Similarly, Kalmbacher et al. (1982) found that turnips produced greater forage mass in a multiple cut system as compared to a stockpiling system (2900 and 1200 kg ha^{-1} respectively; $P < 0.05$). However, lower root mass were observed in the multiple cut system than when stockpiled (2060 and 3580 kg ha^{-1} respectively; $P < 0.05$; Kalmbacher et al., 1982).

Overall, research suggest that rape, turnip, and turnip hybrids accumulate forage biomass more rapidly than kale (Horn and Rao, 1986; Harper and Compton; 1980). However, the winter hardiness of kale can be beneficial in systems where a longer growing season and a single cutting is necessary (Kalmbacher et al., 1982). Turnip and turnip hybrids show to yield greater forage biomass with multiple cuttings, which would suggest that it could be advantageous in a grazing system. Alternatively, the edible root mass of turnip and turnip hybrids is negatively affected when subjected to multiple cuttings (Kalmbacher et al., 1982). Rape can produce higher foliage biomass in multiple cut systems than turnip and turnip hybrids; however, when assessing both root and shoot yield of turnips, they produce higher overall biomass than rape (Rao and Horn, 1986; Harper and Compton, 1980; and Kalmbacher et al., 1982).

Bulb Yields of Brassicas

A benefit to incorporating brassicas as forage is the production of nutrient-dense bulbous taproots that are able to be consumed by livestock. Species depending, the bulbous taproots can greatly contribute to the overall forage yield available for livestock to graze. Westwood et al. (2012) observed that across cultivars, bulb turnips are consistently at a leaf to root ratio of 55% leaf and 45% root. Inversely, swede root biomass was found to potentially contribute over 75% of total DM yield. Westwood et al. (2012) also observed that as foliage biomass increased, root biomass decreased; this suggest that there is converse relationship between foliage yield and root yield. During the fall growing season, Guillard et al. (1988) observed greater foliage biomass in the turnip hybrid and greater total biomass (foliage and root) in the turnip hybrid and swede as compared to kale and rape. Swede, however, proved to have a greater percentage of the total yield in root yield (2027 kg ha^{-1}) compared to the turnip hybrid (1327 kg ha^{-1}). Kalmbacher et al. (1982) had similar observations with higher forage biomass in turnip (2310 kg ha^{-1}) compared to swedes (1440 kg ha^{-1}) however, swedes produced higher root biomass (1600 kg ha^{-1}) than turnips (930 kg ha^{-1}; $P < 0.05$).

The differences in forage yield and root yield can also be a product of management and environmental factors. Kalmbacher et al. (1982) observed significantly lower root biomass in turnips and swedes in a multiple cutting system (930 kg ha^{-1} and 1600 kg ha^{-1}, respectively; $P < 0.05$), whereas higher root biomass were observed in a stockpiling system (1930 kg ha^{-1} and 2480 kg ha^{-1}, respectively; $P < 0.05$). It was also noted that the turnip and swede leaf and root ratio decreased proportionally as the day of planting was delayed (7.8, 6.9, and 4.9 cm, respectively). Likewise, Jung et al. (1993) found that an increase in seeding rate and narrower row spacings caused a decrease in root diameter. Planting date and temperature also contributed to a change in the proportion of root DM between the June/July planting dates.

Jung et al. (1993) observed that drought conditions may induce dormancy that can notably reduce root biomass. Likewise, Dragland (1982) observed swede bulb biomass to be considerably lower when experiencing drought conditions. This proves that the adverse relationship between root and forage biomass in brassica is not outright, as both can decrease depending on growing conditions.

Forage Quality of Brassicas

Brassicas have the potential to be a highly digestible forage for livestock. *In Vitro* Dry Matter Digestibility (IVDMD) values were reported to range from 770 to 991 g kg^{-1}, these values surpass what is typically reported in most grasses. The average DM content was low and was reported at a range from 75 to 230 g kg^{-1} across all species of brassica (Kalmbacher et al., 1982; Westwood et al., 2012; Bokhari et al., 1981; Rugoho et al., 2014). Rugoho et al. (2018), observed that DM utilization was found to be higher in brassicas as compared to Perennial ryegrass (*Lolium perenne* L.;97% and 76%, respectively; $P < 0.05$).

Westwood et al., 2012 observed the highest whole plant CP concentrations in leafy turnips (226 g kg^{-1}) among forage brassicas, followed by bulb turnips, swedes, and rape (142, 137, and 108 g kg^{-1}, respectively). Similarly, in a study conducted by Jung et al. (1986) comparing spring-planted brassica cultivars, it was observed that the highest average CP concentrations were in turnips (225 g kg^{-1}) and the lowest in rape (155 g kg^{-1}). Additionally, Jung et al. (1986) observed that CP concentrations ranged from 110 g kg^{-1} in the roots of certain brassica cultivars to 270 g kg^{-1} in turnip tops. Likewise, Kalmbacher et al. (1982) found that CP concentrations were higher in the leaves of swede (236 g kg^{-1}) and turnip (207 g kg^{-1}) as compared to the roots (184 g kg^{-1} and 153 g kg^{-1}, respectively; $P < 0.05$). Rugoho et al. (2014) found whole plant CP concentrations between kale and Italian ryegrass (*Lolium multiflorum* Lam.) comparable (175 and 187 g kg^{-1}, respectively; $P = 0.05$).

Planting dating and growing season have been observed to affect CP concentration in brassicas (Kalmbacher et al., 1982; Rao and Horn, 1986). A study conducted in Southern Great Plains of the United States by Rao and Horn (1986), found CP concentrations decreased less rapidly in fall grown brassica compared to spring grown crops. Kalmbacher et al. (1982) observed reduced CP concentrations in turnip and kale leaves when planted earlier in October compared to a later, January planting (183 g kg^{-1} and 197 g kg^{-1}, respectively).

Furthermore, an inverse relationship between yield and CP concentration has been observed. For example, Jung et al. (1993) observed the lowest CP concentrations (242 g kg^{-1}) when forage mass were highest and CP concentration was greatest when forage mass were lowest (281 g kg^{-1}). This relationship is consistent with the above-mentioned results from

Kalmbacher et al. (1982) where low CP concentrations were found in greater-yielding brassicas planted earlier. Additionally, Denman et al. (2018) observed higher CP concentrations at lower forage mass when planted earlier but lower CP concentrations with greater forage mass when planted later. Harvest frequency appears to negatively affect CP concentrations. Westwood et al. (2012) found that CP concentration in turnips decreased between the first and second harvest (226 g kg_{-1} and 153 g kg_{-1}, respectively). The CP values observed across species and cultivars meet the requirements for a 249 kg feeder steer to gain 1 kg day_{-1} of 124 g kg_{-1} CP (NRC 2016).

Relatively low values of neutral detergent fiber (NDF; range of 140 to 420 g kg_{-1}) and acid detergent fiber (ADF; range of 110 to 360 g kg_{-1}) were reported across all species of forage brassicas in several studies compared to values that are usually observed in legumes and some grasses (Westwood et al., 2012; Guillard et al., 1988; Bokhari et al., 1981). Guillard et al. (1988) observed higher NDF values in rape and kale compared to swedes and turnips due to the higher stem to leaf ratio. It was also observed by Guillard et al. (1988) that NDF and ADF values were higher in fall grown brassicas compared to summer grown ($P = 0.05$). Neutral detergent fiber values reported across all brassica species are below the optimum for ruminal function (270 – 300 g kg_{-1}; NRC 2016) which indicate it is a low fiber and highly digestible forage. Livestock consuming such a low NDF diet require a high NDF supplement and can be subject to ruminal acidosis without a supplement (Westwood et al., 2012).

In Vitro Dry Matter Digestibility of brassica was observed and ranged from 847 to 930 g kg_{-1} (Guillard et al., 1988; Jung et al., 1986). Research conducted at the University of Connecticut by Guillard et al. 1988, observed high IVDMD values across all cultivars of brassicas in both root and foliage. Values of foliage were similar for turnip, turnip hybrid, and swede in both summer (900, 893, and 891 g kg_{-1}, respectively) and fall-grown crops (901, 904, and 897 g kg^{-1}, respectively). However, foliage values for rape were reduced from fall to summer-grown crops (906 and 847 g kg^{-1}, respectively) likely due to the higher production of stems compared to the other species. Jung et al. (1986) observed high IVDMD values across all cultivars of brassica at 90 to 120 DAP but observed lower values for kale (~821 to 836 g kg^{-1}). Based on previous research, the CP and IVDMD of forage brassicas meet the requirements for most ruminant livestock (Jung et al., 1993; NRC, 2016), however, the ADF and NDF values are too low to be feed without a fibrous supplement (Westwood et al., 2012; NRC, 2016).

Root and Bulb Quality of Brassicas

The bulbous taproot of brassica species is often large enough to be removed and consumed by livestock. Like the vegetation of brassicas, these bulbs have been shown to provide additional highly digestible nutrients when included in livestock diets. Westwood et al. (2012) found that in bulb turnips, the bulbs were more digestible compared to the leaves (mean values of 96.4% and 83.0%, respectively). However, much like the foliage of brassicas, DM content of the bulbs are low (ranging 150 to 230 g kg^{-1}) and would not provide adequate DM for optimum ruminal function (Bokhari et al., 1982; NRC, 2016).

Bohkari et al. (1982) observed mean CP concentrations to be 123 g kg^{-1} in the roots compared to 196 g kg^{-1} in the shoot portion of the brassica plant. Whereas, Rao and Horn (1986) found CP levels to be 25 to 60 g kg^{-1} lower in the root than the shoot. Jung et al. (1986) observed no significant differences between turnip and swede bulb CP concentrations (136 and 130 g kg^{-1}, respectively). The growing season was shown to have an effect on CP concentrations as well. Rao and Horn (1986) observed a decline in CP levels more rapidly in the spring grown brassicas compared to fall grown and that the mean rate of CP concentration decreased by 1.0 g kg^{-1} day^{-1} in the roots of the brassica crops.

Bohkari et al. (1986) reported mean NDF values in the roots (179 to 206 g kg^{-1}) similar to those in the leaves (184 to 251 g kg^{-1}). Guillard et al. (1988), observed the mean NDF values of the bulbs of fall grown brassicas to be only 72% of that found for summer grown brassicas. In contrast, they found no effects due to season or species on concentrations of ADF, with a mean value of 141 g kg^{-1}. It was also reported by Guillard et al. (1988) that digestible energy (DE) for fall growth was higher than that of summer growth (14.9 and 13.5 MJ kg^{-1}, respectively; $P = 0.05$). Guillard et al. (1988) observed, IVDMD values of the bulbs ranged from 922 to 976 g kg^{-1} and were affected by season and species. While, Rao and Horn (1986) found the IVDMD of the bulbs ranged from 800 to 860 g kg^{-1} and increased with each harvest date, likely due to the increased concentrations of both starch and non-structural carbohydrates.

Mineral and Chemical Composition of Brassicas

The mineral composition of livestock diets is an important factor to consider when creating a well-balanced diet. Unfortunately, little research has been conducted on the mineral composition of brassicas.

Calcium levels of brassica are typically high, averages are often up to 40 g kg^{-1} (Ruiter et al. 2009), which meet the Ca requirement for most ruminant species and classes (e.g., NRC, 2016). Cows or heifers close to calving require less than 60 g Ca day^{-1} (Ruiter et al., 2009). Therefore, because of the high calcium levels, brassica intake needs to be monitored when fed to cows close to calving because of the effects cow Ca metabolism (Ruiter et al., 2009). Phosphorus levels in brassicas were found to be low at 2 to 4 g kg^{-1}, which may be inadequate for dry, pregnant cows (24 g P day^{-1}; NRC 2016), as well as other ruminant species (Ruiter et al., 2009). Therefore, incorporating a high-P forage or supplement into the diet may be needed. Ruiter, et al. (2009) also reported that brassicas are low in Mg and high in K, which can cause hypomagnesemia and is problematic during late gestation and early lactation. Therefore, magnesium supplementation is highly recommended to combat the low levels of Mg found in brassicas (Ruiter, et al., 2009). It has also been found that cattle grazing brassicas as a majority of the diet can often suffer from Cu deficiency (Ruiter et al., 2009). Consequently, Cu supplementation is needed if cattle are grazing brassicas for an extended period of time (Ruiter et al., 2009).

Brassicas have been shown to far exceed the maximum tolerable sulfur concentration in a ruminant diet (4.0 g kg_{-1}) with S concentrations ranging from 5.6 to 8.5 g kg_{-1} (Sargison, 2003; Sun et al., 2012; NRC, 2016). The toxic concentrations of sulfur in brassicas is probably to a be a result of the secondary S-compounds found in brassicas, S-methyl-cysteine sulfoxide (SMCO) and glucosinolates (Sargison, 2003; Barry 2013). SMCO is converted by bacterial fermentation in the rumen to dimethyl disulfide, which may result in haemolytic anemeia and depressed voluntary feed intake (Sargison, 2003; Barry 2013). High levels of glucosinolates in brassicas may cause an inhibition of goitrogens and reduce uptake of iodine in the thyroid gland. As a result, iodine deficiency becomes an issue and increases the risk of health issues such as goiters and scours (Barry, 2013; Sargison, 2003).

The oncentrations of SMCO has shown to decline with different management practices and species selection. Kunelius (1987) observed slightly lower SMCO concentrations in radish and turnip hybrids compared to rape or kale (4.9, 5.0, and 6.2 g kg_{-1} DM, respectively). While, Forss and Barry (1983) observed higher glucosinolate concentrations in swedes compared to kale (23.7 and 9.1 g kg_{-1} DM, respectively). Kunelius (1987) also found that SMCO concentrations increased with later planting dates from May to August (4.2 and 8.2 g kg_{-1} DM, respectively). Similar results were observed by Whittle et al. (1976), concluding that SMCO levels increase with plant maturity and exposure to frost conditions. Ruiter et al. (2009) recommended using reduced rates of S fertilizer to decrease the SMCO concentration in the brassicas used as forage. Feeding supplemental forages that are low in SMCO and glucosinolate compounds can dilute the concentration from the brassica and therefore decrease the potential of toxicity to the animal. Controlling planting date and brassica species that are lower in concentrations of SMCO and glucosinolates may help with mitigating the risks (Kunelius 1987; Whittle et al., 1976).

Animal Performance and Grazing Behavior on Brassicas

As aforementioned, the forage quality of brassicas is comparatively high, being highly digestible and containing high concentrations of CP and energy. However, the low fiber content of brassicas has been shown to attribute to slower gains than expected in livestock consuming a sole brassica diet (Ruiter et al., 2009). Therefore, other high fiber forages are needed to stimulate rumination in grazing livestock. The use of high fiber supplements would benefit by slowing the rate of passage, allowing more of the nutrients to be absorbed and utilized; as well as, increased saliva production to stabilize rumen pH and promote normal microbial function in the rumen (Ruiter et al., 2009). Increased fiber content could also dilute the concentration of SMCO and glucosinolates found in brassica species, which have been shown to negatively affect animal performance by reducing voluntary feed intake (VFI) (Ruiter et al., 2009; Barry, 2013).

Barry (2013) observed average weight gains of young sheep grazing forage rape and turnips (225 g kg^{-1} and 173 g kg^{-1}) to be greater than that of those grazing kale and swedes (120 g kg^{-1} and 95 g kg^{-1}). The low growth of the lambs on kale and swedes correlates with the higher concentration of SMCO observed in both kale and swedes, supporting that SMCO concentrations affect animal performance. Fitzgerald and Black (1984) performed a study comparing rape, kale, and fodder radish (*Raphanus sativus*) on finishing lambs. Fitzgerald and Black (1984) observed low intake on rape and kale (500 g DM day^{-1}) compared to fodder radish (750 g DM day^{-1}) over the first 2 weeks of grazing. Fitzgerald and Black (1984) observed lesser liveweight gain in those grazing kale (5.56 kg lamb^{-1} and 230 kg ha^{-1}) compared to those grazing rape (7.85 kg lamb^{-1} and 327 kg ha^{-1}). Fitzgerald and Black (1984) also observed the feed conversion efficiency from rape, based on the estimated DM intake of the crop, was superior to that from both kale and fodder radish for liveweight gain (7.1, 11.6, and 10.9 kg DM kg^{-1} live weight gain, respectively; $P < 0.001$) and carcass gain (15.1, 23.8, and 26.6 kg DM kg^{-1} carcass gain, respectively; $P < 0.001$). Similar to Barry (2013), Fitzgerald and Black (1984) believes the poorer performance on kale compared to rape was due to higher concentrations of SMCO in kale.

Animal preference to brassicas has been shown to impact the intake of brassicas when first allowed access, this has been referred to as the adjustment time to brassicas (Nicol and Barry, 1980; Barry et al., 1981; Brunsvig et al., 2017). Nicol and Barry (1980) observed slower initial growth rates of lambs transferred from grass pasture to grazing brassicas. However, higher growth was observed at 4 to 6 weeks of adaption. Comparably, Barry et al. (1981) observed low initial gains (0.23 to 0.27 kg d^{-1}) in young cattle grazing kale as a sole diet but increased to 0.49 kg d^{-1} after 6 weeks. Brunsvig et al. (2017) observed cattle to consume larger amounts of grass compared to brassica within the first two days of the trial. However, brassica consumption increased at 24 days after the trial began before declining again at 46 days after initiation. Results from Brunsvig et al. (2017) indicate that grazing behavior may affect brassica consumption. They noted that ruminants often avoid selection of plants with toxins that may reduce digestion.

Brunsvig et al. (2017) observed prominent variations in rumen function over 46 days since the initiation of the grazing trial. It was observed that acetate:propionate concentrations were lowest on day 24, while ruminal nitrate concentration tended to linearly ($P = 0.06$) decrease as the cattle were on the pasture for a greater amount of time. Likewise, Brunsvig et al. (2017)

observed ruminal liquid and particulate fill were less with greater amounts of time on the pasture. Differentiations in concentrations and quantity of ruminal end products were likely indicative of greater selection of grass compared to brassicas (Brunsvig et al., 2017). Particulate fill in the gut decreased by 52% from day 2 to 24 as the proportion of brassica in the diet increased (Brunsvig et al., 2017). Brunsvig et al. (2017) also observed NDF values at its highest at 2 days after grazing (428 g kg^{-1}; $P = 0.05$) and then decreased as the proportion of brassicas in the diet increased (355 g kg^{-1}; $P = 0.05$). A similar trend was noted with ADF values as well (336 and 341 g kg^{-1}, respectively). These results show that the amount of brassica in the diet can directly impact the rumen, therefore, impacting the performance of the animal (Brunsvig et al., 2017). To ensure effective adaptation to grazing brassicas, it is important to slowly allow livestock access for a few hours a day then gradually increase their time and allowance over the progression of 10 days. A slow introduction will help alleviate health concerns that may occur with abrupt diet changes (Brunsvig et al., 2017; Ruiter et al., 2009). As mentioned above, it is also beneficial to add a high fiber supplement to ensure optimum ruminant function and dilution of toxins found in brassicas (Ruiter et al., 2009).

Brassica has been shown to provide benefits when used as a supplemental forage in livestock diets. Moorby et al. (2003) conducted a study comparing the nutritive value of barley (*Hordeum vulgare*)/kale silage with perennial ryegrass silage for lactating dairy cattle. Moorby et al. (2003) observed lower CP concentrations in the barley/kale silage compared to the grass only (108 and 168 g kg^{-1}, respectively). However, cows produced significantly greater milk yields with the barley/kale silage compared to the grass silage (24.0 and 22.6 kg d^{-1}, respectively; $P < 0.01$). Conversely, cattle consuming the barley/kale silage had lower milk fat than those consuming grass only (1020 and 1076 g d^{-1}, respectively; $P < 0.01$). These difference in milk fat are likely due to the lower fiber digestibility in the barley/kale crop compared to the grass (0.49 and 0.72 g kg^{-1}, respectively; Moorby et al., 2003). This indicates that the nutritional value of kale in the barley/kale silage offered sufficient nutrition for superior milk yields however, milk fat may be reduced.

Ingram et al. (2018) conducted a grazing trial in Watkinsville, GA utilizing canola as a dual-purpose crop. Weight gains of 1.21 kg d^{-1} in stocker cattle were observed on the canola, consequently, this shows that if grazed properly, canola can be used as a dual-purpose crop to be harvested for oilseed. Another grazing trial conducted in Watkinsville, GA by Franzluebbers and Stuedemann (2006) looked at cattle performance on a winter cover crop of cereal rye and a summer cover crop of pearl millet (*Pennisetum glaucum* L. R. Br.). They found that calf daily gain was higher on rye (2.18 ± 0.18 kg $head^{-1}$ d^{-1}) than on pearl millet (1.93 ± 0.17 kg $head^{-1}$ d^{-1}). Overall, both rye and pearl millet cover crops provided an ample and high-quality diet for both yearling calves or cow-calf pairs for 26-77 days (Franzluebbers and Stuedemann, 2006).

Brassicas have the ability to improve livestock diets due to the high nutritive value of all species (Ruiter et al., 2009; Barry, 2013; Fitzgerald and Black, 1984). However, due to the lack of animal preference, brassicas may cause lower gains than expected for such a high-quality forage (Nicol and Barry, 1980; Barry et al., 1981; Brunsvig et al., 2017). Therefore, it may be more beneficial to offer brassicas as a supplemental feed to ensure optimum animal growth (Ruiter et al., 2009).

Brassica Impact on Soil health in a Forage Mixture

The effect of grazing animals on the environment is typically perceived as negative. In improperly managed grazing systems, soil compaction can play a major role in decline of soil quality (Franzluebbers and Stuedemann, 2008). Rotations of tap-rooted crops have been shown to help alleviate the detrimental effects of soil compaction (Chen et al., 2013). When planting in already compacted soil, Chen and Weil (2009) observed that tap-rooted species have the ability to penetrate soils better than fibrous rooted species and therefore are ideal for the practice of "biological tillage".

Chen and Weil (2009) compared root counts for forage radish (FR: *Raphanus sativus* var. *longipinnatus*), rapeseed, and rye (cereal rye: *Secale cereale* L.) under different levels of compaction, FR had a mean of 1.47, 1.10, and 1.21 times as many roots as rye had under high, medium, and no compaction respectively at a 15-50 cm depth. This data indicates that FR root counts rarely decreased no matter the level of compaction, whereas rapeseed roots were moderately decreased and rye roots were severely decreased. It was concluded that roots with larger diameters would favor penetration even in compacted soil because of the need to overcome less friction pressure of the soil. Therefore, FR and rapeseed can be expected to perform better as a biological tillage crop as compared to rye. However, it was suggested that the combination of rye and FR may provide benefits of bio-tillage and mulching Chen and Weil (2009). Similarly, Williams and Weil (2004) observed that following a forage radish plus rye mixture cover crop, soybean biomass were significantly higher ($P = 0.10$) compared to the use of no cover crop, a forage radish cover crop or a rye cover crop separately. Williams and Weil (2004) results signify that a forage brassica with rye may provide increased benefits to the soil if used in a forage mixture due to the combination of low-resistance paths in the subsoil from the brassica taproot and the mulch from the rye.

Franzluebbers and Stuedemann, (2008) conducted a trial assessing soil physical responses to cattle grazing cover crops under conventional and no-tillage systems in the Southern Piedmont USA. Within conventional tilled soil, the grazing of cover crops resulted in a trend for lower bulk densities at a soil depth of 3-6 cm at the middle of the first year ($P = 0.06$), lower bulk densities at a soil depth of 0-3 cm at the end of 2.5 years ($P = 0.05$), and lower bulk densities at a soil depth of 12-20 cm at the end of 4.5 years ($P = 0.08$; Franzluebbers and Stuedemann, 2008). These results could have been due to the frequent disturbance of conventionally tilled soils. For no-tilled soils, the grazing of cover crops resulted in a trend for greater bulk densities at a soil depth of 0-3 cm at the end of 2 years ($P = 0.07$) and greater bulk densities at a soil depth of 0-3 cm at the end of 4.5 years ($P = 0.005$; Franzluebbers and Stuedemann, 2008). Overall, Franzluebbers and Stuedemann, (2008) found that grazing cover crops had little effect on soil bulk density.

Unfortunately, research assessing the benefits of additional soil organic matter (SOM) from brassicas in a forage mixture is uncommon. The introduction of perennial forage pastures to cropland is known to increase soil organic carbon and nitrogen, which leads to retaining organically bound nutrients in the soil (Franzluebbers and Stuedemann, 2008). Many of the benefits to SOM from cover crops comes from the carbon retained in the roots rather than above-ground biomass (Drewnoski et al., 2018). Therefore, it is possible that if grazing is managed properly, it would not decrease the SOM benefits that are typically observed from the use of cover crops (Franzluebbers and Stuedemann, 2008; Drewnoski et al., 2018). Instead, carbon accumulation in the soil would be enhanced by the recycling of plant carbon through the manure of livestock (Drewnoski et al., 2018).

Previous research shows that the use of cover crops in grazing systems may provide a high-quality forage for livestock while not contributing to soil compaction (Franzluebbers and Stuedemann, 2008). The use of a tap-rooted cover crop such as forage brassicas may even provide alleviation due to its ability to “biologically till” the soil (Chen and Weil 2009; Williams and Weil 2004). Therefore, it is possible that if grazing is managed properly by matching stocking density to forage availability and not allowing areas to become too highly trafficked, grazing cover crops may still benefit the soil by decreasing compaction and adding organic matter (Franzluebbers and Stuedemann, 2008; Drewnoski et al., 2018).

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CHAPTER 3

FORAGE YIELD, NUTRITIVE VALUE, AND ANIMAL PERFORMANCE USING FORAGE BRASSICAS IN A COOL SEASON MIXTURE[1]

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[1] L.S. Powell, R.L. Stewart, J. Sherrier, D.W. Hancock, and T.D. Denman. To be submitted to *Crop Science*.

Abstract

Forage *Brassicas* spp. have become a popular addition to winter grazing mixes, but there is limited research on the benefits of adding forage brassicas. The objective of this study was to compare a winter grazing mixture with and without forage brassica on forage productivity and animal performance. A two-year grazing trial was conducted to compare performance of two treatments: 1.) Control (CONT) including annual ryegrass (*Lolium multiflorum*), cereal rye (*Secale cereale* L.), and crimson clover (*Trifolium incarnatum*) or 2) *Brassica* (BRAS) including the mixture used in CONT with the addition of the forage-type rape, (cv. 'T-Raptor') in a randomized complete block design with three replications. Experimental units were 2.0-ha paddocks with four tester steers per unit. Additional steers were used to adjust stocking rate as needed. Every 28 d, forage samples were collected to evaluated forage yield and nutritive value, and cattle were weighed. Treatments showed no difference in forage yield early in the grazing season, greater biomass for the mixture without brassica in early spring, and greater biomass for the mixture with brassica in late spring were observed. Steer average daily gains were generally greater for the mixture without brassica in the first half of the grazing season but tended to be greater for the mixture with brassica in the last two months. Crude protein, TDN, and lignin concentrations were all within recommended ranges for stocker cattle and other grazing livestock with high nutrient requirements. Overall, it appears that using forage *Brassicas* spp. in a forage mixture does not significantly improve forage and animal performance performance over the duration of the winter annual grazing season.

Introduction

Forage production in Georgia, like much of the southeastern United States, can be achieved throughout the year when using suitable forage mixtures. Attaining year-round forage production can greatly reduce the need for supplemental feeding during the winter months when forage growth is often low, and livestock nutrient requirements are high. It has been shown that grazing winter annual crops may expand the number of grazing days by as much as 80 days (Stewart et al., 2013). Livestock producers in the southeastern United States typically take advantage of the climate by using both warm-season perennials and cool-season annuals. However, there are few, if any, species that can fill the gap between October and December when neither warm or cool-season forages typically grow (Hancock et al., 2011).

Varieties of *Brassica* spp., including turnips, kale, canola, and swedes have been used as forage in other parts of the United States and the world. Several forage brassica species are known to establish rapidly and produce approximately 4000 kg ha^{-1} in late fall or early winter in locations with mild winters (Lemus et al., 2014). Forage production during this time can effectively condense the number of days that preserved forage feeing is necessary (Stewart et al., 2013). Forage-type turnips (*Brassica rapa* L.) have shown to be able to grow in the south and have the potential to provide high-quality forage for grazing animals within 60 to 75 days after planting (DAP; Ball et al, 2015).

Forage brassicas have an observed crude protein of 200 to 250 g kg^{-1}, Neutral Detergent and Acid Detergent fiber around 19.8 and 16.8, respectively and *in vitro* Digestible Dry Matter ranging from 650 to 800 g kg^{-1} (Smart et al., 2004). The high forage quality of brassicas could be valuable during fall calving season or increasing daily gains on stocker cattle when nutrient requirements are high (Stewart et al., 2013). However, the low fiber content of brassicas has shown to attribute to slower gains in livestock consuming a sole brassica diet than expected (Ruiter et al., 2009). Forage brassicas have been found to be a successful source of forage for livestock in other countries. Likewise, research in the United States indicates that forage type turnips and turnip hybrids may be a nutritional forage as well (Lemus et al., 2014). However, there is insufficient research on the use of forage brassicas in a forage mixture in the southeastern United States.

The objective of this study was to assess the effects of using forage brassicas in a forage mixture by evaluating forage yield, forage nutritive value, and animal performance.

Materials and Methods

This experiment was conducted in two growing seasons, the 2017 – 2018 (YR 1) and 2018 – 2019 (YR 2) growing seasons, at one site. The site was located at the J. Phil Campbell, Sr. Research and Education Center in Watkinsville, GA (33°52'54.3"N 83°25'33.7"W; Watkinsville) on moderately and severely eroded Cecil sandy loam soil (fine, kaolinitic, thermic Typic Kanhapludults) with two to six percent slopes. Based on soil test results and recommendations from the University of Georgia's Soil, Plant, and Water Laboratory, the site was limed with dolomitic limestone at a rate of 1120 kg ha$_{-1}$ prior to planting and fertilized with 56.0 kg ha$_{-1}$ of UAN 32% at planting and 28.0 kg ha$_{-1}$ in the spring. Soil test were done prior to planting for both years and results were averaged among the six paddocks. Soil test results for YR 1 showed an average pH of 5.9, low to medium P content with an average of 54.3 kg ha$_{-1}$, medium to high K content with an average of 447.0kg ha$_{-1}$, and an average lime buffering capacity of 317. Soil test results for YR 1 showed an average pH of 6.0, low to medium P content with an average of 20.2 kg ha$_{-1}$, low to medium K content with an average of 119.0 kg ha$_{-1}$, and an average lime buffering capacity of 311.

Experimental Design

Forage

This experimental design was a randomized complete block design with three replications, repeated over two growing seasons. Six, 2.0-ha paddocks were randomly assigned one of the two treatments , which were the control (CONT) of annual ryegrass (*Lolium multiflorum* cv. 'Marshall'), cereal rye (*Secale cereale* L. cv. 'Wrens abruzzi'), and crimson clover (*Trifolium incarnatum* cv. ‘Dixie’) and this same mixture with the addition of the forage-type rape-turnip hybrid, (cv. ‘T-Raptor’). The six 2.0-ha paddocks were divided into three 0.66-ha sub-paddocks for rotational grazing (Figure 3.1).

In both years, the site had previously been planted to pearl millet [*Pennisetum glaucum* (L.) R. Br.] the preceding April and had a substantial amount of volunteer crabgrass [*Digitaria ciliaris* (Retz). Koel.]. These pastures were grazed through late August of each year. Following grazing of the pearl millet-crabgrass mixture, the site was mowed with a flexible wing rotatory mower (John Deere© Moline, Illinois) and received a burndown application of glyphosate (Helosate®) at a rate of 3.5 L ha$_{-1}$ one week prior to planting. Paddocks were planted at the following rates, treatment without brassica: ARG: 17.0 kg ha$_{-1}$, Rye: 84.0 kg ha$_{-1}$, CC: 17.0 kg ha$_{-1}$; treatment with brassica: ARG: 13.0 kg ha$_{-1}$, Rye: 67.0 kg ha$_{-1}$, CC: 11.0 kg ha$_{-1}$, T-Raptor: 3.00 kg ha$_{-1}$. The paddocks were planted on 19.1-cm row spacing and a depth between 1.27 and 1.90 cm using a Great Plains no-till drill (1006NT; Great Plains Manufacturing Inc; Salina, Kansas). The ARG and Rye were planted together from the main seed box at a depth of 0.63 cm; while the CC and T-Raptor were planted together from the small seed box and dropped on top of the row and packed down by the drive wheel. For the 2017-2018 season, paddocks were planted on 26 September 2017 and for the 2018-2019 season, they were planted on 20 and 21 September 2019. Both treatments received 56 kg N ha$_{-1}$ after planting and then another 28 kg N ha$_{-1}$ in the spring.

Cattle Management

This experiment was conducted using Angus (*Bos taurus*) and Angus cross stocker cattle and received IACUC project approval from the University of Georgia committee (number =

A2016 02-021-Y3-A1). For both years, 24 total tester steers were used, four steers were assigned to each paddock so that each group had approximately the same average body weight. The four testers remained on the designated 2.0-ha paddock throughout the grazing period. Each year, grazing was initiated when forage availability reached approximately 2300 kg ha$_{-1}$. Rotational decisions within the paddocks were determined weekly and made based on visual assessments and estimated DM forage biomass. Steers were rotated when forage biomass were estimated below 560 kg ha$_{-1}$. Forage allowance of steers differed due to changes in environmental conditions for both years that affected temperature, forage DM yield, and forage maturity. Additional grazer steers and heifers were used to adjust stocking rate through the put and take method. Put and take decisions were also based on visual assessments and estimated DM forage biomass to maintain target forage allowance of 1 kg DM per 1 kg bodyweight. A steer was added or removed if forage allowance was below or above target. Both stocking rate and gain per hectare (GPH) included weight data from the grazer cattle. Grazing was terminated when forage growth declined and would no longer support grazing.

For the 2017-2018 season, the tester steers had a mean weight of 224.9 kg (-51.7/+41.2 kg) and for the 2018-2019 season, the testers had a mean weight of 200.48 kg (-48.9/+36.4 kg). Grazing was initiated when conditions were deemed acceptable (temperature, forage mass, biomass accumulation rates, etc.). Average quality (RFQ: 116.8) bermudagrass [*Cynodon dactylon* (L.) Pers.] hay was provided on an ad libitum basis throughout the trial to sustain adequate fiber levels to maintain ruminal health. During the grazing period, a mineral blend with high Mg was provided to steers weekly at a rate of 828 ml per head for seven days. All animals were supplied with ad libitum access to water and shade throughout the trial.

Data Collection

Forage

A destructive harvest was conducted prior to the initiation of grazing to assess forage yield using a custom PTO driven three-point flail harvester with a 76.2-cm swath to a residual height of 6.35 to 7.62 cm for a distance of 8.00 to 10.0 m. Destructive harvests were then conducted every 28 days following grazing initiation. Harvest periods for year 2017-18 were 1: 18 December 2017, 2: 19 January 2018, 3: 16 February 2018, 4: 16 March 2018, 5: 6 April 2018, and 6: 20 April 2018. Harvest periods for year 2018-19 were: 1: 18 December 2018, 2: 16 January 2019, 3: 13 February 2019, 4: 13 March 2019, 5: 10 April 2019, and 5: 8 May 2019.

Each paddock had a total of nine forage yield measurements (three per sub-paddock) from each harvest, making a total of 27 measurements for each treatment per harvest. A subsample was taken from each measurement for both DM and forage nutritive value analysis. The wet weights of the subsamples were obtained and then the subsamples were dried in a forced-air drying oven at 60°C until weight was within 0.1 grams of the last measurement. Dry weight was then obtained and used for DM correction to calculate total DM yield of the harvested area.

After drying, samples were ground to pass a 2-mm sieve through a Wiley® Mill (Thomas Scientific, Swedesboro, NJ) and then through a 1-mm screen, in a CT 293 Cyclotec™ Labtec™ Line (Foss, Hillerod, Denmark). Subsamples were submitted to the University of Georgia's Feed and Environmental Water Lab (Athens) for determination of crude protein (CP), lignin, total digestible nutrients (TDN), and digestible Neutral Detergent Fiber at 48 hours (dNDF48) by near-infrared reflectance spectroscopy using a model FOSS 6500 (FOSS NIRS system Inc., Laurel, Maryland) spectrophotometer.

Botanical composition was assessed at the beginning (December), middle (February), and end (May) of the experiment. Botanical composition was measured by placing a 0.9-m_2 quadrat in six randomly chosen locations throughout each paddock for all botanical measurements. The quadrat was clipped to the soil surface and transported to a lab where it was then separated into subsamples of the following categories: ARG, rye, CC, brassica, and weeds. Wet weight was obtained for each of the subsamples and dried in a forced-air drying oven at 60°C until weight was stable. A dry weight was then obtained and used for DM correction to calculate the percentage of plants on a DM basis. A single rising plate meter (RPM) measurement, using a manual Filip’s folding plate pasture meter made by Jenquip, was taken before each quadrat harvest and total botanical composition sample weight was used to create a calibration for RPM measurements for each treatment. Rising plate meter measurements were taken weekly to estimate forage yield by walking a transect across the longest distance of each sub-paddock and recording the initial and final number on the RPM, as well as the number of measurements taken within the sub-paddock. Grooves in the shaft of the RPM are used to measure the travel of the metal plate which is used to measure forage mass. A continuous counter is located on the RPM to record the beginning and ending measurements. The final number was subtracted by the initial number to calculate the number of clicks from the grooves on the shaft, then the number of clicks was divided by the number of measurements taken that paddock to get an average number of clicks for the pasture. The average number of clicks was then put into the calibration equation to get an estimated DM yield per hectare. The initial calibration equations for YR1 were, CONT: $y = 104.11x - 398.79$ (r_2=0.73) and BRAS: $y = 32.226x + 723.72$ (r_2=0.33). Initial calibrations equations for YR 2 were, CONT: $y = 40.61x + 233.75$ (r_2=0.50) and BRAS: $y = 50.141x + 254.8$ (r_2=0.33); where y is estimated DM biomass and x is number of clicks.

Cattle

YR 1 grazing started on November 28, 2017 and ended April 28, 2018. However, weather conditions resulted in a prolonged period wherein herbage accumulation rates declined, and grazing was temporarily halted for 29 days from 31 January 2018 through 1 March 2018. There were a total of 106 grazing days in 2017-18. For YR 2, grazing started on November 21, 2018 and ended May 8, 2019 for a total 169 days of grazing. Steers were weighed on day 0 and every 28 days after initiation of grazing. Prior to weighing, steers were fasted in dry-lots for 16 hours to increase accuracy of actual bodyweights (Stuedemann and Matches, 1989). The weights obtained every 28 days were used to calculate ADG and GPH. Gain per hectare was calculated as the total weight gained divided by the area of the pasture (2.02 hectares). Total weight was the sum of the weight gained by the tester animals during the entire grazing season and the weight gained by the grazers during the time they were present on the pastures. Grazers were moved between pastures and treatments as needed. To minimize handling stress, these animals were not weighed every time they were moved. Rather, their weight gain was estimated for the period grazing a specific treatment by multiplying the ADG of the tester animals for that period by the number of days grazing. For YR 1, ADG periods were as followed: 2 (November 14, 2017 – November 28, 2017), 3 (November 28, 2017 – January 3, 2018), 4 (January 3, 2018 – March 1, 2018), 6 (March 1, 2018 – March 28, 2018), and 7 (March 28, 2018 – April 26, 2018). For YR 2, ADG periods were as followed: 2 (November 21, 2018 – December 19, 2018), 3 (December 19, 2018 – January 16, 2019), 4 (January 16, 2019 – February 13, 2019), 5 (February 13, 2019 – March 13, 2019), 6 (March 13, 2019 – April 10, 2019), and 7 (April 10, 2019 – May 8, 2019).

Statistical Analysis

Data were analyzed using the GLIMMIX procedure in SAS 9.4 (Cary, NC) to determine interaction and main effects of treatment and year. When applicable, harvest period or weigh period was used as main effect and analyzed with interactions. Pasture and block (three replications of both treatments) were considered random effects and an alpha level of 0.05 was used to determine significance of main effects, with least squares mean separated by pairwise comparison.

Results and Discussion

Weather

Mean maximum temperatures for both years (2017-18 and 2018-19) were at their peak at week 1 of the study (Figure 3.2). The mean minimum weekly temperature also peaked at week 1 in 2018-19 but did not peak until week 3 in 2017-18. In 2017-18, the mean maximum and minimum temperatures decreased on average by 0.38°C and 0.35°C per week, respectively. In 2018-19, the mean maximum and minimum temperatures decreased by 0.39°C and 0.37°C per week, respectively, on average across the duration of the trial. The 2017-18 season had a total of 5 weeks where the average low temperature was below 0°C, including two consecutive weeks in a row (weeks 14 and 15). However, in 2018-19, only one week had an average low temperature below 0°C.

A weekly average of 25.2 mm of rainfall occurred during the 2017-18 year. The aftermath of hurricanes Irma and Nate caused an average of 42.2 mm of rainfall between weeks 2 and 5 in 2017-18. During the 2017-18 season, a total of 4 weeks went without rainfall; however, in the 2018-19 season only one week no rainfall. A weekly average of 30.4 mm of rainfall occurred throughout the duration of the 2018-19 year.

Forage Yield

A significant difference between year ($P < 0.01$) and harvest period ($P < 0.0001$) was found therefore, statistical comparisons are presented by harvest periods within years. Data are presented for each year (Figure 3.3;3.4).

In YR 1, there were no treatment differences (*P* > 0.05) in forage yield in periods 1,2,3,4, and 5 of the grazing season. Treatment differences were only observed within the harvest period 6. During this period forage biomass were greater (*P* < 0.01) in the treatments with brassica compared to the treatment without brassica (4443 and 3401 kg DM ha_{-1}, respectively); however, during this time botanical composition measurements indicated that brassica was not present (Figure 3.5). To the contrary, it was observed that the increased forage biomass during harvest period 6 for the treatment with brassica were caused by ARG and CC and not the presences of brassica. It should be noted that in February of 2018 all steers, including testers, were removed from the trial due to low forage availability likely caused by low rainfall, steers returned to the trial in March when enough forage was present to support the four testers in each paddock.

In YR 1, botanical composition (Figure 3.5) showed a steady decline in the percentage of brassica starting in December with a negligible amount of brassica observed in February and onward, which would be expected as T-Raptor is an early maturing variety. For both treatments, rye composition peaked in February and slowly declined for the remainder of the study. However, it appears that the presence of brassica hinders the growth of cereal rye as percentages of rye at its peak are greater in treatments without brassica compared to treatments with brassica (84% and 65%, respectively). The competition between the cereal rye and brassica could be attributed to the similarities of growth curves between the two forages. Since brassicas are forbs, the broad leaf plant structure may cause competition for sun light with the cereal rye. This competitive advantage could cause the observation of less cereal rye during early botanical composition data. In contrast, the composition of ryegrass and crimson clover began to increase in February and continued for the duration of the study. Overall, there were no significant trends for forage yield between the two treatments.

In YR 2 the treatment with brassica showed greater forage biomass in harvest period 1 ($P < 0.01$) compared to the treatments without brassica (683 and 466 kg DM ha$_{-1}$, respectively). During this time brassicas were the most prominent species (Figure 3.6). In harvest periods 3 ($P < 0.0001$) and 4 ($P < 0.0001$), the treatment without brassica showed greater forage biomass as compared with the brassica-containing mixture (262 and 110 kg DM ha$_{-1}$ at period 3, respectively and 649 and 162 kg DM ha$_{-1}$ at period 4, respectively. In harvest period 6, the treatment with brassica had significantly greater ($P < 0.0001$) forage biomass as compared to the treatment without brassica (1876 and 1080 kg DM ha$_{-1}$, respectively). Similar to the 2017-18 season, the percentage of brassicas decreased considerably in the later part of the season (Figure 3.5).It is believed that the paradox that brassica herbage did not contribute to the late season increase in forage yield for the brassica treatment can be explained by the brassica's presence competing with or somehow interfering with the productivity of the cereal rye, which set the stage for less competition or interference from the rye with the annual ryegrass later in the season. Consequently, the greater yield potential of the annual ryegrass during late winter and early spring resulted in greater total biomass in the later part of the grazing season.

In the treatment without brassica, botanical compositions showed a peak in rye percentage in February with a steady decrease for the extent of the study. The treatment with brassica showed a similar peak in rye percentage in February then a continual decrease. However, it appears that the presence of brassica hinders the growth of cereal rye. The proportion of rye in the herbage biomass was approximately 200% greater without brassica than the treatments with brassica at the beginning of both grazing seasons. Likewise, the proportion of herbage biomass that was rye continued to greater in the treatment without brassica compared to the treatment with the brassica. For both treatments, ryegrass percentages continually increased throughout the study and crimson clover started rapidly increase in February. Overall, there were no apparent trends for forage yield between the two treatments.

The results were not consistent with those of Kalmbacher et al. (1982) that found high forage biomass (4040 kg DM ha$_{-1}$) in October sown brassica. Likewise, Kalmbacher et al. (1982) also found that rape provided the highest biomass (4630 kg ha$_{-1}$) when subject to multiple cuttings; which suggests that rape is able to recover rapidly from harvesting and causing the overall forage yield to increase with each harvest. Similarly, turnips produced greater biomass in a multiple cut system as compared to a stockpiling system (2900 and 1200 kg ha$_{-1}$ respectively). In contrast, the botanical composition data for both years indicate that brassica does not continue to produce high biomass when subjected to multiple grazing periods when grown in these mixtures.

Forage Nutritive Value

Statistical comparisons were done within harvest periods within years for all metrics of forage nutritive value. The forage nutritive value data are summarized in Table 3.1.

Crude Protein

In YR 1, CP concentrations differed by harvest period ($P < 0.001$) but were not affected by treatment ($P = 0.7826$) and there was no interaction. Crude protein concentrations were highest during harvest period 3 (234.4 g kg$_{-1}$) and lowest during period 6 (123.2 g kg$_{-1}$). Mean CP concentrations were 176.0 g kg$_{-1}$ for the 2017-18 year. In YR 2, there was an interaction between harvest period and treatment ($P < 0.001$) for the 2018-19 year. Crude protein concentrations were greater in the treatment with brassica at harvest period 5 compared to the treatment without brassica (Table 3.1). The lowest CP concentrations across all periods were observed during harvest period 6 for both treatments and there were no differences between the treatments (Table 3.1).

Westwood et al. (2012) observed similar CP concentrations in bulb turnips, swedes, and rape (142, 137, and 108 g kg$_{-1}$, respectively). However, Westwood et al. (2012) observed slightly higher CP concentrations in leafy turnips (226 g kg$_{-1}$) than those observed in this study. Jung et al. (1993) and Kalmbacher et al. (1982) both observed an inverse relationship amongst forage yield and CP concentrations. This inverse relationship was also observed in this experiment where the greater yielding harvest dates showed the lowest CP concentrations. The decline in CP concentration may also be the result of increasing plant maturity.

The CP concentrations observed in this study are sufficient to support a lactating beef cow (110 to 130 g kg$_{-1}$ CP; NRC, 2016) and growing cattle (74 to 166 g kg$_{-1}$ CP; NRC, 2016) with the exception of the later harvest dates. However, the proportion protein that is rumen-digestible, rumen-undegradable, and indigestible will require further research.

Total Digestible Nutrients

In YR 1, interaction of between harvest period and treatment (*P* = 0.0253) was found to affect TDN for the 2017-18 year. A greater TDN was found for the treatment without brassica compared to the treatment with brassica for harvest 2 (Table 3.1). Overall, there were no other significant differences between treatments within each harvest period. The mean TDN value over the whole season (591 g kg$_{-1}$) was not affected by treatment.

Similarly, an interaction of between harvest period and treatment (*P* = 0.0160) was found to affect total digestible nutrients for the 2018-19 grazing season. A greater TDN was found for the treatment without brassica compared to the treatment with brassica for harvest period 2 (Table 3.1). The mean TDN value over the whole season (574 g kg$_{-1}$) was not affected by treatment. The TDN values observed in this study are less than those observed by Denman et al. (2018), who observed TDN values for monocultures of forage brassicas (740 and 786 g TDN kg^{-1}) to be higher than those of bud stage alfalfa (640 to 670 g TDN kg^{-1}) or an early flower red clover (640 to 670 g TDN kg^{-1}).

Neutral Detergent Fiber

In YR 1, neutral detergent fiber (NDF) was affected by an interaction between harvest period and treatment ($P = 0.02$). During harvest period 2 NDF was greater for the BRAS treatment compared to the control ($P = 0.02$; Table 3.1). The mean NDF values for the treatments with and without brassica over the whole season were different (293.5 vs. 295.1 g kg^{-1}, respectively).

Similarly, an interaction between harvest period and treatment (P < 0. 01) affect NDF in YR 2. During harvest periods 1 (P < 0. 01) and 3 (P = 0. 03), the BRAS treatment had greater NDF compared to the control (Table 3.1). However, during harvest periods 4 (P = 0. 02) and 5 (P = 0. 01), the control treatment had greater NDF compared to the treatment with brassica (Table 3.1). Neutral detergent fiber values are consistent with several studies that observed relatively low values of neutral detergent fiber (NDF; range of 140 to 420 g kg^{-1}) across all species of forage brassicas (Westwood et al., 2012; Guillard et al., 1988; Bokhari et al., 1981).

Digestible Neutral Detergent Fiber (48 hours)

In YR 1, digestible neutral detergent fiber after 48 hours (DNDF48) was affected by an interaction between harvest period and treatment ($P = 0.02$). During harvest periods 1 ($P = 0.0022$) and 2 ($P = 0.0038$), the control treatment had a greater DNDF48 than with brassica (Table 3.1). The mean DNDF48 values for the treatments with and without brassica over the whole season were different (266.3 vs. 289.0 g kg^{-1}, respectively).

Similarly, an interaction between harvest period and treatment ($P = 0.0007$) affected DNDF48 in YR 2. Treatments without brassica had greater DNDF48 ($P < 0.01$) across the entire season compared to treatments with brassica (Table 3.1). The mean DNDF48 values were 232.0 g kg$_{-1}$ with brassica and 284.0 g kg$_{-1}$ without brassica. Digestible neutral detergent fiber at 48 hours values observed in this study was greater than digestible neutral detergent fiber at 30 hours observed by Denman et al. (2018; 114 - 187 g kg$_{-1}$),

Lignin

In YR 1, there was an interaction between harvest period and treatment ($P = 0.0030$). Lignin was greater for the treatment with brassica compared without brassica in both harvest periods 1 and 2 (Table 3.1). The greatest lignin concentration values were observed at harvest periods 5 and 6 for both treatments with brassica and without brassica (Table 3.1). Across all harvest periods, mean lignin concentrations for treatments with brassica were greater than without brassica (52.4 vs. 47.9 g kg$_{-1}$, respectively).

In YR 2, there was an interaction between harvest period and year ($P < 0.0001$). Lignin was greater in harvest periods 1, 2, and 3 for brassica treatments compared to treatments without brassica (Table 3.1). The greatest lignin concentration values were observed at harvest period 6 for both treatments with brassica and without brassica (Table 3.1).). Across all harvest periods, mean lignin concentrations for treatments with brassica were greater than without brassica (60.1 vs. 54.4 g kg$_{-1}$, respectively). Sun et al. (2012), observed similar lignin concentrations in monocultures of kale, rape, swedes, and turnips (57, 63, 51, and 63 g kg$_{-1}$, respectively). Lignin concentrations across this study are not high enough expected to be detrimental to forage quality or ruminal health.

Animal Performance

A difference (*P* < 0.0001) between year was found, therefore, statistical comparisons were done within weigh periods within years for animal performance. As aforementioned, steers were taken off of the study in February 2018 due to declined forage availability therefore, no measurements were taken for period 5. Gain per hectare was not affected by treatment overall or within any given year (*P* = 0.4196).

Average Daily Gain

In YR 1, there were no differences between treatments for steer weights throughout the trial (*P* > 0.06; Figure 3.7). Steers assigned to the treatment with brassica were observed to be heavier at the initiation of the trial compared to those on the treatment without brassica. Consequently, the steers remained that way for the duration of the trial which indicates those steers may have been more advanced in their growth prior to being on the trial.

Average daily gain (ADG) was greater (*P* < 0.0001) during weigh period 4 for livestock with the brassica treatment as compared to the treatment without brassica (0.49 and 0.18 kg/day, respectively; Figure 3.7). No statistical significance was found for ADG between treatments for the remainder of the trial. It was observed that ADG was greater without brassica early in the season (weigh periods 2 and 3), while greater ADG were observed with brassica later in the season (weigh periods 4, 6, and 7). However, as previously mentioned, botanical composition at this time showed little to no amounts of brassica present which indicates that brassica had no influence on the greater gains (Figure 3.5). Overall ADG across the study was not different between treatments with and without brassica (0.99 and 0.91 kg/day, respectively). Overall, there appears to be no obvious trend between the two treatments.

In YR 2, similar to the preceding year, there were no significant differences between treatments for steer weights throughout the trial (P > 0.10; Figure 3.8). Steers assigned to the treatment without brassica were observed to have a heavier at the initiation of the trial compared to those on the treatment without brassica. Consequently, the steers remained that way for the duration of the trial which indicates those steers may have been more advanced in their growth prior to being on the trial.

ADG was greater ($P < 0.0001$) during weigh periods 2, 3, and 4 for steers without brassica (0.85, 1.52, and 1.65 kg/day, respectively) compared to steers with brassica (0.51, 1.18, and 1.36 kg/day, respectively; Figure 3.8). During weigh period 6, ADG was greater ($P < 0.0001$) for steers with brassica compared to steers without brassica (1.60 and 1.21 kg/day, respectively). However, like 2017-18, botanical composition during this time indicate that brassica had no effect on greater gains as there were little to no brassica present (Figure 3.6). Overall ADG across the study was not different between treatments with and without brassica (1.11 and 1.22 kg/day, respectively). Overall, there appears to be no obvious trend between the two treatments.

Lower ADG observed in the treatment with brassica early on in the grazing season may be attributed to the steers failing to graze the brassica herbage. This was also found by Brunsvig et al. (2017), who observed cattle to graze greater amounts of grass compared to brassica in the beginning of the trial. However, Brunsvig et al. (2017) observed an increase in brassica consumption 24 days after the initiation of the trial. Likewise, Nicol and Barry (1980) observed slower growth rates initially in lambs that were transferred to grazing brassica from a grass pasture. These results suggest that grazing livestock must become acclimated to brassica before intake of this herbage will ensue.

Stocking Rate and Gain Per Hectare

In YR 1, there was an interaction between harvest period and year ($P = 0.048$) for stocking rate. Greater stocking rates were observed in the pastures without brassica at the initiation of the trial compared to the pasture with brassica (79 and 68 AU 2.02 ha$_{-1}$, respectively) and again at weigh period 5 (99 and 60 AU 2.02 ha$_{-1}$, respectively). In the remainder of the study there were no significant difference between treatments. However, both treatments reached their lowest stocking rates at weigh period 3 of 11 AU 2.02 ha$_{-1}$. Pastures with brassica had an average stocking rate of 39.5 AU 2.02 ha$_{-1}$ and pastures without brassica had an average stocking rate of 54.0 AU 2.02 ha$_{-1}$.

Similarly, there was an interaction between harvest period and year ($P < 0.0001$) for stocking rate in YR 2. Greater stocking rates were observed in the pastures with brassica compared to pastures without brassica at weigh periods 2 (51.3 and 33.3 AU 2.02 ha$_{-1}$, respectively) and 3 (60.3 and 31.0 AU 2.02 ha$_{-1}$, respectively). However, greater stocking rates were observed without brassica compared to with brassica during weighing periods 5 (61.0 and 47.0 AU 2.02 ha$_{-1}$, respectively) and 6 (87.3 and 49.0 AU 2.02 ha$_{-1}$, respectively). Pastures with brassica had an average stocking rate of 58.0 AU 2.02 ha$_{-1}$ and pastures without brassica had an average stocking rate of 63.3 AU 2.02 ha$_{-1}$.

Results from this study indicate that there is no overall trend for either treatment with regards to stocking rate. In YR 2, the greater stocking rates early in the trial for treatment with brassica coincide with the substantial biomass forage brassicas are known to produce early in the season. However, those results are not concurrent with YR 1 where greater stocking densities were obtained by the treatment without brassica. Gain per hectare was not affected by treatment ($P = 0.3761$) or year ($P = 0.4196$). Overall gain per hectare was observed to be greater for the treatment without brassica compared to with brassica (592 and 524 kg ha^{-1}, respectively) however, the differences were of no statistical significance (*P* = 0.3761).

Conclusion

There is very limited information on the use of forage brassicas in a forage mixture for raising stockers in a beef system and even smaller amounts of information for the implications in the southeastern United States. Results from this study indicate that forage biomass were not significantly impacted by the use of forage brassicas. Similarly, these results show that forage nutritive value was not significantly impacted by the use of forage brassica. All results obtained from this study show that either treatment, which were the control (CONT) of annual ryegrass (*Lolium multiflorum* cv. ‘Marshall’), cereal rye (*Secale cereale* L. cv. ‘Wrens abruzzi’), and crimson clover (*Trifolium incarnatum* cv. ‘Dixie’) and this same mixture with the addition of the forage-type rape-turnip hybrid, (cv. ‘T-Raptor’). can meet the requirements of most livestock classes. Likewise, steers grazing treatments with brassica and without brassica performed similarly throughout the trial. Forage treatments did not appear to affect weight, average daily gain, gain per hectare or stocking rate. Overall, it appears that using forage brassicas in a forage mixture does not significantly impact forage biomass and animal performance in Georgia. Producers can utilize both of these grazing systems. Therefore, selection of forage should depend on other factors including production goals, production cost, and adaptability into forage program.

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Tables and Figures

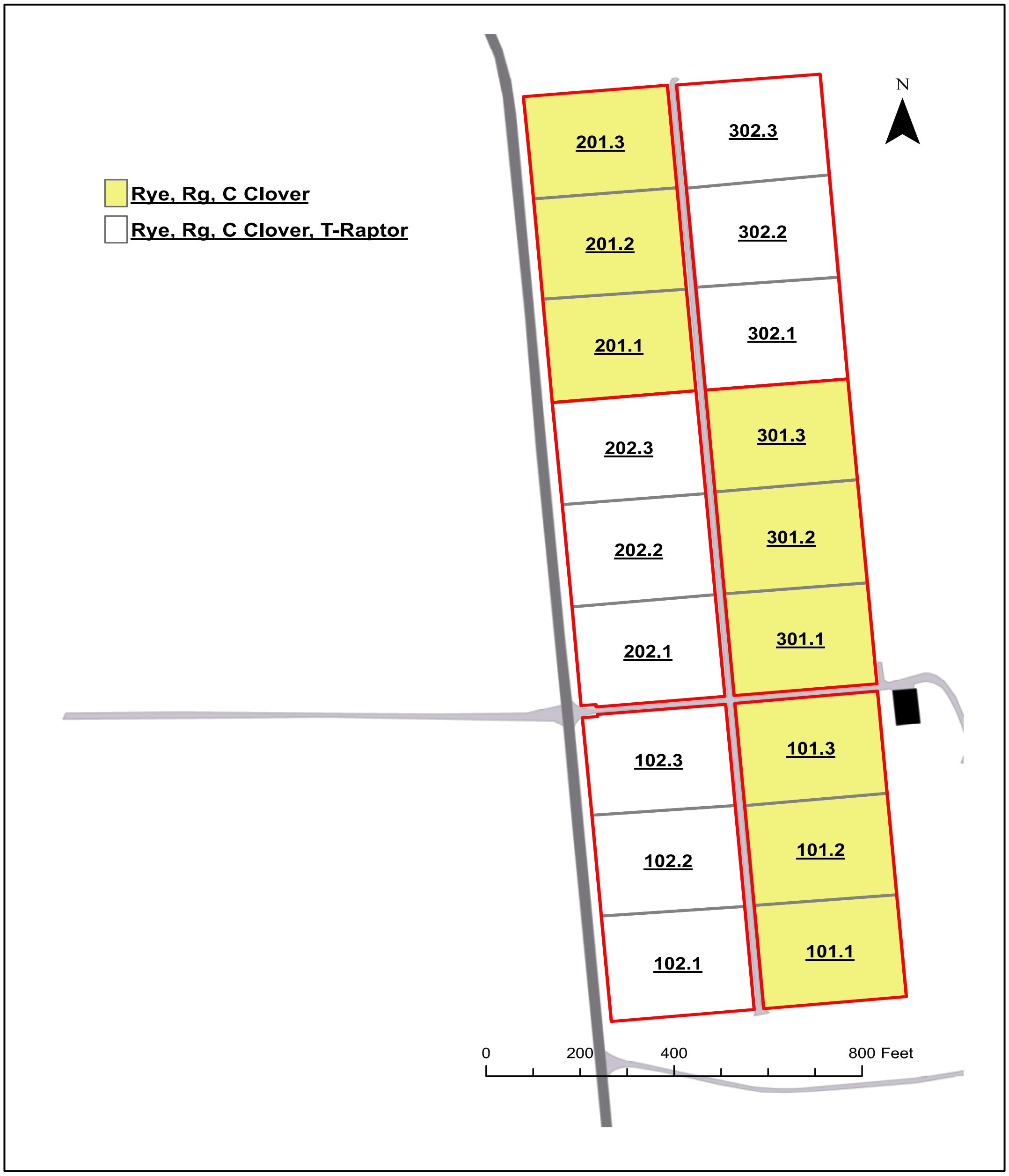

Figure 3.1: Plot layout map of the trial for both seasons. Red outline indicates 2.0-hectare paddocks for treatments without brassica (yellow) and with brassica (white). Light grey lines indicate 0.66-hectare sub-paddocks used for rotational grazing.

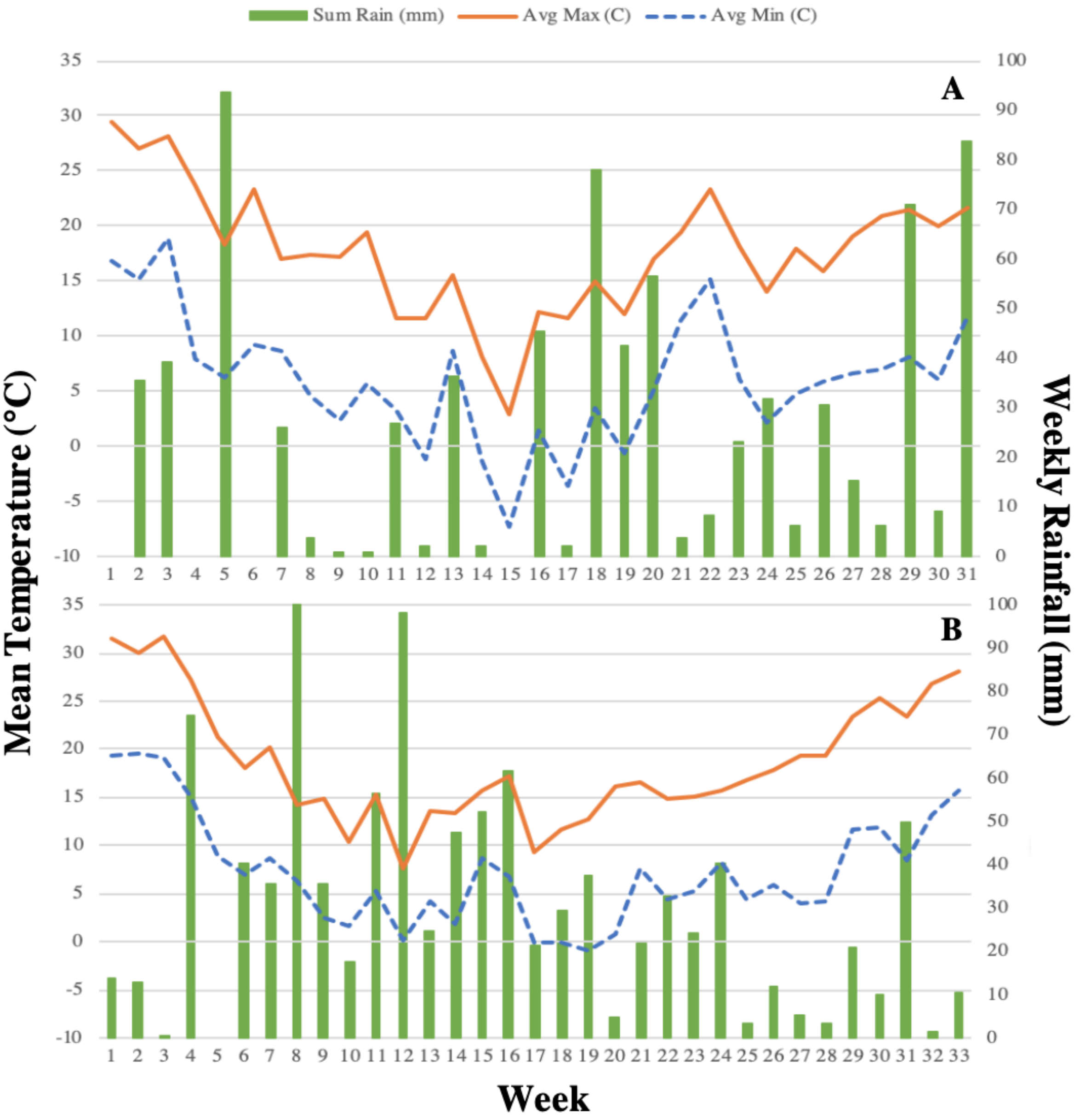

Figure 3.2: Mean maximum (solid orange line) and minimum (dashed blue line) temperature for the 2017-18 (A) and 2017-18 (B) growing seasons. Week 1 corresponds to the initiation of grazing date of the grazing trial, November 28, 2017 and November 21, 2018, respectively. Week 31 and 33 corresponds to the date of termination of grazing, April 28, 2018 and May 8, 2019, respectively.

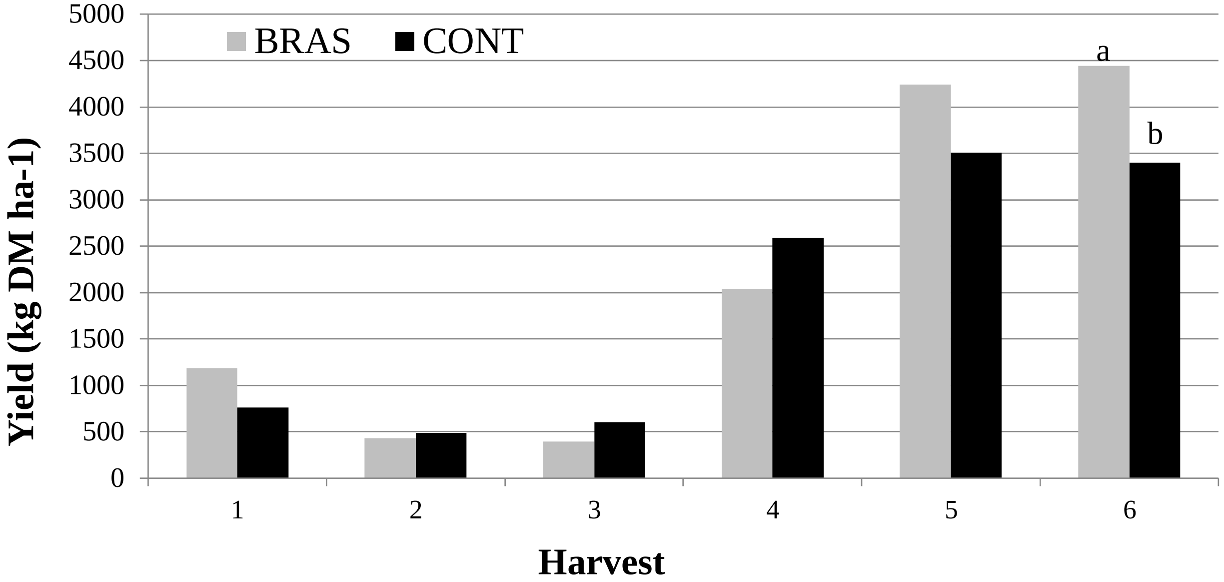

Figure 3.3: Forage yield in year 2017-2018 for treatments with brassica (gray columns) and without brassica (black columns). Harvest periods for year 2017-18 were 1: 18 December 2017 (SEM_1= 270), 2: 19 January 2018 (SEM= 91.4), 3: 16 February 2018 (SEM= 95.6), 4: 16 March 2018 (SEM= 193), 5: 6 April 2018 (SEM= 334), and 6: 20 April 2018 (SEM= 542). Means within harvest period without a common letter differ (a = 0.05).

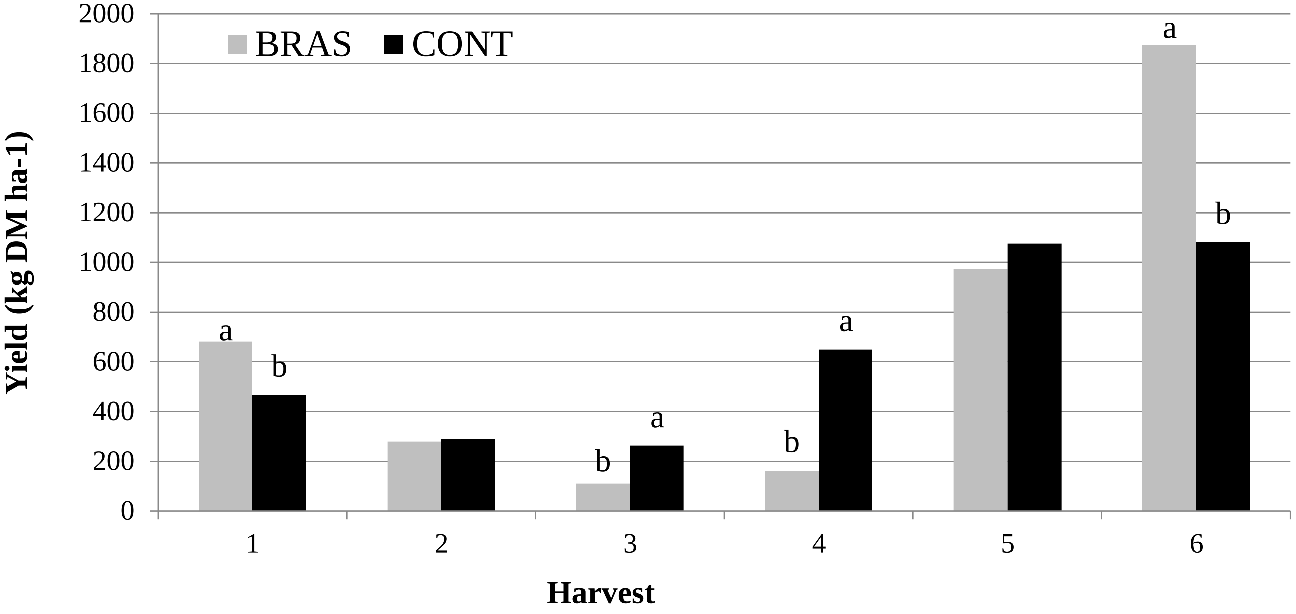

Figure 3.4: Forage yield in year 2018-2019 for treatments with brassica (gray columns) and without brassica (black columns). Harvest periods for year 2018-19 were: 1: 18 December 2018 (SEM$_1$= 70.0), 2: 16 January 2019 (SEM= 72.0), 3: 13 February 2019 (SEM= 42.0), 4: 13 March 2019, (SEM= 102)5: 10 April 2019 (SEM= 106), and 6: 8 May 2019 (SEM= 136). Means within harvest period without a common letter differ (a = 0.05).

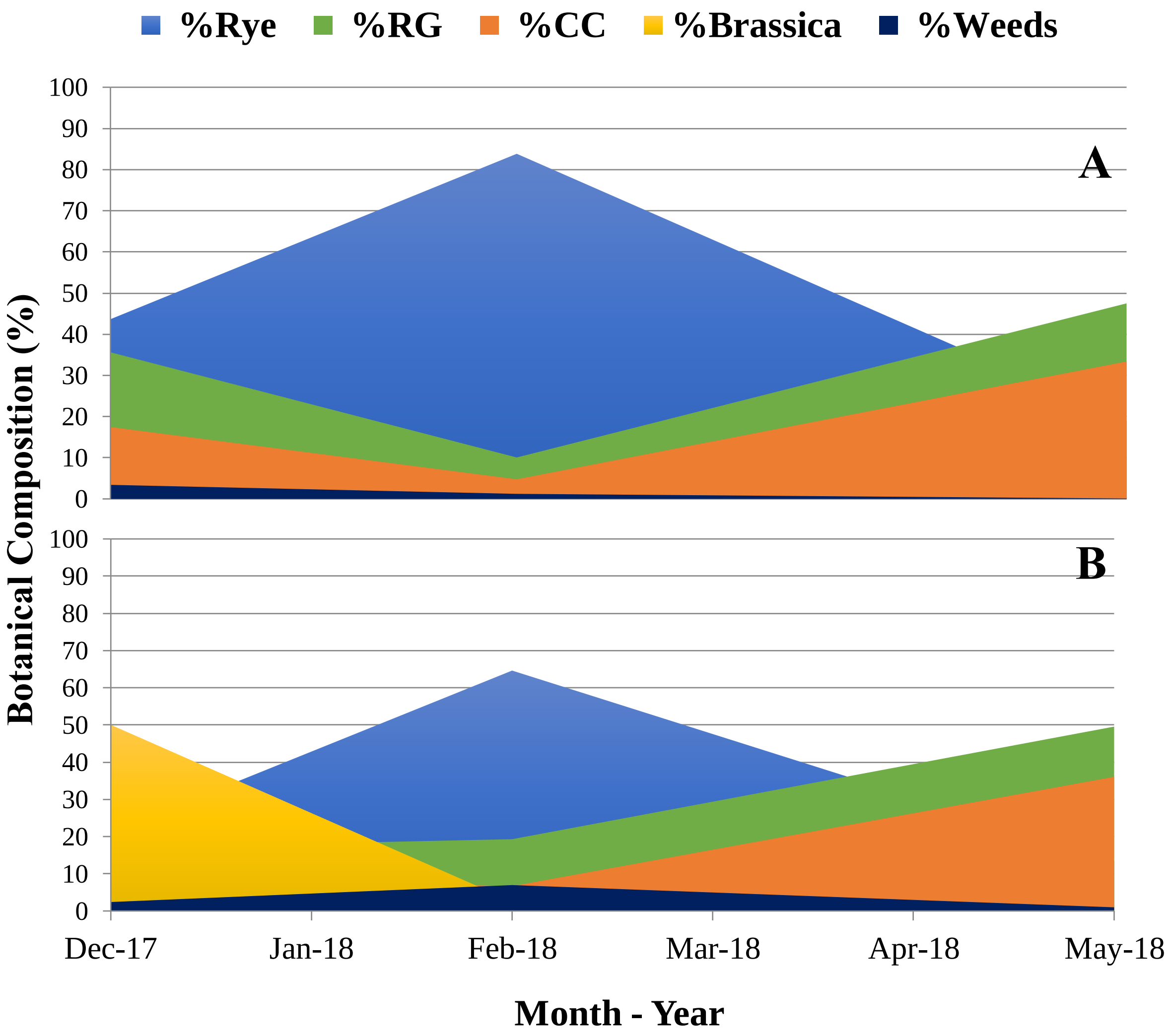

Figure 3.5: Botanical composition of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. ‘T-Raptor’, a hybrid of forage turnip) in year 2017-2018 for percentage rye (light blue), ryegrass (RG; green), crimson clover (CC; orange), brassica (yellow), and weeds (navy blue). Actual botanical compositions were obtained in December, February, and May for treatments without brassica (A) and with brassica (B). Other dates are estimates.

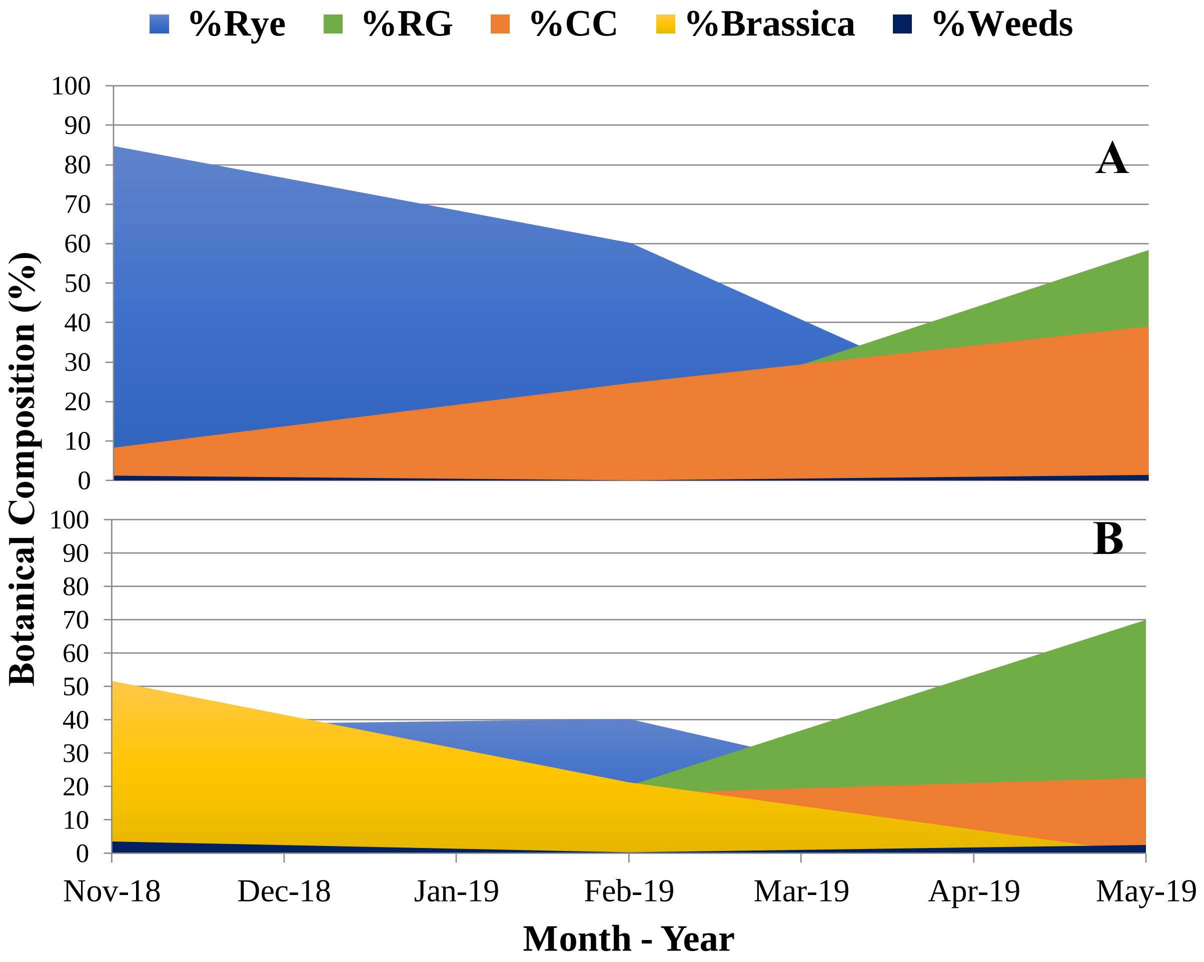

Figure 3.6: Botanical composition of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip) in year 2018-2019 for percentage rye (light blue), ryegrass (RG; green), crimson clover (CC; orange), brassica (yellow), and weeds (navy blue). Actual botanical compositions were obtained in November, February, and May for treatments without brassica (A) and with brassica (B). Other dates are estimates.

Table 3.1: Forage nutritive values of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip) for each year (2017-18 and 2018-19) and each harvest period (1 – 6) in Watkinsville, GA. Means within row without a common superscript differ (a = 0.05).

		Forage Treatment		
Year	Harvest	BRAS	CONT	SEM
Crude Protein		***g kg^{-1}***		
2017-18				
	1	185^{c}	182^{c}	2.68
	2	179^{c}	192^{c}	
	3	243^{a}	226^{b}	
	4	186^{c}	185^{c}	
	5	140^{d}	146^{d}	
	6	126^{e}	121^{e}	
2018-19				
	1	185^{a}	210^{a}	10.7
	2	187^{a}	199^{a}	
	3	187^{a}	212^{a}	
	4	212^{a}	190^{a}	
	5	197^{a}	154^{b}	
	6	121^{c}	121^{c}	
TDN^{1}		***g kg^{-1}***		
2017-18				
	1	576^{efd}	597^{bcd}	1.11
	2	565^{f}	607^{abcd}	
	3	596^{bcde}	611^{abc}	
	4	629^{a}	625^{ab}	
	5	597^{bcd}	582^{def}	
	6	583^{cdef}	565^{ef}	
2018-19				

	1	566_{bcd}	609_{ab}	1.67
	2	548_{cde}	605_{ab}	
	3	583_{abc}	590_{abc}	
	4	611_{a}	572_{abc}	
	5	525_{de}	518_{e}	
	6	551_{cde}	607_{ab}	
NDF[2]		***g kg***$^{-1}$		
2017-18				
	1	283_{de}	282_{def}	
	2	291_{d}	259_{ef}	
	3	258_{f}	261_{ef}	
	4	266_{ef}	277_{def}	
	5	317_{c}	333_{bc}	
	6	347_{ab}	358_{a}	
2018-19				
	1	288_{de}	240_{g}	
	2	284_{def}	261_{fg}	
	3	296_{cd}	270_{ef}	
	4	271_{ef}	299_{cd}	
	5	317_{c}	350_{b}	
	6	415_{a}	411_{a}	
DNDF48[3]		***g kg***$^{-1}$		
2017-18				
	1	235_{c}	284_{a}	10.2
	2	254_{b}	285_{a}	
	3	282_{a}	297_{a}	
	4	271_{ab}	287_{a}	
	5	283_{a}	294_{a}	
	6	274_{a}	285_{a}	
2018-19				
	1	207_{f}	275_{c}	6.01
	2	214_{f}	286_{bc}	
	3	241_{de}	299_{ab}	
	4	249_{d}	300_{a}	
	5	252_{d}	287_{abc}	

	6	227$_{e}$	257$_{d}$	
Lignin		***g kg$_{-1}$***		
2017-18				
	1	49.6$_{bc}$	42.1$_{def}$	1.88
	2	50.8$_{b}$	39.2$_{f}$	
	3	45.1$_{cde}$	40.9$_{ef}$	
	4	50.1$_{b}$	45.8$_{bcd}$	
	5	57.6$_{a}$	57.8$_{a}$	
	6	61.3$_{a}$	61.7$_{a}$	
2018-19				
	1	52.7$_{c}$	41.1$_{d}$	1.84
	2	52.0$_{c}$	42.3$_{d}$	
	3	55.4$_{c}$	43.9$_{d}$	
	4	55.0$_{c}$	52.6$_{c}$	
	5	66.0$_{b}$	67.3$_{b}$	
	6	79.8$_{a}$	79.4$_{a}$	

[1] TDN is total digestible nutrients.
[2] NDF is neutral detergent fiber.
[3] DNDF48 is digestible neutral detergent fiber at 48 hours.
- Harvest periods for YR 1 were 1: 18 December 2017, 2: 19 January 2018, 3: 16 February 2018, 4: 16 March 2018, 5: 6 April 2018, and 6: 20 April 2018.
- Harvest periods for YR 2 were: 1: 18 December 2018, 2: 16 January 2019, 3: 13 February 2019, 4: 13 March 2019, 5: 10 April 2019, and 5: 8 May 2019.

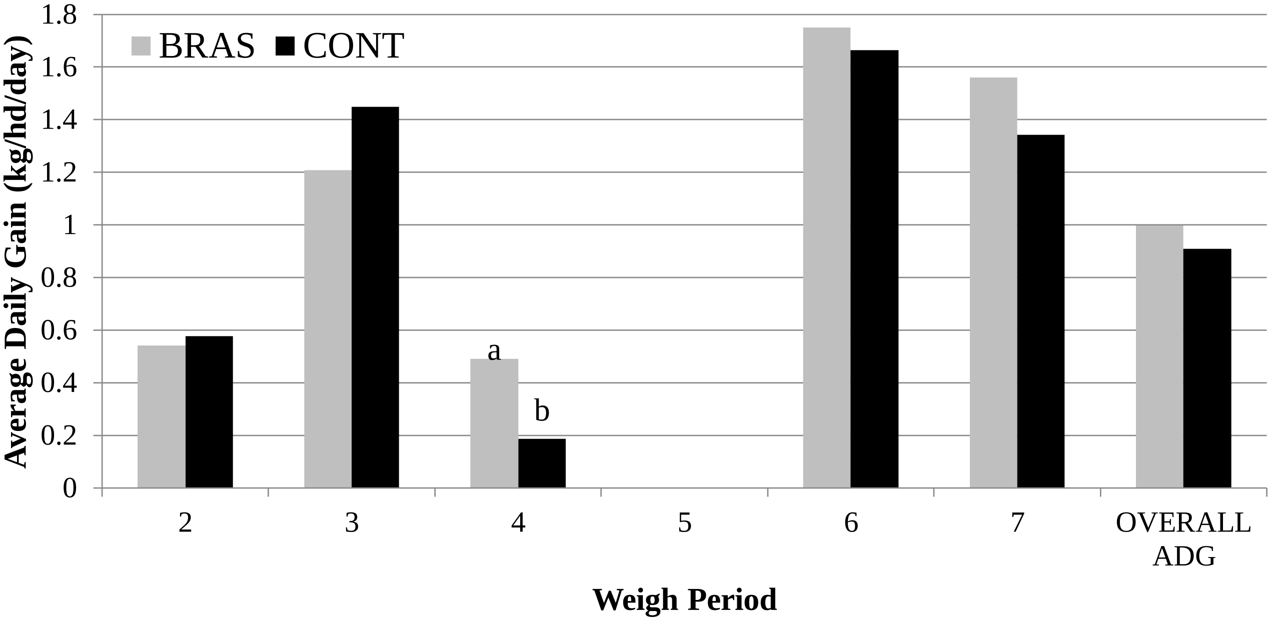

Figure 3.7: Average daily gains of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip) for 2017-2018 for treatments with brassica (gray columns) and without brassica (black columns). For year 2017-2018 average daily gain (ADG) periods were: 2 (14, November 2017 –28 November 2017; SEM_1=0.08), 3 (28 November 2017 –3 January 2018; SEM=0.09), 4 (3 January 2018 –1 March 2018; SEM=0.06), 6 (1 March 2018 –28 March 2018; SEM=0.10), and 7 (28 March 2018 –26 April 2018; SEM=0.11). Means within weigh period without a common letter differ (a = 0.05).

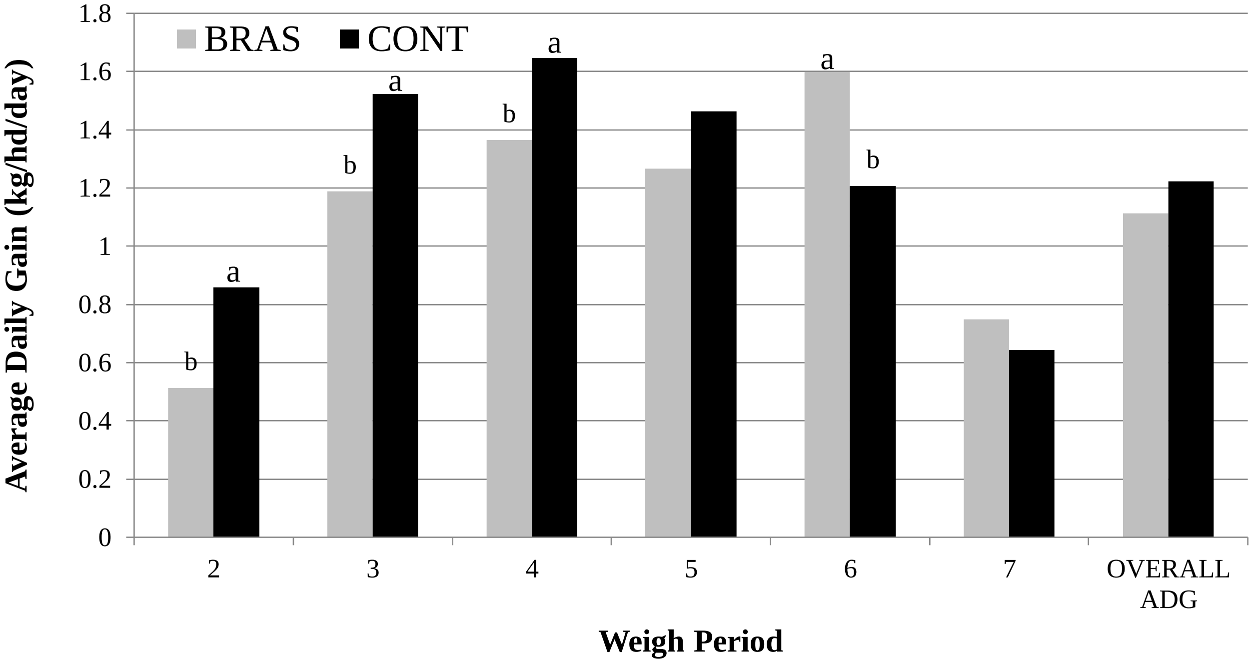

Figure 3.8: Average daily gains of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip) for 2018-2019 for treatments with brassica (gray columns) and without brassica (black columns). For year 2018-2019 ADG periods were as followed: 2 (21 November 2018 –19 December 2018; SEM_1=0.09), 3 (19 December 2018 –16 January 2019; SEM=0.11), 4 (16 January 2019 –13 February 2019; SEM=0.07), 5 (13 February 2019 –13 March 2019; SEM=0.07), 6 (13 March 2019 –10 April 2019; SEM=0.07), and 7 (10 April 2019 –8 May 2019; SEM=0.04). Means within weigh period without a common letter differ (α = 0.05).

CHAPTER 4

ASSESING SOIL HEALTH CHARACTERISTICS WHEN USING FORAGE BRASSICAS IN A COOL SEASON MIXTURE

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Abstract

Forage *Brassicas* spp. have become a popular addition to winter grazing mixes, but there is limited research on the benefits of adding forage brassicas. The objective of this study was to compare a winter grazing mixture with and without forage brassica on changes in compaction, water holding capacity, and soil organic matter. A two-year grazing trial was conducted to compare performance of two treatments: 1.) Control (CONT) including annual ryegrass (*Lolium multiflorum*), cereal rye (*Secale cereale* L.), and crimson clover (*Trifolium incarnatum*) or 2) *Brassica* (BRAS) including the mixture used in CONT with the addition of the forage-type rape, (cv. 'T-Raptor') in a randomized complete block design with three replications. Experimental units were 2.0-hectare paddocks, each paddock had four exclusion cages placed depending on the watershed of the paddock (high topography and low topography). Soil cores were taken prior to grazing and post grazing to assess soil characteristics between the two treatments. Post-season soil bulk density was slightly greater after the grazing season ended in the paddocks containing brassica compared to pre-grazing samples, but likely of little practical significance and no differences were observed in areas where no brassica was used. Water holding capacity post-grazing was found to be significantly greater in the areas that were excluded from grazing compared to the grazed, inclusion areas. Soil organic matter was greater post-grazing for treatments without brassica compared to treatments with brassica in the 2018-19 season.

Introduction

Improving soil health is critical to successfully achieve high biomass in both forage and crop systems. Compaction and lack of organic matter are two of the major factors contributing to poor soil health in Georgia. Soil compaction is often a product of heavy equipment traffic or hoof damage in livestock operations (Chen et al., 2013). Producers plant cover crops to improve soil organic matter, reduce erosion, improve soil water holding capacity, and to produce forage for livestock (Drewnoski et al., 2018). Rotations of crops with large taproots have shown to help mitigate the damaging effects of soil compaction (Chen et al., 2013). Chen and Weil (2009) observed that tap rooted species have the ability to penetrate compacted soils better than fibrous rooted species and therefore are ideal for the practice of “biological tillage”.

Soil organic matter (SOM) content contributes to overall soil health, as it decreases, problems with fertility, water availability, compaction, and erosion become more common (Magdoff and van Es, 2012). One significant benefit to SOM from cover crops is a product of the carbon retained in the roots rather than forage biomass (Drewnoski et al., 2018). Consequently, it is important to properly manage grazing to ensure root growth is not negatively impacted to benefit from the SOM of using cover crops like brassicas such as turnips (*Brassica rapa)*, rape (*Brassica napus),* and swedes (*Brassica napobrassica*; Drewnoski et al., 2018). Grazing cover crops can affect the soil microbial abundance through increased manure production which provide more easily decomposable organic matter than the plant material supplied in non-grazed systems (Drewnoski et al., 2018).

Unfortunately, little research is available assessing the potential benefits of additional soil organic matter (SOM) and compaction relief from brassicas in a forage mixture. However, the data from the utilization of brassicas as a cover crop indicates their use could be advantageous to producers in Georgia (Drewnoski et al., 2018; Magdoff and van Es, 2012). Therefore, the objective of this research was to assess soil organic matter, water holding capacity, and bulk density when using forage brassicas in a forage mixture grazed by beef cattle.

Methods and Materials

This experiment was conducted during the growing season of two years (the 2017 – 2018 and 2018 – 2019) at one site. The site was located at the J. Phil Campbell, Sr. Research and Education Center in Watkinsville, GA (33°52'54.3"N 83°25'33.7"W; Watkinsville) on moderately and severely eroded Cecil sandy loam soil (fine, kaolinitic, thermic Typic Kanhapludults) with two to six percent slopes.

Experimental Design

This experiment was conducted within a two year grazing experiment comparing inclusion of a forage-type hybrid brassica in winter annual mixtures, which was a randomized complete block design with three replications. Six, 2.0-ha paddocks were randomly assigned one of two treatments, which were the control (CONT) of annual ryegrass (*Lolium multiflorum*), cereal rye (*Secale cereale* L.), and crimson clover (*Trifolium incarnatum*) and this same mixture with the addition of the forage-type rape-turnip hybrid, (cv. ‘T-Raptor’). The six 2.0-ha paddocks were divided into three 0.66-ha sub-paddocks for rotational stocking.

Individual experimental units were within the six 2.0-ha paddocks and included two replications of each watershed (top and bottom; Figure 4.1) and four grazing treatments (pre-grazing/post-grazing and exclusion/inclusion). Two exclusion cages (1 m × 0.5 m) were placed at the top of the watershed and two at the bottom within each paddock to prevent grazing. Animal and forage management can be found in chapter 3 materials and methods.

Data Collection

A stainless-steel ring with a volume of 318 cm$_3$ (7.62 cm long, 7.62 cm wide) was used to obtain soil cores. Rings were placed evenly on the soil surface and driven into soil until the ring was flush with the soil. 'Exclusion' measurements were taken within the exclusion cage, while 'inclusion' measurements were taken 1.52 to 3.05 m from the location of the exclusion cage. Exclusion cages were made from steel panels. Four cages were placed within each paddock depending on the watershed of the paddock for the duration of the trial. Two cages were placed at the top of the watershed and two at the bottom (Figure 4.1). 'Pre-grazing' cores were obtained the week of grazing initiation and 'post-grazing' the week of grazing termination. Once cores were obtained and shaved to be flush with the ring, initial wet weights were taken then cores were saturated and allowed to drain to field capacity. Weights were obtained at field capacity then placed in a compact gravity convection oven (Thermo Scientific™ Precision™, location of company) at 60-80°C for 5 to 7 days or until final dry weights were within 0.1 g of previous weight measured. A final dry weight was recorded and used to calculate bulk density and water holding capacity (WHC). Bulk densities were calculated by dividing the final dry weight of the sample with the ring weight by the volume of the stainless-steel ring. Water holding capacity was calculated by subtracting the final dry weight of the sample with the ring weight from the weight at field capacity of the sample with the ring weight then dividing by the field capacity and multiplying by 100 to get a percentage. The cores were then broken up and sent to the University of Georgia's Soil, Plant, and Water Laboratory where soil organic matter was measured using the loss on ignition method. The loss on ignition method estimates soil organic matter based on gravimetric weight change associated with high temperature oxidation of organic matter. Initially, approximately 5 g of soil was dried at 105°C, the soil samples were then ignited in a muffle furnace for 2 hours at 360ºC. The percent weight loss during the ignition step is reported as OM-LOI (Nelson and Sommers, 1996).

Statistical Analysis

All statistical analysis was performed using the GLIMMIX procedure in SAS 9.4 (Cary, NC) to determine interaction and main effects of treatment, pre/post, inclusion/exclusion, topography, and year. Pasture and block were considered random effects and an alpha level of 0.05 was used to determine significance of main effects, with least squares mean separated by pairwise comparison.

Results

Bulk Density

Bulk densities were affected (*P* = 0.014) by an interaction of year, pre/post, and inclusion/exclusion (Table 4.1). Forage treatment and topography did not have an effect (*P* = 0.1961) on bulk density. In 2017-18, the grazed, inclusion areas increased (*P* = 0.0036) bulk density by 0.13 g/cm$_3$ from pre to post grazing. Additionally, while other statistically significant differences were observed between the inclusion and exclusion areas bulk density values for each year, the results are not biologically significant (Table 4.1). Bulk densities across the study varied from 1.32 - 1.46 g/cm$_3$. The NRCS states that for sandy loam textured soils, bulk densities less than 1.40 g/cm$_3$ are ideal for plant growth. It is also stated that bulk densities of 1.63 g/cm$_3$ start to affect root growth and bulk densities greater than 1.80 g/cm$_3$ restrict root growth (NRCS). Therefore, all bulk densities observed from this study are below the maximum bulk density where plant and root growth would be restricted (NRCS).

These results are dissimilar to previous research suggesting that the use of tap rooted crops provides elevation of soil compaction through the creation of more root channels in compacted soil compared to rye (Chen et al., 2013). However, Chen and Weil (2009) observed there was an increase in root penetration for the second year that was likely due to the formation of root channels by the brassica cover crop. However, there were no significant changes in bulk density between the first and second year for high and medium compacted soils using brassicas compared to rye (Chen and Weil 2009). While Chen and Weil (2009) observed tap rooted species to penetrate compacted soil and causing “biological tillage”. Franzluebbers and

Stuedemann (2008) observed a trend of greater bulk density with grazing cover crops in a no-till system at the end of 2 years ($P = 0.07$) compared with bulk density at the initiation of the trial cm (0.75 and 0.77 g/cm$_3$ at a soil depth of 0-3 cm, respectively). Overall, Franzluebbers and Stuedemann (2008) observed that cattle grazing cover crops caused relatively small changes in bulk density during the trial which concurs with results found in this study. However, based on pre-grazing measurements, soil compaction was not of major concern as the majority of bulk density levels were below 1.40 g/cm$_3$; therefore, this could be why no change was observed.

Volumetric Water Holding Capacity

Water holding capacities were affected ($P = 0.0368$) by an interaction of pre/post and inclusion/exclusion (Figure 4.2). Forage treatment ($P = 0.3596$) and year ($P = 0.0898$) did not have a significant effect on WHC. Since no significant differences between forage treatments were found with bulk density, the WHC was also not affected by forage treatment as WHC is correlated to bulk density (NRCS). Water holding capacities post-grazing were found to be greater in the areas that were excluded from grazing compared to the grazed, inclusion areas (13.5 and 12.7%, respectively). Water holding capacities were also affected by topography ($P = 0.0328$; Figure 4.3). Locations of high topography had greater WHC as compared to locations of low topography (13.9 and 13.3%, respectively). Similar to bulk density, these slight differences are likely of little to no practical significance.

While no research was found looking at WHC with the use of brassicas, Chen et al. (2013), they did observed that tap-rooted brassica cover crops, especially rapeseed (*Brassica napus*), were able to increase the least limiting water range in the surface of a loamy and sandy type soil.

Soil Organic Matter

Soil organic matter content was affected (*P* = 0.0485) by an interaction of year, treatment, and pre/post-grazing. Therefore, data are presented by year. For the 2017-18 season, forage treatment did not affect SOM however, it was affected by pre/post-grazing (*P* = 0.0182; Figure 4.4). Soil organic matter content was greater pre-grazing as compared to post-grazing (4.17 and 3.71%, respectively). For the 2018-19 season, an interaction of forage treatment and pre/post-grazing affected SOM (*P* = 0.0089; Figure 4.4). Soil organic matter content was greater post-grazing for treatments without brassica compared to treatments with brassica (4.09 and 3.31%, respectively).

Soil organic matter was also affected (*P* = 0.0002) by topography when data were pooled across years. There were greater amounts of SOM found at locations of high topography compared to locations of low topography (4.09 and 3.56%, respectively). Although some significant differences between treatments were observed, they are not biologically significance as the differences were less than 1%.

Unfortunately, no research has been done assessing the benefits of using forage brassicas in a forage mixture on soil organic matter. However, it is possible that if grazed properly, the use of brassicas would not negatively impact soil organic matter and the carbon accumulation in the soil may be enhanced by manure from livestock (Drewnoski et al., 2018).

Conclusion

Overall, it appears that using forage brassicas in a forage mixture does not significantly impact soil organic matter, bulk density, or water holding capacity in Georgia. Results from this study indicate that compaction was not affected by the forage treatments. It is worth noting that in this study, soils were not previously compacted as bulk densities were in the ideal range for sandy loam soils prior to the study. Similar to Franzluebbers and Stuedemann (2008), soil compaction had increased post-grazing in the inclusion areas which would be anticipated due to cattle foot traffic. However, these differences were of no biological significance.

Likewise, volumetric water holding capacity was not affected by forage treatments. Soil organic matter was found to be greater in treatments without brassica post-grazing in the 2018-19 season. While there were some significant differences in data for all soil health conditions measured, little to no practical significance can be concluded from the results of this study. In conclusion, the use of forage brassicas in a mixture show no practical significance to improving soil health conditions. Producers can utilize both of these grazing systems without seeing changes in their soil health. Therefore, selection of forage should depend on other factors including production goals, production cost, and adaptability into forage program.

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Tables and Figures

Figure 4.1: Plot layout map of the trial for both seasons. Yellow shaded paddocks indicate the treatment without brassica and blue shaded paddocks indicate with brassica. Exclusion cages are indicated by a green dot and labeled with a number 1-24.

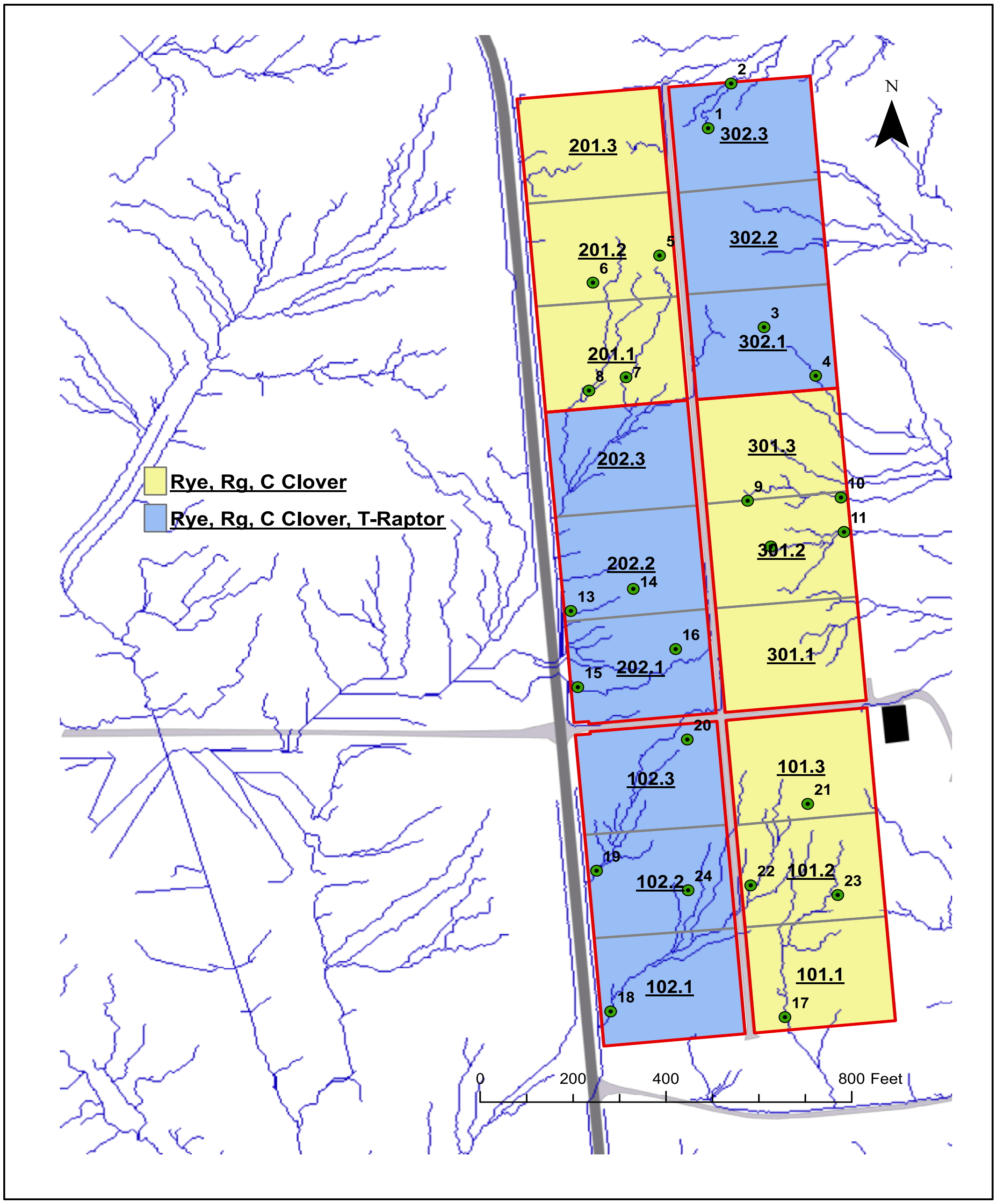

Table 4.1: Bulk density in g/cm$_3$ for inclusion/exclusion areas, pre and post grazing, and years 2017-18 and 2018-19 (SEM$_1$= 0.03) for two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip). Means within row without a common superscript differ (a = 0.05).

		Bulk Density	
	Grazing Treatment		
Year	Pre/Post	Inclusion	Exclusion
		g/cm3	
2017-18	Pre	1.37bc	1.41ab
	Post	1.46a	1.35bc
2018-19	Pre	1.33c	1.32c
	Post	1.36bc	1.37bc

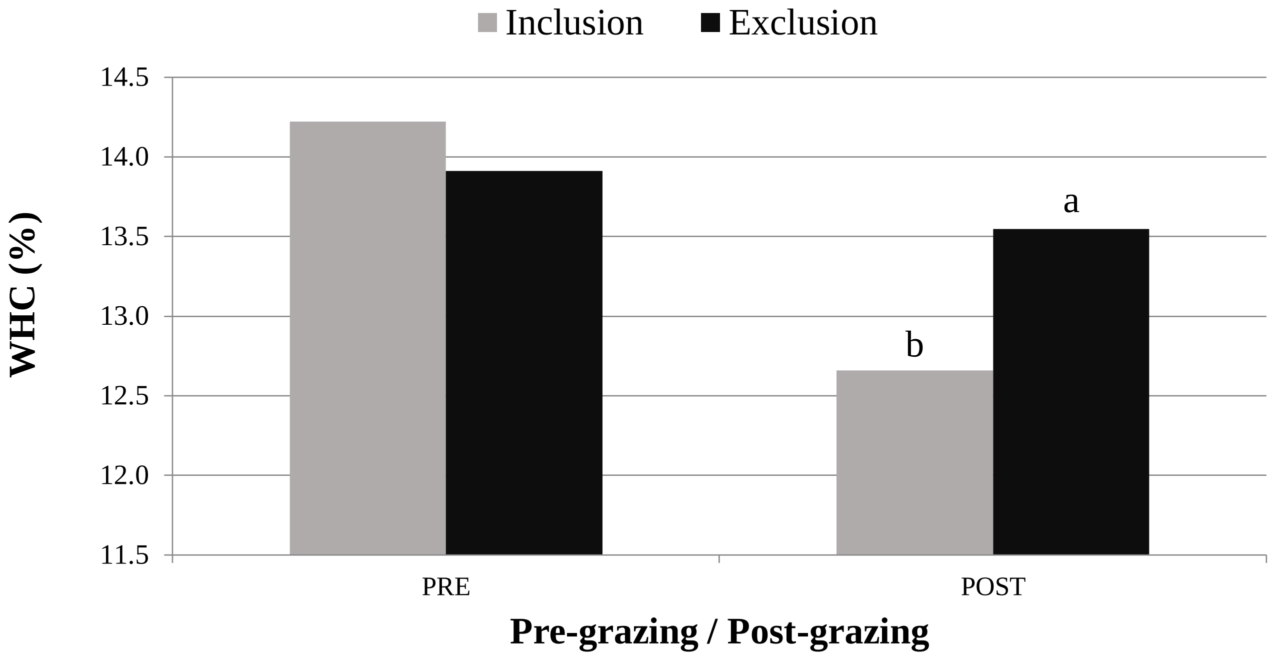

Figure 4.2: Volumetric water holding capacity (%) pre and post-grazing for inclusion (gray columns) and exclusion (black columns) areas for two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. ‘T-Raptor’, a hybrid of forage turnip) (SEM_1= 0.41). Means within treatment without a common letter differ (a = 0.05).

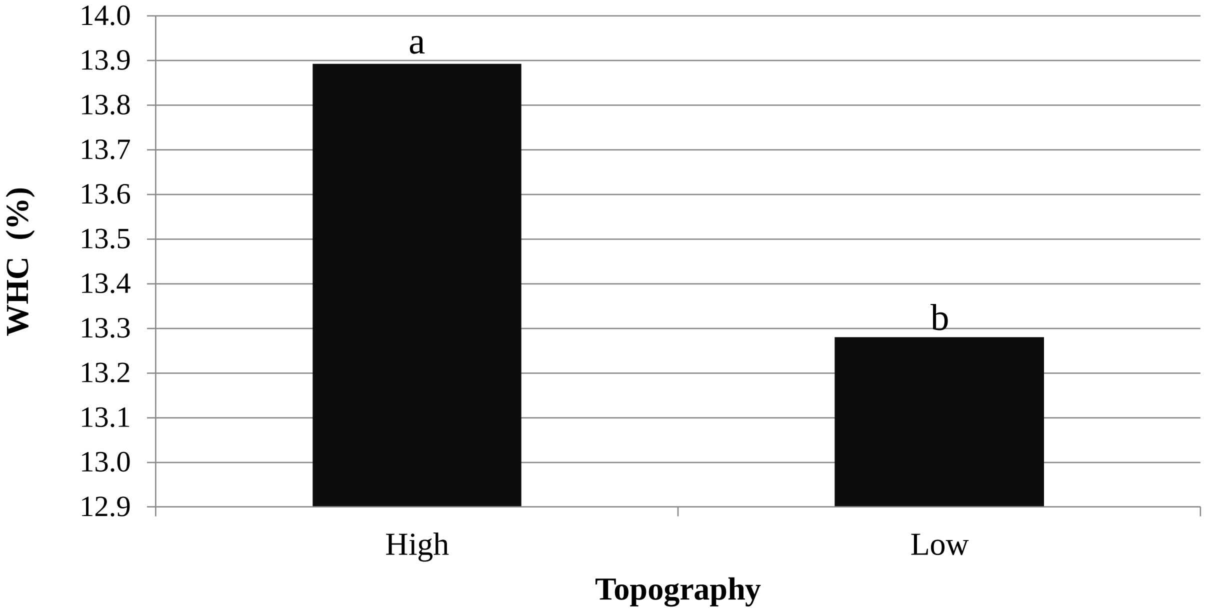

Figure 4.3: Volumetric water holding capacity (%) for high and low topography (SEM_1=0.36) of two treatments: 1.) CONT., including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS, including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. ‘T-Raptor’, a hybrid of forage turnip). Means without a common letter differ (α = 0.05).

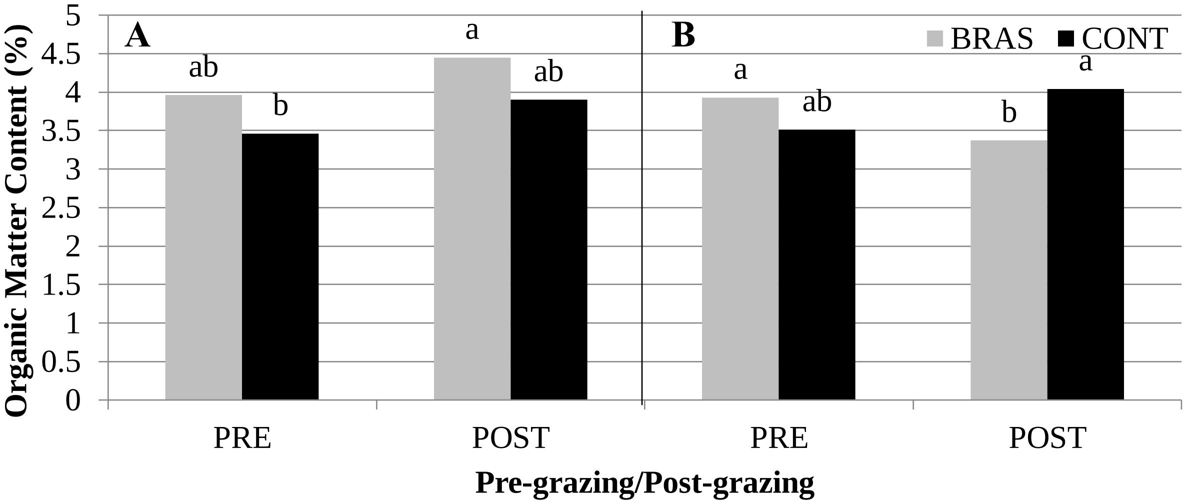

Figure 4.4: Soil organic matter content (%) for year 2017-18 (A; SEM1=0.28) and 2018-19 (B; SEM= 0.23), pre and post grazing for two treatments: 1.) CONT. (grey column), including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (R;*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) and 2) BRAS (black column), including the mixture used in treatment 1 with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip). Means within year without a common letter differ (α = 0.05).

CHAPTER 5

SUMMARY AND CONCLUSION

Reducing input cost on livestock operations is essential for optimizing efficiency and profitability. One way to greatly reduce overall input cost is by reducing the need for stored feeds when forage quantity or quality is limiting. Due to the mild climate of Georgia and the southeastern United States, producers are able to utilize both warm-season and cool-season annual forages for almost year-round grazing. However, even with the use of both warm and cool-season forages, there is still a gap in forage production during October – December during the transition period which causes a shortage of forage availability for grazing livestock. Forage brassicas ability to rapidly establish may help fill the gap and extend the grazing season while cutting cost of stored feeds.

Forage brassicas have been used effectively for grazing livestock in other countries and have shown some potential for grazing in the United States. However, there is a lack of information on the use of forage brassicas in forage mixtures for grazing stocker cattle, especially in Georgia. It is anticipated that forage brassica's ability to establish rapidly will fill the gap when warm-season and cool-season forages are not producing.

Considering this, a two-part trial was conducted to evaluate forage brassicas to increase grazing days in grazing-based systems. This study had two experiments: 1) using forage brassicas in a forage mixture for raising stockers and 2) using forage brassicas in a forage mixture for improving soil conditions. Both experiments utilized two treatments: 1.) Control (CONT) including Annual ryegrass (ARG; *Lolium multiflorum*), Cereal rye (*Secale cereale* L.), and Crimson clover (CC; *Trifolium incarnatum*) or Annual ryegrass (*Lolium multiflorum*), Cereal rye (*Secale cereale* L.), and Crimson clover (*Trifolium incarnatum*), or 2) Brassica (BRAS) including the mixture used in CONT with the addition of the forage-type rape, (cv. 'T-Raptor', a hybrid of forage turnip). Experiment 1 assessed cattle average daily gain, gain per hectare and stocking rate as well as forage dry matter biomass and nutritive value. Experiment 2 assessed soil bulk density, water holding capacity, and soil organic matter.

Results from the first experiment indicate that the use of forage brassicas has no overall significant effects on animal and forage performance. Forage biomass and nutritive value during this study were not significantly impacted by the use of forage brassicas. An inverse relationship was observed in this experiment between yield and CP concentration. The decline in CP concentration may also be the result of increasing plant maturity. Overall, CP and TDN values are sufficient to stain livestock with high nutrient requirements such as growing stocker calves. Similarly, forage treatments did not affect animal weight, average daily gain, gain per hectare or stocking rate.

To assess soil changes in soil health in the second experiment, samples were taken both pre and post grazing as well as within exclusion and inclusion areas. Comparably, results from this experiment indicate that using forage brassicas in a forage mixture does not significantly impact soil health conditions in Georgia. It was observed that compaction was not affected by the forage treatments. However, it is worth noting that at the initiation of the study, soils were not found to be compacted as bulk densities were in the ideal range for sandy loam soils. Soil compaction had increased post-grazing in the inclusion areas; however, the differences observed were of no biological significance. Likewise, water holding capacity was not affected by forage treatments. Soil organic matter was found to be greater in treatments without brassica post-grazing in the 2018-19 season. While there were some significant differences in data for all soil health conditions measured, little to no practical significance can be concluded from the results of this study.

Overall, it appears that using forage brassicas in a forage mixture does not significantly impact forage biomass, animal performance, or soil health in Georgia. Producers can utilize both of these grazing systems without seeing significant differences in soil health and animal performance. Therefore, selection of forage should depend on other factors including production goals, production cost, and adaptability into forage program.

Additional research using forage brassicas in a forage mixture, specifically in the southeastern United States, would be beneficial as there is still limited information for other states. Research utilizing forage brassicas in a limit grazing beef cattle system could better evaluate exclusively the effects of brassica on animal performance compared to a system that does not have access to brassicas.