DISSERTATION

ANNUAL COOL-SEASON FORAGE SYSTEMS FOR FALL GRAZING BY CATTLE

Submitted by

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ABSTRACT

ANNUAL COOL-SEASON FORAGE SYSTEMS FOR FALL GRAZING BY CATTLE

Extending the grazing season is one method that beef producers can use to reduce the need for preserved forages and supplements as these are the major inputs influencing profitability of their operations. Annual forages planted during mid- to late-summer have great potential for extending the grazing season into the fall and early winter in northern Colorado and similar environments. The development of forage systems for livestock operations must start with selection of forage species/cultivars that can yield enough biomass and have a high enough nutritive value to meet the requirements of the livestock to be fed. Accordingly, the research in this dissertation started with an evaluation of nine forage brassica cultivars from which four were chosen based on their unique traits. Barnapoli rape (*Brassica napus* L. var. *napus*) had the highest yields and stood up under a snow load; Groundhog radish (*Raphanus sativus* var.*oleifer* Strokes) and Barkant turnip (*Brassicas rapa* L. var. *rapa*) had fast growth and their bulbs provided extra feed and penetrated the soil, potentially reducing compaction; and Pasja hybrid (Chinese cabbage [*Brassica rapa* L. *chinensis*] x Turnip hybrid) had a high leaf-to-stem ratio which provided high quality forage for beef cattle. These were combined in a four-way mixture and evaluated in subsequent studies. In addition, the above study evaluated the impact of planting date on resulting yields of the brassicas and determined that they need to be planted by mid- to late-July to yield high amounts of biomass that can be stockpiled for fall grazing. The nutritive value of the brassicas was high and did not decline over time, but they were very low in fiber which can create rumen upset for beef cattle grazing them in monocultures or in brassica only mixtures.

To develop a more balanced diet for beef cattle, the brassica mixture was seeded with cool-season grasses (triticale [×*Triticosecale* Wittm ex A. Camus {*Secale* x *Triticum}*], winter wheat [*Triticum aestivum* L.], and barley [*Hordeum vulgare* L.]) following a warm-season hay crop (pearl millet [*Pennisetum glaucum* L.]) that was either controlled or allowed to regrow. When the latter was controlled by spraying, brassicas dominated the mixtures to the detriment of the cool-season grasses which contributed little to available dry matter. The seed proportions of the cool-season grasses within the mixture were much lower than those used when grown in monocultures. When the proportions of cool-season grasses within mixtures were increased, their contribution to yield increased. Oats (*Avena sativa*) were particularly competitive when grown with the brassica mix. When the millet was allowed to regrow, it dominated the available dry matter, which influenced overall yield and nutritive value of the mixtures. Mixtures of cool-season forages and millet regrowth had lower quality than the same mixtures grown where the millet was controlled. This resulted from the brassicas dominating the mixtures where the millet regrowth was controlled, which resulted in higher quality that will likely require fiber supplements for grazing cattle. Mixtures grown with millet had higher fiber content, which negates the need for fiber supplementation.

Cool-season forages and mixtures were also interseeded into corn at the V6 growth stage, which resulted in higher quality biomass on offer to beef cattle grazing cornstalks during fall and winter months. Their higher quality negates the need for supplementation, especially of protein, that is usually required to offset the low nutritive value of cornstalks. Of the forages evaluated, the brassica mix and annual ryegrass (*Lolium perenne* L. ssp. *multiflorum* [Lam.] Husnot) had the highest yields which was the determining factor for interseeded cool-season forages to compete with the costs of preserved forages that are normally used as supplements for beef cattle grazing cornstalks. Thus, the forage systems described in this dissertation provide insight into how annual forages can extend the grazing season into the fall and early-winter months, reducing the need for preserved forages to be fed in beef cattle operations. Sustainability of production systems can be enhanced when producers integrate current knowledge into their operations. Planting annual forages has the potential to benefit production of livestock and crops.

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CHAPTER 1. INTRODUCTION

During the late-fall, cold temperatures reduce the growth of perennial forages as they go dormant through the winter (Allen and Collins, 2003). At that time, the nutritional requirements of livestock often exceed the nutritive value that perennial forages provide (Keogh et al., 2012). Beef producers typically supplement with preserved forages (e.g. hay and silage) to maintain their livestock through the late-fall and early-winter months. These feed inputs have the greatest influence on profitability of cow-calf operations, accounting for just over 63% of total costs (Miller et al., 2001; Mulliniks et al., 2015)

Extending the grazing season into the late-fall and early-winter months can significantly impact the production costs of beef cattle operations by reducing the need for preserved feeds, either grown or purchased (Entz et al., 2002). When the grazing season is extended, producers can reduce the costs of harvesting, hauling, and feeding forages to their cattle later in the fall and winter (McCartney and Baron, 2013). Grazing systems across different environments appear to be the least expensive nutrient source to feed livestock (Mulliniks et al., 2015).

Planting cool-season forages from mid-summer through early-fall is one method of providing biomass that can be grazed by beef cattle in late-fall and early-winter (Lawley, 2013; Sulc and Franzluebbers, 2014). The more days that livestock graze during fall and winter, the more money producers can save due to the reduced need for preserved forages (McCartney and Baron, 2013; Mulliniks et al., 2015). A longer grazing season can increase returns over total direct costs in forage systems (Scaglia et al., 2014). Producing annual forages requires higher amounts of inputs than perennials, but these inputs can be offset by their higher biomass and nutritive value (Ball et al., 2008; Sulc and Franzluebbers, 2014).

Stockpiling is a technique by which forage biomass produced during the growing season is accumulated for later grazing (Allen and Collins, 2003; Cuomo et al., 2005). Cool-season forages tend to maintain their nutritive value through time, which makes them desirable for stockpiling. Stockpiling cool-season forages in the fall and winter can reduce the need for preserved feeds and their associated costs (Hitz and Russell, 1998). Strip grazing cool-season forages can maximize the utilization of the forage biomass while reducing waste due to trampling and dunging (Lawley, 2013). Higher levels of forage utilization translate into more grazing days. Every day the grazing season is extended translates into beef producers saving money (McCartney and Baron, 2013; Mulliniks et al., 2015). According to previous research, strip grazing is also one of the most common methods employed to utilize biomass grown following grain harvest (Sedivec et al., 2011).

Grazing cereal stubble following grain harvest is a common practice during the fall, which has proven to be cheaper than feeding only preserved forages to beef cattle (McCartney and Baron, 2013). Grazing winter wheat stubble and cornstalks with beef cattle has been used extensively as an economical way to utilize crop residues during late-fall and winter months (Klopfenstein et al., 1987; Sulc and Franzluebbers, 2014). However, the nutritive value of these residues is usually lower than the nutritional requirements of beef cattle and supplementation is necessary, which increases costs for producers (Fernandez-Rivera and Klopfenstein, 1989). Planting cool-season forages following grain crop harvest has been promoted as a means of integrating livestock and cropping systems while growing a higher quality forage that can be grazed by livestock (Sulc and Franzluebbers, 2014).

Small grains and forage brassicas have been successfully established when planted in early to mid-August following winter wheat harvest (Sulc and Franzluebbers, 2014), providing a higher nutritive value than grazing the stubble alone. Interseeding cool-season forages into corn has also resulted in increased quality of forage available to beef cattle in the fall (Lawley, 2013). Winter wheat and corn remove large amounts of nutrients during grain harvest (Samarappuli et al., 2014), while most nutrients consumed by grazing cattle are excreted in the form of manure and urine, having N return values up to 83% (Allen and Collins, 2003). Even though grazing cattle assimilate a small proportion of the nutrients contained in ingested forage and the nutrients returned to the soil undergo some losses after deposition, integration of livestock with cropping systems can reduce the environmental impact of intensive production systems where soils are exposed to degradation (Sulc and Franzluebbers, 2014). Based on this evidence, growing cool-season forages following grain harvest for fall grazing can provide nutritional and economic benefits for beef operations. Cropping systems, on the other hand, can benefit from the nutrients returned to the soil, thereby reducing the amount of fertilizer that needs to be applied during the next growing season and leaving enough plant residue to cover, protect, and build the soil (Lawley, 2013).

The majority of forage species used in this research have been recommended and investigated for their potential use as cover crops (SARE-CTIC, 2015; Sulc and Franzluebbers, 2014). However, in this study, annual cool-season crops were planted specifically for fall forage as they can continue to grow as the temperatures drop.

The goal of this dissertation was to evaluate forage systems based on annual cool-season forages that need to be established by late-summer in order to extend the grazing season into the fall and early-winter months in northern Colorado, or similar environments. These forage systems were evaluated using dry matter yield and nutritional quality as the main indicators of their potential to be successfully established and later grazed in the fall. The forage systems evaluated are innovative options for supplying dry matter to beef cattle during fall and winter, thereby extending the grazing season while reducing reliance on harvested and stored feeds (Mulliniks et al., 2015).

The main crops used in this research were forage brassicas as they are cool-season forages that can grow during the cooler periods of fall and early winter, yielding high amounts of biomass that can be stockpiled, and their high nutritive value does not decline significantly as they mature (Smith and Collins, 2003). Forage brassicas were evaluated in monocultures and in mixtures. When grown in monocultures, forage brassicas were evaluated under different agronomic management systems that provided insight into the species/cultivars with the greatest potential to grow in Colorado. Based on this, a forage brassica mixture was used for all further evaluations where warm- and cool-season grasses were added to the mixture as a means of enhancing overall utilization of the brassicas by grazing beef cattle. The forage brassica mixture was then evaluated under grazing by young beef cattle as well as interseeded into grain corn. Because grazing cornstalks with beef cattle is a common practice during the fall and winter, our approach was intended to improve the nutritive value of this source by interseeding other high quality forages. Based on previous findings from other studies (Fernandez-Rivera and Klopfenstein, 1989; Lawley, 2013), a wide variety of cool-season forages were interseeded, thus integrating the knowledge gained earlier in this study with experiences from others that were developed elsewhere. Also, interseeding was a way to integrate cropping systems with livestock, as was part of the overall goal of developing forage systems based on annual species.

This dissertation provides evidence of cool-season forages and mixtures with potential to grow in Colorado and similar environments. Even though this research did not analyze the effects of cool-season forages on subsequent crops, the forage systems evaluated have great potential to be integrated following grain harvest of cash crops such as winter wheat and corn (Entz et al., 2002). Thus, these forage systems are intended to extend the grazing season into the fall and early winter while decreasing feed costs in beef cattle operations, which in turn can increase their profitability (Mulliniks et al., 2015).

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CHAPTER 2. FORAGE BRASSICAS STOCKPILED FOR FALL GRAZING: YIELD AND NUTRITIVE VALUE[1]

Forage brassicas can potentially be used to extend the grazing season into the fall for beef cattle operations, thereby reducing input costs. Nine cultivars of forage brassicas were seeded on two planting dates, and their yield and nutritive value were measured for two fall harvest dates over two years in northern Colorado. Cultivars evaluated included: three turnips ([*Brassica rapa*]; Purple Top, Barkant, and Appin); three rapes ([*Brassica napus*]; Winfred, Barnapoli, and Bonar); Groundhog radish (*Raphanus sativus*); Major Plus swede (*Brassica napobrassica*); and Pasja hybrid (Chinese cabbage [*Brassica rapa* ssp. *chinensis*] x turnip hybrid). Dry matter yield (DMY), crude protein (CP), neutral detergent fiber (aNDF), and *in-vitro* true digestibility (IVTD) were evaluated using a 3-way factorial treatment structure. Planting date was the overriding factor impacting DMY with an overall reduction of 3770 lb/acre by delaying planting from mid- to late-July to mid-August. Additional forage was also obtained by delaying the harvest date until mid-November, but the increase was minor in comparison to yields obtained with earlier planting. The rapes tended to yield the highest when seeded in mid- to late July, but there were only minor differences among cultivars seeded in mid-August. Fiber content of forage brassicas was low (19.0-25.2%) and CP content (18.6-25.5%) and IVTD (85.5-92.9%) were above the requirements for all classes and stages of beef cattle. Forage brassicas had minor changes in nutritive value during the fall, which makes them suitable for stockpiling when combined with lower-quality forages to dilute their high nutrient content and thereby minimize the potential for rumen upset.

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2.1. Introduction

The utilization of preserved forages (i.e. hay and silage) is the primary input cost in beef cattle operations during the fall and winter. In recent years, rising input costs have been a main driver for the integration of annual forages into livestock operations as a means of reducing overall costs (Sulc and Franzluebbers, 2014). Stockpiling is a management technique by which forage produced during a period of higher production is allowed to accumulate and be grazed later, when growth rates are lower (Allen and Collins, 2003). Stockpiling has been widely used with perennial cool-season grasses such as tall fescue (*Schedonorus arundinaceus*) (Hitz and Russell, 1998). However, the quality of many stockpiled forages tends to decline over time, which makes it necessary to utilize species with the ability to maintain nutritive value over time. During the fall and winter, when perennial forages go dormant, the nutritional requirements of livestock often exceed the nutritive value that these types of forages provide (Keogh et al., 2012). Cold-tolerant species tend to maintain their quality, which makes them desirable choices to extend the grazing season through stockpiling in the western US.

Brassicas are annual, cool-season crops adapted to a wide range of temperatures, especially those below freezing, which allows them to grow during cooler periods of the fall and early winter when many cool-season perennial grasses and legumes have limited growth (Smith and Collins, 2003). Brassicas are commonly sown from spring to late summer in northern and southern temperate areas (McCartney et al., 2009) and should not be grazed earlier than 60 days after planting to avoid nitrate poisoning (Smith and Collins, 2003) and to allow for higher biomass accumulation (Jung and Shaffer, 1995). Unlike most forage grasses and legumes, the nutritive value of brassicas does not decline significantly when plants mature (Smith and Collins, 2003), which makes them suitable to be stockpiled for use from fall through early winter. Frost tolerance, high forage yield and nutritive value, and planting and harvest management flexibility make forage brassicas ideal for use in the western US and similar environments (Lauriault et al., 2009).

Successful establishment and subsequent yield of forage brassicas depend on climatic factors (Lauriault et al., 2009) and agronomic management practices (Jung and Shaffer, 1995), which in turn affect their ability to fill the gaps when production of more common forages becomes limiting. Planting date is a major determinant of forage yields obtained in the fall, and differences between species or cultivars affect the growth pattern of such forages. Lauriault et al. (2009) evaluated three brassica species (kale, rape, and turnip) under irrigation in New Mexico and found that planting them in mid-July provided earlier availability of forage than planting in mid-August; however, nutritive value was lower when they were planted earlier due to longer growing days. In the same study, within the same planting date, yield and nutritive value differed among the species of forage brassicas evaluated. Also, they found the highest yields in the first harvest, but nutritive value was higher in the second harvest after 30 days of regrowth. Those results suggest the importance of including multiple planting and harvest dates when evaluating brassicas grown in different environments because these variables can significantly affect both yield and quality.

The objective of this study was to evaluate the yield and nutritive value of nine forage brassicas stockpiled for fall grazing in response to two planting dates and two harvest dates. Previous studies have evaluated the growth and/or regrowth of fewer forage brassica species or cultivars. In our study, changes in yield and nutritive value as affected by planting and harvest dates were considered indicators of the potential to stockpile forage brassicas and extend the grazing season into the fall and early-winter.

2.2. Materials and Methods

2.2.1. Study Location and Implementation

This study was conducted during two summer through fall growing seasons at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) (2012) and Horticulture Field Research Center (2013), located about nine miles northeast of Fort Collins, Colorado (40.39°N, 104.59°W, elevation 5100 feet [1555 m]). Soils are a Fort Collins loam at the ARDEC location and a Nunn clay loam at the Horticultural Farm (Soil Survey Staff et al., 2013). The sites are approximately three miles apart. The previous crop was grain corn at ARDEC and alfalfa at the Horticultural Farm. Weather data were collected from an automated station located at ARDEC, which is part of the Colorado Agricultural Meteorological Network (Table 1) (CoAgMet, 2015). Average maximum and minimum temperatures were determined for the months of July to November in 2012 and 2013.

Table 1. Average maximum and minimum daily temperatures and total precipitation per month for 2012 and 2013.

Year	Weather variable	Month				
		Jul	Aug	Sep	Oct	Nov
2012	Avg. max. temp. (°F)	89	86	78	60	54
	Avg. min. temp. (°F)	58	53	46	31	24
	Total precipitation (inches)	1.75	0.07	1.00	0.40	0.10
2013	Avg. max. temp. (°F)	85	86	76	58	51
	Avg. min. temp. (°F)	58	54	50	32	22
	Total precipitation (inches)	1.53	0.50	5.20	1.16	0.04

Nine cultivars of forage brassicas were evaluated: three turnips (Purple Top, Barkant, and Appin); three rapes (Winfred, Barnapoli, and Bonar); Groundhog radish; Major Plus swede; and Pasja hybrid. For all cultivars, a bulk seeding rate of 5 lb/acre was used except for Groundhog radish for which the bulk seeding rate was 8 lb/acre due to the larger seed size. Kestral kale (*Brassica oleracea* ssp. *acephala*) was evaluated in the first year of the study, but because of poor establishment and low yield, was removed in the second year. Cultivars were randomly assigned in a factorial complete block design with four replications. All cultivars were seeded with a no-till drill (Model 3P605NT, Great Plains Mfg., Inc., Salina, KS) fitted with a cone seeder attachment (Kincaid Equipment Manufacturing, Haven, KS) set at a 7.5-inch row spacing in plots measuring 6 x 42 ft. Sprinkler irrigation was used at both sites, and the plots were fertilized with urea at 50 lb N/acre prior to seeding. Cultivars were planted on two dates each year (16 July and 14 August in 2012 and 2 August and 18 August in 2013), and each planting was sampled on two different harvest dates (10 October and 13 November in 2012 and 16 October and 13 November in 2013). The second harvest was taken from sections of a plot where biomass had accumulated since establishment (i.e. not regrowth from the first harvest).

2.2.2. Harvesting Protocol and Laboratory Analysis

Dry matter yield (DMY) was assessed by harvesting a 3.5 x 20 ft strip from each plot using a walk-behind sickle-bar mower with an approximate cutting height of 3.5 inches. The material was gathered onto a tarp and weighed using a hanging electronic scale. A representative sample was taken (1.3 lb of fresh material) and dried at 140 °F for 72 h to determine moisture content. The dried samples were then ground for nutritional analysis through a shear mill (Wiley® Model 4, Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen and then through a cyclone mill (Foss® Tecator Cyclotec Model 1093, Udy Corp., Fort Collins, CO), also equipped with a 2-mm screen, to homogenize the material. The samples were analyzed using an elemental combustion analyzer (LECO TruSpec® Model CN268, St Joseph, MI) to obtain the nitrogen content which was multiplied by 6.25 to estimate crude protein (CP) content (AOAC, 1990). Neutral detergent fiber (aNDF) was determined according to Van Soest et al. (1991) using an Ankom® 200 fiber analyzer (Method 6, ANKOM Technology Corp., Macedon, NY). *In-vitro* true digestibility (IVTD) was determined using an Ankom® Daisy II incubator (Method 3, ANKOM Technology Corp., Macedon, NY). The samples were incubated for 48 h in a buffer solution mixed with rumen fluid (1600 ml and 400 ml, respectively) (Van Soest and Robertson, 1985). Rumen fluid was collected from two fistulated steers that were being fed a mixed grass hay and corn diet (60:40 forage/corn). After incubation, samples were analyzed following the aNDF procedure described above.

2.2.3. Statistical Analyses

The study had a 3-way factorial treatment structure (nine cultivars x two planting dates x two harvest dates) with four replicates in a complete split-split-plot design, with cultivar as the whole plot, planting date as the subplot, and harvest date as the sub-subplot. All statistical analyses were conducted using the GLIMMIX procedure in SAS® 9.3 (SAS-Institute, 2011). Year and replicates (blocks) were included in the model statement but were considered random variables, while all other factors were fixed. All possible two- and three-way interactions were estimated. Because none of the three-way interactions were significant, the model was then adjusted to estimate only main effects and two-way interactions. Least Square Means (LSM) were estimated using the SLICE statement when a two-way interaction was significant, and the PDIFF LINES statement was used to separate means (SAS-Institute, 2011). Significance was determined at $P \leq 0.05$.

2.3. Results and Discussion

2.3.1. Dry Matter Yield of Forage Brassicas

Brassica cultivar yields differed according to how early they were seeded as indicated by the significant cultivar by planting date interaction (Table 2). The longer growing season associated with the earlier planting date resulted in all cultivars yielding significantly more dry matter compared to the later planting date (Table 3). Overall, cultivars yielded 6450 lb/acre for the first planting date, which was more than double the second planting date at 2680 lb/acre. Rapes tended to have the highest yields when planted early, but rapes experienced a large reduction in DM, 65% between the early and late planting dates, compared to turnips in which yields were only reduced by 46% (Table 3). These trends are supported by previous studies that have shown rape cultivars to have a longer day length requirement for continued growth compared to turnips and radishes (Jung et al., 1986).

Table 2. *P*-values for the factors included in the model statement for each variable analyzed.

Factors	DMY	aNDF	CP	IVTD
Planting date (P)	<0.001	<0.001	0.041	0.044
Cultivar (C)	<0.001	<0.001	<0.001	0.021
Harvest date (H)	<0.001	0.446	<0.001	0.560
C*P	<0.001	0.001	0.005	0.054
C*H	0.057	<0.001	0.228	0.001
P*H	0.008	0.762	0.999	0.555

Table 3. Influence of planting date on dry matter yield of forage brassica cultivars. The first planting date was on 16 July in 2012 and 2 August in 2013, while the second planting was on 14 and 18 August in 2012 and 2013, respectively.

Cultivar	Planting I	Planting II	Mean separation [+]
	------------Dry matter yield (lb/acre)------------		
Appin turnip	6310[cd++]	3000[ab]	*
Barkant turnip	6360[cd]	3290[a]	*
Purple Top turnip	4900[e]	3090[ab]	*
Pasja hybrid	6890[bc]	2870[ab]	*
Bonar rape	6990[bc]	2230[bc]	*
Barnapoli rape	8460[a]	3070[ab]	*
Winfred rape	7510[b]	2840[ab]	*
Groundhog radish	5490[de]	2300[bc]	*
Major Plus swede	5160[e]	1430[c]	*

+ Within a cultivar, * indicates that LS means are significantly different between planting dates at the $P \leq 0.05$ level (ns=non-significant).
++ LS means followed by different letters within a planting date are significantly different at the $P \leq 0.05$ level using the PDIFF mean separation test.

Agronomic management had a major impact on the yield of forage brassicas as was evidenced by the significant interaction of planting by harvest date (Table 2). As mentioned above, yields were significantly higher for all cultivars when planted earlier. Harvest date also had a significant impact on yields within both planting dates. For the first planting date, delaying the harvest until mid-November resulted in a significant increase in DM of 470 lb/acre (6220 versus 6690 lb/acre for the first and second harvest dates, respectively). In contrast, the yield increase for the second planting date was 2.3 times greater between harvest dates at 1080 lb/acre (2140 versus

3220 lb/acre for the first and second harvest dates, respectively). Although delaying the harvest date allowed more DM to accumulate for both planting dates, the magnitude was much greater for the second planting date. This finding implies that, despite differences in growth patterns among cultivars, forage brassicas have the potential to continue to grow from mid-October through mid-November, but because the plants are more immature when planted later, they have a greater growth potential. Despite the yield advantage associated with later harvesting, the overriding factor affecting yield was planting date.

2.3.2. Nutritive Value of Forage Brassicas

Although fiber content differed among the brassica cultivars evaluated within a planting date, the aNDF content varied within a narrow range (0.0-4.9 percentage points), and fiber changed little between planting dates within a cultivar (Table 4). Only the rape cultivars and Purple Top turnip had significantly lower aNDF values for the second planting date, which contributed to the interaction of cultivar by planting date (Table 2). Overall, delaying the planting date resulted in a decrease in aNDF of only 1.6 percentage points (22.8 versus 21.2% for the first and second planting dates, respectively). The aNDF content also varied among cultivars within each harvest date (Table 5). On the second harvest date, Purple Top turnip and Groundhog radish had significantly higher aNDF values, while Barnapoli rape had a significantly lower value; thus resulting in a significant interaction of cultivar by harvest date (Table 2). Turnips and radishes tend to mature more quickly than rapes (Jung et al., 1986), so one would expect a higher fiber content for these cultivars because an increase in aNDF is one of the most common changes exhibited by mature forages (Putnam and Orloff, 2014).

Table 4. Influence of planting date on nutritive value of forage brassica cultivars as measured by neutral detergent fiber (aNDF) and crude protein (CP). The first planting date was on 16 July in 2012 and 2 August in 2013, while the second planting was on 14 and 18 August in 2012 and 2013, respectively.

	Planting		Mean	Planting		Mean
Cultivar	I	II	separation [+]	I	II	separation
	-------aNDF (%)-------			--------CP (%)--------		
Appin turnip	22.5^{bc++}	22.7^{ab}	ns	19.2^{de}	20.4^{cd}	ns
Barkant turnip	22.6^{bc}	21.8^{abc}	ns	18.6^{e}	19.3^{d}	ns
Purple Top turnip	22.7^{bc}	20.3^{cd}	*	20.6^{bcd}	20.9^{bcd}	ns
Pasja hybrid	20.3^{d}	20.7^{bcd}	ns	22.5^{a}	21.3^{bc}	ns
Bonar rape	22.0^{bcd}	19.0^{d}	*	21.4^{abc}	25.5^{a}	*
Barnapoli rape	25.2^{a}	21.6^{abc}	*	22.0^{ab}	22.5^{b}	ns
Winfred rape	23.5^{ab}	19.1^{d}	*	21.7^{abc}	22.2^{bc}	ns
Groundhog radish	25.2^{a}	23.1^{a}	ns	21.4^{abc}	20.5^{cd}	ns
Major Plus swede	21.3^{cd}	22.8^{ab}	ns	19.9^{cde}	22.3^{bc}	*

+ Within a cultivar, * indicates that LS means are significantly different between planting dates at the $P \leq 0.05$ level (ns=non-significant).
++ LS means followed by different letters within a planting date are significantly different at the $P \leq 0.05$ level using the PDIFF mean separation test.

One rape cultivar, however, tended to have a lower fiber content when harvested later. The reason for this trend is not clear, but it might be related to changes in the leaf-to-stem ratio. Based on field observations, this rape was growing additional stem material in November, but the size and number of leaves was also increasing, possibly at a higher rate, which would have increased the leaf-to-stem ratio thereby reducing the aNDF content. Regardless, the changes in aNDF exhibited by this forage brassica cultivar can be considered relatively small when compared to changes in aNDF of cool-season forages that are commonly stockpiled for fall grazing (Hitz and Russell, 1998; Putnam and Orloff, 2014).

In general, the aNDF content of the brassica cultivars evaluated was substantially lower than most annual cool-season grasses (NRC, 2000; Keogh et al., 2012). Even though it is typically desirable for forages to have a low fiber content, fiber has important functions in animal nutrition that should not be neglected (Putnam and Orloff, 2014). Very low levels of aNDF (<30%) can impact rumen function because dietary fiber stimulates rumination, chewing, and saliva production which in turn stabilizes rumen pH (Putnam and Orloff, 2014). The aNDF values found in our study provide evidence that forage brassicas grown in monoculture for beef cattle grazing are likely to require some additional source of fiber to avoid acidosis and other medical problems (Mertens, 2010).

The CP content of the forage brassicas evaluated was high regardless of initial planting date (Table 4). Values were 18.6% or higher, which can more than meet the CP requirements of all categories of beef cattle (NRC, 2000). For the second planting date, cultivars grew an average of 58 days before they were first sampled, compared to the first planting date in which plants grew for 80 days before sampling. One would expect a higher CP content in immature plants because leaf material typically concentrates more nutrients and represents a greater proportion of total biomass (Putnam and Orloff, 2014). However, Bonar rape and Major Plus swede were the only cultivars with CP values significantly higher for the second planting date, which helps explain the significant interaction of cultivar by planting date (Table 2). This increase in CP for Bonar rape and Major Plus swede relates back to the fact that they had the highest reductions in DM yield of 68% and 72%, respectively, between the early and late planting dates (Table 3). Delaying the planting date for these two cultivars significantly impacted growth and maturity, which resulted in a higher leaf-to-stem ratio and corresponding increase in CP content as was reported in other studies (Wiedenhoeft and Barton, 1994).

Table 5. Influence of harvest date on nutritive value of forage brassica cultivars as measured by neutral detergent fiber (aNDF) and *in-vitro* true digestibility (IVTD). The first harvest was taken on 10 and 16 October in 2012 and 2013, respectively, while the second harvest was taken on 13 November in both years.

	Harvest		Mean	Harvest		Mean
Cultivar	I	II	separation +	I	II	separation
	--------aNDF (%)-------			--------IVTD (%)-------		
Appin turnip	22.1 bc++	23.1 b	ns	90.3 ab	90.0 ab	ns
Barkant turnip	21.9 bcd	22.5 bc	ns	91.2 a	90.7 ab	ns
Purple Top turnip	19.9 d	23.1 b	*	91.6 a	89.9 b	ns
Pasja hybrid	20.4 cd	20.7 cd	ns	91.3 a	92.0 ab	ns
Bonar rape	20.8 bcd	20.1 d	ns	90.5 a	92.9 a	ns
Barnapoli rape	24.9 a	21.9 bcd	*	87.5 b	90.7 ab	*
Winfred rape	22.1 bc	20.5 cd	ns	89.3 ab	91.9 ab	ns
Groundhog radish	22.4 bc	25.9 a	*	91.1 a	85.5 c	*
Major Plus swede	22.5 b	21.6 bcd	ns	88.7 ab	90.6 ab	ns

+ Within a cultivar, * indicates that LS means are significantly different between harvest dates at the $P \leq 0.05$ level (ns=non-significant).
++ LS means followed by different letters within a harvest date are significantly different at the $P \leq 0.05$ level using the PDIFF mean separation test.

Although the brassica cultivars evaluated had lower overall CP at 20.8% for the first planting date compared to the second planting date at 21.6%, the magnitude of change for any given cultivar was small and of no consequence when it comes to meeting the protein requirements of beef cattle (NRC, 2000).

Harvest date also had an overall significant effect on CP content of the forage brassicas (Table 2). Averaged across cultivars and planting dates, the CP content was lower for the second (19.9%) compared to the first harvest date (22.5%), which one would expect with the plants being more mature at the later harvest date. Although CP content of the brassica cultivars was lower at the second harvest, it still exceeded requirements for all categories of beef cattle (NRC, 2000). When supplying forage with high CP to cattle, the need for protein supplementation is reduced or eliminated, which results in reduced maintenance costs for beef systems (Jung and Shaffer, 1995). Forage brassicas grazed during the fall would not require the purchase and feeding of protein supplements, and thereby have the potential to positively impact the profitability of beef cattle operations.

The digestibility of forage brassicas varied according to how early the cultivars were harvested (Table 5), having values that ranged between 87.5-91.6% and 85.5-92.9% for the first and second harvest dates, respectively. Barnapoli rape and Groundhog radish were the only cultivars with IVTD values significantly higher and lower for the second harvest date, respectively, which contributed to the significant interaction of cultivar by harvest date (Table 2). Barnapoli rape had lower fiber (aNDF) while Groundhog radish had higher fiber for the second harvest (Table 5), which ultimately affected their digestibilities. For the other cultivars, IVTD varied within a narrow range (0.3-2.6 percentage points) between harvest dates. Thus, harvest date can be delayed from mid-October to mid-November with only minor impacts on forage nutritive value. Although planting date also had a significant effect on digestibility of the forage brassicas (Table 2), its impact was minor with a one percentage point higher IVTD value when planted early (90.8 versus 89.8% for the first and second planting dates, respectively).

Digestibilities of forage brassicas in our study were consistent with those reported in other experiments where they exceeded 90% (Keogh et al., 2012) and were higher than most annual cool-season forages (Sedivec et al., 2011; Putnam and Orloff, 2014). Our results also support other previous research where brassica cultivars are equated to concentrate feeds, with low aNDF and high CP and digestibility (Wiedenhoeft and Barton, 1994). In general, cultivar choice, delaying the harvest date, or planting earlier had minor impacts on forage nutritive value, which supports the use of forage brassicas for stockpiled grazing in the fall.

2.4. Implications for Producers

Planting date was the main factor affecting DM yield of forage brassicas being grown and stockpiled for fall grazing. When planted early (i.e. mid- to late July), all brassica cultivars evaluated had the potential to fill the void in DM that commonly occurs during the late-fall period, when productivity of most cool-season forages is low (Wiedenhoeft and Barton, 1994; Jung and Shaffer, 1995). Given that rapes are longer-day plants, they were able to take advantage of the longer growing season when planted earlier to produce the highest yields. Delaying planting until mid-August resulted in only minor differences in yield among the cultivars evaluated and would be the latest recommended date to seed in order to obtain sufficient biomass for fall grazing in environments similar to northern Colorado. Delaying the harvest date until mid-November resulted in a significant increase in DM, but it was minimal compared to the average yield reduction (3770 lb/acre) measured of when the planting date was delayed until mid-August. This reduction in yield due to delayed planting ultimately translates to fewer days of fall grazing or the need to reduce the stocking rate.

The maturity stage at which plants are grazed is usually the most critical factor determining quality of forage crops. Irrespective of planting and harvest dates, all of the forage brassicas evaluated in this study maintained their nutritive value over the growing season, which makes them suitable for stockpiled grazing during fall and early winter under Colorado or similar growing conditions.

Forage brassicas are sometimes equated to concentrate feeds due to their relatively low aNDF and high CP and digestibility. Although grazing forage brassicas can affect rumen function unless roughage (e.g. hay) is provided (McCartney et al., 2009), mixtures with warm- (e.g., sorghum, sudangrass, or millets) and cool-season grasses (e.g., small grains) have also been evaluated as a means of increasing DM and fiber content provided to beef cattle (Sedivec et al., 2011). Even though our study did not include grazing evaluations, previous evidence suggests that strip grazing should be used as a means to avoid trampling of the stand and to decrease waste, especially when soils are wet (Sedivec et al., 2011). By using this grazing management technique in conjunction with mixing brassicas with higher fiber forages, producers can take full advantage of the high yield and nutritive value provided by forage brassicas in the fall and early winter.

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CHAPTER 3. COOL-SEASON ANNUAL FORAGES AND MIXTURES TO EXTEND THE GRAZING SEASON INTO THE FALL

Cool-season forages and their mixtures can be planted after a summer hay crop or winter wheat grain harvest to provide biomass for beef cattle grazing during the fall and early-winter. Ten forage species/mixtures were seeded in early-August, and their species composition, yield, and nutritive value were measured. Pearl millet (*Pennisetum glaucum* L.) was previously grown during the summer and allowed to regrow in half of the plots, while the other half were sprayed with glyphosate. A two-way factorial treatment structure (10 forage treatments x 2 spraying treatments) was used to evaluate the treatments on two fall harvest dates over two years in northern Colorado. Species/cultivars evaluated included: spring triticale (VNS) (×*Triticosecale* Wittm ex A. Camus [*Secale* x *Triticum*]), Willow Creek awnless winter wheat (*Triticum aestivum* L.), and P-919 winter beardless forage barley (*Hordeum vulgare* L.). Each grass was then added to a brassica mixture comprised of Barkant turnip (*Brassicas rapa* L. var. *rapa*), Barnapoli rape (*Brassica napus* L. var. *napus*), Groundhog radish (*Raphanus sativus* var. *oleifer* Strokes), and Pasja hybrid (Chinese cabbage [*Brassica rapa* L. *chinensis*] x Turnip hybrid). A legume mixture of hairy vetch (*Vicia villosa* Roth) and Austrian winter peas (*Pisum sativum* subsp. *arvense*) was then added to the cool-season grass plus brassica mixtures. Control plots consisted of pearl millet regrowth. The millet and brassicas dominated in the unsprayed and sprayed mixtures, respectively. The treatments evaluated yielded biomass (3080-5580 kg ha^{-1}) that can be stockpiled for fall grazing, and most treatments produced greater than 4000 kg ha^{-1}. The CP (143-210 g kg^{-1}), aNDF (229-610 g kg^{-1}), and IVTD (778-922 kg^{-1}) were primarily influenced by the percentage of brassicas and millet in sprayed and unsprayed mixtures, respectively. The low levels of fiber found in the sprayed

mixtures can impact feeding costs as supplementation with higher fiber feeds may be required. The higher input costs to suppress regrowth of the summer hay crop prior to seeding the cool-season forages must be offset by higher yield and quality of the cool-season forages compared to unsprayed mixtures where fiber levels are high enough to avoid rumen upset when grazed by beef cattle.

3.1. Introduction

Feeding of preserved forages accounts for the majority of costs associated with wintering beef cows (McCartney and Baron, 2013b). During late-fall months, perennial forages are preparing to go dormant which reduces their nutritive value; therefore, supplementation is needed to improve utilization of these forages by livestock (Bohnert et al., 2011). Extending the grazing season allows producers to reduce their feeding costs compared to preserved forages (McCartney and Baron, 2013a). Each day that livestock graze during fall and winter saves the livestock producer money (McCartney and Baron, 2013b). Planting annual forages has the potential to increase total yield and calendar days of grazing compared to only perennial pastures (Ball et al., 2008; Ketterings et al., 2015). The cost per unit of dry matter produced by annual forages is usually higher than perennials, but these increased costs can be offset by their higher quality (Ball et al., 2008; Hansen et al., 2015; Sedivec, 2011; Sulc and Franzluebbers, 2014; Titlow et al., 2014).

Integration of annual forages and livestock offers an economical approach to using land more efficiently, providing feed for livestock while additional environmental benefits can be achieved (Putnam and Orloff, 2014; Sulc and Franzluebbers, 2014). Deep-rooted annual forage crops are effective at water use and scavenging soil mineral N which reduces leaching (Acuña and Villamil, 2014; Samarappuli et al., 2014; Thilakarathna et al., 2015), while root penetration reduces soil bulk density (Sedivec, 2011). The integration of annual forages into cropping systems (e.g. after winter wheat harvest) (Sulc and Franzluebbers, 2014) has resulted in increased crop yields and nitrogen use efficiency compared to fallowing (Burgess et al., 2014; Lin and Chen, 2014).

The 2014-2015 SARE/CTIC Cover Crop Survey found that cereal rye (*Secale cereale* L.), annual ryegrass (*Lolium perenne* L. ssp. *multiflorum* [Lam] Husnot), oat (*Avena sativa* L.), triticale, and winter barley are the top five annual grasses used by producers in the US. Brassicas are also increasingly used with radish, rapeseed, turnips, and canola (*Brassica rapa* L. var. *oleifera* DC.) being the most widely planted. Crimson clover (*Trifolium incarnatum* L.), winter pea, hairy vetch, and cowpea (*Vigna unguiculata* [L.] Walp) are the most commonly planted legume species (SARE-CTIC, 2015). Most of the species used as cover crops are also good sources of forage for livestock grazing (Sulc and Franzluebbers, 2014) with high biomass potential and nutritional quality (Burgess et al., 2014; Lin and Chen, 2014; Samarappuli et al., 2014).

When annual forages are mixed, economic and environmental benefits can be achieved (Samarappuli et al., 2014), resulting from the individual characteristics of each species used. Cool-season grasses are a good source of dry matter and fiber (Islam et al., 2013), while legumes have a higher protein content and fix nitrogen that can be used by later crops (Samarappuli et al., 2014; Titlow et al., 2014), and brassicas maintain their nutritional quality into late-fall and early-winter (McCartney and Baron, 2013a).

The objective of this study was to evaluate the species composition, yield, and nutritive value of ten forage species/mixtures following a warm-season hay crop that was either controlled or allowed to regrow. Previous studies have evaluated the use of annual forages in monocultures or mixtures for use as cover crops (Acuña and Villamil, 2014; Burgess et al., 2014; Hansen et al., 2015; Ketterings et al., 2015; Lin and Chen, 2014; Reese et al., 2014, Ritchey et al., 2015;

Thilakarathna et al. 2015). In our study, changes in species composition indicated competition of the species within the forage treatments, while their yield and nutritive value were considered indicators of their potential to provide high quality biomass to extend the grazing season into the fall and early-winter months.

3.2. Materials and Methods

3.2.1. Study Location and Implementation

This study was conducted during two summer-fall growing seasons at Colorado State University's Horticultural Research Farm, located about 15 km northeast of Fort Collins, CO (40°39′N, 104°59′W) at an elevation of 1555 m. The soil is a Nunn clay loam (fine-loamy mesic Aridic Haplustalf) (Soil Survey Staff et al., 2013). Weather data were collected from an automated station located at the Colorado State University' Agricultural Research, Development and Education Center which is part of the Colorado Agricultural Meteorological Network (CoAgMet, 2015). Average maximum and minimum temperatures and precipitation were determined for the months of August to November in 2013 and 2014 (Table 6).

Table 6. Average maximum and minimum temperatures and total precipitation per month for 2013 and 2014.

Year	Weather variable	Month			
		August	September	October	November
2013	Avg. max. Temp. (°C)	30.1	24.4	14.3	11.0
	Avg. min. Temp. (°C)	12.7	10.2	0.2	-5.5
	Total precipitation (mm)	12.7	132.1	29.5	1.0
2014	Avg. max. Temp. (°C)	28.2	24.8	19.9	8.7
	Avg. min. Temp. (°C)	11.8	8.1	2.3	-7.7
	Total precipitation (mm)	26.2	23.1	28.2	12.4

The field was previously in alfalfa which was killed by plowing and then applying glyphosate [N-(phosphonomethyl)glycine] at 1.54 kg a.i ha^{-1} to control any regrowth. Tifleaf 3 hybrid pearl millet was drill-seeded on May 20 in 2013 and May 21 in 2014 at a rate of 26 kg ha^{-1}. Fertilizer was applied prior to seeding the pearl millet at a rate of 78 kg N ha^{-1} and 47 kg P_2O_5 ha^{-1} using urea (46-0-0) and MAP (11-52-0). No additional fertilizer was applied to the experimental plots later in the growing season. The pearl millet was swathed, allowed to dry, and then baled on July 22 in 2013 and July 24 in 2014.

Ten forage species/mixtures were evaluated: three annual cool-season grasses (spring triticale [VNS], Willow Creek awnless winter wheat, and P-919 winter beardless forage barley) were grown in monoculture and functioned as a baseline for the rest of the treatments to which other cool-season forages were added (Table 7). Each grass was seeded in combination with a brassica mixture ('brassica mixture' hereafter) comprised of Barkant turnip, Barnapoli rape, Groundhog radish, and Pasja hybrid. Due to its larger seed-size, the proportion of Groundhog radish was increased (34% of the bulk rate) to approximate the density (seeds kg^{-1}) of the other 3 species in the brassica mixture which were seeded at a smaller proportion (22% of the bulk rate). The cool-season grass plus brassica mixtures were then added to a legume mixture of hairy vetch and Austrian winter peas ('brassica-legume mixture' hereafter). Control plots consisted of pearl millet regrowth for a total of ten forage treatments that were seeded and either sprayed or allowed to regrow for a total of twenty treatments. The unsprayed (US) treatments were comprised of the forage treatments seeded into pearl millet regrowth, while the sprayed (S) treatments comprised the same treatments seeded into the pearl millet stubble that was sprayed with glyphosate at 1.54 kg a.i ha^{-1} prior to seeding.

Table 7. Forage treatments evaluated and seeding rates used for ten cool-season forage mixtures.

Treatment	Treatment code[1]	Seeding rate (kg ha^{-1})
Control (C)	C	--
Triticale (TT)	TT	123.5
Triticale-brassica mixture	TTBM	26.9=16.2 (TT)+10.7 (BM)
Triticale-brassica and legume mixture	TTBML	33.7=18 (TT) +6.8 (BM) +2.2 (HV) +6.7 (WP)
Winter wheat (WW)	WW	112
Winter wheat-brassica mixture	WWBM	26.9=16.2 (WW)+10.7 (BM)
Winter wheat-brassica and legume mixture	WWBML	33.7=18 (WW) +6.8 (BM) +2.2 (HV) +6.7 (WP)
Forage barley (FB)	FB	112
Forage barley-brassica mixture	FBBM	26.9=16.2 (FB)+10.7 (BM)
Forage barley-brassica and legume mixture	FBBML	33.7=18 (FB) +6.8 (BM) +2.2 (HV) +6.7 (WP)

[1.] BM=Brassica mixture, and L=Legume mixture (Hairy Vetch [HV] +Winter Peas [WP])

All treatments were randomly assigned in a factorial complete block design with four replications (eighty plots). All forage mixtures were seeded with a no-till drill (Model 3P605NT, Great Plains Mfg., Inc., Salina, KS) fitted with a cone seeder attachment (Kincaid Equipment Manufacturing, Haven, KS) set at a 19 cm row spacing in plots measuring 4.5 x 12 m. Three passes were required to seed the plots. Sprinkler irrigation was applied at a rate of 25.4 mm wk^{-1}. The forage mixtures were planted on August 06 in 2013 and August 04 in 2014 (following 15 and 11 days of pearl millet regrowth) and sampled two different times in 2013 (Oct. 15 and Nov. 18). Due to a hard, killing freeze and snow cover during the second week of November, the plots were only harvested once in 2014 (Oct. 16). Most treatments exhibited some lodging after the freeze and maintained partial snow cover which limited our ability to take the second harvest. The second harvest in 2013 was taken from sections of a plot where biomass had accumulated since establishment (i.e. not regrowth from the first harvest).

3.2.2. Harvesting Protocol and Laboratory Analysis

Dry matter yield (DMY) was assessed by harvesting a 1.1 x 6.1 m strip from each plot using a walk-behind sickle-bar mower with an approximate cutting height of 9 cm. The material was gathered onto a tarp and weighed using a hanging electronic scale. A representative subsample was taken (~600 g fresh wt.) and dried at 60°C for 72 hours to determine moisture content. The dried samples were then ground for nutritional analysis through a shear mill (Wiley® Model 4, Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen and then through a cyclone mill (Foss® Tecator Cyclotec Model 1093, Udy Corp., Fort Collins, CO), also equipped with a 2-mm screen, to homogenize the material. Another sample was taken (~1500 g fresh wt.) and frozen to be later separated into six plant components: pearl millet, brassicas, cool-season grass (i.e. triticale, winter wheat, or forage barley), legumes (i.e. hairy vetch and/or winter peas), alfalfa, and weeds. Following separation, the components were dried at 102°C for 24 hours and weighed to assess species composition on a DM basis within each forage treatment.

The ground samples were analyzed using an elemental combustion analyzer (LECO TruSpec® Model CN268, St Joseph, MI) to obtain the nitrogen content which was multiplied by

6.25 to estimate crude protein (CP) content (AOAC, 1990). Neutral detergent fiber (aNDF) was determined according to Van Soest et al. (1991) using an Ankom® 200 fiber analyzer (Method 6, ANKOM Technology Corp., Macedon, NY). *In-vitro* true digestibility (IVTD) was determined using an Ankom® Daisy II incubator (Method 3, ANKOM Technology Corp., Macedon, NY). The samples were incubated for 48 h in a buffer solution mixed with rumen fluid (1600 ml and 400 ml, respectively) (Van Soest and Robertson, 1985). Rumen fluid was collected from two fistulated steers that were being fed a mixed grass hay and corn diet (60:40 forage/corn). After incubation, samples were analyzed following the aNDF procedure described above. Both analyses were used to estimate aNDF digestibility (Hoffman et al., 2001).

3.2.3 Statistical Analyses

The study had a three-way factorial treatment structure (ten forage treatments x two spraying treatments x two harvest dates) with four replicates in a randomized complete block (RCB) design (n=80). Because the plots were harvested only once in 2014, harvest date was not included in the model and a two-way factorial structure was used for the analyses. All statistical analyses were conducted using the GLIMMIX procedure in SAS® 9.3 (SAS-Institute, 2011). Year and replications (blocks) were considered random variables while forage mixture, spraying, and their two-way interaction were fixed. Year, forage, and spraying treatments were first fixed in the model, but year was not significant while forage and spraying treatments consistently had the same effects. Because of this, year was nested within replication in the model and the treatments were averaged over the three harvests. Least Square Means (LSM) were estimated using the LSMEANS statement for the main effects and for the significant two-way interactions, and the PDIFF LINES statement was used to separate means (SAS-Institute, 2011). Orthogonal contrasts were estimated using the LSMESTIMATE statement within the GLIMMIX procedure of SAS version 9.3 (SAS-

Institute, 2011) to assess the overall effects of adding forage species/mixtures and spraying treatments on species composition, yield, and forage quality. Species composition was run separate for each of the six plant components evaluated. *P*-values obtained for the contrasts were corrected using the Bonferroni multiple testing adjustment which is used for correcting for multiple comparisons. Significance was determined at $P \leq 0.05$. The SE of the mean was estimated for data shown in figures.

3.3. Results and Discussion

3.3.1. Species composition

Species composition was affected by both forage species and spraying treatments, resulting primarily from the high competition of brassicas within sprayed brassica and brassica-legume mixtures. Forage treatment had a significant effect on the percentage of pearl millet, cool-season grasses, alfalfa, and weeds (Table 8). Except for weeds, spraying was significant for all species within the mixtures. The two-way interactions were only significant for the percentage of cool-season grasses, alfalfa, and weeds.

The unsprayed treatments were comprised primarily of pearl millet, while sprayed grass monoculture and brassica mixture treatments were dominated by the cool-season grasses and forage brassicas, respectively (Figure 1). The greater percentage of pearl millet found in the unsprayed treatments was attributed to its capacity to regrow quickly after having been harvested for hay. The cool-season species planted for fall forage had slower initial growth which limited their ability to compete with the warm-season grass. Forage brassicas were the primary component of the DM available in sprayed brassica and brassica-legume treatments (Figure 1), with the cool-season grasses and legumes comprising a small fraction of the mixtures. Previous studies have shown forage brassicas to be highly competitive when mixed with other species and under different seeding methods, which has been primarily attributed to their quick growth (Samarappuli et al., 2014). Also, the unsprayed treatments had lower percentages of pearl millet when seeded with forage brassicas compared to the unsprayed control (Table 3), which can be explained by the quick growth of brassicas underneath the millet canopy.

Table 8. Statistical significance and contrasts of the main effects for species composition of forage treatments.

Species	Pearl Millet	Brassica mixture	Cool-season grass	Legumes	Alfalfa	Weeds
Forage treatment (T)[1]	*	ns	*	ns	*	*
Spraying (S)	*	*	*	*	*	ns
T*S	ns	ns	*	ns	*	*
Contrast			Adjusted P-value (Bonferroni method)			
				Pearl Millet		
Unsprayed control versus unsprayed grass monoculture				0.1128		
Unsprayed control versus unsprayed brassica mixtures				0.0570		
Unsprayed control versus unsprayed brassica-legume mixtures				0.0480		
				Cool-season grasses		
Sprayed brassica mixtures versus sprayed brassica-legume mixtures				0.0002		
Unsprayed brassica mixtures versus unsprayed brassica-legume mixtures				0.0130		
				Legumes		
Unsprayed brassica-legume mixtures versus sprayed brassica-legume mixtures				0.0024		

1. * P<0.05, ns=non-significant.

Annual cool-season forages can be planted in warm-season grass stands after summer grazing or hay harvest. These types of forage mixtures can be stockpiled for fall grazing in order to take full advantage of the productivity from regrowth of the warm-season grasses in combination with the high quality growth of the cool-season forages. Producers will likely make their decision to plant cool-season forages based on the facilities, labor, and inputs available as those can be reduced when planting into a warm-season grass stubble. The additional costs of seeding cool-season forages into a warm-season grass should be offset by higher biomass and quality as well the money saved in supplementation. Furthermore, when a warm-season regrowth is suppressed, tillage or spraying are required prior to seeding the cool-season forages.

The establishment of cool-season grasses was affected by the spraying treatments which resulted in differences in species composition within forage mixtures. As one would expect, cool-season grasses dominated the sprayed grass monocultures (Figure 1). Although the percentage of cool-season grasses was significantly different when the sprayed and unsprayed brassica mixtures vs. brassica-legume mixtures were compared (Table 8), their percentages represented a small fraction (1.9-8.3%) of the DM available within the mixtures. Seeding rates of small grains such as wheat, rye, oats, barley, or triticale vary depending on establishment method and seeding mixtures (Ball et al., 2008). In our study, seeding rates for the cool-season grasses in the brassica and brassica-legume mixtures were 15% of normal rates used when grown in monocultures (Table 2). Titlow et al. (2014) found that turnips contributed 1.6 to 3.9% to available DM when mixed with oat (80.0-94.3%) and field pea (5.7-17.8%) using seeding rates of 2, 45, and 45 kg ha^{-1}, respectively. The low percentages of cool-season grasses found in species composition can be attributed to the high competition of forage brassicas and the lower seeding rates of the cool-season grasses. Overall, the forage brassicas had the greatest ability to compete within the sprayed forage mixtures while the pearl millet regrowth limited the ability of all cool-season forages to compete within the unsprayed treatments.

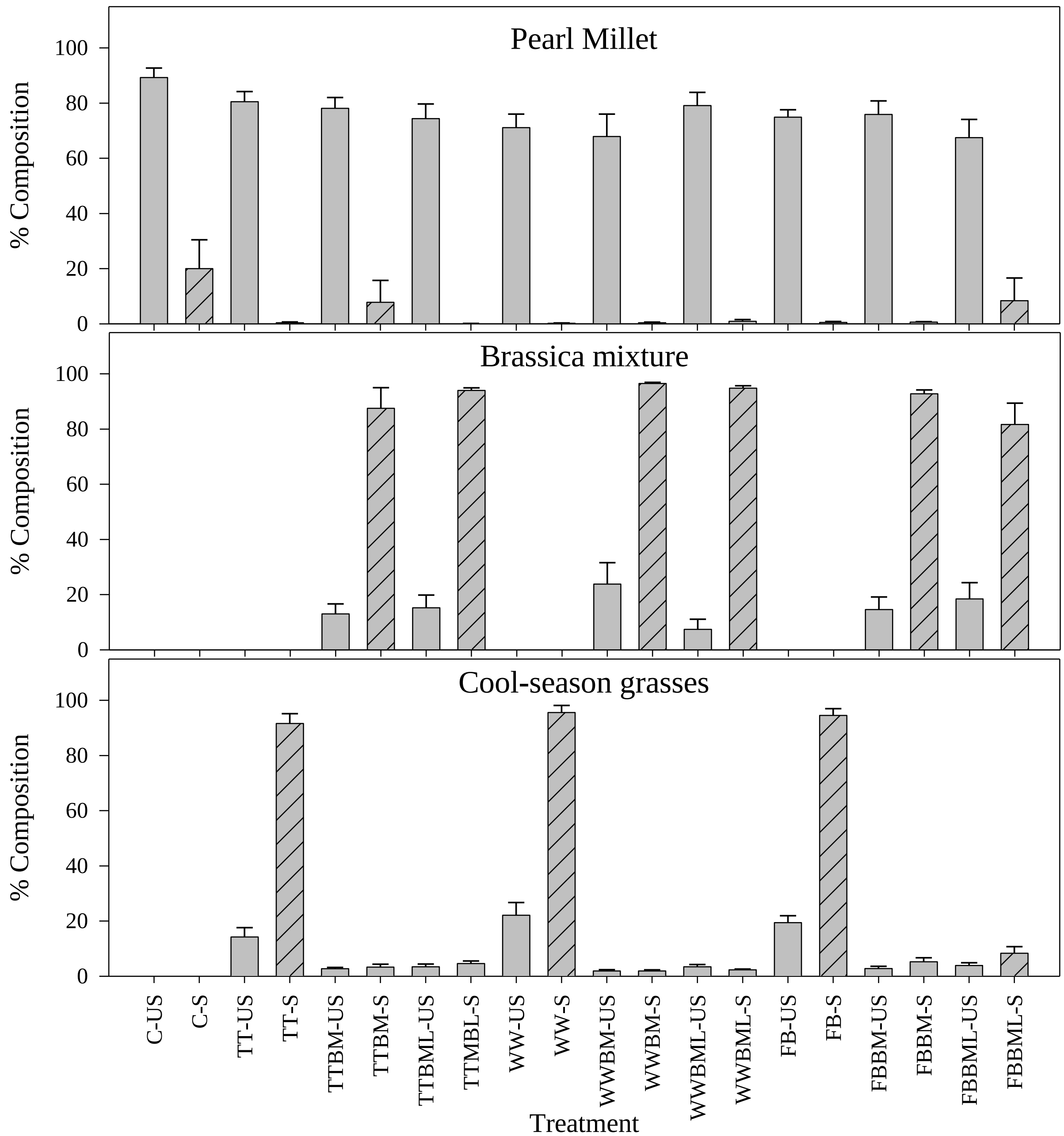

Figure 1. Species composition of forage treatments for the pearl millet, brassica mixture, and cool-season grasses. C=control, TT=triticale, WW=winter wheat, FB=forage barley, BM=brassica mixture, BML=brassica-legume mixture, US=unsprayed (solid), and S=sprayed (striped). Vertical bars represent the SE of the mean for each treatment.

Legumes contributed very little biomass in the brassica-legume mixtures (0.2-1.7%), but the unsprayed treatments had more legumes than sprayed treatments (Table 8). Field peas have contributed up to 18% of total DM yield when seeding rates were increased (34-49%) within the total bulk seeding rate of forage mixtures (56-92 kg ha^{-1}) (Hansen et al., 2015; Titlow et al., 2014). In our study, legumes comprised 26% of the bulk seeding rate used in the brassica-legume mixtures. Samarappuli et al. (2014) found lower biomass yield of Austrian winter pea and hairy vetch due to their slower establishment compared to a forage pea (cv. Arvika), two forage turnips, and a forage radish. This is consistent with our results where forage brassicas outcompeted not only the legumes, but the cool-season grasses in sprayed mixtures while the pearl millet dominated the unsprayed mixtures. A greater proportion of legumes within forage mixtures is desirable to provide higher quality forage (Burgess et al., 2014), increase N fixation, and accelerate N cycling (Lin and Chen, 2014; Ritchey et al., 2015). Agronomic management practices such as staggered seeding (Hayden et al., 2015) or fertilization (Thilakarathna et al., 2015) can improve the rate of establishment of species within forage mixtures; however, the increased costs related with these practices must be offset by higher forage biomass and nutritional quality. Although hairy vetch and winter peas are among the most used annual forage crops by producers (SARE-CTIC, 2015), the low percentages found in our study make it unlikely that they will impact forage yield and nutritional quality when planted in brassica-legume mixtures.

Despite having been mostly suppressed before seeding the pearl millet in the first year of the study, volunteer alfalfa was found in the plots during both years. Except for the sprayed control treatments (36.7%), low percentages of alfalfa were found in all treatments (0.1-2.0%). Similar to alfalfa, and with the exception of the sprayed control plots (44.3%), weeds were effectively suppressed in the sprayed treatments (0.04-6.80%). The unsprayed plots had higher percentages of weeds (5.3-10.4%), and the second year of study had the highest percentages and variety of species, especially pigweed (*Amaranthus retroflexus* L.), lambsquarter (*Chenopodium album* L.), and Canada thistle (*Cirsium arvense* L.).

3.3.2. Dry matter yield

The forage mixtures evaluated had high biomass yields with differences resulting primarily from the effects of spraying on species composition. Forage mixture and the two-way interaction had a significant effect (P<0.05) on yield (Table 9). The unsprayed control, winter wheat, and forage barley had similar yields and those were significantly higher than when sprayed (Figure 2). This can be primarily attributed to the yield from the millet regrowth, as the yield in the unsprayed control was significantly higher than the yield of the two cool-season grasses when sprayed. Sedivec et al. (2011) evaluated an unsprayed single cropping system (annual forage crop) with an unsprayed and sprayed dual (hay crop/annual forage crop) cropping system. These authors found that dual cropping systems had lower yields than the single cropping system for the annual forage crops. However, the sprayed system was more effective at suppressing weeds and increasing DM yield of the annual forage crops compared to the unsprayed dual system, which resulted in 80% lower DM yields than the single system. In our study, the reductions in total yield in the unsprayed mixtures were smaller, ranging from 4-20% of the yield of the sprayed treatments.

Triticale grown in monoculture had higher yields than winter wheat and forage barley in both the unsprayed and sprayed treatments, which can be attributed to the fact that the triticale planted was a spring variety while the other two were winter varieties. This is consistent with previous studies in the Central High Plains (CHP) where spring triticale cultivars have shown higher biomass yields compared to winter wheat cultivars (6500 vs. 5600 kg ha^{-1}) (Islam et al., 2013). Because triticale takes more growing degree days to reach the soft dough stage, it potentially produces more biomass than other cereals (McCartney and Baron, 2013b).

Table 9. Statistical significance and contrasts of the main effects for yield and nutritional quality of forage treatments.

Variable	Yield	CP	aNDF	IVTD	NDFD
Forage treatment (T)[1]	*	*	*	*	*
Spraying (S)	ns	*	*	*	*
T*S	*	*	*	*	*
Contrast			Adjusted P-value (Bonferroni method)		
			Dry matter yield		
Sprayed grass monoculture versus sprayed brassica mixtures			0.0009		
Sprayed grass monoculture versus sprayed brassica-legume mixtures			0.0036		
			aNDF		
Unsprayed control versus unsprayed brassica mixtures			0.0378		
Unsprayed control versus unsprayed brassica-legume mixtures			0.0063		
Unsprayed grass monoculture versus unsprayed brassica-legume mixtures			0.2061		
Sprayed grass monoculture versus sprayed brassica mixtures			0.0009		
Sprayed grass monoculture versus sprayed brassica-legume mixtures			0.0009		
			IVTD		
Sprayed grass monoculture versus sprayed brassica mixtures			0.0009		
Sprayed grass monoculture versus sprayed brassica-legume mixtures			0.0009		

1. * P<0.05, ns=non-significant.

Most annual forages seeded in late-summer reach peak biomass after 60-80 days of growth in the Great Plains (Sedivec et al., 2011). This range was accomplished in our study, and except for the sprayed control, winter wheat, and forage barley, all treatments had yields higher than 4000 kg ha^{-1} (Figure 2) with good potential to meet the DM requirements of livestock under high stocking rates (Ball et al., 2008).

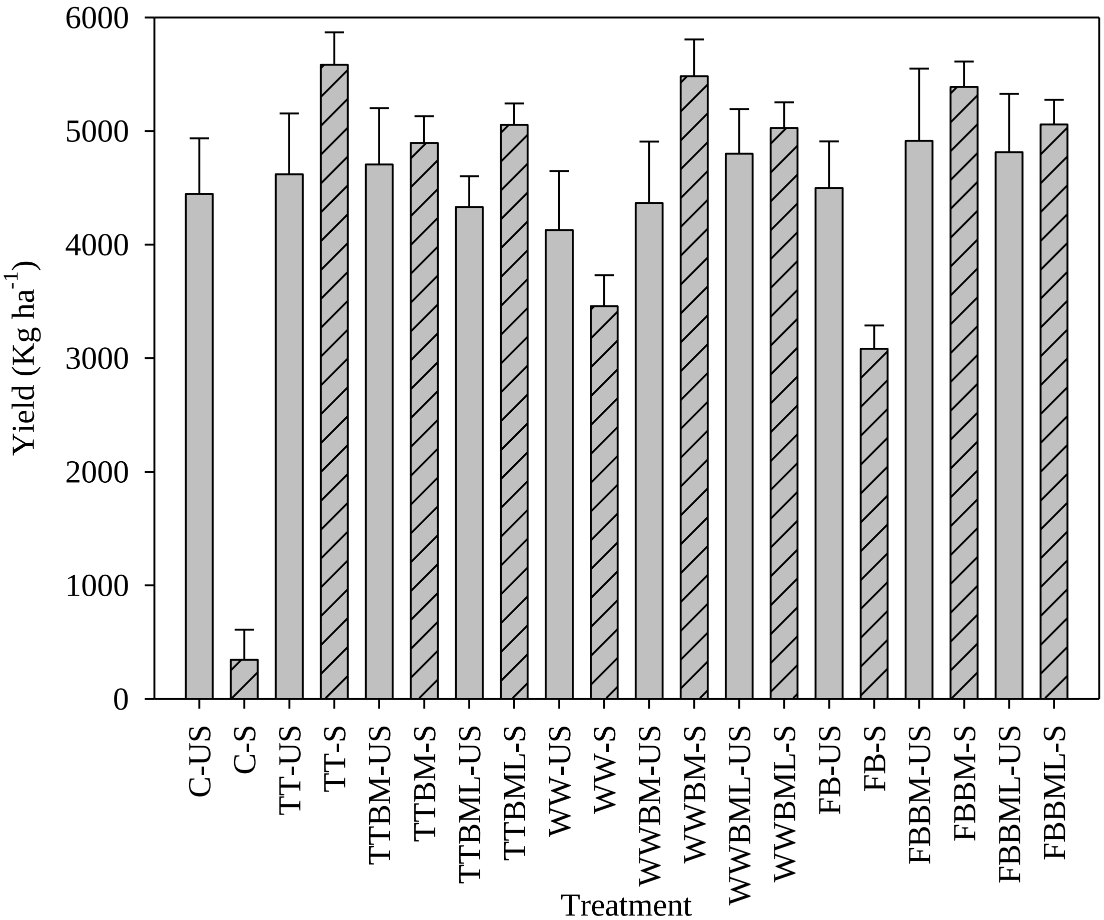

Figure 2. Dry matter yield of forage treatments evaluated during the fall of 2013 and 2014. C=control, TT=triticale, WW=winter wheat, FB=forage barley, BM=brassica mixture, BML=brassica-legume mixture, US=unsprayed (solid), and S=sprayed (striped). Vertical bars represent the SE of the mean for each treatment.

Spraying the millet prior to seeding decreased competition for the seeded forage mixtures which resulted in higher yields within a range of 190 to 1110 kg of DM ha^{-1} compared to the same unsprayed treatment (Figure 2). This is consistent with other studies where spraying a previous summer crop resulted in higher DM yield and potential stocking rates later in the fall (Sedivec et al., 2011). Overall, the sprayed grass monocultures had yields significantly lower than sprayed brassica and brassica-legume mixtures (Table 9).

The high DM yields of the annual forage mixtures evaluated make them well suited for use as stockpiled forage for grazing during the fall and early-winter months. When stockpiling, it is desirable to attain yields of more than 2000 kg ha^{-1} (McCartney and Baron, 2013a) which was doubled by most treatments in our study. The costs related to inputs and labor required to kill a previously grown crop and establish an annual cool-season mixture must be offset by greater yield, increased forage quality, and economic returns for producers (Schomberg et al., 2014). Less labor is required to have animals graze compared to providing them with harvested feed; the latter being two to three times more expensive than pasture (Ball et al., 2008).

3.3.3. Nutritional quality

Except for triticale and forage barley plus the brassica-legume mixture, all unsprayed treatments had significantly lower protein content than sprayed treatments as a result of the pearl millet regrowth (Figure 3). The forage treatment, spraying, and their interaction had a significant (P<0.05) effect on protein content of the forage mixtures (Table 9). The forage treatments evaluated had CP concentrations (143-210 g kg^{-1}) similar to those found in previous studies for forage mixtures (113-270 g kg^{-1}) (Hansen et al., 2015) and monocultures (136-247 g kg^{-1}) (Thilakarathna et al., 2015).

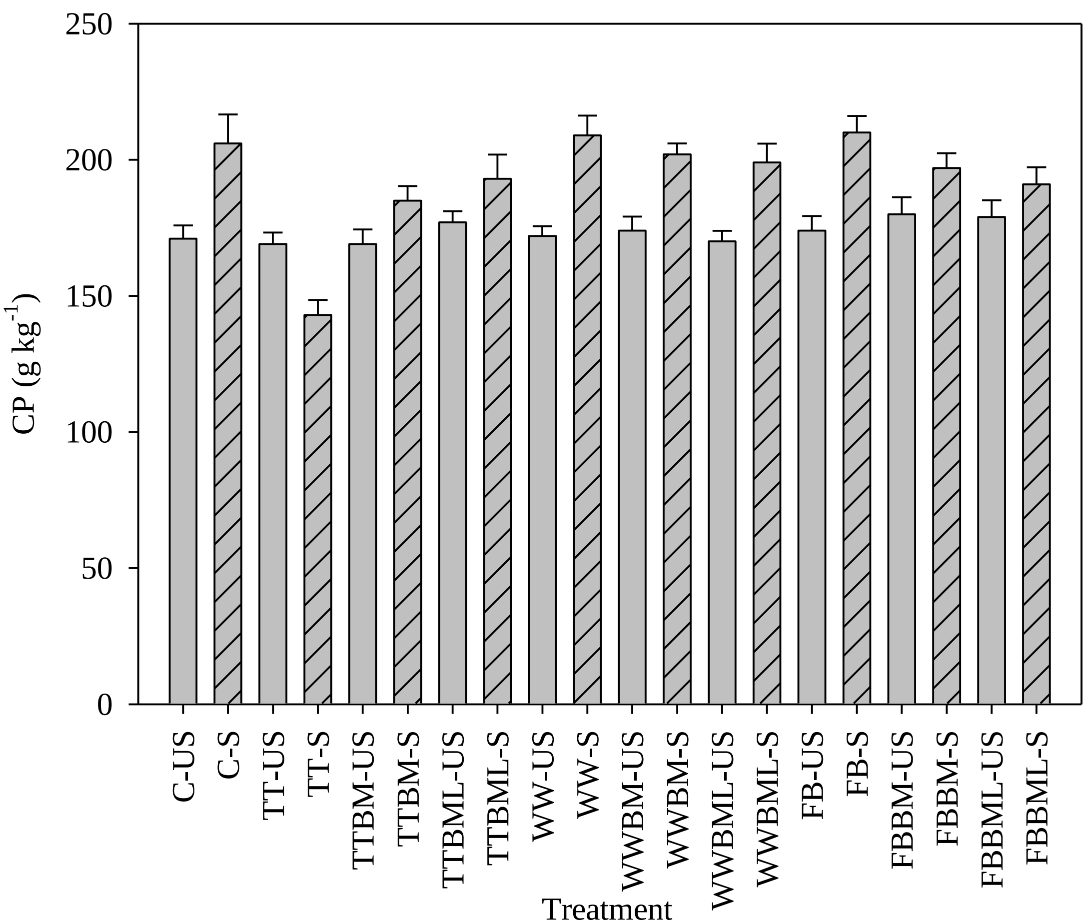

Figure 3. Crude protein content of forage treatments evaluated during the fall of 2013 and 2014. C=control, TT=triticale, WW=winter wheat, FB=forage barley, BM=brassica mixture, BML=brassica-legume mixture, US=unsprayed (solid), and S=sprayed (striped). Vertical bars represent the SE of the mean for each treatment.

The sprayed monoculture triticale treatment had the lowest CP content (Figure 3), which can be attributed to dilution resulting from the high DM yield (Figure 2). The CP concentrations found in our study (143-210 g kg^{-1}) for the three cool-season grass monocultures are consistent with those reported by Islam et al. (2013) for small grains (127-235 g kg^{-1}). The unsprayed brassica and brassica-legume mixtures had CP values similar to the unsprayed grass monoculture treatments, which can be explained by the low percentages of brassicas (7.4-23.8%) and cool-season grasses (14.1-22.1%) and high percentages of pearl millet (67.5-80.5%) found in these treatments (Figure 1). The sprayed triticale monoculture had a CP content significantly (P<0.05) lower than the brassica and brassica-legume mixtures (Figure 3). Regardless of these differences, all forage mixtures had the potential to meet the CP requirements of beef cattle (NRC, 2000) grazing during late-fall and early-winter, reducing the need for supplementation (Hansen et al., 2015).

The sprayed brassica and brassica-legume mixtures had significantly ($P<0.05$) lower aNDF values than sprayed cool-season grasses grown as a monoculture (Table 9). The forage treatment, spraying, and their interaction had a significant ($P<0.0001$) effect on both aNDF and IVTD (Table 9). The lower aNDF content found in the sprayed treatments is explained by the lush green growth of the cool-season forages while the unsprayed treatments were comprised primarily of pearl millet regrowth (Figure 1). The sprayed triticale had a significantly ($P<0.05$) higher aNDF content than sprayed winter wheat and forage barley; the latter two remained vegetative, whereas triticale underwent elongation of reproductive stems which increased the fiber content. Although relatively small percentages (7.4-23.8%) of forage brassicas were found in unsprayed brassica and brassica-legume mixtures, their aNDF content (avg. = 554 and 543 g kg^{-1}, respectively) was significantly ($P<0.05$) lower than the unsprayed control treatment (610 g kg^{-1}) which was comprised of pearl millet regrowth (Figure 1, Table 9). This is consistent with previous studies where addition of brassicas to mixtures have significantly reduced fiber content compared to grass monocultures (Titlow et al., 2014).

The aNDF content for the sprayed brassica and brassica-legume mixtures ranged from 229 to 246 g kg^{-1}, which was consistent across treatments irrespective of the cool-season grass they were mixed with. Previous studies have reported that forage brassicas significantly reduce the fiber content when they represent more than 50% of the DM available in forage mixtures (Hansen et al., 2015). This is consistent with our results where brassicas comprised more than 80% of the DM available in the sprayed brassica and brassica-legume mixtures. Based on this latter finding, the sprayed brassica and brassica-legume mixtures can be considered high quality forages (aNDF<390 g kg^{-1}) (Samarappuli et al., 2014). However, very low levels of aNDF can create problems as fiber is needed to stimulate rumination, chewing and saliva production (Putnam and Orloff, 2014).

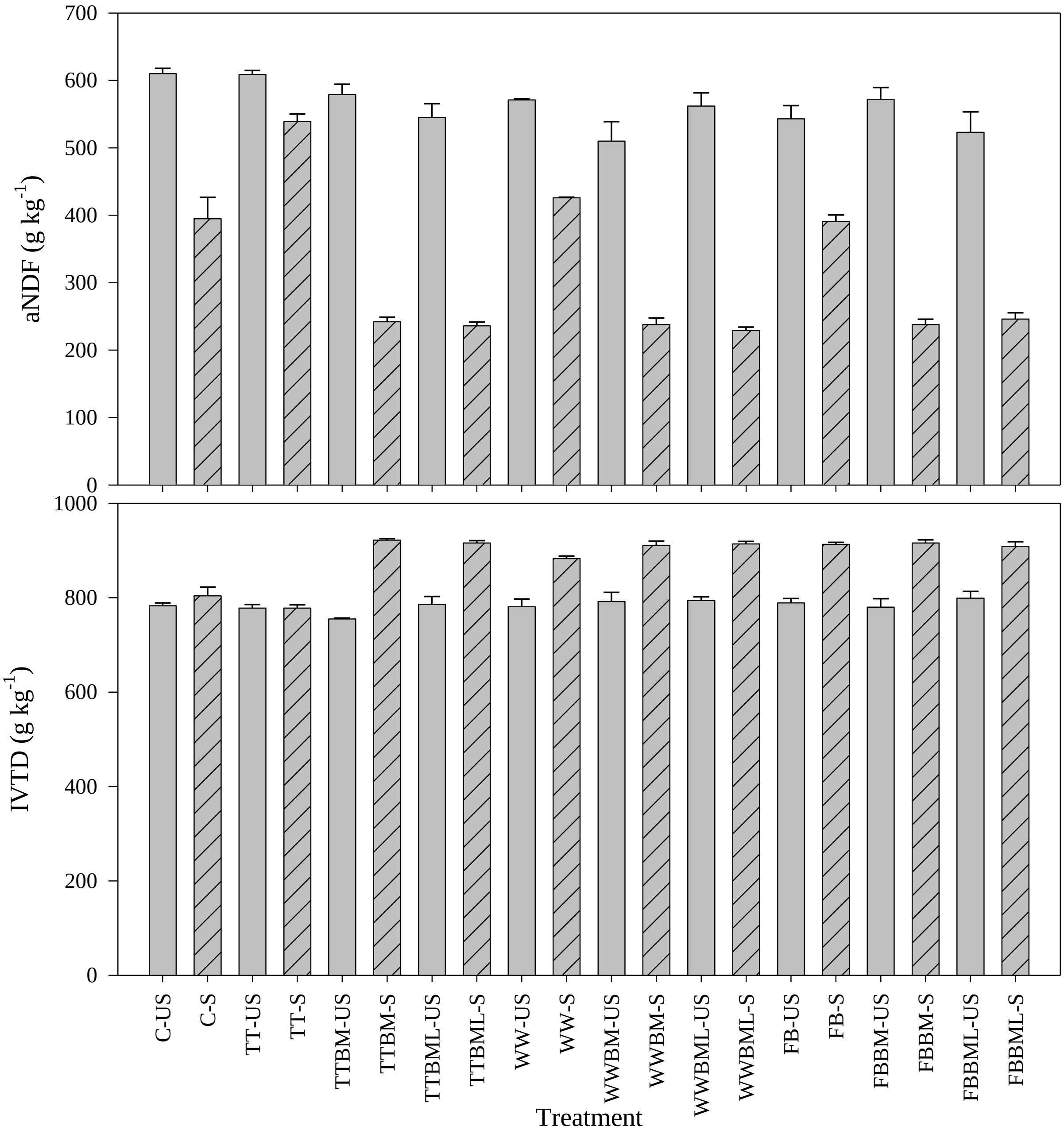

Figure 4. Neutral detergent fiber (aNDF) and digestibility (IVTD) of forage treatments evaluated during the fall of 2013 and 2014. C=control, TT=triticale, WW=winter wheat, FB=forage barley, BM=brassica mixture, BML=brassica-legume mixture, US=unsprayed (solid), and S=sprayed (striped). Vertical bars represent the SE of the mean for each treatment.

In our study, the low fiber content found in sprayed brassica and brassica-legume mixtures can be attributed to the high competition of brassicas and the low seeding rates of the cool-season grasses within the bulk rate of the mixtures, thereby requiring supplementation of some source of roughage for cattle grazing these forage mixtures.

Except for triticale, the sprayed treatments had higher IVTD than unsprayed treatments where the pearl millet was the dominant species within the mixtures (Figure 4). The sprayed triticale mixed with brassicas and brassica-legumes had higher IVTD than the monoculture. Species composition was a major determinant of the resulting digestibility of forage mixtures. The orthogonal contrasts indicated that the sprayed grass monocultures had significantly (P<0.05) lower IVTD values than sprayed brassica and brassica-legume mixtures (Table 9). The sprayed triticale underwent elongation of reproductive stems which resulted in lower IVTD values than sprayed winter wheat and forage barley that remained vegetative during the growing season. Winter wheat has been shown to have higher nutritive value, but lower DM yield than triticale and rye cultivars (Islam et al., 2013). In our study, the sprayed winter wheat monoculture had IVTD values significantly higher than triticale, but similar to forage barley. Our results illustrate how the inclusion of forage brassicas in the sprayed treatments increased overall digestibility above 90% (90.9-92.2%), which can be attributed to their dominance in the composition and associated high digestibility (Ball et al., 2008; Samarappuli et al., 2014).

The sprayed forage barley monoculture treatment had the highest NDFD while the sprayed control had the lowest value (Figure 5). The forage treatment (P=0.0001), spraying (P=0.0286), and their interaction (P<0.0001) had significant effects on NDFD. Overall, the unsprayed and sprayed treatments (62.3% vs. 64.6%, respectively) had similar NDFD values, which resulted in many overlapping values across treatments. Except for the sprayed control, all treatments had

NDFD values higher than low-quality straw of Kentucky bluegrass (*Poa pratensis* L.) and warm-season prairie grasses (410 and 470 g kg^{-1}, respectively) (Bohnert et al., 2011), but lower than forage legumes (780-849 g kg^{-1}) and forage brassicas (901-910 g kg^{-1}) grown in monocultures (Samarappuli et al., 2014).

Although total cell wall content is not highly correlated with NDFD (Putnam and Orloff, 2014), lower weight gain has been found when beef cattle graze forages with low cell wall digestibility (McCartney and Baron, 2013b). Our results were not conclusive with respect to how NDFD is affected by changes in species composition within annual cool-season forage mixtures. However, the stage of growth among the three cool-season grasses evaluated resulted in differences in NDFD. The sprayed winter wheat and forage barley monocultures had the highest NDFD values (725 and 774 g kg^{-1}, respectively) as they remained vegetative during the growing season and also dominated the composition (95.6 and 94.5%, respectively). One would expect that due to the high digestibilities found in the sprayed brassica and brassica-legume mixtures, high values would be found for NDFD. However, these mixtures had lower NDFD values than those found for the sprayed winter wheat and forage barley monocultures, which can be attributed to differences in the type of cell wall of brassicas compared to cool-season grasses.

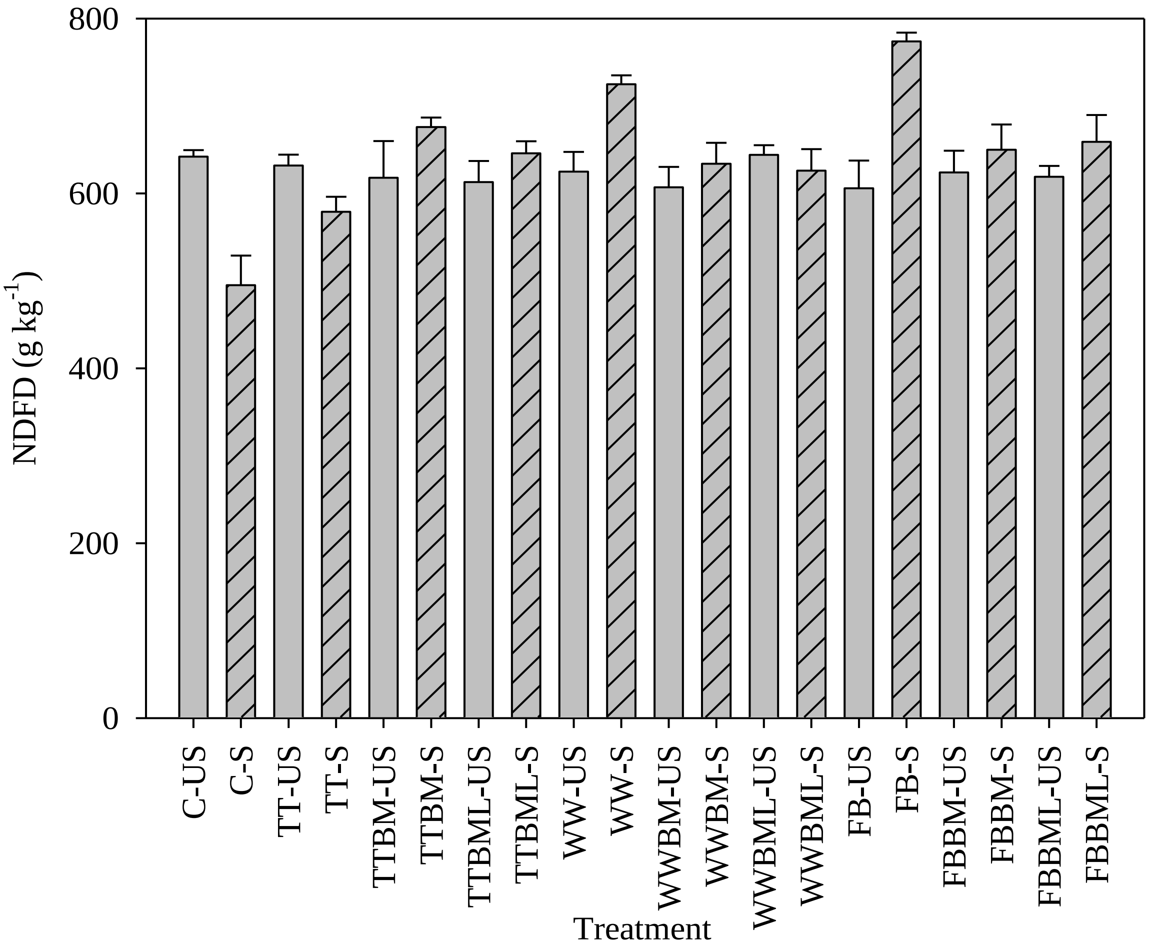

Figure 5. Cell wall digestibility (NDFD) of forage treatments evaluated during the fall of 2013 and 2014. C=control, TT=triticale, WW=winter wheat, FB=forage barley, BM=brassica mixture, BML=brassica-legume mixture, US=unsprayed (solid), and S=sprayed (striped). Vertical bars represent the SE of the mean for each treatment.

3.4. Conclusions

Spraying to control regrowth of pearl millet was the main factor that determined which species dominated within the forage treatments evaluated. Pearl millet was the dominant species in the unsprayed treatments and impacted the ability of the cool-season forages to establish and grow. The sprayed mixtures were primarily dominated by brassicas which outcompeted the cool-season grasses and legumes, the latter comprising only a small percentage of the DM as a result of the low seeding rates used within the bulk rate of the mixtures. Further research is required on how higher seeding rates of cool-season grasses might increase their percentages within brassica mixtures. Because brassicas are highly competitive forages, planting them at lower seeding rates within mixtures is an option worth trying, however, higher rates of the cool-season grasses should still be used in order to encourage higher establishment rates of the grasses within mixtures.

With the exception of the control, winter wheat, and forage barley treatments, spraying the pearl millet resulted in higher DM yield values than unsprayed treatments. Brassica and brassica-legume mixtures had similar yields which implies that, with the seeding rates used in our study, legumes are not worth including due to their low contribution to available DM. All of the forage species and mixtures evaluated can potentially be stockpiled and used to extend the grazing season into the fall as the biomass yields obtained can more than meet the DM requirements of beef cattle and reduce the need for feeding of preserved forages.

The dominant species was the primary factor influencing nutritive value within the brassica and brassica-legume mixtures. Thus, unsprayed treatments had lower CP values as a result of the pearl millet regrowth while only the sprayed triticale mixed with the brassica and brassica-legume mixtures had CP values higher than grass monocultures. The high percentage of brassicas in the sprayed mixtures reduced the fiber content to levels where supplementation with some source of roughage may be required, which will increase feeding costs. Also, additional inputs will be required to suppress regrowth of the pearl millet prior to seeding the cool-season mixtures, which will also impact production costs in beef cattle operations. Thus, in order to justify spraying a warm-season grass prior to seeding cool-season forages, the additional costs must be offset by higher yields and nutritive value of the forages.

Even though the unsprayed brassica and brassica-legume mixtures had lower yields and nutritive value than sprayed mixtures, their biomass and quality were high enough to warrant being used as stockpiled forage; the brassicas within the unsprayed mixtures can provide a higher quality forage during late-fall and early-winter months as they undergo small declines in quality over time. Pearl millet regrowth within the unsprayed treatments increased the fiber content within the mixtures to levels where supplementation with higher fiber forages would not be required. This results in reduced feeding costs as well as negates the need for use of herbicides to suppress the warm-season grass prior to seeding the cool-season forages.

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CHAPTER 4. PROPORTIONS OF COOL-SEASON FORAGES IN SEED MIXTURES AFFECT YIELD AND QUALITY

Annual cool-season forage mixtures can extend the grazing season into the fall. Ten forage species/mixtures were seeded in early August, and their species composition, yield, and nutritional quality were measured in mid-October in northern Colorado. Species/mixtures evaluated included: Fridge winter triticale (X *Triticosecale*), Jerry oats (*Avena sativa*), and a brassica mix comprised of Barkant turnip (*Brassicas rapa*), Barnapoli rape (*Brassica napus*), Groundhog radish (*Raphanus sativus* var. *oleifer*), and Pasja hybrid (Chinese cabbage [*Brassica rapa chinensis*] x Turnip hybrid). Two seeding rates (5.6 and 11.2 kg ha^{-1}) were used for the brassica only mixture, while four rates were used for oat (39.3, 73.0, 106.7, and 134.8 kg ha^{-1}) and winter triticale (33.7, 61.7, 89.8, and 112.3 kg ha^{-1}) when mixed with the brassica mixture, for which the seeding rate was held constant. Oat had higher dominance than winter triticale when mixed with brassicas which was evidenced by yields (7330-7870 kg ha^{-1}) significantly higher than brassica only (6090-6210 kg ha^{-1}) and winter triticale treatments (4810-5380 kg ha^{-1}). Oat reached the reproductive stage which resulted in significantly lower crude protein (CP) (165-183 g kg^{-1}) and digestibility (IVTD) (721-804 g kg^{-1}), and higher fiber (aNDF) (482-555 g kg^{-1}) than the brassica only and winter triticale treatments. Oat mixed with forage brassicas has the potential to provide high quality forage to beef cattle during the fall without the need for any fiber or protein supplementation. Planting annual cool-season forages for fall grazing can impact the production costs in beef cattle operations by reducing the need for feeding of preserved forages and supplements.

4.1. Introduction

Planting annual forages is a means of extending the grazing season by filling the void in yield common during the late-fall and early-winter months when perennial pastures go dormant, resulting in significant savings for livestock enterprises (Coblentz and Walgenbach, 2010; Entz et al., 2002). Fall growth from annual forages can provide a source of high quality pasture for beef cattle and may limit the need for supplemental hay during winter (Coblentz and Walgenbach, 2010). Although there are establishment costs associated with growing annual forage mixtures, those can be offset when yields are similar or greater than forage crops grown in monocultures and if nutritive value is improved (Strydhorst et al., 2008).

Cover crops have been primarily promoted to improve soil health; however, the biomass from these crops provide a valuable source of forage that can be used by cattle producers while returning most of the nutrients to the soil when grazed (Titlow et al., 2014). Producers are increasingly planting complex mixtures of forages due to the benefits provided to cattle through higher quality forage (Deak et al., 2007), enhanced soil health (Sanderson et al., 2005), and stability in biomass distribution (Entz et al., 2002).

A wide range of annual forages are currently used in forage mixtures, but little information is available on how the proportions of each species in a seed mixture should be balanced to obtain adequate production and quality for livestock (Sanderson et al., 2013). Forage mixtures of cereal grains with legumes or forbs (e.g. forage brassicas) may provide for more balanced forage production; the cereal grains are high yielding but lower quality crops, whereas legumes or forbs have the potential to increase the nutritional quality of the resulting mixture (Strydhorst et al., 2008; Vasilakoglou and Dhima, 2008). Seeding rates influence competitive interactions within forage mixtures, and brassicas are highly competitive (Samarappuli et al., 2014). Legumes, for instance, are often less competitive than cereal grains and typically require higher seeding rates relative to cereals in order to achieve significant yields and N fixation (Strydhorst et al., 2008).

The objective of this study was to evaluate the yield and nutritional quality of forage mixtures for fall grazing that were comprised of different proportions of cool-season grasses mixed with a forage brassica mix for which the seeding rate was held constant. When brassicas dominate within forage mixtures, their quality increases, but the dry matter and fiber contents are often reduced to levels where supplementing with some source of fiber is required (Reid et al., 1994). Previous studies have evaluated mixtures of annual forages (Titlow et al., 2014), but little information is available about how forage brassicas compete as the proportion of annual cool-season grass is increased in the mixture. In our study, the increasing proportions of cool-season grasses were intended to increase DM and fiber contents to levels where no supplementation is required, without sacrificing the nutritive value of the mixtures in order to meet the requirements of beef cattle during late-fall and early winter.

4.2. Materials and Methods

4.2.1. Study Location and Implementation

This study was conducted during the 2014 summer-fall growing season at Colorado State University's Horticultural Research Farm, located about 15 km northeast of Fort Collins, CO (40.39°N, 104.59°W) at an elevation of 1555 m. The soil is a Nunn clay loam (fine-loamy mesic Aridic Haplustalf) (Soil Survey Staff et al., 2013). Weather data was collected from an automated station located at the Colorado State University Agricultural Research, Development and Education Center which is part of the Colorado Agricultural Meteorological Network (CoAgMet 2015). Monthly total precipitation and average monthly maximum and minimum temperatures were estimated for August through November 2014 (Table 10).

Table 10. Average maximum and minimum temperatures and total precipitation per month for 2014.

Weather variable	Month			
	August	September	October	November
Avg. max. Temp. (°C)	28.2	24.8	19.9	8.7
Avg. min. Temp. (°C)	11.8	8.1	2.3	-7.7
Total precipitation (mm)	26.2	23.1	28.2	12.4

The field was previously in forage brassicas during the 2013 summer-fall growing season. The plot area was rototilled two times during the summer of 2014 to control weeds prior to planting. Forty plots measuring 3.6 m wide by 13.7 m long were marked in the field. Ten forage species/mixtures were seeded on August 06, 2014 (Table 11). The species seeded included Fridge winter triticale, Jerry oats, and a brassica mix. The brassica mix was comprised of Barkant turnip, Barnapoli rape, Groundhog radish, and Pasja hybrid. Due to its larger seed-size, the proportion of Groundhog radish was increased (34% of the bulk rate) to approximate the density (seeds kg^{-1}) of the other 3 species in the mixture which were seeded at a smaller proportion (22% of the bulk rate). The brassica mixture was seeded at two rates, the lower of which was used when mixed with the cool-season grasses. Average full seeding rates of oats and winter triticale were used as a baseline for grass monoculture treatments (100%). When mixed with the brassicas, seeding rates of the grasses were reduced to 25, 50, and 75% of the full seeding rate. Urea fertilizer was applied to the experimental plots prior to seeding at a rate of 56 kg of N ha^{-1}.

Table 11. Seeding rates of species and mixtures of forages with different seed proportions.

Forages (code)	Seeding rate (kg ha^{-1})
Brassica mixture (BM5)	5.6
Brassica mixture (BM11)	11.2
Oat 25%+brassica mix (O25%+BM5)	33.7+5.6
Oat 50%+brassica mix (O50%+BM5)	67.4+5.6
Oat 75%+brassica mix (O75%+BM5)	101.1+5.6
Oat 100% (O100%)	134.8
Winter triticale 25%+ brassica mix (WT25%+BM5)	28.1+5.6
Winter triticale 50%+ brassica mix (WT50%+BM5)	56.1+5.6
Winter triticale 75%+ brassica mix (WT75%+BM5)	84.2+5.6
Winter triticale 100% (WT100%)	112.3

All treatments were randomly assigned in a complete block design with four replications. Plots were seeded with a no-till drill (Model 3P605NT, Great Plains Mfg., Inc., Salina, KS) fitted with a cone seeder attachment (Kincaid Equipment Manufacturing, Haven, KS) set at a 19 cm row spacing. Sprinkler irrigation was applied at a rate of 25 mm wk^{-1}. Due to a hard, killing freeze and snow cover during the second week of November, the plots were only harvested once on October 16. Most treatments exhibited some lodging after the freeze and maintained partial snow cover which limited our ability to take the planned second harvest.

4.2.2. Harvesting Protocol and Laboratory Analysis

Dry matter yield (DMY) was assessed by harvesting 1.1 m wide by 4.6 m long strips from each plot using a walk-behind sickle-bar mower. The material was gathered onto a tarp and weighed using a hanging electronic scale. A representative subsample was taken (600 g fresh wt.) and dried at 60°C for 72 hours to determine moisture content. The dried samples were then ground for nutritional analysis through a shear mill (Wiley® Model 4, Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen and then through a cyclone mill (Foss® Tecator Cyclotec Model 1093, Udy Corp., Fort Collins, CO), also equipped with a 2-mm screen, to homogenize the material. Another sample was taken (1500 g fresh wt.) and frozen to be later separated into three plant components: brassicas, cool-season grass (i.e. triticale, or oats), and weeds. Following separation, the components were dried at 102°C for 24 hours and weighed to assess species composition on a DM basis within each forage treatment.

Ground samples were analyzed using an elemental combustion analyzer (LECO TruSpec® Model CN268, St Joseph, MI) to obtain the nitrogen content which was multiplied by 6.25 to estimate crude protein (CP) content (AOAC, 1990). Neutral detergent fiber (aNDF) was determined according to Van Soest et al. (1991) using an Ankom® 200 fiber analyzer (Method 6, ANKOM Technology Corp., Macedon, NY). *In-vitro* true digestibility (IVTD) was determined using an Ankom® Daisy II incubator (Method 3, ANKOM Technology Corp., Macedon, NY). The samples were incubated for 48 h in a buffer solution mixed with rumen fluid (1600 ml and 400 ml, respectively) (Van Soest and Robertson, 1985). Rumen fluid was collected from two fistulated steers that were being fed a mixed grass hay and corn diet (60:40 forage/corn). After incubation, samples were analyzed following the aNDF procedure described above. Both analyses were used to estimate aNDF digestibility (Hoffman et al., 2001).

4.2.3. Statistical Analyses

The study had a one-way factorial treatment structure with ten forage treatments randomly assigned in a randomized complete block (RCB) design with four replications (*n*=40). Data for species composition, yield, and forage quality were analyzed using an ANOVA appropriate for an RCB design using the PROC GLIMMIX procedure of SAS version 9.3 (SAS-Institute, 2011). Forage treatment was considered fixed in the model statement, while replications (blocks) were considered random variables. Least Square Means (LSM) for the forage treatments were estimated using the LSMEANS statement, and the PDIFF LINES statement was used to separate means within the GLIMMIX procedure of SAS version 9.3 (SAS-Institute, 2011). All results were considered significant at the $P \leq 0.05$ level. The SE of the mean was estimated for data shown in figures.

4.3. Results and Discussion

4.3.1. Species Composition

Forage treatment had a significant effect ($P \leq 0.0001$) on species composition (Figure 6). Oat was highly competitive with the forage brassicas, with low percentages of the latter when the cool-season grass proportion was increased within the mix. When mixed with winter triticale, the proportion of brassicas in the mix was significantly higher (51.2-77.8%) than when mixed with oat (3.9-21.0%, Figure 6). Titlow et al. (2014) found that turnips contributed only 1.6 to 3.9% to available DM when mixed with oat (80.0-94.3%) and field pea (5.7-17.8%) using seeding rates of 2, 45, and 45 kg ha^{-1}, respectively, showing that oat is highly competitive with brassicas.

Winter triticale remained mostly vegetative during the growing season, showing a high leaf-to-stem ratio based on visual observations, which reduced competition with the forage brassicas due to their growth form and height. On the other hand, oat grows upright (with a lower leaf/stem ratio) and the canopy closes early in the season, shading the soil and affecting initial development of the brassicas. Erect, taller-growing grasses tend to perform better in forage mixtures due to their ability to compete for light (Sanderson et al., 2005). Similar to our study, Titlow et al. (2014) found that oat was the dominant species in a three-way annual mixture, followed by pea and then turnip. Forage barley was more competitive than berseem clover (*Trifolium alexandrinum*) when mixed at three different seeding rates (25-75, 50-50, and 75-25% of the full rate for each species) (Vasilakoglou and Dhima, 2008). Botanical composition is influenced by the interaction of the particular species included in the mixtures as well as the climatic conditions they are grown under (Deak et al., 2007). Forage mixtures are more successful when each species occupies and accesses resources at different times during the growing season, which minimizes competitive interactions (Strydhorst et al., 2008).

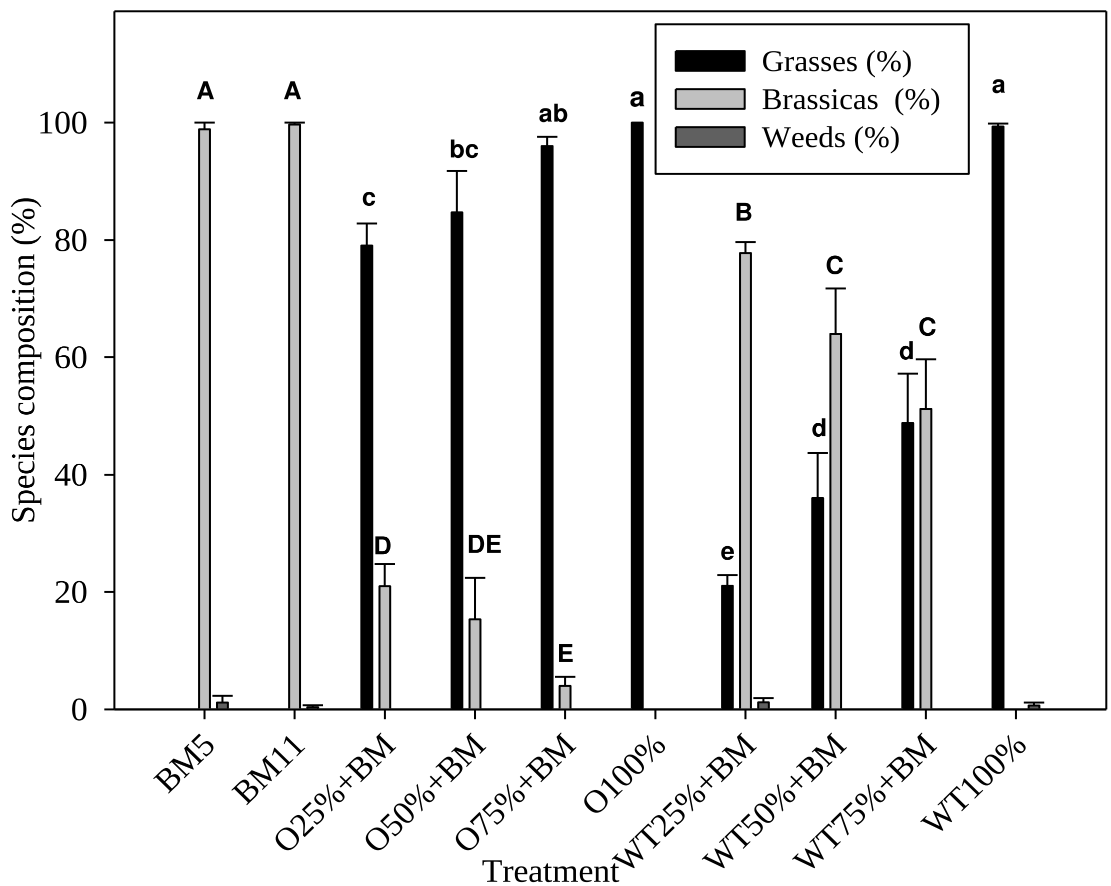

Figure 6. Species composition of annual cool-season forages and mixtures with varying seeding rates of grasses. Bars with the same lower (grass) or uppercase (brassica) letter are not significantly different at P≤0.05 by the pairwise comparison test of least square means.

On average, all forage treatments effectively covered the tilled area, and by doing so, suppressed weed abundance. The oat plus forage brassica mixtures were the most significant treatments at suppressing weeds (0%), but the winter triticale plus brassica (0.6-1.2%) and brassica only mixtures (0.3-1.1%) also had low percentages of weeds (Figure 6). Monocultures of grasses and legumes usually result in greater proportions of weeds in harvested biomass compared to forage mixtures (Sanderson et al., 2012). In our study, the low percentages of weeds found in the plots had little impact on yield and quality of the forage treatments evaluated.

4.3.2. Dry Matter Yield

Forage treatment had a significant ($P \leq 0.0001$) effect on DM yield with the treatments separating out into two distinct groups (Figure 7). The oat treatments had the highest yields (7330-7870 kg ha^{-1}), while the brassica only mixtures (6090-6210 kg ha^{-1}) and winter triticale treatments had lower values (4810-5380 kg ha^{-1}), and the triticale monoculture had the lowest yield. However, all forage treatments had relatively high yields (greater than 4500 kg ha^{-1}) with differences being primarily attributed to species composition. In our study, the higher yield in oat plus brassica mixture treatments can be primarily attributed to the greater percentages of oat within the mixtures. Winter triticale grown in monoculture had the lowest yield among the treatments, but when mixed with brassicas, the DM yield increased, reaching values similar to the brassica only mixtures. Previous studies have noted that legumes and forbs have the potential to improve yield and quality of forage mixtures through the release of nutrients that are used by other plants (e.g. N from legume nodulation) or by increasing the tonnage produced as they can access nutrients from other regions of the soil (Strydhorst et al., 2008).

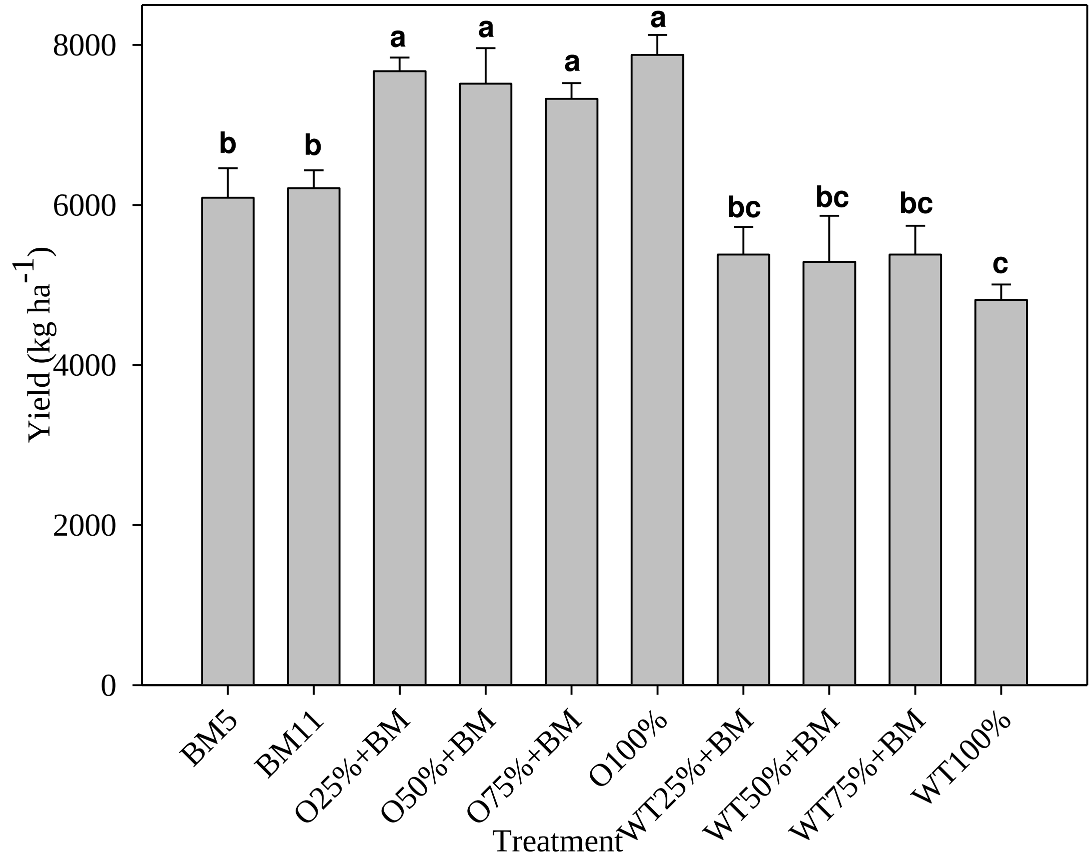

Figure 7. Dry matter yield of annual cool-season forages and mixtures with varying seeding rates of grasses. Bars with the same lowercase letter are not significantly at P≤0.05 by the pairwise comparison test of least square means.

Increasing the seeding rate of the brassica only mixture did not significantly affect DMY (*P*=0.8023, diff=120 kg ha^{-1}). All winter triticale treatments had yields significantly lower than the three oat plus forage brassica mixtures as a result of slower growth compared to oat, resulting in a more even competition with the brassicas (Figure 6). However, when either grass was planted with the brassica mix, changing the grass seeding rate did not affect the yield. Both grasses had similar species composition of the grass and brassica components when the highest rates of grass (i.e., 50 and 75%) were seeded in the mixture (Figure 6), which resulted in similar yields across the treatments of each forage crop. Forage mixtures of barley and berseem clover have yielded similar amounts of DM (22.8 Mg ha^{-1}) as berseem monocultures (24.9 Mg ha^{-1}), but higher than barley monocultures (12.7 Mg ha^{-1}) (Vasilakoglou and Dhima, 2008). In our study, the triticale treatments had yields similar to both brassica treatments and both had yields significantly lower than oat treatments (Figure 7).

4.3.3. Nutritional Quality

Forage treatment had a significant ($P \leq 0.0001$) effect on CP content of the species and mixtures evaluated (Figure 8). Two distinct groups separated out based on CP content: the forage brassica only mixtures and winter triticale treatments had the highest CP contents (251-274 g kg^{-1}), while the oat treatments had lower values (165-183 g kg^{-1}). More generally, doubling the seeding rate had no effect (P=0.0815) on CP content of the brassica mixture.

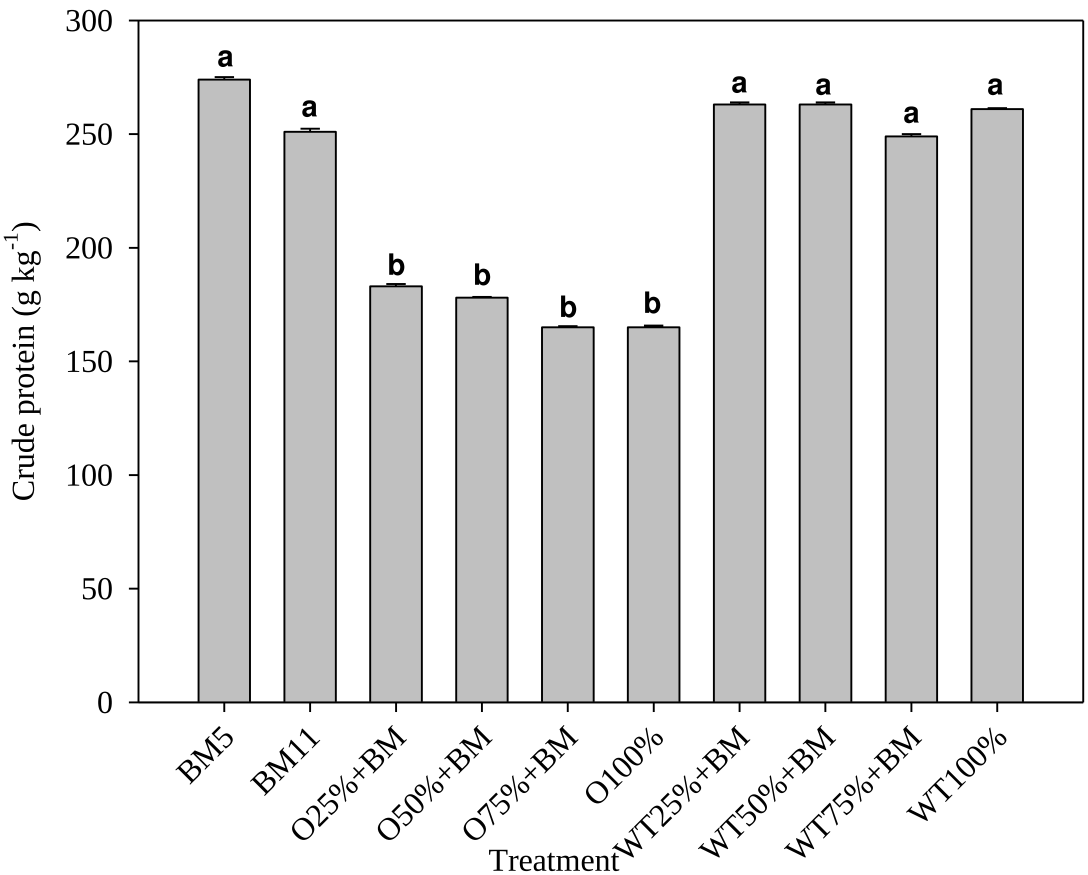

Figure 8. Crude protein content of annual cool-season forages and mixtures with varying seeding rates of grasses. Bars with the same lowercase letter are not significantly different at P≤0.05 by the pairwise comparison test of least square means.

Cereal grain monocultures typically provide high DM yields, while their CP content is primarily affected by the growth stage at which they are harvested or grazed (Vasilakoglou and Dhima, 2008). The forage brassicas in our study had CP values similar to those reported for forage legumes (Deak et al., 2007); however, neither of the two distinct groups of treatments had CP contents that varied significantly as a result of lower proportions of brassicas in the mix when the seeding rate of the cool-season grasses was increased (Figure 6). In the oat mixtures, the grass component varied less (79-96%) than in winter triticale (21-48%), which resulted in similar CP contents among the treatments, while the latter remained vegetative through time, resulting in CP values similar to those of the brassicas as was the case for the triticale grown in monoculture (Figure 8).

The low percentages of brassicas (3-20%) found in the oat mixtures (Figure 6) did not impact the CP content of the mixtures, while the yields for oat were significantly higher than the other treatments (Figure 7), which diluted the higher protein content of the brassicas. However, even the oat mixtures had protein contents above 160 g kg^{-1} which can more than meet the requirements of beef cattle during the late-fall and early-winter months (NRC, 2000). The winter triticale monoculture and the three winter triticale plus forage brassica mixtures had similar CP values to the forage brassica only mixtures and those were higher than the oat mixtures (Figure 8). Unlike oat, most of the winter triticale plants remained in a vegetative stage through the growing season, which resulted in a higher protein content compared to both oat monoculture and oat plus forage brassica mixtures.

Forage treatment had a significant ($P \leq 0.0001$) effect on aNDF (Figure 9). The variation among species and species composition among the forage mixtures evaluated (Figure 1) resulted in a wide range of aNDF values (253-555 g kg^{-1}). The oat monoculture and oat plus forage brassica mixtures had the highest aNDF contents (482-555 g kg^{-1}), with the 25% of full seeding rate treatment being significantly lower than the other treatments. Winter triticale grown as a monoculture had significantly higher aNDF values compared to triticale mixed with the forage brassicas. Seeding rates of 50 and 75% of the full rate for winter triticale mixed with brassicas resulted in intermediate values (294 and 324 g kg^{-1}, respectively), while the lowest rate had values similar to the brassica only mixtures (241-259 g kg^{-1}). Strydhorst et al. (2008) found lower relative feed values (RFV) for barley monocultures (111%) compared to three legume-barley mixtures (132-151%). The authors attributed such differences in RFV to the higher aNDF and ADF concentrations associated with the barley. Titlow et al. (2014) found aNDF values greater than 500 g kg^{-1} in three-way mixtures of oat, pea, and turnip, with average species composition values of 81.5, 15.9, and 2.6% of the available DM, respectively. This is consistent with our results in which oat dominated in mixtures (79.0-96.0%) with forage brassicas resulting in higher fiber values.

Both winter triticale and oat had lower aNDF content at their lowest percentage seeding rate (25%) within the overall mixture compared to the treatments with higher rates of the cool-season grasses (Figure 9). The grass component was primarily responsible for the aNDF content in the mixtures evaluated. Deak et al. (2007) found that the grass proportion explained most (r^2=0.85) of the variation in fiber content within two- to nine-species mixtures.

The higher cell wall content and lower digestibility in the oat treatments can be explained by increases in fiber associated with elongation of reproductive stems by the oat plants during the growing season. Except for the four oat treatments and the winter triticale grown as a monoculture, all mixtures had fiber values (241-324 g kg^{-1}) lower than those used when formulating diets for beef cattle (Marshall et al., 1992). These authors evaluated diets with similar NDF levels (379-471 g kg^{-1}) containing different sources of roughage (grass hay, crushed alfalfa [*Medicago sativa*] cubes, and pelleted corn cobs) for beef cattle and found similar DM and nutrient intakes across treatments, with palatability of the fiber source being responsible for changes in ruminal parameters due to a reduction in fiber intake. Based on fiber values measured in this study, the brassica only and winter triticale plus brassica mix treatments (241-324 g kg-1) will likely require fiber supplementation when grazed by cattle to avoid rumen upset.

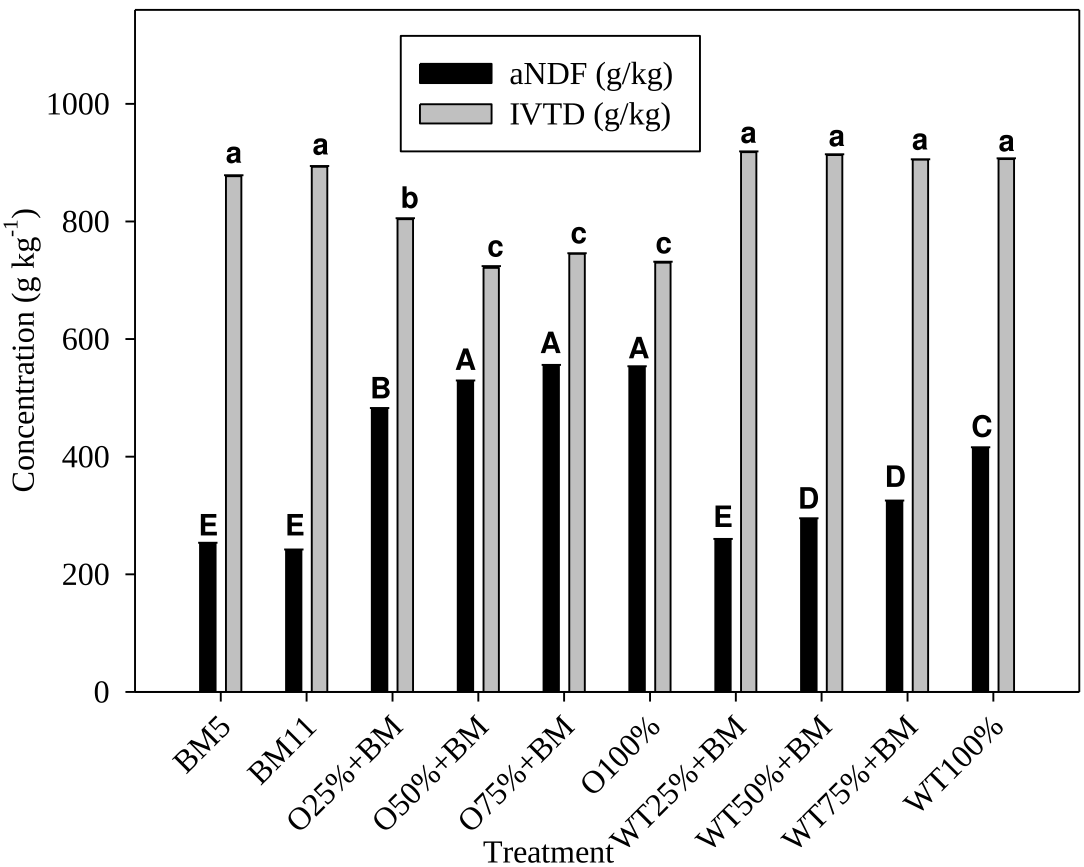

Figure 9. Cell wall content (aNDF) and digestibility (IVTD) of annual cool-season forages and mixtures with varying seeding rates of grasses. Bars with the same upper (aNDF) or lowercase (IVTD) letter are not significantly different at P≤0.05 by the pairwise comparison test of least square means.

Forage treatment also had a significant ($P \leq 0.0001$) effect on IVTD. On average, the four winter triticale treatments and the forage brassica only mixtures had significantly ($P<0.05$) higher IVTD (877-918 g kg^{-1}) compared to the oat treatments (721-804 g kg^{-1}) (Figure 9). Our results are consistent with previous research where Ogle oat harvested at the boot and fully headed stages had lower IVTD values (75.3% and 72.9%, respectively) than barley, rye (*Secale cereale*), and wheat (*Triticum aestivum* L.) (avg=89.6%) harvested at boot stage (Coblentz and Walgenbach, 2010).

Although the oat treatments had the lowest digestibilities across all treatments evaluated, IVTD was higher than the *in-vitro* dry matter disappearance (IVDMD) for three-way mixtures (oat, pea, and turnip, 60.1-72.1%) and native pastures (46.3-56.9%) that go dormant in the fall (Titlow et al., 2014). The potential for high yield and quality are among the primary benefits obtained from planting annual forage mixtures. Cool-season grasses that undergo stem elongation during the fall have resulted in yield advantages going into winter over species/cultivars that remained vegetative (Coblentz and Walgenbach, 2010). Based on visual observations, winter triticale plants seemed to be more affected after a snow load compared to oat treatments.

Forage treatment had a significant ($P \leq 0.0001$) effect on cell wall digestibility (Figure 10). Similar to aNDF content, NDFD varied widely which can be partially explained by differences in species composition (i.e. forage brassicas vs. cool-season grasses). The four winter triticale mixtures had the highest NDFD values (685-774 g kg^{-1}), with the mixture planted at the lowest seeding rate being similar to oat at the same rate. The other oat treatments (474-594 g kg^{-1}) and the brassica only mixtures (516-560 g kg^{-1}) had similar NDFD values. The higher cell wall digestibility of winter triticale compared to oat is most likely explained by the reproductive stage reached by oat while triticale remained vegetative (Rustas et al., 2011). Cool-season forages such as oat, triticale, and winter wheat have shown similar NDFD values when harvested on different dates through the fall (Coblentz and Walgenbach, 2010).

In our study, except for the winter triticale plus brassica mixture at the lowest seeding rate, all winter triticale treatments had significantly ($P<0.05$) higher NDFD values than oat treatments

(Figure 10). Unlike with the other nutrients measured, NDFD values overlapped across the treatments, which can be attributed to differences in the type of cell wall between broadleaf species (e.g. forbs and legumes) and grasses. Even for forage species that belong to the same genus, cell wall digestibility has been shown to vary. Schaefer et al., (2014) reported that meadow fescue (*Schedonorus pratensis*) and tall fescue (*Schedonorus arundinaceus*) had similar CP and NDF values, but higher IVTD and NDFD values were found for meadow fescue. In our study, due to the similar NDFD values found, the treatments were not separated into distinct groups as was the case for yield and protein.

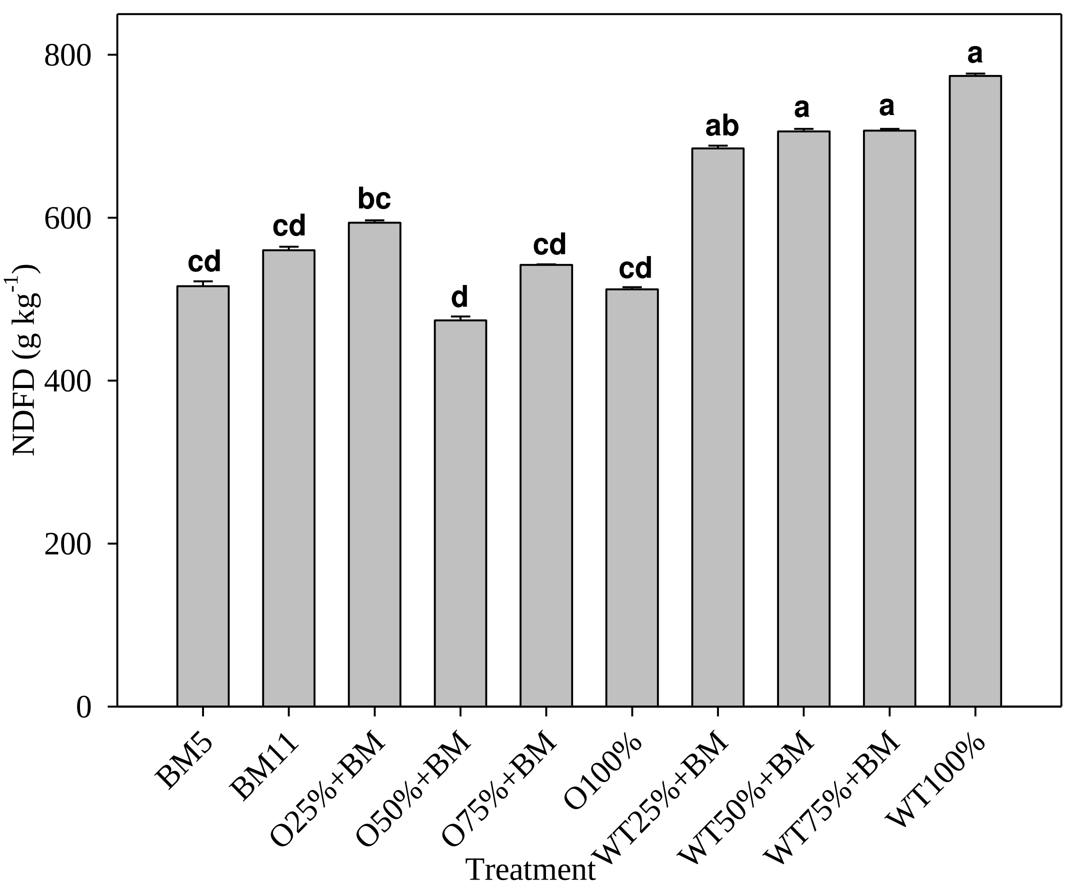

Figure 10. Cell wall digestibility (NDFD) content of annual cool-season forages and mixtures with varying seeding rates of grasses. Bars with the same lowercase letter are not significantly at P≤0.05 by the mean separation test.

4.4. Conclusions

Both selection of the appropriate forage species and the proportions used in the bulk seeding rate had important implications on yield and nutritive value of the forage treatments evaluated. The dominant species within the forage treatments was the primary factor that affected species composition, which in turn affected yield and nutritive value of the forage treatments. The proportions of oat were higher than winter triticale when mixed with brassicas. All forage mixtures effectively suppressed weeds, with the oat treatments being more effective than both the brassica only and winter triticale plus brassica mixtures. Dry matter yield of the oat treatments was significantly higher than the brassica only and winter triticale treatments, but all had potential to fill the void in dry matter during late-fall and early-winter months.

The nutritive value of the forage treatments evaluated was affected by the dominant species within the mixtures and stage of growth of the cool-season grasses. Oat treatments underwent stem elongation, resulting in lower protein and digestibility and higher fiber values than brassica only mixtures and winter triticale treatments. All forage treatments evaluated can potentially meet the requirements of grazing beef cattle during the late-fall and early-winter months; however, oat grown as a monoculture or mixed with forage brassicas had the highest biomass yields and fairly high nutritive value that would reduce the need for fiber supplementation. Oat also stood up under a snow load. Planting annual cool-season forages for fall grazing can reduce the need for feeding of preserved forages and supplements and impact the profitability of beef cattle operations.

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CHAPTER 5. INTERSEEDING COOL-SEASON FORAGES INTO CORN TO INCREASE YIELD AND QUALITY OF RESIDUE GRAZED IN THE FALL[2]

Six forage species/mixtures were interseeded into irrigated grain corn to evaluate their yield and nutritional quality as a means of improving diets for beef cattle grazing cornstalks during the fall. Species/mixtures evaluated included annual ryegrass (*Lolium multiflorum*), crimson clover (*Trifolium incarnatum*), Fridge winter triticale (X *Triticosecale*), a mixture of annual ryegrass plus crimson clover, a brassica mixture (Barkant turnip [*Brassicas rapa*], Barnapoli rape [*Brassica napus*], Groundhog radish [*Raphanus sativus* var. *oleifer*], and Pasja hybrid [Chinese cabbage {*Brassica rapa chinensis*} x Turnip hybrid]), and a mixture of winter triticale plus the brassica mix. Dry matter yield (DMY), crude protein (CP), neutral detergent fiber (aNDF), and digestibility (IVTD) differed among the interseeded forages. The brassica mix had the highest DMY (790 kg ha^{-1}) and CP of all interseeding treatments (18.3-26.1%) could increase the protein supply when grazing cornstalks (5.2%). The low fiber content (aNDF) of the interseeded forages (23.4-44.2%) should not affect rumen function as cattle will have a fiber supply from the cornstalks (73.5%). Except for crimson clover (77.7%), all treatments had high digestibilities (90.7%) that will increase the nutrient supply to beef cattle grazing cornstalks (57.7%). Costs of the interseeded forages varied widely because of differences in seeding rates, seed cost, DMY, and CP content. Annual ryegrass and the brassica mix had the lowest costs (\$0.17 and \$0.15 kg^{-1} of utilizable DM and \$0.88 and \$0.64 kg^{-1} of utilizable CP, respectively), with values similar to or lower than those for good quality alfalfa hay with a current market price of \$154 t^{-1}. Interseeding cool-season forages

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can increase the quality and quantity of biomass offered to beef cattle grazing cornstalks during the fall while reducing supplementation costs for producers.

5.1. Introduction

Cornstalks grazed by beef cattle, mostly cow/calf systems, represent a cheap and efficient way to utilize the plant biomass left after grain harvest (Klopfenstein et al., 1987). The main problem with grazing cornstalks is the relatively low protein content and digestibility of the corn residue (Fernandez-Rivera and Klopfenstein, 1989) which makes supplementation, especially with protein, necessary in order to meet the nutritional requirements of cattle (NRC, 2000).

Grazing cornstalks can be expanded to yearling cattle, but adequate forage quality must be available in order to maintain animal gains (Fernandez-Rivera and Klopfenstein, 1989). Such opportunities must fit economically and logistically in a farming-ranching system (Klopfenstein et al., 1987). Interseeding cool-season forage species into corn is an agronomic management practice by which producers can increase the quality of the forage offered to beef cattle. Interseeding annual forages into grain crops depends on an adequate selection of species that can establish beneath a crop canopy, tolerate weed control practices, survive until harvest (in a shady, droughty or humid understory) without reducing yield or interfering with mechanical harvest of the crop and tolerate equipment traffic at harvest (Lawley, 2013).

The objective of this study was to evaluate the yield and nutritional quality of cool-season forages interseeded into corn for fall grazing under Colorado growing conditions. Most studies where forages have been interseeded into corn have been conducted in the eastern United States (Scott et al., 1987; Baributsa et al., 2008) and some parts of the Pacific Northwest and British Columbia, Canada (Lawley, 2013). In our study, differences in yield and quality as affected by forage species/mixture were considered indicators of the potential to increase forage quality provided to beef cattle grazing cornstalks into the fall and winter.

5.2. Materials and Methods

5.2.1. Study Location and Implementation

This study was conducted during the summer-fall growing season of 2014 at Colorado State University's Agricultural Research, Development and Education Center (ARDEC), located about 15 km northeast of Fort Collins, Colorado (40.39°N, 104.59°W, elevation 1555 m).

Six forage species/mixtures were interseeded into grain corn that was at the V6 growth stage on June 30, 2014 (Table 12). The species seeded included annual ryegrass, crimson clover, and Fridge winter triticale. The brassica mix was comprised of Barkant turnip, Barnapoli rape, Groundhog radish, and Pasja hybrid. Due to its larger seed-size, the proportion of Groundhog radish was increased (34% of the bulk rate) to approximate the density (seeds kg^{-1}) of the other 3 species in the mixture which were seeded at a smaller proportion (22% of the bulk rate).

To interseed the forages, a 3 m wide Gandy® box was mounted on a 3-point toolbar to meter the seeds. Three sets of 3 wavy-blade coulters were attached to the toolbar to lightly disturb the soil in the strips between corn rows. The seeds were broadcasted into each tilled strip through 3 tubes that were mounted about 30 cm above the soil surface. The wavy blades were set to prepare a 30 cm wide seedbed between each row. Seeding rates were estimated by multiplying the recommended full seeding rate for each species/mixture by the percentage of effective area tilled by the wavy blades (30 cm wide x 3 strips = 90 cm) which represented a fraction of the total area seeded (90/225 cm = 40%) (Table 12). Sprinkler irrigation was applied to the corn at a rate of 25 mm per week through mid-September.

Table 12. Seeding rates of species and mixtures of forages interseeded into corn.

Forages (code)	Seeding rate (kg ha^{-1}) †
Annual ryegrass (AR)	9.0
Crimson clover (CC)	5.5
AR + CC	5.4 + 3.6
Winter triticale (WT)	45.0
Brassica mix (BM)	4.5
WT + BM	24.2 + 2.7

† Seeding rates were based on recommended full rates for each species/mixture multiplied by 40% which represented the percentage of area tilled between corn rows.

5.2.2. Harvesting Protocol and Laboratory Analysis

Dry matter yield (DMY) was assessed for the species/mixtures on November 10, 2014, by hand clipping three, 0.75 m by 0.75 m frames per treatment to ground level, one within each interseeded row. Cornstalks were sampled by placing the frames on the rows instead. Plant material was collected in paper bags, placed in a forced-air oven and dried at 60°C for 72 hours, and weighed. Yields were then converted to kg ha^{-1}. The dried samples were then ground for nutritional analysis through a shear mill (Wiley® Model 4, Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen and then through a cyclone mill (Foss® Tecator Cyclotec Model 1093, Udy Corp., Fort Collins, CO), also equipped with a 2-mm screen, to homogenize the material. The samples were analyzed using an elemental combustion analyzer (LECO TruSpec® Model CN268, St Joseph, MI) to obtain the nitrogen content which was multiplied by 6.25 to estimate crude protein (CP) content (AOAC, 1990). Neutral detergent fiber (aNDF) was determined according to Van Soest et al. (1991) using an Ankom® 200 fiber analyzer (Method 6, ANKOM Technology Corp., Macedon, NY). *In-vitro* true digestibility (IVTD) was determined using an Ankom® Daisy II incubator (Method 3, ANKOM Technology Corp., Macedon, NY). The samples were incubated for 48 h in a buffer solution mixed with rumen fluid (1600 ml and 400 ml, respectively) (Van Soest and Robertson, 1985). Rumen fluid was collected from two fistulated steers that were being fed a mixed grass hay and corn diet (60:40 forage/corn). After incubation, samples were analyzed following the aNDF procedure described above. Both analyses were used to estimate aNDF digestibility (NDFD) (Hoffman et al., 2001)

5.2.3. Statistical Analyses

The study was laid out in a randomized complete block design with three replicates per treatment. Dry matter yield, CP, aNDF, IVTD, and NDFD were analyzed by analysis of variance using PROC GLIMMIX of SAS version 9.3 (SAS Institute, 2011). The model included forage species/mixture as the main factor and block (replicate) as the random factor. Mean separations were estimated using the Tukey test within PROC MEANS of SAS (SAS Institute, 2011).

5.2.4. Cost Analysis

The cost of interseeding cool-season annual forages into corn was estimated by using the seed cost and cost of machinery used (tractor, interseeder, labor, and fuel). Biomass yield was multiplied by 75% as was the utilization factor previously found for strip grazing (Chapter 6, Table 18); and the total cost was then divided by the utilizable biomass of each treatment to estimate the cost per kilogram of utilizable DM. Biomass yield was then multiplied by the percent CP to obtain yield of protein in kilograms per hectare which was then multiplied by the utilization factor of 75%. Total cost per hectare was then divided by the kilograms of utilizable protein per hectare to estimate the cost per kilogram of CP. Resulting costs for the cool-season forages interseeded into corn were compared to an average quality alfalfa with a market price at \$154 t^{-1}. Furthermore, the breakeven costs (BEC) per ton of DM were estimated. The cost of operating the tractor and interseeder per hectare was considered the fixed cost (FC) whereas the variable cost (VC) was obtained by dividing the seed cost for each treatment by the DMY. The BEC was then obtained for both using the following equation: BEC = (FC/DMY) + VC.

5.3. Results and Discussion

5.3.1. Dry Matter Yield and Nutritional Quality

Dry matter yields differed among the interseeded forage species (P=0.0013), with the annual ryegrass and brassica mixture having the highest yields whereas crimson clover and winter triticale produced much less biomass (Table 13). The two mixtures evaluated (AR+CC and WT+BM) had yields significantly higher (P<0.05) than crimson clover while WT+BM had values significantly higher than the winter triticale monoculture, but not different than annual ryegrass (P>0.05). Competition in an interseeding system may be determined by the time of interseeding, crop density, or competitive ability of the interseeded species (Baributsa et al., 2008). Yield of the mixtures was dominated by the annual ryegrass and brassicas and was lower than the monoculture treatments due to the lower seeding rate for these species in the mix (Table 12). Annual cool-season forages can be interseeded as monocultures, in mixtures, or with different species in alternate rows as a means of reducing competition (Lawley, 2013).

All treatments had DM yield values lower than 800 kg ha^{-1}. Red clover (*Trifolium pratense* L. var. *frigidum* auct. non Gaudin) and chickling vetch (*Lathyrus sativus* L., var. AC Greenfix) were interseeded into corn in Michigan and had yields (70-480 and 130-690 kg ha^{-1}, respectively) comparable to those obtained in our study (Baributsa et al., 2008). Beef producers are typically encouraged to seed annual forages with high yields to reduce the cost per cow grazing day (McCartney and Baron, 2013). However, evidence has shown that species/cultivars interseeded into grain corn have lower yields compared to monoculture plantings (Baributsa et al., 2008). Thus, cool-season forages interseeded into crops are intended to provide multiple benefits such as increased biomass yields and higher quality forage offered to beef cattle, nutrient recycling from cattle manure, and higher efficiency in land use during the late-fall and early-winter months.

Table 13. Dry matter yield and nutritional quality of forages interseeded into corn.

Forages*	Yield (kg ha^{-1})	CP (%)	aNDF (%)	IVTD (%)	NDFD (%)
Cornstalks**	6873	5.2	73.5	57.7	42.4
AR	596^{ab}	18.9^{c}	39.9^{a}	90.7^{a}	76.9^{a}
CC	18^{d}	18.3^{c}	42.9^{a}	77.7^{b}	48.1^{c}
AR + CC	358^{bc}	20.1^{bc}	39.3^{a}	91.5^{a}	78.5^{a}
WT	58^{cd}	22.3^{abc}	44.2^{a}	90.0^{a}	77.4^{a}
BM	790^{a}	23.9^{ab}	25.3^{b}	89.4^{a}	58.6^{bc}
WT + BM	428^{b}	26.1^{a}	23.4^{b}	92.1^{a}	66.6^{b}

*AR=annual ryegrass, CC=crimson clover, WT=winter triticale, and BM=brassica mix.
**Not included in statistical analysis.

The CP content also differed among the interseeded forage species (*P*=0.0149). On average, CP for the cool-season forages was four times the content of the cornstalks (Table 13). A low CP content has been reported as the first-limiting factor for weight gain when calves graze irrigated cornstalks (Klopfenstein et al., 1987; Fernandez-Rivera and Klopfenstein, 1989). The brassica and WT+BM mixtures were the treatments with the highest CP. Although annual ryegrass and crimson clover had lower CP values, their content would still exceed the requirements of most classes of beef cattle if fed in combination with cornstalks (NRC, 2000).

For fiber content as measured by aNDF, the interseeded species evaluated fell into 2 groups (*P*=0.0001, Table 13). The brassica and WT+BM mixtures were the treatments with the lowest aNDF contents averaging 24.4%. The other species and mixtures evaluated averaged 41.6% aNDF. All the forage species in this study had an aNDF content numerically lower than that of the cornstalks. Fernandez-Rivera and Klopfenstein (1989) reported NDF values similar for irrigated and dryland cornstalks (85% and 80.7%, respectively).

Although the treatment effect was significant for IVTD (*P*=0.0027), only one species, crimson clover, was significantly lower in digestibility compared to the other species and mixtures evaluated, averaging just under 78% (Table 13). All of the other cool-season forages had values of IVTD higher than 89%. Compared to the cornstalks, all of the forages evaluated had IVTD values numerically higher. Cornstalks can only be grazed following grain harvest after the plants have reached physiological maturity when digestibility is low (Klopfenstein et al., 1987; Fernandez-Rivera and Klopfenstein, 1989). In general, warm-season grasses (e.g. corn, sorghum, and sudangrass) have lower digestibilities than cool-season forages planted in the fall as they deposit higher levels of cell wall and lignin (Putnam and Orloff, 2014). Digestibility integrates the nutritional quality of a feedstuff and is an indicator of the potential nutrients available to livestock.

Cell wall digestibility as measured by NDFD varied significantly (*P*=0.0006) among the interseeded cool-season forages (Table 13). Although forage brassicas had low aNDF and high IVTD, their cell wall digestibility was lower than the treatments with a higher grass component (i.e. AR, AR+CC, and WT). Although digestibility of the fiber fraction was lower, this would have little impact on overall animal nutrition due to the fact that the brassicas had low total fiber contents. One would expect that the low NDFD values as well as the low fiber content found in brassicas would have a minor impact on the potential to provide other nutrients to beef cattle grazing cornstalks. As mentioned above, the forage brassica mix was one of the treatments with lowest aNDF, which might affect rumen function if grazed as monoculture (NRC, 2000), but the forage brassica mix can provide a highly digestible forage with potential to meet the nutrients lacking in cornstalks. Overall, the low fiber content of cool-season forages can be offset by the the seeming higher values of cornstalks, which makes it unlikely that beef cattle grazing interseeded corn experience rumen upset. The inclusion of forage brassicas in the mixture with winter triticale reduced the overall cell wall digestibility compared to growing triticale in monoculture. As one would expect, NDFD of cornstalks was the lowest, followed by crimson clover which had the lowest digestibility (IVTD) of the cool-season forages evaluated.

The addition of cool-season forages to corn through interseeding can provide high quality protein while also having a positive impact on other forage quality parameters when grazing cornstalks in the fall; however, the type of grazing management used could impact overall forage utilization and subsequent nutrient intake (Fernandez-Rivera and Klopfenstein, 1989). Rotation systems, in particular strip grazing with moves every day or every few days, can control the tendency of animals to select for the cool-season forages while encouraging more even utilization of the cornstalks (Allen and Collins, 2003). This will result in a more uniform intake of nutrients over time and capitalize on the higher quality of the cool-season forages.

5.3.2. Dry Matter and Crude Protein Costs

The cost of interseeding cool-season forages into corn was impacted by the seed cost and the seeding rates used (Table 14). The cost to operate the tractor and interseeder was the same for all treatments. Winter triticale was the treatment with the highest seeding rate and highest total cost. The two treatments with lower yields (i.e. crimson clover and winter triticale) resulted in the highest costs per kg of DM produced. If using good quality alfalfa (18% CP and 150 RFV) with a current market price of \$154 t^{-1} as a supplement, the cost per kg of DM would be \$0.175 after adjusting to a dry matter basis (\$154/(1000 kg x 88% DM)). The annual ryegrass and brassica mix had the lowest costs per kg of DM produced which were similar and lower than the cost for alfalfa hay, respectively. Breakeven costs (BEC) for the cool-season forages evaluated followed the same trends as the cost of utilizable DM. Crimson clover and winter triticale had the highest BEC due to their low DMY while annual ryegrass and the brassica mix had the lowest BEC because of their higher DMY. The BEC provides further support that the biomass obtained in our study for the brassica mix and annual ryegrass can compete with preserved feeds such as alfalfa hay to provide additional DM when grazing cornstalks.

Table 14. Costs for interseeding forages into corn and resulting cost per kilogram of dry matter (DM) yield.

Forages	Seed cost ($ ha^{-1})	Total cost ($ ha^{-1})*	Utilizable DM cost ($ kg^{-1})**	Breakeven cost ($ t^{-1} of DM)***
Alfalfa hay	--	--	0.17	--
AR†	25.20	74.20	0.17	125
CC	38.38	87.88	6.52	4890
AR + CC	40.70	89.70	0.34	252
WT	103.96	153.46	2.65	2645
BM	41.32	90.82	0.15	115
WT + BM	81.41	130.91	0.41	306

* Cost to operate the tractor, interseeder, labor, and fuel was estimated at $49.50 ha^{-1}.
** Assuming 75% utilization by cattle.
*** BEC= (FC/DMY) + VC. FC= cost to operate the tractor and interseeder. VC= (seed cost/ DMY)
†AR=annual ryegrass, CC=crimson clover, WT=winter triticale, and BM=brassica mix.

Annual ryegrass and the brassica mix also had the lowest costs per kg of utilizable protein (Table 15). These latter values were lower than the cost of protein from good quality alfalfa hay (18% CP, $0.97 kg^{-1}) with the brassica mix being cheapest at $0.64 kg^{-1}. The cost of a kg of utilizable CP for the brassica mix was about two thirds the cost of a kg of CP for good quality alfalfa hay. Being a cash crop, alfalfa hay prices are variable. At the current market price of \$154 t^{-1}, interseeding cool-season forages such as annual ryegrass and brassicas is cheaper than the common practice of feeding alfalfa hay as a supplement when grazing cornstalks. If the market price for alfalfa goes up, the economics of interseeding cool-season forages into corn will be even more favorable and can definitely help provide the nutrients required to maintain rumen microbial activity (Klopfenstein et al., 1987).

Table 15. Protein yield and resulting cost per kilogram of crude protein yield of forages interseeded into corn.

Forages	Protein yield ($kg\ ha^{-1}$)	Utilizable protein ($kg\ ha^{-1}$)*	Protein cost (\$ kg^{-1})
Alfalfa hay**	--	--	0.97
AR***	112.80	84.60	0.88
CC	3.29	2.47	35.61
AR + CC	72.16	54.12	1.67
WT	12.94	9.70	15.81
BM	189.14	141.85	0.64
WT + BM	111.65	83.74	1.56

*Assuming 75% utilization by cattle.
**Good quality alfalfa (18% CP and 150 RFV) with a current market price of \$154 t^{-1}.
***AR=annual ryegrass, CC=crimson clover, WT=winter triticale, and BM=brassica mix.

5.4. Conclusions

Interseeding of cool-season forages into corn can provide a higher-quality forage for beef cattle grazing cornstalks during the fall. Supplementation of harvested feeds such as alfalfa hay represents a large expense for producers who graze their cattle on cornstalks. Production costs in beef cattle systems can be reduced by interseeding cool-season forages that have the potential to meet the nutritional requirements of cows as well as growing and finishing animals.

Cool-season forages interseeded into corn can be strip grazed in order to achieve high levels of utilization of the corn residue/forage combination. Livestock managers may require training in these types of grazing management techniques and there will be some labor costs associated with moving electric fences every day or every few days. Although the additional labor required to move electric fences was not estimated in our study, these costs might be offset by the costs associated with the storage, hauling, and feeding of other types of protein supplements. The cattle may also need time to acclimate to this type of management.

At current market prices of purchased supplements such as alfalfa hay (\$154 t^{-1}), producers have the potential to save money by interseeding cool-season annual forages such as annual ryegrass and forage brassicas into corn at the V6 stage of growth. Integration of crop and livestock systems is feasible and can provide benefits to producers and to the environment. Grazing of cornstalks interseeded with cool-season forages would also allow a more evenly spread of the manure across the entire field, thus reducing the need for fertilization.

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CHAPTER 6. PERFORMANCE OF YOUNG BEEF CATTLE GRAZING A FORAGE BRASSICA MIXTURE

Forage brassicas can yield high quality biomass and extend the grazing season into the fall. A 4-way brassica mix was seeded in early August and grazed by a group of 32 steers and heifers (avg. = 238 kg) from October 10 to November 21, 2013. The yield, utilization, and nutritional quality of brassica forage and bulbs were measured through the evaluation. Weight gains were estimated for the grazing group and compared with a feedlot group of 74 steers and heifers (avg. = 295 kg). The brassica mix was comprised of Barkant turnip (*Brassicas rapa*), Barnapoli rape (*Brassica napus*), Groundhog radish (*Raphanus sativus* var. *oleifer*), and Pasja hybrid (Chinese cabbage [*Brassica rapa chinensis*] x Turnip hybrid). The brassica mix had high yields (4480-5530 kg ha^{-1}) and utilization (avg. = 77.6%), while estimated dry matter intake (DMI) reached values up to 3.5% (avg. = 7.37 kg d^{-1}) of body weight of the steers and heifers. The CP content (118.8 g kg^{-1}) was lower than previous studies while fiber (aNDF=190.7 g kg^{-1}) and digestibility (IVTD=943.5 g kg-1) were similar to those reported. The grazing group had a null weight gain (-4.46 kg $animal^{-1}$) while the feedlot group achieved the targeted weight gain of 33 kg $animal^{-1}$ by the end of the evaluation. Nutrient concentrations for the grazing group revealed CP and aNDF were lower than the feedlot ration. Grass hay was supplemented to the grazing group, but brassicas comprised about 90% of total DM which affected animal performance. Mixtures of forage brassicas with warm- or cool-season grasses can counterbalance the low DM and aNDF intakes found when beef cattle graze brassica only mixtures. Strip grazing is recommended to achieve high levels of utilization and more even intake of the components included in cool-season forages stockpiled for fall grazing.

6.1. Introduction

Feeding of preserved forages and supplements accounts for the majority of costs associated with wintering beef cattle (McCartney and Baron, 2013). Extending the grazing season is one of the main ways for producers to reduce their reliance on feeding of preserved forages, thus lowering production costs (McCartney and Baron, 2013; Sedivec et al., 2011). During the late-fall and early-winter months, cool-season perennial grasses and legumes have limited growth (Smith and Collins, 2003) which makes it necessary to seed forage species that tolerate colder temperatures. Annual forages planted in late-summer provide a late-fall, early-winter grazing option to complement perennial pastures (Sedivec et al., 2011). Brassicas are a good option because they have a high tolerance to frost, and their forage quality does not decline significantly with advancing maturity (Smith and Collins, 2003).

Forage brassicas have high nutritive value which makes them suitable to be stockpiled for later grazing by livestock (Villalobos and Brummer, 2015). Controlled grazing systems, such as strip grazing, are preferred for brassicas in order to maximize use of available forage and bulbs. The high intensity used in strip grazing stresses and ultimately terminates the forage crop following grazing. This grazing system is commonly used in crops such as brassicas where no regrowth is expected once grazed (Lawley, 2013). In the Pacific Northwest, central Great Plains, and Midwest, brassicas have shown potential as a second crop following wheat grain harvest (Smith and Collins, 2003).

The objective of this study was to evaluate the yield, quality, and performance of young beef cattle grazing a forage brassica mixture. Previous studies have evaluated forage brassicas as monocultures with mixed results on livestock performance (Smith and Collins, 2003). Brassicas are high quality, cool-season forages with potential to extend the grazing season and fill the void in biomass during late-fall months. The beef cattle grazing the forage brassica mixture in this study were supplemented with grass hay, and weight gains were compared with another group consuming a feedlot ration.

6.2. Materials and Methods

6.2.1. Study location and forage establishment

A grazing trial was conducted over a 28-day period in the 2013 summer-fall growing season at Colorado State University's Agricultural Research Development and Education Center (ARDEC), located about 15 km northeast of Fort Collins, CO (40.39°N, 104.59°W) at an elevation of 1555 m. The soil was a Nunn clay loam (fine-loamy mesic Aridic Haplustalf) (Soil Survey Staff et al., 2013). Weather data was collected from an automated station located at ARDEC which is part of the Colorado Agricultural Meteorological Network (CoAgMet, 2015). Total precipitation and average maximum and minimum temperatures were estimated for 2013 per month from August to November (Table 16).

Table 16. Average maximum and minimum temperatures and total precipitation per month for 2013.

Weather variable	Month			
	August	September	October	November
Avg. max. Temp. (°C)	30	24	14	10
Avg. min. Temp. (°C)	12	10	0	-5
Total precipitation (mm)	13	132	29	1

The field was drill seeded with a sorghum-sudangrass hybrid (*Sorghum bicolor* var. *bicolor* × *bicolor* var. *sudanense* [Super Sugar]) on May 28, 2013, at a rate of 67 kg ha^{-1}. Fertilizer was applied for the sorghum-sudangrass at a rate of 78 kg of N ha^{-1} and 47 kg of P_2O_5 ha^{-1} using urea

(46-0-0) and MAP (11-52-0) on May 30. No additional fertilizer was applied to the experimental plots that were later seeded with brassicas. The sorghum-sudangrass was swathed, allowed to dry, and then baled on August 8, 2013. Following haying, the field was sprayed with glyphosate (1.54 kg a.i ha^{-1}) to suppress regrowth of the sorghum-sudangrass in preparation for seeding the cool-season mixtures.

Three forage mixtures were drill seeded on August 8, 2013 (Table 17) on three paddocks, each with an approximate area of 0.6 ha. The three mixtures seeded included a brassica mix, Fridge winter triticale plus the brassica mix, and Willow Creek winter wheat plus the brassica mix. The brassica mix was comprised of Barkant turnip, Barnapoli rape, Groundhog radish, and Pasja hybrid. Due to its larger seed-size, the proportion of Groundhog radish was increased (34% of the bulk rate) to approximate the density (seeds kg^{-1}) of the other 3 species in the mixture which were seeded at a smaller proportion (22% of the bulk rate). The forage brassicas outcompeted the cool-season grasses, with very low proportions of both evident in the final growth. Consequently, the three units were treated as a single brassica mixture. The field was split into six grazing units, each with different areas (2000-3400 m^2). All forage mixtures were seeded with a pull-type no-till drill (Model 812, Truax Company, Inc., New Hope, MN) set at a 20-cm row spacing. Flood irrigation was applied to the field at a rate of 38 mm every 10 days through September.

Table 17. Forage mixtures and seeding rates used for the grazing trial in the fall of 2013.

Forage mixture	Seeding rate (kg ha^{-1})
Forage brassica mixture (BM)	12
Triticale (TT) and forage brassica mixture	13 (TT) + 12 (BM)
Winter wheat (WW) and forage brassica mixture	15 (WW) + 12 (BM)

6.2.2. Dry matter yield and nutritional quality

Dry matter yield (DMY) was assessed 60 days after seeding using a 0.56 m^2 (0.75 m x 0.75 m) sampling frame by taking five random samples from each grazing unit. Forage samples (stems and leaves) were taken to ground level from the six grazing units while bulbs were only taken from unit's four through six. Bulbs were washed and sliced before drying. DMY was also assessed after cattle finished grazing each unit. Both forage and bulb post-grazing samples were washed to avoid contamination from soil particles. Plant material was collected in paper bags, placed in a forced-air oven and dried at 60°C for 72 hours, and weighed. Yields were then converted to kg ha^{-1}. The pre-grazing DMY values were used to allocate biomass based on cattle requirements (3% of body weight [BW]) (NRC, 2000). The post-grazing DMY values allowed estimation of the percent grazing utilization for forage and bulbs as well as the dry matter intake (DMI) per animal. Three grass-hay round bales (450 kg) were fed *ad-libitum* to cattle during the experimental period. One sample was taken from each for later nutritional analysis. Dry matter intake was also estimated for the bales according to the number of days it took for the calves to consume each bale.

The dried samples were ground for nutritional analysis through a shear mill (Wiley® Model 4, Arthur H. Thomas Co., Philadelphia, PA) equipped with a 2-mm screen and then through a cyclone mill (Foss® Tecator Cyclotec Model 1093, Udy Corp., Fort Collins, CO), also equipped with a 2-mm screen, to homogenize the material. The samples were analyzed using an elemental combustion analyzer (LECO TruSpec® Model CN268, St Joseph, MI) to obtain the nitrogen content which was multiplied by 6.25 to estimate crude protein (CP) content (AOAC, 1990). Neutral detergent fiber (aNDF) was determined according to Van Soest et al. (1991) using an Ankom® 200 fiber analyzer (Method 6, ANKOM Technology Corp., Macedon, NY). *In-vitro* true digestibility (IVTD) was determined using an Ankom® Daisy II incubator (Method 3, ANKOM

Technology Corp., Macedon, NY). The samples were incubated for 48 h in a buffer solution mixed with rumen fluid (1600 ml and 400 ml, respectively) (Van Soest and Robertson, 1985). Rumen fluid was collected from two fistulated steers that were being fed a mixed grass hay and corn diet (60:40 forage/corn). After incubation, samples were analyzed following the aNDF procedure described above. Both analyses were used to estimate aNDF digestibility (NDFD) (Hoffman et al., 2001)

6.2.3. Cattle grazing management

Thirty-two Angus, Hereford and crossbred Angus-Hereford calves (17 heifers and 15 steers) weighing 150-276 kg (avg. = 236 kg) were used to graze the experimental field (1.8 ha) from October 10 through November 21, 2013. Total DMI was obtained by combining the estimated intake of forage brassicas, bulbs, and grass hay. The utilization level was multiplied by DMY of forage and bulbs in each grazing unit, this was divided by the days of occupation to estimate intake of the group per day, and then divided by the number of animals grazing to obtain individual intake. The CP and aNDF contents of pre-grazing samples were multiplied by the DMI to estimate nutrient intakes for each grazing unit and compared to the requirements of beef cattle (NRC, 2000).

The grazing units were strip grazed using portable electric fence with a new section opened every day. Initial paddock sizes were based on estimates of available forage and cattle intake with adjustments in size made as needed based on visual observations of forage remaining at the end of each day and associated cattle behavior. No back fence was used within each grazing unit and the only supplement provided was plain salt. Another group of cattle with similar breed characteristics (39 heifers and 28 young bulls), weighing 195-368 kg (avg. = 291 kg), was fed a feedlot ration (DM=58.0-61.2%, CP=13.5-15.5%, aNDF=28.9-39.6%, and, TDN=70.9-75.2%). Both groups of cattle were weighed at the beginning and end of the experimental period and average daily gains were estimated.

6.3. Results and Discussion

6.3.1. Dry Matter Yield and Forage Utilization

The brassica mixture had DM yields that ranged from 4480 to 5530 kg ha^{-1} (Table 18). Reid et al. (1994) found that two turnip cultivars (Forage Star and Green Globe) and a Chinese cabbage hybrid (*Brassica rapa* L. x *Brassica pekinensis* [Lour.] Rupr.) grown in monocultures had yields similar (3.72-6.55 and 4.28-5.26 t of DM ha^{-1}, respectively) to our results. Another study evaluated nine cultivars of forage brassicas and yields ranged from 5500 to 9500 and 1600 to 3690 kg ha^{-1} for earlier (mid-July) and later (mid-August) planting dates, respectively (Villalobos and Brummer, 2015). High yields of annual forages allow extension of the grazing season, as they affect the number of grazing days and/or the number of animals that can be grazed (McCartney and Baron, 2013).

Introducing animals to brassica pastures gradually over a period of several days while supplementing dry forage is the general recommendation when grazing brassica only stands or their mixtures (Smith and Collins, 2003). Grazing unit one was used as the acclimation area for the calves, and on this unit, they were getting most of their DM from the grass hay while adjusting to the taste of the brassicas and increasing their consumption. A bale feeder ring was brought into the following grazing units (2-6) to discourage the calves from bedding and dunging on the hay as was the case in the acclimation unit. The area allocated to the calves on a daily basis was adjusted during the trial based on the DM yield within each unit, and visual observations were made in which the calves were increasingly grazing more of the brassicas. The calves finished grazing their allocation of forage brassicas in shorter periods over time. These assessments were later confirmed with the level of utilization estimated in the grazing units. Especially for grazing units four through six, the biomass and allocated areas were higher while the level of utilization remained similar (Table 18).

Table 18. DM yield from forage brassicas pre- and post-grazing, and level of utilization.

Grazing unit	Grazing period (d)	Allocated area (m^2 d^{-1} $animal^{-1}$)	Pre-grazing biomass (kg ha^{-1})	Post-grazing biomass (kg ha^{-1})	Utilization (%)
1*	4	16	--	--	--
2	4	16	4480	800	82.1
3	4	16	4680	1320	71.8
4	6	17	5250	820	84.4
5	6	18	5530	880	84.1
6	4	21	5170	1770	65.8
Mean**	4.7	17.6	5020	1120	77.6
SD***	1.0	1.9	385	375	7.5

*Acclimation unit
**Mean weighted by the number of days grazing across units 2-6.
***Standard deviation.

Grazing units were sized in order to achieve between four and six days of grazing in each. Units four and five were grazed for six days due to their higher available biomass that allowed for more grazing days. Grazing unit six had a lower level of utilization as a result of allocating more area per animal. Strip grazing is particularly applicable for use with forage crops where no regrowth is expected following grazing, having utilization values as high as 80 to 90% (Allen and Collins, 2003). Strip grazing reduces waste due to trampling and soiling while utilization of the available forage is increased compared to unlimited access to large areas for long periods (Smith and Collins, 2003). This is consistent with our results for the forage brassica mixture where utilization levels were high (65.8-84.4%), averaging just over 77%. When grazing annual forage crops, the DM requirements of beef cattle must be met while enough plant residue must be left in order to avoid excessive exposure and disturbance of the soil (Lawley, 2013).

The yield from bulbs was lower than aboveground biomass in the last three grazing units (Table 19). Few studies have measured biomass yield of brassica bulbs. The yield and quality of Barkant turnip and Groundhog radish bulbs were measured as part of the study of Villalobos and Brummer (2015) (unpublished data). These authors found yields for two harvest dates (mid-October and mid-November) of 6535 and 9270 kg ha^{-1} and 2565 and 4290 kg ha^{-1} for the turnip and radish, respectively. Turnips and Chinese cabbage had bulb yields between 3.47-4.22 and 1.30-5.57 t ha^{-1}, respectively, when grown in monoculture (Reid et al., 1994). In our study, biomass from bulbs was lower (550-880 kg ha^{-1}) than these studies due to the fact that Barkant turnip and Groundhog radish were the only two cultivars in the mixture that grew a harvestable bulb. The high competition among the four cultivars compared to brassicas grown in monoculture likely impacted bulb size, thereby reducing total bulb biomass. The utilization of brassica bulbs varied widely (42-93%) which can be related to their variation in yield among the grazing units as well as the calves needing time to adjust to the taste of the brassica bulbs. Biomass of brassica bulbs is typically not considered within the total biomass allocated to grazing cattle, but extra DM can be obtained from bulbs which can in turn benefit the overall performance of beef cattle and add to the number of potential grazing days.

Through visual observations, it was noted that the calves first grazed the leaves of the brassicas while pulling some of the bulbs out of the ground, but dropping them aside. Later in the day, the calves were observed picking up these extracted bulbs from the ground and chewing them before swallowing. Certain individuals within the group seemed to relish the bulbs, seeking them out and having a higher preference for the turnip over the radish, which might have also influenced the levels of utilization found as the field had areas with different densities of each bulb as a result of competition. Also, Villalobos and Brummer (unpublished data) found that weather conditions by mid-November made bulb sampling more complicated as the soil freezes and the bulbs could not be easily pulled from the ground, as was also the case with earlier harvesting in mid-October. Based on this finding, the levels of utilization of brassica bulbs can vary depending on the time of year and brassica cultivar, while weather conditions affect the ability of calves to pull bulbs from the ground.

Table 19. DM yield of brassica bulbs pre- and post-grazing, and level of utilization.

Grazing unit	Grazing period (d)	Pre-grazing biomass (kg ha^{-1})	Post-grazing biomass (kg ha^{-1})	Utilization (%)
4	6	880	510	42.0
5	6	860	60	93.0
6	4	550	200	63.6
Mean*	5.3	760	260	66.2
SD**	1.2	185	230	25.6

*Mean weighted by the number of days grazing across units 4-6.
**Standard deviation.

6.3.2. Nutritional Quality

The protein content of the forage brassica mixture was lower than expected and similar to the grass hay bales (Table 20). Previous studies where forage brassicas were grown in monocultures have reported higher CP values that ranged from 130-214 g kg^{-1} (Reid et al., 1994) and 186-255 g kg^{-1} (Villalobos and Brummer, 2015). In our study, the CP values were lower than other studies, probably because of high N removal by the sorghum-sudangrass and the fact that no further fertilizer was applied. Brassicas are known to be highly dependent on available soil N (Smith and Collins, 2003). Crude protein was higher in the forage pre-grazing, but bulbs had lower CP content pre- than post-grazing. One would expect a higher CP content in the samples taken prior to grazing because leaf material concentrates nutrients, and it was mostly removed during grazing, leaving primarily stems.

Table 20. Nutritional quality of the forage brassicas and bulbs pre- and post-grazing.

Variable		Pre		Post	
(g kg^{-1})	Grass hay	Forage*	Bulbs	Forage	Bulbs
CP**	117.3	118.8 (6.3)	78.3 (2.5)	86.0 (9.3)	89.5 (9.3)
aNDF	580.8	190.7 (3.6)	119.2 (5.1)	262.3 (26.4)	118.7 (5.7)
IVTD	670.6	943.5 (2.2)	983.4 (3.1)	867.2 (21.4)	970.3 (3.4)
NDFD	434.6	703.7 (12.4)	860.6 (26.4)	488.8 (49.0)	756.4 (10.4)

*Pre-grazing forage n=12 and bulbs n=6. Post-grazing forage n=11 and bulbs n=6.
**Standard deviation in parenthesis.

Villalobos and Brummer (unpublished data) harvested Groundhog radish and Barkant turnip bulbs in mid-November and found CP values numerically higher (174 and 129 g kg^{-1}, respectively) than those found in our study. Based on this, the higher CP content in the bulbs post-grazing could be the result of the higher preference shown by calves for turnip over radish.

The aNDF values of forage and bulbs in the brassica mixture were lower than the grass hay (Table 20). The brassica forage had a higher aNDF content post-grazing, while bulbs had values numerically similar both pre- and post-grazing. A high proportion of leaves were probably removed during grazing, resulting in more structural (i.e. stems) material remaining after grazing, which is typically higher in fiber (Smith and Collins, 2003). The aNDF content found by Villalobos and Brummer (unpublished data) for the bulbs of Barkant turnip and Groundhog radish were higher (138 and 204 g kg^{-1}, respectively) than both the pre- and post-grazing samples. These researchers grew the brassicas in monocultures which allowed for larger-sized bulbs with higher aNDF content, while in our study, the brassica bulbs were small-sized due to high competition within the mixture which resulted in a lower aNDF content. The aNDF content of the grass -hay was three to four times that of the forage and bulbs. Overall, forage and bulb components of brassicas are low in fiber compared with other common forages (Smith and Collins, 2003). Supplementing the grass hay during the grazing trial was intended to provide an additional source of fiber as has been recommended in previous studies where cattle grazed brassica monocultures (Ball et al., 2008; McCartney et al., 2009).

Digestibilities of forage and bulbs were higher than 850 g kg^{-1} both pre- and post-grazing (Table 20). Digestibilities of forage brassicas generally range from 750 to 950 g kg^{-1}, stem tissues being less digestible than leaves and bulbs (Smith and Collins, 2003). Villalobos and Brummer (2015) found IVTD values of 855 to 929 g kg^{-1} for forage brassicas grown in monocultures and harvested by mid-November. The post-grazing forage samples had higher aNDF values than pre-grazing, which impacted IVTD, as values numerically lower were found. In our results, forage brassicas maintained relatively high digestibilities throughout the grazing trial.

Villalobos and Brummer (unpublished data) found IVTD values of 951 and 958 g kg^{-1} for Barkant turnip and Groundhog radish grown in monocultures. The bulbs had numerically similar IVTD values pre- and post-grazing (Table 20). As one would expect, the grass -hay was numerically lower in digestibility than the brassica forage and bulbs.

Fiber digestibility was numerically lower in the forage brassicas post-grazing as one would expect because of the numerically higher and lower aNDF and IVTD values, respectively. The bulbs had NDFD values just under 6% lower post- than pre-grazing (Table 20). Our results for NDFD in bulbs was similar to those reported by Villalobos and Brummer (unpublished data) with values of 718 and 820 g kg^{-1} for Barkant turnip and Groundhog radish bulbs, respectively, grown in monocultures. The lower NDFD values found in the bulbs post-grazing can be attributed to preferences of calves as they pulled bulbs from the ground but only consumed the parts with higher digestibilities

6.3.3. Nutrient Intake

Based on visual observation, DM allowance had to be increased during the grazing trial (Tables 18, 21). The calves grazed the brassica mixture more intensively as the trial progressed. The size of the daily allotted areas for grazing had to be increased as the animals increased DMI from unit three to five and then declined in unit six. On average, DMI of forage brassicas was 3.1% of initial body weight (BW) of the grazing group. Similar to DM, CP and aNDF intakes increased from unit three to five and declined in unit six. Further analysis of the implications of nutrient intakes found in our study will be developed in the next section. Our results provide evidence of the importance of allocating an acclimation area for grazing evaluations with forage brassicas, as DM and nutrient intakes increased through the trial.

Table 21. DM, CP and aNDF intake from forage brassicas by steers and heifers.

Grazing unit	DM allowance (kg d^{-1} $animal^{-1}$)	DM intake (kg d^{-1} $animal^{-1}$)	CP intake (g d^{-1} $animal^{-1}$)	aNDF intake (g d^{-1} $animal^{-1}$)
2	7.05	5.78	632	1129
3	7.36	5.27	575	993
4	8.49	7.16	781	1370
5	9.59	8.06	880	1538
6	10.46	6.89	751	1374
Mean*	8.66	7.37	742	1310
SD**	1.45	1.11	121	217

*Mean weighted by the number of days grazing across units 2-6.
**Standard deviation.

The changes in DM and nutrient intakes from brassica bulbs can be attributed to the high amounts of bulbs found in the furrows of the field post-grazing, which limited our ability to discriminate between bulbs grown in the area sampled or moved there by the calves. This also could be the result of the grazing behavior shown by the calves, since they had a higher preference for the turnips over the radish (Table 22). When forage and bulbs were combined to estimate total DMI from forage brassicas, they represented about 3.5% of initial BW for the grazing group. CP and aNDF intake from brassica bulbs were lower and represented only 7.5% and 7.3% of the total estimated from forage, respectively. However, bulbs can still help to meet the overall nutrient requirements of grazing beef cattle.

Table 22. DM, CP and aNDF intake from brassica bulbs by steers and heifers.

Grazing unit	DM allowance ($kg\ d^{-1}\ animal^{-1}$)	DM intake ($kg\ d^{-1}\ animal^{-1}$)	CP intake ($g\ d^{-1}\ animal^{-1}$)	aNDF intake ($g\ d^{-1}\ animal^{-1}$)
4	1.43	0.60	41	71
5	1.48	1.39	96	165
6	1.11	0.69	48	82
Mean*	1.37	0.92	63	109
SD**	0.20	0.43	30	51

*Mean weighed by the number of days grazing across units 4-6.
**Standard deviation

6.3.4. Cattle Weight Gains

There was an initial difference in BW between the grazing and feedlot groups, the latter being 55 kg heavier (Table 23). After the 28-day evaluation period, both groups of cattle were weighed, and the feedlot group achieved an average daily gain (ADG) above one kg per day, which was the target based on previous experience with calves on this feedlot ration. The grazing group had essentially the same weight at the end of the evaluation period, so their total gain can be considered null as it was close to the scale accuracy plus the fasting period when they were weighed off of pasture was different than when weighed on.

Table 23. Initial and final weights and average daily gains (ADG) of two groups of steers and heifers grazing forage brassicas or under a feedlot ration.

Variable*	Grazing	Feedlot	Difference
Initial weight (kg)	236	291	-55
Final weight (kg)	231[b]	324[a]	-93
Total gain (kg)	-4.45[b]	33.38[a]	-37.83
ADG (kg d^{-1})	-0.16[b]	1.19[a]	-1.35

*LS means for the two groups followed by different letters are significantly different at the $P \leq 0.05$ level using the PDIFF mean separation test.

A comparison was made for our estimates for the grazing group versus the requirements estimated from NRC (2000) Beef Cattle Requirement tables for an animal with similar BW and targeted ADG (Table 24). The CP and DM intakes of the calves were similar to the estimated requirements. The CP content and intake were numerically higher for the grazing group. Except for the micronutrients, Cu, Mn, and Zn, forage brassicas can meet the nutrient requirements of grazing livestock. These micronutrient deficiencies and imbalances can be easily amended through supplementation (Smith and Collins, 2003). Based on previous data, we took on the task to make one further comparison to find possible reasons for the null weight gain in the grazing group.

Table 24. Average DM and CP intakes of steers and heifers grazing forage brassicas compared to requirements from NRC (2000).

Variable	Grazing	NRC	Difference
Body weight (kg)	238.0	250.0	-12.0
Target ADG (kg d^{-1})	0.9	0.8	0.1
Total DMI (kg d^{-1})*	7.4	7.3	0.1
CP of the ration (g kg^{-1})	118.8	98.0	20.8
Total CP intake (g d^{-1})	742.0	715.0	27.0

*Based on the forage component of brassicas.

Both nutrient concentrations and total nutrient intakes allowed for a better understanding of differences between the two rations (Table 25). The nutrient concentration of the ration was estimated for both groups. For the feedlot ration, nutritional analyses of the total mixed ration (TMR) fed during the trial were provided and then used to estimate an average ration. The grazing group ration included DM and nutrient intakes from the forage and bulb components of the brassicas as well as the grass hay.

DM in the feedlot ration was more than double that of the grazing group. One would expect a lower DM concentration in the ration of the grazing group as brassicas are a highly succulent material (Smith and Collins, 2003). Once the nutrients were expressed on a DM basis, comparisons between the two rations provided more insight into possible reasons for the poor performance of the grazing group. The CP concentration of the feedlot ration was 45% higher than the grazing group, this could be attributed as one of the possible explanations for the differences in weight gains as the brassica ration could not meet the CP requirements.

Table 25. Nutrient density of the forage brassica and feedlot rations.

Variable	Grazing*	Feedlot	Difference
DM (g kg^{-1} ration)	225.4	596.0	-370.6
CP (g kg^{-1} DM ration)	99.4	145.0	-45.6
aNDF (g kg^{-1} DM ration)	203.9	342.5	-138.6

*Weighted for forage, bulbs and grass hay intake.

The aNDF concentration in the feedlot ration was 68% higher than the grazing group. Previous studies evaluated diets with similar NDF levels (37.9-47.1%) containing different sources of roughage (grass hay, crushed alfalfa [*Medicago sativa*] cubes, and pelleted corn cobs) for beef cattle (Marshall et al., 1992). These authors found similar DM and nutrient intakes across treatments, with changes in ruminal parameters due to a reduction in fiber intake for sources with lower palatability. Based on this study, the grazing group probably received a ration with a lower aNDF concentration than they require to maintain normal rumen function. Ball et al. (2008) recommended that brassicas should not comprise more than two-thirds of cattle diets to avoid rumen upset. When animals graze pure stands of brassicas or brassica mixtures, the grass hay supplemented should provide about 25% of total intake, especially after the acclimation period when brassica intake increases (Reid et al., 1994). In our study, forage brassicas comprised, on average, more than 90% of DMI, and only 10% came from the hay. Although grass hay was supplemented to the grazing group, low intake was evidenced as the two last bales lasted longer as a result of increasing DMI of forage brassicas over time.

Mixed results have also been found where cows grazing pure stands of turnips have decreased in body weight compared to consistent weight gains reported when grazing brassicas mixed with small grains and legumes (Sedivec et al., 2011). Another study reported winter gains of animals grazing mixed pastures of forage rape and annual ryegrass inferior to those on pastures of winter rye, annual ryegrass, and crimson clover (Smith and Collins, 2003). Overall, the levels of performance achieved when grazing forage brassicas fall far short of those considered normal for forage species of comparable nutrient concentration (Reid et al., 1994).

Brassicas may also contain sulfur compounds such as glucosinolates and S-methyl cysteine sulfoxide which can lead to poor animal performance in some, but not all feeding situations (Smith and Collins, 2003). Low and variable growth rates have been observed for cattle grazing brassicas grown in monocultures, and those results have been attributed to metabolic inhibitors in the plants or to a lack of fiber in the ration (Reid et al., 1994). In our study, the low aNDF concentration in the grazing group ration likely impacted rumen function, which resulted in the poor weight gains observed in the calves.

6.4. Conclusions

The forage brassica mixture evaluated had high biomass yields (>4000 kg ha^{-1}) and could be stockpiled for grazing later in the fall. The level of utilization of the mixture was higher than 70% of the DM available. After five to seven days of acclimation, DMI (forage plus bulbs) increased to levels equivalent to 3.5% of BW of the calves. Except for CP, the brassica mixture had high nutritive value as has been found in previous studies, aNDF being low (<200 g kg^{-1}) and IVTD higher (>900 g kg^{-1}) than common warm- and cool-season grasses used for grazing during the late-fall and early-winter months.

The null weight gains found in the grazing group can be attributed to the lower concentrations of CP and aNDF in the forage compared to the feedlot ration. Fiber is a primary key factor that affects normal rumen function. Thus, mixing forage brassicas with warm- or cool-season grasses rather than growing them in pure stands is a means of limiting consumption of brassicas while increasing DM and fiber supplied to beef cattle. The latter can impact costs in beef cattle operations by reducing the feeding of preserved feeds (e.g., grass hay).

Forage brassicas are known for containing antiquality compounds (e.g. nitrates and glucosinolates) and low micronutrient levels (Smith and Collins, 2003) which could have also impacted the physiological response of the animals. The low fiber concentration in the brassica forage could have impacted our results inducing subclinical acidosis in the calves, but no signs were evident from visual observations during the trial. However, any rumen malfunction could make the cattle more susceptible to the potential effects of antiquality compounds that otherwise would be of minor importance when forage brassicas represent a smaller proportion of the DM offered to young beef cattle.

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CHAPTER 7. MANAGEMENT IMPLICATIONS

This dissertation provides findings of how annual forages can play a significant role in extending the grazing season into the fall and early winter months in northern Colorado and similar environments. A wide variety of annual forages can be planted for fall grazing. Warm- and cool-season grasses are among the most commonly used, while legumes and forbs have been primarily evaluated for their specific functions from which either the soil or another main crop benefit. Forage brassicas have been selected and evaluated under different temperate environments with mixed results in terms of adaptation and overall performance. They have been mostly promoted as cover crops. However, multiple benefits can be achieved when planting forage brassicas. They are especially known for their forage potential (i.e. production and quality) which was the focus of the studies conducted for this dissertation.

In northern Colorado, results indicate that forage brassicas should be planted by mid- to late July in order to yield high amounts of biomass and fill the void in dry matter that typically occurs by late fall when temperatures drop. Quality of the forage brassicas evaluated was high and varied little among species/cultivars or over time, which makes them suitable for stockpiling for fall grazing. Four brassica cultivars were selected from those evaluated based on their potential to provide different qualities when planted in a four-way mixture: Barnapoli rape had the highest yields and stood up under a snow load; Groundhog radish and Barkant turnip had fast growth, and their bulbs provided extra feed and penetrated the soil, potentially reducing compaction; and Pasja hybrid had a high leaf-to-stem ratio which provided high quality forage for beef cattle. This brassica mixture grew well with high yields and quality comparable to other supreme quality forages. Brassica mixtures comprised of two to three species need to be evaluated in further research to assess differences in yield and nutritive value as a result of their competition in a stand.

Subsequent evaluations consisted of this four-way brassica mix seeded by itself or in mixtures with other warm- or cool-season forages. When mixed with cool-season grasses (spring and winter triticale, winter wheat, and forage barley), the forage brassica mix dominated the composition, providing high biomass yields and high nutritive value forage. For producers that plant warm-season grasses for summer hay, forage brassicas are ideal for planting following hay harvest. Tilling or spraying the warm-season plants following the hay harvest are methods used to control their regrowth. Spraying the previous forage crop facilitates successful establishment and productivity of brassicas and cool-season grasses, while their growth was impaired when the warm-season grass was allowed to regrow following harvest. Even though forage brassicas comprised small proportions of the composition when grown following a warm-season hay -crop, the overall biomass of the mixtures was high and their nutritive value can meet the requirements of most categories of beef cattle. Also, the brassicas are known for their stockpiling potential, which can justify their use in mixtures with warm-season grasses to increase the quality of the forage offered to beef cattle during the fall and winter.

Forage brassicas are highly competitive within mixtures, which affects the establishment of other species such as cool-season grasses. The seeding rates of cool-season grasses within the bulk seeding rate of mixtures were lower than when grown in monocultures, which resulted in low contributions to available dry matter. Increasing their rates to represent up to three quarters of those used in monocultures resulted in higher proportions of the grass in the composition. Oat was found to be highly competitive with brassicas without suppressing their growth which resulted in high yields of fairly high nutritive value forage. Based on this, the dominant species within forage mixtures was the result of both the species seeded and the agronomic management prior to seeding, which translates into the main factor influencing the resulting yield and nutritive value. More research is required to evaluate how the yield and nutritive value of forage mixtures change when the seeding rates of cool-season grasses are increased while the rates of the brassica mixture is reduced. Further research should be conducted to evaluate forage mixtures comprised of annual warm-season grasses and brassicas as they can also extend the grazing season.

Brassicas grown in monocultures or mixtures can be planted following harvest of cash crops such as winter wheat. Many producers that grow corn utilize the cornstalks left after grain harvest as a feed source for beef cattle during fall and early winter-months. Interseeding cool-season forages and mixtures when the corn was at the V6 growth stage increased the overall biomass and quality of the forage offered to beef cattle. The nutritive value was high and similar among interseeded forages, while their biomass was the overriding factor impacting their economic feasibility. Annual ryegrass and the brassica mixture had the highest yields and their costs per kilogram of dry matter compared favorably with preserved forages that are usually supplemented to beef cattle grazing cornstalks. Evaluation of different seeding rates of annual ryegrass and the brassica mixture interseeded into corn would allow for a better understanding of their potential biomass yields in combination with monitoring their potential effects on grain corn yields. A forage mixture of annual ryegrass and the brassica mixture is worth evaluating as both were successfully established, while a large scale grazing evaluation with cattle would provide insight into the management implications associated with interseeding cool-season forages into corn.

Whether producers establish cool-season forages following winter wheat harvest or summer hay -crops, or interseed them into corn for fall grazing, strip grazing is recommended to achieve high levels of utilization (>70%), which translates into more grazing days and a longer grazing season. Specifically for forage brassicas grown with warm- or cool-season grasses, strip grazing can ensure that cattle will have a more even consumption of the forage as a means of increasing dry matter and fiber intake thereby avoiding rumen upset. Based on the results from Chapters 4 and 6, additional research should be conducted to evaluate animal performance when grazing forage mixtures during the fall comprised of oats plus brassicas.

The findings that arose from the forage systems evaluated in this dissertation are worth being employed by crop and livestock producers. These findings will, hopefully, allow better integration of the two production systems while increasing the dry matter and nutrient supply to grazing beef cattle during the fall and early-winter months. By doing so, the grazing season can be extended, which was the ultimate goal of these evaluations, and the need for preserved forages and supplements can be reduced thereby improving the bottom line and long-term sustainability of beef production.