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FORAGES AND FEEDS: *Original Research*

Assessment of forage brassica species for dairy and beef-cattle fall grazing systems*

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ABSTRACT

Objectives: In temperate environments of the United States, winter forage management has traditionally necessitated either (a) feeding conserved forages or (b) stockpiling grazeable perennial forage. Forage brassicas might offer a low-cost alternative to these strategies. This project evaluated different annual forage brassicas in a temperate forage fall production system.

Materials and Methods: Three brassicas, Barsica forage rape (*Brassica napus* L.), Inspiration canola (*B. napus* L.), and Appin turnip (*B. rapa* L.) were compared against KB Supreme annual ryegrass [(*Lolium multiflorum* Lam.) ARG] for DM yield and nutritive value over 2 fall seasons. Plot sizes were 5.5 × 9.1 m and seeded in August of 2015 and 2016 in a randomized complete block design with 4 replications. Harvests occurred at 2-wk intervals in 2015 and 2016.

Results and Discussion: Brassica DM yields (734 to 861 kg of DM/ha) were greater ($P < 0.001$) than ARG (344 kg of DM/ha), and NE_l (1.73 to 1.79 Mcal/kg), NE_g (1.04 to 1.11 Mcal/kg), and NE_m (1.65 to 1.72 Mcal/kg) concentrations in Inspiration canola and Barsica forage rape were greater than ARG ($P < 0.001$). Additionally, total nutrient yields (kg of DM/ha) of CP (176 to 204 kg of DM/ha) and NE_l (1,200 to 1,500 Mcal/ha) were greater ($P < 0.001$) for brassicas than ARG (CP = 88 kg of DM/ha; NE_l = 555 Mcal/ha).

Implications and Applications: Brassicas had greater DM and nutrient yields, allowing for twice as many potential grazing days as ARG, thereby conceivably extending the grazing season with high-quality forage and reducing feeding costs.

Key words: canola, forage quality, forage rape, forage yield, turnip

INTRODUCTION

Perennial cool-season forages, such as orchardgrass (*Dactylis glomerata* L.) and tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort], often fail to meet year-round forage DM production needs of grazing livestock (Paterson et al., 1994; Sleugh et al., 2000). Traditionally, producers have been reliant on cool-season annual forages, such as annual ryegrass [(*Lolium multiflorum* Lam.) **ARG**], to fill this gap (Rotz et al., 2003). However, ARG rapidly declines in nutritive value as it grows. Forage brassicas are cool-season annuals that may provide lower-cost and higher-quality forage to grazing ruminants during late fall and early winter (Begna et al., 2017; Villalobos and Brummer, 2017). For example, McCormick et al. (2006) determined that forage rape [(*Brassica napus* L.) **RAP**] had less seed cost per area than ARG due to the combined effects of lower cost of seed and lower seeding rate.

Winter annual forage grasses such as ARG have long been established mainstays of late fall and spring forage production for grazing (Evers et al., 1997). However, ARG productivity in the fall is limited due to adverse environmental conditions and plants that are sensitive to grazing pressure during the first several months of growth (Alison, 1992; Rouquette et al., 1997). Brassicas are characterized by relatively greater leaf-to-stem ratios and nutritive values that are maintained longer into the plant life cycle compared with other forages (Jung et al., 1986; Smith and Collins, 2003). Historically, brassicas have served an agricultural function as oilseeds [e.g., canola (*B. napus* L., **CAN**) and RAP] or as cover and horticultural crops [e.g., turnip (*B. rapa* L., **TUR**); Francisco et al., 2011; Jankowski et al., 2015]. Forage brassicas grow rapidly postgermination and tolerate higher temperatures than ARG (28–30°C), allowing for earlier establishment (Villalobos and Brummer, 2015) and grazing later into the season (August–December in temperate regions of the United States). These characteristics make brassicas ideal for forage production. However, knowledge of brassica management for forage compared with ARG is lacking, which has inhibited producer adoption. Therefore, our objective was to quantify and compare yield potential and forage quality among 3 forage brassica species with those of ARG. We

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hypothesized that fall brassica yield and quality would exceed that of ARG, providing a high-quality forage that can be grazed longer than ARG.

MATERIALS AND METHODS

This study was conducted at the Pennsylvania State University Russell Larson Agricultural Research Farm in Rock Springs, Pennsylvania (40°43′04″N, 77°56′28″W; 370 m above sea level). The soil type was a Hagerstown silt loam (fine, mixed, semi-active, mesic, Typic Hapludalfs). Weather data were monitored throughout the duration of the experiment with an on-site Met 1 Weather Station (Campbell Scientific, Logan, UT). Treatments were as follows: 3 brassicas—(1) Barsica RAP, (2) Inspiration CAN, and (3) Appin TUR—compared with KB Supreme ARG. The field had previously been planted in wheat (*Triticum aestivum* L.). Seedbed preparation was conducted as follows: 4 wk before planting, a burndown of glyphosate (RoundUp Weathermax; Monsanto, St. Louis, MO) was executed at 0.95 L of active ingredient per hectare, followed by deep tillage with a moldboard plow 2 d later and surface tillage sequentially with a disk, harrow, and cultipacker. Plots were planted (brassicas at 5.6 kg/ha, ARG at 22.4 kg/ha) in mid-August 2015 and 2016 using a Wintersteiger Plotseed XL drill (Wintersteiger AG, Ried im Innkreis, Austria) and were arranged in a randomized complete block design with 4 replications. Each year, plots were rerandomized and seeded in an adjacent field so that each planting followed a crop of winter wheat. Plot size was 5.5 × 9.1 m, with a 1.8-m-wide orchardgrass border alley between each replication. Soil testing before planting in 2015 indicated a need for K fertilization at 37 kg of K/ha, which was applied as potash (0-0-63), whereas no P or K fertilization was needed in 2016. Following planting each year, plots were fertilized with 71 kg of N/ha as ammonium sulfate (21-0-0-24S) and were not fertilized again for the remainder of the season.

Plots were harvested 3 times in 2015 and 4 times in 2016 during the fall season (September to November), dependent on growing conditions. The size of these plots allowed subsampling to occur without harvesting the entire plot, so material was 2, 4, 6, or 8 wk old at each harvest date, respectively. At each harvest, 3 samples from each plot were collected using three 0.25-m^2 quadrats for determination of forage biomass production and nutritive value. Initial harvests occurred 5 to 6 wk after planting, followed by subsequent harvests every 2 wk. Harvests were made in the fall of 2015 on October 7 [42 d after planting (**DAP**)], October 21 (56 DAP), and November 3 (70 DAP) and then the fall of 2016 on September 28 (35 DAP), October 12 (49 DAP), October 26 (63 DAP), and November 8 (77 DAP). Forage yield was determined both as average seasonal yield (kg of DM/ha) and average DM yield per day (kg of DM/ha per day).

A composite sample from each plot was then collected. Samples were freeze-dried, ground to pass through a 1-mm mesh screen (Wiley Mill, Philadelphia, PA), and sent to Dairy One Laboratories (Ithaca, NY) for nutritive quality via wet chemistry. Variables measured included DM (method 930.15; AOAC International, 2006), CP (method 930.15; AOAC International, 2006), RDP (Cornell *Streptomyces griseus* enzymatic digestion; Coblentz et al., 1999), soluble protein (**SP**; Cornell sodium borate-sodium phosphate buffer procedure), NDF (Ankom model A200, Ankom Technology, Macedon, NY; Mertens, 2002), ADF (Ankom model 200, method 973.18; AOAC International, 2006), and ash (method 942.05; AOAC International, 2006). Energy concentrations were calculated from nutritive values [TDN (Weiss, 1993); nonfiber carbohydrates; NE_l; NE_m; NE_g (Van Soest and Fox, 1992)]. Mineral concentrations were also quantified [P, K, Ca, Mg, Na, S, Fe, Zn, Cu, Mn, Mo (Thermo IRIS Advantage HX; CEM Application Note for Acid Digestion, CEM Corp., Matthews, NC), and Cl (Cantliffe et al., 1970)].

Total nutrient yield (kg of DM/ha) for variables most important to animal nutrition and DMI were calculated using the following equation:

$$\text{nutrient, kg of DM/ha} =$$
$$(\text{nutrient, g of DM/kg} \times \text{DM yield, kg/ha})/1{,}000.$$

Thus, we converted nutrient concentration (%) to nutrient yield (kg of DM/ha).

Statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC), using PROC GLIMMIX to conduct ANOVA, with LSMEANS and "/pdiff lines" used to conduct mean separation. Data were analyzed as a randomized complete block design. The statistical model for all dependent variables was $Y_{ijk} = \mu + R_i + H_j + S_k + HS_{jk} + \varepsilon_{ijk}$, in which Y = the dependent variable, μ = mean effects, R = replication, H = harvest number, S = species, and ε = experimental error. Harvest and species were considered fixed effects. Year and any interactions involving year were considered as random effects or pooled into experimental error. Significance was set at $\alpha = 0.05$. Any interactions between harvest and species were separated to determine species effects within each harvest.

RESULTS AND DISCUSSION

Forage Yield and DM

There were no significant harvest × species interactions observed for DM yield or concentration ($P > 0.05$). Dry matter yield of all 3 brassica species (CAN, RAP, and TUR) was 113 to 150% greater ($P < 0.001$) than DM yield of ARG, but no differences ($P > 0.05$) were observed among the 3 brassica species (Table 1). Following a similar pattern, DM yield per day of the brassicas was greater ($P < 0.001$) than DM yield per day of ARG, and no differences ($P > 0.05$) were observed among the brassicas. Conversely, DM concentration of ARG was 59 to 90% greater ($P < 0.001$) than the brassica species. Dry matter

Table 1. Yield and nutrient concentrations of 3 forage brassicas [canola (CAN), forage rape (RAP), and turnip (TUR)] and annual ryegrass (ARG) averaged over 2 fall growing seasons (2015 and 2016; DM basis)

		Species						
Nutrient	Unit	ARG	CAN	RAP	TUR	SE	Species effects	Harvest × species effects
DM yield	kg/ha	344.2[b]	733.7[a]	860.8[a]	752.5[a]	241.4	<0.001	>0.05
DM yield per day	kg/ha per day	24.6[b]	52.4[a]	61.5[a]	53.7[a]	5.98	<0.001	>0.05
DM concentration	% DM	21.31[a]	13.32[b]	12.15[b]	11.19[b]	3.78	<0.001	>0.05
NDF	% DM	34.30[a]	17.01[b]	18.44[b]	18.47[b]	4.23	<0.001	>0.05
Lignin	% DM	2.04	2.04	1.53	1.96	0.24	>0.05	>0.05
TDN	% DM	67.49[c]	72.16[a]	70.19[b]	66.53[c]	1.29	<0.001	>0.05
NE_l	Mcal/kg	1.60[c]	1.79[a]	1.73[b]	1.63[c]	0.03	<0.001	>0.05
NE_m	Mcal/kg	1.55[c]	1.72[a]	1.65[b]	1.53[c]	0.04	<0.001	>0.05
NE_g	Mcal/kg	0.97[b]	1.11[a]	1.04[a]	0.93[b]	0.04	<0.001	>0.05
CP	% DM	28.09[a]	25.14[b]	25.39[b]	24.19[b]	2.26	<0.001	>0.05
Ash	% DM	13.34[b]	13.52[b]	15.09[a]	16.25[a]	1.21	<0.001	>0.05
K	%	4.04[a]	3.34[c]	3.71[b]	4.15[a]	0.11	<0.001	>0.05
Ca	% DM	0.73[c]	1.99[b]	2.03[b]	2.26[a]	0.10	<0.001	>0.05
Na	% DM	0.02[b]	0.04[a]	0.05[a]	0.05[a]	0.01	<0.001	>0.05
S	% DM	0.46[b]	0.95[a]	0.93[a]	0.88[a]	0.04	<0.001	>0.05

[a–c]Within rows, different superscripts indicate significant differences.

concentration did not differ ($P > 0.05$) among the brassica species. The relatively low mean yields were a function of the 2-wk harvest intervals.

Throughout this study, the brassica species consistently yielded more than twice the DM compared with ARG. Previous work conducted in Colorado (Villalobos and Brummer, 2015) found similar DM yields of RAP and TUR in stockpiled systems when seeded in mid-August (RAP ranged from 3,100 to 3,500 kg of DM/ha; TUR ranged from 3,300 to 3,600 kg of DM/ha). They also concluded that earlier planting dates (mid-July to mid-August) provided increased exposure to beneficial temperature and light conditions that resulted in increased yields. Mean maximum and minimum temperature data were similar between Colorado and Pennsylvania during these times, but Colorado was much drier (CoAgMet, 2019). Mean monthly rainfall was only 25.4 mm compared with 90 to 160 mm in Pennsylvania throughout the fall, thus irrigation was used in Colorado. Despite this, our planting dates fell within a similar timeframe (early to mid-August), which could account for the significantly greater yields of brassica species. Annual ryegrass yields in this study were also similar to other work that was conducted in Minnesota under similar rainfall, with colder fall temperatures, when planted at similar times (Grev et al., 2017). This supports the notion that ARG, although productive in the spring, has relatively low yields in fall under cooler temperatures, regardless of planting date. Additionally, the daily growth rate of the brassicas was about 2 to 2.5 times that of ARG. Given that all species received equivalent regrowth periods, this indicates that the observed greater yields of the brassicas over the entire season were largely due to the greater growth rates per day of these species.

Unlike DM yield, DM concentration of ARG was almost double that of the brassica species tested. This was likely due to species morphology, with brassica species having far greater leafy tissue that inherently contains more water and soluble sugars and fewer structural carbohydrates than grasses (Jung et al., 1986; Smith and Collins, 2003). Although the brassicas did have greater DM yield, there are some important implications of ARG having a greater DM concentration. For example, less fresh ARG would need to be grazed to meet daily DMI needs of cattle. Normally, this would allow pastures to be grazed for a longer period of time before exhausting available forage, but the lower DM yield of ARG compared with the brassicas would inhibit this. Nutrient needs may also be met earlier in the day due to the greater ARG DM concentration, provided that fiber levels or forage availability would not inhibit DMI first.

Nutritive Values

Fiber Concentrations. Lignin and NDF had no harvest × species interactions ($P > 0.05$), whereas ADF did show a significant interaction ($P < 0.001$). Neutral detergent fiber was greater ($P < 0.001$) for ARG than all 3 brassica species, which were not different ($P > 0.05$) from each other (Table 1). Greater NDF concentration in ARG was expected, as stem material is far more prevalent in this species (Amaral et al., 2012) than in brassicas (Wiedenhoeft and Barton 1994). Generally, grass fiber (NDF and ADF) concentration exceeds other classes of forage species (i.e., broadleaf plants), even when in the vegetative stage. Previous findings in other cool-season annual forage grasses in the vegetative stage of growth reported a similar range of NDF values to the ARG in the current study (30 to 40%; Edmisten et al., 1998). Despite these differences, NDF ranges for all species were still well below critical thresholds for inhibiting DMI (Belyea et al., 1993). Lignin concentration did not differ among any species ($P > 0.05$). This suggests that deposition of indigestible secondary cell wall material occurs at similar rates across the species.

Acid detergent fiber values fluctuated across the growing season ($P < 0.05$; Figure 1a). These interactions suggest that ADF concentration may be more predicated on harvest timing than on forage species alone. At harvests 1 and 3, ADF concentration was greater in ARG compared with the brassica species ($P < 0.01$), whereas at harvest 4, ADF concentration of ARG was greater than CAN ($P < 0.01$). Additionally, there was less range in ADF concentration (3 to 5%) than NDF concentration (16 to 17%) between ARG and the 3 brassicas.

Previous research on the nutritive value of cool-season grasses found that IVDMD and NDF became more negatively correlated as the plants progressed to reproductive maturity (Pritchard et al., 1963; Karn et al., 2006). Conversely, nutritive values of brassicas have been established to have little change in NDF, ADF, and IVDMD as the plants mature (Villalobos and Brummer, 2015). In comparing values reported for brassicas by Villalobos and Brummer (2015) to those reported for grasses (Karn et al., 2006), brassica NDF (19.9 to 22.0%) was substantially less than in grasses (NDF, 57.1 to 62.2%), and brassica IVDMD (87.0 to 91.0%) was greater than grass IVDMD (75.4 to 80.0%). Our results corroborate these previous findings, but it should be emphasized that our NDF values were considerably lower for grasses, lessening the negative effects on DMI.

Energy Concentrations. No harvest × species interactions were observed for any variable assessing forage energy content ($P > 0.05$). Canola had the greatest ($P < 0.001$) TDN, NE_l, and NE_m, whereas ARG and TUR had the least and did not differ from each other ($P > 0.05$). The NE_g of CAN and RAP was greater ($P < 0.001$) than ARG and TUR. Canola consistently ranked as the greatest TDN or energy-containing (NE_l, NE_m, NE_g) species that was tested. In each of these categories, both ARG and TUR always ranked lowest in net energy concentration. These values indicated that CAN was the optimum

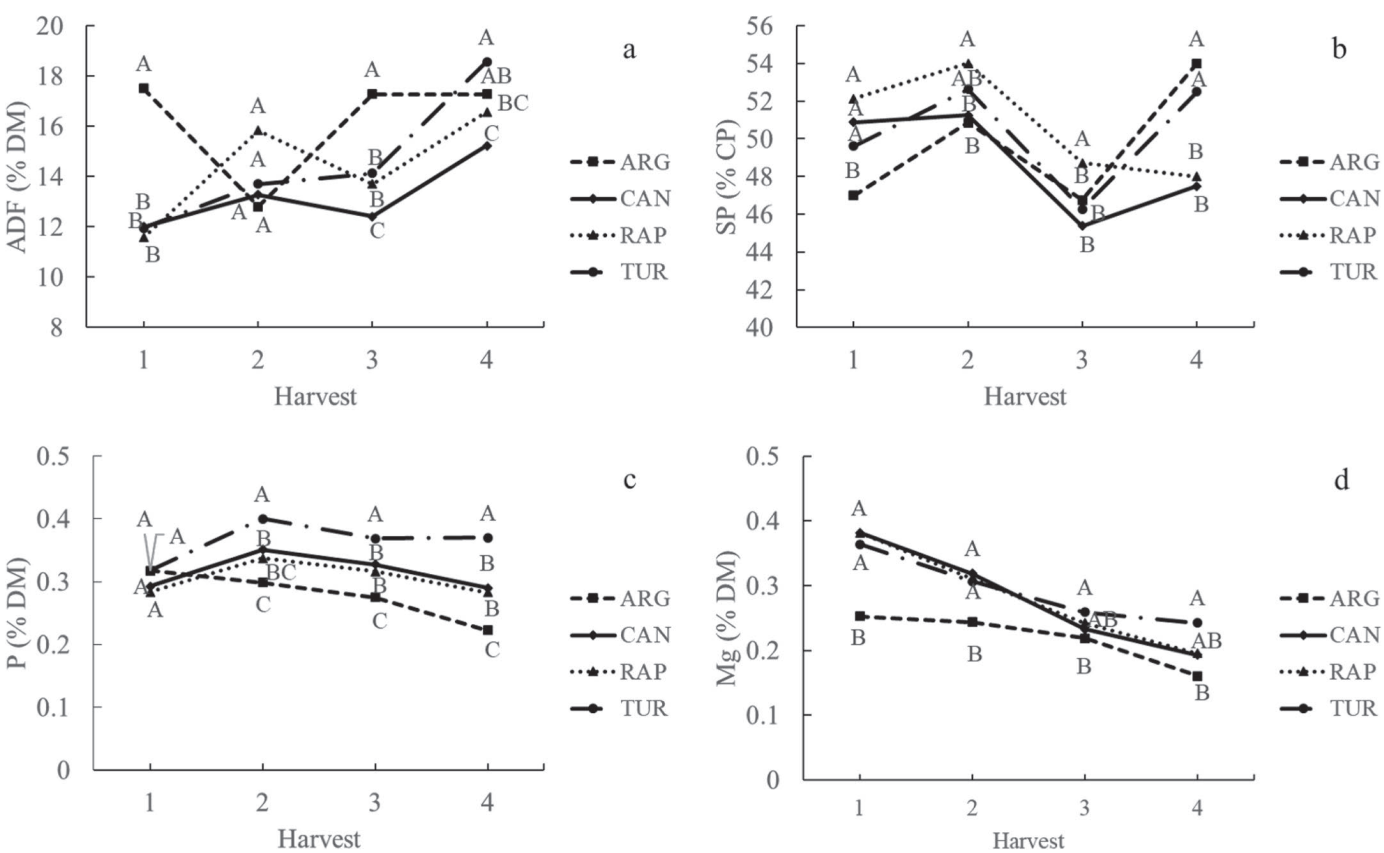

Figure 1. Nutritive value variables with significant harvest × species effects. (a) ADF concentration, (b) soluble protein (SP) concentration, (c) P concentration, and (d) Mg concentration. Species included ARG (annual ryegrass), CAN (canola), RAP (forage rape), and TUR (turnip). Harvests 1 to 4 occurred at 2-wk intervals from September to November 2015 and 2016, with plants having 2 wk, 4 wk, 6 wk, and 8 wk of growth at each harvest, respectively. Harvest 4 only occurred in 2016; thus, only 1 yr of data are represented for that date. Different letters (A–C) at each harvest indicate significant differences between species treatments at $P < 0.01$.

energy species and that the feeding of brassicas may potentially offer benefits to grazing livestock over consumption of a cool-season annual grass species, such as ARG.

Feeding recommendations for brassicas have generally been limited to 50% of DMI, to prevent negative effects of glucosinolates and reduce risk of extremely low-fiber, high-CP diets (Hall and Jung, 1993; Dillard et al., 2018). Therefore, all calculations used in this study set brassica DMI at 50% of total DMI to determine whether CAN and ARG met 50% of NE_l (dairy) at a given BW and level of milk production (NRC, 2001), or NE_g (beef) at a given BW (NASEM, 2016). For dairy cattle NE_l requirements, 2 BW were compared, 454 kg (small frame, representative of a Jersey) and 680 kg (large frame, representative of a Holstein). Both early and mid-lactation periods were included due to variable nutrient requirements at these times. In both cases, when fed at 50% of DMI, CAN was not able to meet 50% of NE_l requirements at any level of milk production during early lactation. This is indicative of the difficulties in using forage-based diets to meet needs of moderate-producing animals (i.e., >30 kg of milk/d in early lactation; Hammond et al., 2016). However, NE_l needs were met for mid-lactation cows producing 40 kg of milk at 4.5% fat content when feeding CAN at 50% DMI. If ARG were fed at 50% DMI, it could only provide enough energy for a small-frame, mid-lactation dairy cow to produce 30 kg of milk at 5% fat. This indicated that brassicas still had an advantage over ARG, even with their limitation of comprising only 50% of DMI. Supplemental energy would almost always be required to meet nutrient needs of dairy cows producing moderate amounts (25–40 kg/d) of milk.

For beef cattle NE_g requirements, a BW of 250 kg was selected to represent a yearling steer (stocker) calf. This would result in 6 kg of DMI, assuming DMI at 2.4% of BW. If 50% of that total (3 kg) would be composed of CAN, the brassica component of the diet would supply approximately 3.33 Mcal/d NE_g, which meets nutrient requirements for an ADG of 0.8 to 1.0 kg/d. Annual ryegrass also provided a similar NE_g at 3.09 Mcal/d. This indicated that differences between ARG and the brassicas were less pronounced in meeting the nutrient needs of growing steers. This is not surprising, as their dietary needs are much less than those of lactating dairy cattle.

Due to the limitation of brassicas being fed at 50% DMI, the remainder of the diets of dairy cows or beef steers would likely need to be composed of fresh herbage or conserved forages that have a complement of slightly higher fiber to balance the low fiber concentrations of the brassicas. The supplemented forage would serve to slow rate of passage, potentially increasing efficiency of digestion of the brassica forage in the rumen. Concentrates, if warranted based on class and production level of the animal, would provide additional energy that could better recapture ammonia-N in the rumen by conversion to microbial protein, and prevent loss of the large amounts of RDP contained in the brassicas (Titgemeyer and Merchen, 1990).

Protein Concentrations. Crude protein of ARG was greater ($P < 0.001$) than all 3 forage brassicas (Table 1). The elevated CP found in ARG may indicate this grass species has an improved N use efficiency (**NUE**) compared with brassica species. Past research found that NUE for ARG ranged from 44.2 to 52.1 kg of DM/kg of N applied (Marino et al., 2004), suggesting that ARG is efficient in N uptake and incorporation into DM. Conversely, Fismes et al. (2000) reported that oilseed rape was a crop with low NUE (<50%). They also concluded that low soil S can further exacerbate NUE, as S concentration was synergistic with N uptake at greater levels and antagonistic at higher or lower levels. Soil sampling of our plots after harvest revealed that S concentrations were at the low end (10.5 to 12 mg/kg) of acceptable range (10 to 25 mg/kg; data not shown). Thus, these factors may have contributed to the lower CP found in our brassica samples.

Despite lower CP concentration found in the brassicas, RDP was not affected by species but was affected by harvest interval ($P < 0.01$; Figure 2). Mean RDP declined steadily from harvest 1 to 4. Daily RDP requirements of both small- and large-breed dairy cows range only from 9 to 11% of CP (NRC, 2001). Based on these requirements, RDP of the forages in this study (72 to 84% of CP) far exceeded RDP needs of dairy cows. Although microbial protein synthesis in the rumen is not likely to be significantly affected by feeding a brassica compared with ARG, there may be other concerns for dairy producers. From a management perspective, producers frequently supplement high RDP forages with adequate amounts of concentrate or cellulosic carbohydrates to reduce excessive N losses as urea in urine and milk (Titgemeyer and Merchen, 1990; Clark et al., 1992). With elevated RDP concentrations of the forages observed in this study, producers would either need to limit DMI of high-protein forages or provide higher-fiber forage to slow rate of passage. Energy supplementation would then be necessary to capture as much RDP as possible from the brassicas, minimizing the amount of N lost as urine or milk urea.

A significant harvest × species interaction was observed for SP ($P < 0.001$, Figure 1b). Until harvest 4, mean SP concentration of RAP was greater than ARG but declined following harvest 2. Conversely, SP of ARG exceeded all but TUR at the end of the trial. Overall, SP comprised about 50% of the CP from the forages tested. These SP feed values from the 3 brassicas and ARG suggest that their protein is of high quality and will rapidly be converted to microbial protein in the rumen. However, the NRC (2001) states that dairy cows are only approximately 67% efficient at using MP, but more recent work (Moraes et al., 2018) suggests that at greater levels of MP, efficiency could be less than 50%. Thus, a greater supply of readily available protein in animal feed may result in excessive losses as urea, similar to concerns with RDP.

Mineral Concentrations. There were no harvest × species interactions for ash, K, Ca, Na, and S ($P > 0.05$). Turnip and RAP had greater ($P < 0.001$) ash concentra-

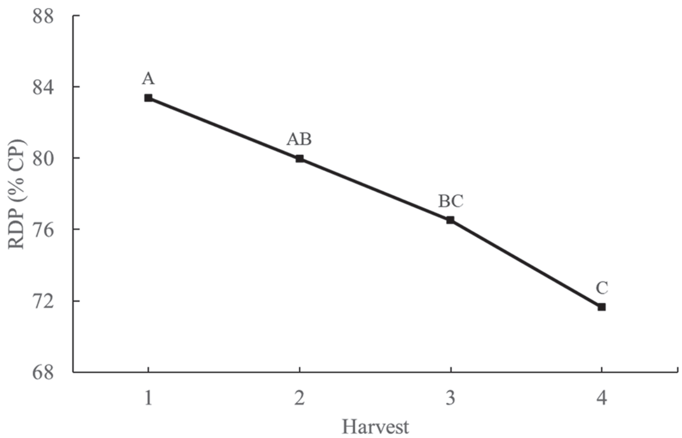

Figure 2. Harvest effects on RDP. Harvests 1 to 4 occurred at 2-wk intervals from September to November 2015 and 2016, with plants having 2 wk, 4 wk, 6 wk, and 8 wk of growth at each harvest, respectively. Harvest 4 only occurred in 2016; thus, only 1 yr of data are represented for that date. Different letters (A–C) at each harvest indicate significant differences between harvest treatments at $P < 0.01$.

tions than CAN and ARG (Table 1). Potassium concentrations were greatest ($P < 0.001$) for TUR and ARG and least for RAP and CAN. Concentrations of Ca were greatest ($P < 0.001$) for TUR and least for ARG. Both Na and S concentrations were greater ($P < 0.001$) in the brassica species than in ARG, with no differences among brassicas ($P > 0.05$).

Significant interactions were found between species and harvest ($P < 0.01$) for P (Figure 1c) and Mg (Figure 1d) concentrations in the forages tested. In both cases, ARG consistently ranked among the lowest in P and Mg concentrations at each harvest. Conversely, TUR consistently ranked greatest in P concentration among the other species at harvests 2 to 4 ($P < 0.01$), and brassica Mg concentrations did not differ from each other at any of the harvests ($P > 0.05$). Additionally, ARG P concentration declined from harvest to harvest, and Mg concentration declined in all 4 species at successive harvests.

These results were indicative of several key mineral relationships in both crop and livestock production. In relation to P, soils could be depleted as a result of growing brassicas, particularly in soils already low in P before planting. This would necessitate increased P fertilization. However, many temperate soils are generally high in P concentration due to historic manure application and overfertilization of P (Sharpley et al., 2000). As a result, this often limits P fertilization in regional production systems due to runoff concerns, particularly in watersheds such as the Chesapeake Bay (Boesch et al., 2001; Mulkey et al., 2017). However, brassicas have shown the potential for use in phytoremediation of high P soils (Delorme et al., 2000). This presents a potentially added benefit of growing brassicas in areas where runoff is a concern. Potassium concentrations were greatest in ARG and TUR, which may pose issues with crop removal and necessitate fertilization. In this study, TUR offered similar K concentrations to ARG, while having many other nutritive value and yield benefits that ARG lacks. Therefore, TUR may prove a sufficient source of K if producers shift to more brassica-based diets. However, high K concentration of forages can negatively affect DCAD and lead to increased incidence of hypocalcemia (milk fever) in periparturient dairy cows (Saborío-Montero et al., 2017). The greater K in TUR may limit its use due to this risk and instead favor balanced ratios of CAN, RAP, and TUR if incorporating brassicas in a ration.

Annual ryegrass also had reduced Mg concentration compared with the brassicas at harvests 1, 2, and 3 (Figure 1d). In cattle, Mg deficiencies can result in hypomagnesemia (grass tetany) and contribute to milk fever (Tremblay et al., 2009). Perennial cool-season forages are known to cause grass tetany when fed in spring, due to an increase in growth rate and nutrient uptake, which reduce Mg DM concentration (Grunes and Welch, 1989). However, annual crops, such as ARG and brassicas, are capable of rapid growth during seedling stages after germination; this rapid growth potentially exacerbates the risk of low Mg concentration in forages. Previous work has established a threshold for Mg concentration to avoid grass tetany (hypomagnesemia) as >0.2% DM for pregnant or lactating cattle (Grunes et al., 1970). Although our results indicate Mg deficiency was only an issue during later months (October and November, during harvests 3 and 4), our data suggest that elevated Mg levels in brassicas may reduce the risk of nutritional disorders to cattle grazing or fed brassica forage. In tandem with elevated Mg, our findings indicate that brassica species had greater amounts of Ca by a factor of almost 3-fold. This is beneficial in animal nutrition for several reasons. Low blood Ca (hypocalcemia) is often associated with low K and Mg concentrations (Grunes et al., 1970; Anast et al., 1972); this symptom is particularly evident in prepartum and peripartum dairy cows and beef cattle (Kronqvist et al., 2011). Additionally, the association with milk fever makes managing Ca intake of the utmost importance in ration formulation and dietary supplementation (NRC, 2001). Risk of milk fever is also exacerbated by DCAD and may be lessened by feeding brassica species that are lower in alkaline ions such as K but higher in acidic ions such as S and Cl (Block, 1984; Iwaniuk and Erdman, 2015). Canola and RAP were 2 species in this study that met these criteria, while also having greater Mg and Ca concentrations. Therefore, CAN and RAP could potentially lower risks of hypocalcemia and reduce the incidence of these issues.

All brassicas also had greater Na and S concentrations than ARG. The greater S concentration is particularly noteworthy, as CAN, RAP, and TUR all had approximately twice the S concentration of ARG. Because glucosinolate structure is heavily composed of S (Tripathi and Mishra, 2007), elevated S in the brassicas provides a strong indication of elevated glucosinolate levels (Zhao et al., 1993). This is problematic for producers feeding these forages to dairy cows, as they have been frequently associated with reduced DMI and milk production, along with I and Cu deficiencies if fed in excess (Gustine and Jung, 1985). Additionally, S toxicity has been observed in livestock consuming brassicas with S concentrations similar to our findings (>0.8%; Hill and Ebbett, 1997), which further supports limiting brassicas to 50% DMI in ruminant livestock.

Nutrient Yield

When total nutrient yields (kg of DM/ha) were calculated, RAP and TUR had greater ($P < 0.05$) NDF yields per hectare than ARG (Table 2). However, CAN and ARG had similar ($P > 0.05$) NDF yields per hectare. Yields per hectare of the following nutrients were all greater ($P < 0.001$) in the brassica species than in ARG: CP was 98 to 130% greater, TDN was 109 to 156% greater, NE_l was 118 to 168% greater, and NE_g was 108 to 170% greater. There were no differences ($P > 0.05$) among brassica species for CP, TDN, NE_l, and NE_g yields per hectare. There were no interactions between species and harvest ($P > 0.05$) for any of these nutrient yield variables.

By factoring together nutrient concentrations and DM yield, all 3 brassica species had greater nutrient yields than ARG. This is important to note, as there was little, or no, differences in CP, TDN, NE_l, and NE_g concentrations between ARG and the brassicas. These greater yields of protein and energy support our hypothesis that forage brassicas contain overall greater nutritional value than ARG. Previous work has also established the superior yield and nutritive value of brassicas, particularly during fall (Rao and Horn, 1986). Neutral detergent fiber yields per hectare of RAP and TUR were 30 to 46% greater than ARG. However, NDF yield for all species in this study fell considerably below thresholds that have been established to reduce DMI (Van Soest, 1965; Belyea et al., 1993; Allen, 1996). Maximum dairy cow and beef cattle NDF DMI is about 5 kg/d, and if fed at 50% DMI, the brassicas provided only 2 kg of NDF to the animal, whereas ARG provided 4 kg of NDF. Thus, DMI for all of these forages would not be affected by the relatively low fiber fractions found in these cool-season annual forages and other fiber sources would be needed for optimal rumen function. Sulfur yields of the brassicas were greater than ARG by 200 to 300%. As previously stated, this was indicative of elevated glucosinolates in the brassicas (Aghajanzadeh et al., 2014), which could hamper DMI and cause other micronutrient deficiencies, including Cu and I (Dillard et al., 2018).

The advantages of greater nutrient yields of the brassica species became more evident when compared with nutritional needs of cattle. This comparison allows for a direct translation of nutrient yield into carrying capacity and number of grazing days, based on supply of nutrients, and enables a practical application of nutritional concentration of forages in this study. All nutrient requirements were sourced from the NRC (2001) for dairy cattle and from the NASEM (2016) for beef cattle. In terms of nutrient DM yields per hectare, CAN, RAP, and TUR had greater NE_l, NE_g, and CP yields than ARG. Thus, the lowest-value brassica, TUR, was compared with ARG to determine carrying capacity based on energy and protein needs for both dairy and beef cattle.

In general, the nutrient yields of the brassicas would allow for about twice the carrying capacity of ARG. Turnip NE_l yield was about 1,200 Mcal/ha, with mid-lactation, small-frame (454 kg) dairy cows requiring about 40 Mcal if NE_l/d. With 50% of DMI being from brassicas, each animal would need about 20 Mcal of NE_l/d. This allows enough energy to support an animal for 60 d. However, ARG NE_l yield was only 555 Mcal/ha and, when fed at 50% DMI, can only provide about 28 d of energy to sustain optimal milk production. When comparing NE_g, beef stocker cattle starting at a BW of 250 kg require 1.9 Mcal/d when fed at 50% DMI to meet an ADG of 1.2 kg/d. With TUR yielding 694 Mcal/ha, this allows enough energy to support 365 d of grazing in a beef stocker. Annual ryegrass only provided enough NE_g to allow 175 d of grazing. These values

Table 2. Total nutrient yield per hectare (DM basis) of 3 forage brassicas [canola (CAN), forage rape (RAP), and turnip (TUR)] and annual ryegrass (ARG) averaged over 2 fall growing seasons (2015 and 2016; DM basis)

		Species						
Nutrient	Unit	ARG	CAN	RAP	TUR	SE	Species effects	Harvest × species effects
NDF	kg of DM/ha	110.9[b]	130.4[ab]	162.8[a]	146.1[a]	17.15	<0.05	>0.05
CP	kg of DM/ha	88.3[b]	181.3[a]	203.5[a]	175.6[a]	21.61	<0.001	>0.05
TDN	kg of DM/ha	236.7[b]	528.4[a]	605.6[a]	496.9[a]	61.08	<0.001	>0.05
NE_l	Mcal/ha	555.3[b]	1,304.4[a]	1,489.4[a]	1,214.6[a]	147.9	<0.001	>0.05
NE_g	Mcal/ha	333.5[c]	804.6[ab]	905.2[a]	693.8[b]	93.3	<0.001	>0.05
S	kg of DM/ha	1.80[b]	6.67[a]	7.70[a]	6.72[a]	0.74	<0.001	>0.05

[a–c]Within rows, different superscripts indicate significant differences.

lend support to the superior nutritional yield of brassicas during the fall grazing season when compared with annual grass species and further indicated that nutrient values in brassicas did not decline over the course of the fall growing season.

Grazing-based operations should also consider risks associated with feeding these species, as CP far exceeded recommended dietary intake. At the previously given BW and productivity levels for dairy cows and beef stockers, CP needs are only about 2.2 and 0.38 kg/d, respectively. However, the brassica species yielded enough CP ($\geq$175.6 kg of DM/ha) for about 80 grazing days at minimum with dairy and 460 d with beef; ARG, although yielding less CP (88.3 kg of DM/ha) than the brassicas, still provided enough CP for 40 grazing days with dairy and 232 d with beef. Although higher-CP forages are generally desired by producers, levels this far in excess of dietary needs present substantial risk of excess dietary protein if stocking rates are not properly managed. This could result in animal nutrition and health issues related to increased rate of passage, loss of N as urea in urine, and elevated MUN levels. Due to potentially variable CP, feeding these high-CP forages would need to be accompanied by both high-fiber, low-protein feed sources such as a low quality grass hay or baleage, or high-energy feeds (i.e., concentrates) to balance C to N ratios in the rumen and allow more efficient conversion to microbial protein that the animal can use for production.

APPLICATIONS

Forage brassicas have the capacity to occupy a unique niche within forage-animal production systems in temperate environments. Our findings indicated that brassica species (CAN, RAP, and TUR) had twice the DM yield potential, along with greater digestible and net energy than was observed in ARG during the fall growing season in a temperate region of the United States. Nutrient yields indicated that forage brassicas provided 2 to 3 times the CP, TDN, NE_l, and NE_g observed in ARG (on a per hectare basis) when harvested at identical intervals. This may allow for almost twice the available fall grazing days compared with ARG. Lastly, our findings suggest that brassicas maintain quality later into the fall season than ARG. By incorporating brassicas into grazing systems, livestock producers may benefit from these high-yielding, high-quality crops during periods when other forage species would suffer reduced yield or nutritive value.

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