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Authors: Van Die, Myra, and Entz, Martin H.

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ARTICLE

Mid-summer annual forage performance in organic, grass-fed production

Myra Van Die and Martin H. Entz

Abstract: Grass-fed ruminant production does not have the convenience of feeding easily-storable grains during periods of low forage availability. This study examined the forage yield, quality, and utilization of warm- and cool-season annual forages grown under organic management during the mid-summer "feed gap" period. Annual ryegrass (*Lolium multiflorum* Lam. cv. Tetra Brand), winter triticale (× *Triticosecale* Wittmack cv. common), oat (*Avena sativa* L. cv. Souris), millet (*Panicum miliaceum* L. cv. Crown Proso), corn (*Zea mays* L. cv. BMR84 and CM440 Canamaize), and sorghum-sudangrass (*Sorghum bicolor* [L.] Moench × *Sorghum sudanense* [Piper] Stapf cv. common) were grown in Carman, Manitoba, over 3 site-years in 2018 and 2019. Combined forage and weed dry matter (DM) yield was 7159 kg·ha^{-1} for sorghum-sudangrass (29% weeds), 5506 kg·ha^{-1} for corn (36% weeds), 4687 kg·ha^{-1} for oat (45% weeds), 4617 kg·ha^{-1} for annual ryegrass (95% weeds), 4542 kg·ha^{-1} for millet (28% weeds), and 2945 kg·ha^{-1} for winter triticale (51% weeds); significant differences in crop and weed biomass were observed. All forage systems were palatable to sheep with utilization rates from 47% to 65%. When all quality parameters were considered, corn, winter triticale, millet, and oat displayed adequate quality for mid-summer grazing, while sorghum-sudangrass had suboptimal crude protein concentrations. Direct measurements of forage quality on weeds showed that weeds did not compromise forage quality. This Canadian first study demonstrated the potential of forage production for mid-summer grazing in an organic, grass-fed regime with oat, millet, and corn resulting in the best combination of yield and quality.

Key words: annual forages, organic, grass-fed, forage-based.

Résumé : Nourrir les ruminants à l'herbe n'est pas aussi commode que les engraisser avec des céréales qu'on peut entreposer aisément et utiliser quand les fourrages manquent. Les auteurs ont examiné le rendement, la qualité et l'usage d'annuelles fourragères de saison chaude ou froide cultivées de façon biologique pendant la période d'engraissement de la mi-été. Les auteurs ont cultivé de l'ivraie multiflore (*Lolium multiflorum* cv. Tetra Brand), du triticale d'hiver (× *Triticosecale* Wittmack cv. common), de l'avoine (*Avena sativa* L. cv. Souris), du millet commun (*Panicum miliaceum* L. cv. Crown Proso), du maïs (*Zea mays* L. cv. BMR84 et CM440 Canamaize) et du sorgho-sorgho du Soudan (*Sorghum bicolor* [L.] Moench × *Sorghum sudanense* [Piper] Stapf cv. common) à Carman (Manitoba) pendant trois années-sites, en 2018 et 2019. Le rendement combiné en fourrage et en matière sèche s'élevait à 7 159 kg par hectare pour le sorgho-sorgho du Soudan (29 % de mauvaises herbes), à 5 506 kg par hectare pour le maïs (36 % de mauvaises herbes), à 4 687 kg par hectare pour l'avoine (45 % de mauvaises herbes), à 4 617 kg par hectare pour l'ivraie multiflore (95 % de mauvaises herbes), à 4 542 kg par hectare pour le millet (28 % de mauvaises herbes) et à 2 945 kg par hectare pour le triticale d'hiver (51 % de mauvaises herbes). Les auteurs ont noté des variations significatives dans la biomasse agricole et celle des adventices. Tous les systèmes fourragers conviennent aux ovins, avec un taux d'utilisation de 47 à 65 %. Quand on tient compte de tous les paramètres qualitatifs, le maïs, le triticale d'hiver, le millet et l'avoine s'avèrent adéquats pour la paissance à la mi-été, mais la teneur en protéines brutes du sorgho-sorgho du Soudan est inférieure à la concentration optimale. Jauger directement la qualité des fourrages cultivés avec des mauvaises herbes montre que ces dernières ne nuisent pas à la qualité des premiers. Cette étude canadienne, une première, illustre qu'on peut produire des fourrages pour la mise à l'herbe à la mi-été dans un régime de culture de graminées organique, l'avoine, le millet et le maïs offrant la meilleure combinaison en ce qui concerne le rendement et la qualité.. [Traduit par la Rédaction]

Mots-clés : fourrages annuels, culture biologique, mise à l'herbe, engraissement fourrager.

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M. Van Die and M.H. Entz. Department of Plant Science, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.

Corresponding author: Myra Van Die (email: vandiem@myumanitoba.ca).

Introduction

Extending the grazing season benefits livestock producers by reducing costs associated with feed harvest, storage, distribution, and manure spreading. Maximizing grazing is especially important in organic grass-fed production, where ruminants such as cattle, sheep, and goats must be fed a solely forage-based diet to comply with national and international grass-fed standards, as grains and grain by-products cannot be used to sustain livestock during feed gaps (Gwin 2009; Riely 2011). The primary feed sources in grass-fed production are perennial forages, though annual forages are used strategically within the grazing season (Steinberg and Comerford 2009; Van Die 2020).

One important feed gap period is mid-summer, when cool-season perennial forage species often become less productive. Annual forages, including grasses and cereal grains, can be a particularly valuable feed supply during this time period (McCartney 1993; McCartney et al. 2008, 2009). In grass-fed systems, however, cereals must be harvested prior to the milk stage of development (Manitoba Grass-Fed Beef Association undated) to ensure the crop is considered a forage and not a grain, whereas in conventional systems cereals can be harvested at later development stages (McCartney et al. 2004). As such, additional research is required on the role of annual forages in organic grass-fed production.

Annual forage species have been widely researched in Canada including annual (Westerwold) and biennial (Italian) ryegrasses (Kunelius and Narasimhalu 1983; Narasimhalu et al. 1992; Stout et al. 1997; McCartney et al. 2004), spring planted winter cereals (Baron et al. 1992; McCartney et al. 2008), oat (Aasen et al. 2004; Omokanye et al. 2019), and others. A survey of Canadian beef producers indicated that 14% of producers grazed annuals (Sheppard et al. 2015), whereas a survey of northwest United States grass-fed producers indicated 35% of producers used annual forages for grazing (Steinberg and Comerford 2009). However, the limited growth potential of cool-season forages during the hot summer period (Baron et al. 1993) has created interest in using warm-season annuals such as millet, corn, and sorghum-sudangrass (May et al. 2007; Foster and Malhi 2013; Baron et al. 2014; McGeough et al. 2018) which have higher heat tolerance (Tracy et al. 2010; Harmon et al. 2019). In a survey of grass-fed producers located in the United States and Canada, warm-season annuals were popular for filling the summer season forage gap (Lozier et al. 2004).

Organic crops almost always include weeds and forages are no exception. Temme et al. (1979) found that a larger percentage of the forage was a mixture of weeds in an organic system where herbicides are prohibited, however, total forage dry matter (DM) yield was often greater. Recent organic grazing research in Manitoba showed that weeds made up 9% to 73% of annual forage mixtures (Cicek et al. 2015). Similar proportions of weeds were observed in herbicide free forage establishment in Alberta (Moyer 1985); however, the weed infestation within annual forage crops may differ depending on forage species planted. For example, under herbicide-free production of annual forages, sorghum-sudangrass had the lowest percent weed DM, attributed to its delayed seeding and competiveness with warm-season weeds (Schoofs and Entz 2000), suggesting that warm-season forages may provide better weed control under some scenarios. In one of the few Canadian studies to consider how species choice affects weed biomass in organic forage production, a soybean monocrop had 54% weed biomass compared with 11% for a pea/oat mixture (Cicek et al. 2015).

While weeds are often considered as undesirable contaminants of forage, in vitro digestible DM, crude protein (CP), and acid detergent fibre (ADF) contents were similar for several common weeds and tame forages (Marten and Anderson 1975; Temme et al. 1979). In Alberta, Moyer and Hironaka (1993) observed that after ensiling, digestible energy was 10.8 for alfalfa (*Medicago sativa* L.), 11.0 for meadow bromegrass (*Bromus biebersteinii* Roem & Schutt), 13.2 for wild oat (*Avena fatua* L.), 11.1 for green foxtail (*Setaria viridis* (L.) Beauv.), 10.7 for lamb's quarters (*Chenopodium album* L.), and 6.9 MJ kg^{-1} for redroot pigweed (*Amaranthus retroflexus* L.). Others have also observed that forage nutritive values are not always negatively impacted by weed infestations (Bergen et al. 1990; Martineau et al. 1994).

Because weeds are common in organic forage production, the question of utilization and palatability becomes an important consideration. In Minnesota, sheep utilized 82% of soybean (*Glycine max* L. (Merr.)) and 75% of cowpea, which were the most palatable forages compared with kochia (*Kochia scoparia* (L.) Schrad.), rape (*Brassica napus* L.), amaranth (*Amaranthus emeritus* L.), sudangrass [*Sorghum bicolor* (L.) Moench], turnip (*Brassica rapa* L.), and pearl millet [*Pennisetum americanum* (L.) Leeke] (Sheaffer et al. 1992). Cicek et al. (2015) found that high abundance of weed species such as lamb's quarters, redroot pigweed, yellow foxtail (*Setaria glauca*), and green foxtail, in an annual forage system did not reduce palatability by sheep. Tracy et al. (2010) observed that when cattle grazed redroot pigweed, which accounted for up to 50% of the forage biomass, no difference in cattle performance was observed in pastures with and without the pigweed infestation.

The objectives of this study were: (*i*) to compare yields of cool- and warm-season annual forages under organic grass-fed production; (*ii*) to measure the proportion of forage biomass consisting of weeds; (*iii*) to determine the forage nutritive value of both crops and weeds; and (*iv*) to observe the utilization of these organically grown crops (and weeds) by grazing sheep. As one of the first grazing studies to consider grass-fed, organic systems in Canada, this study was both observational

Table 1. Sampling dates and crop development stage at time of sampling of six annual forages grown over three site-years.

	Cultivar	Seeding rate (kg·ha^{-1})	Sampling date (days to harvest)[a] Site-year 1	Site-year 2	Site-year 3	Stage
Cool-season forages						
Annual ryegrass	Tetra Brand	20	07 Aug. (64)	23 July (56)	21 Aug. (63)	Stem elongation
Winter triticale	Common	150	14 Aug. (71)	25 July (58)	21 Aug. (63)	Tillering
Oat	Souris	115	25 July (51)	17 July (50)	06 Aug. (48)	Early milk[b]
Warm-season forages						
Millet	Crown Proso	25	24 July (50)	15 July (48)	26 July (37)	Early heading[b]
Corn	BMR84[c] CM440 Canamaize[d]	81	14 Aug. (61)	30 July (63)	06 Aug. (56)	Tasseling
Sorghum-sudangrass	Common	30	21 Aug (78)	14 Aug. (78)	29 Aug. (71)	Booting

[a]Seeding dates were 4 June 2018, 28 May 2019, and 19 June 2019 for site-year 1, site-year 2, and site-year 3, respectively, with the exception of corn in site-year 1 which was reseeded on 14 June 2018.
[b]In site-year 1 only, oat and millet were at the milk development stage at the time of sampling.
[c]In site-year 1.
[d]In site-years 2 and 3.

and hypothesis driven. Our main hypothesis was that the performance of annual forages with a grass-fed organic regime will depend a great deal on the species, with warm-season species providing better overall performance than cool-season species.

Materials and Methods

Field experiments were conducted in 2018 and 2019 at the Ian N. Morrison Research Farm in Carman, Manitoba, in a loamy Orthic Black Chernozem soil of the Denham Series (Manitoba Agriculture undateda) managed organically since 2004. Site-year 1 was conducted in 2018. Site-years 2 and 3 were both conducted in 2019; site-year 3 had a seeding date 3 wk later than site-year 2. The 3-wk spacing between seeding dates ensured that the environmental conditions experienced under site-year 3 were different than those of site-year 2, providing two unique site-years. Soil nitrogen (N, kg·ha^{-1}), phosphorus (kg·ha^{-1}), and potassium (ppm) were 41, 18, and 240, respectively, in 2018 and 78, 8, and 231, respectively, in 2019 from the 0 to 0.61 m depth at each experiment location.

Cereal grain production preceded each experiment and land was tilled to 5 cm immediately before spring seeding. A disc drill (Fabro Industries, Swift Current, Saskatchewan) with 30 cm row spacing was used and plots were 8 m long by 2 m wide. Forage species included annual ryegrass (*Lolium multiflorum* cv. Tetra Brand) seeded at 20 kg·ha^{-1}; winter triticale (× *Triticosecale* Wittmack cv. common) at 150 kg·ha^{-1}; oat (*Avena sativa* cv. Souris) at 115 kg·ha^{-1}; millet (*Panicum miliaceum* L. cv. Crown Proso) at 25 kg·ha^{-1}; corn (*Zea mays* L. cv. BMR84 and CM440 Canamaize) at 81 kg·ha^{-1}; and sorghum-sudangrass (*S. bicolor* × *Sorghum sudanense* [Piper] Stapf cv. common) at 30 kg·ha^{-1}. Each study was arranged in a randomized complete block design with four replications in each site-year. Seeding dates were 4 June 2018, 28 May 2019, and 19 June 2019 for site-year 1, site-year 2, and site-year 3, respectively, with the exception of corn in site-year 1 which was reseeded on 14 June 2018. Interrow cultivation was applied once for weed control.

Plant population density was measured in two 1 m lengths of row after full emergence. Grass-fed management requires that livestock be fed only forages and no grains. For this reason, DM samples were collected prior to crops being fully mature to ensure grain was not harvested with the forage. Days from seeding to harvest ranged from 37 to 78 d (Table 1). Biomass samples were collected by harvesting a 1 m length by 0.6 m width of the two center rows of each plot (including weeds within this area). Crop and weeds were hand separated; weeds were kept as a bulk sample and not separated by species. Biomass samples were dried at 65 °C until a constant weight was achieved, for no less than 48 h, and weighed. Biomass samples from site-years 1 and 2 were ground to pass a 1-mm screen using a Wiley Mill and submitted to Central Testing Laboratory Ltd. (Winnipeg, MB) for wet chemistry analysis for CP, ADF, neutral detergent fibre, and the calculation of total digestible nutrients (TDN). The concentrations of ADF and neutral detergent fibre were determined using an Ankom2000 Automated Fiber Analyzer. N was analyzed using an Elementar Protein Analyzer and multiplied by 6.25 to calculate CP from N. The TDN concentration was calculated as:

$$\%\mathrm{TDN(DM)} = 4.898 + 89.796(1.044 - 0.0119\,\mathrm{ADF}) \tag{1}$$

The crop and weed components from each plot were analyzed for forage quality separately. Whole plot forage quality was determined using the weighted quality of weeds and crops.

Grazing by sheep was performed in all plots immediately after biomass determinations; sorghum-

Table 2. Growing season mean monthly temperature, precipitation, and long-term averages at Carman, Manitoba, 2018 and 2019 (Environment Canada 2019*a*, 2019*b*).

	Air temperature (°C)			Precipitation (mm)		
Month	2018	2019	30 yr average	2018	2019	30 yr average
May	14.8	9.6	11.6	47.9	36.9	69.6
June	19	17.3	17.2	98.3	37.9	96.4
July	19.9	19.5	19.4	42.9	57.4	78.6
Aug.	19	18.1	18.5	31	61.6	74.8

sudangrass was avoided due to drought conditions increasing risk of prussic acid poisoning. The technique of Cicek et al. (2014) was used, and details of sheep management are reported in (Van Die 2020). Briefly, sheep grazed each plot for 24 h in site-years 1 and 2. Fencing was used to confine grazing to each individual plot. Stocking density for each treatment was based on available biomass. Grazing occurred within 2 d of biomass sampling with the exception of oat in site-year 1 which was grazed 7 d after sampling. Following grazing, a residual above ground biomass sample was collected from each plot. Samples were washed with fresh water to remove soil and manure, dried at 65 °C for 48 h, and weighed

Statistical analysis was completed using PROC Mixed in SAS version 9.4 (SAS Institute Inc. 2016). Site-years were combined; treatments and site-years were considered fixed effects and replicates nested within site-years were considered random effects. PROC Univariate was used to test the normality of the residuals. Where normality was not met, data were square root transformed. Means were separated using the lsmeans statement with the Tukey test and considered significant at $P < 0.05$. When the interaction of site-year by treatment was significant, site-years were not combined and each site-year was analyzed separately. In this case, treatments were considered fixed effects and replicates were random effects.

Results and Discussion

Mean monthly temperatures ranged from 9.6 to 19.9 °C during the May to August growing seasons of 2018 and 2019 (Table 2). Temperatures were above average in 2018 and generally consistent with the average in 2019, with the exception of May 2019, which experienced below average temperatures. The total precipitation from May to August was 69% and 61% of the 30 yr average during the 2018 and 2019 growing seasons, respectively. June 2018 was the only month when average monthly precipitation was received. Therefore, the present study was conducted under water-limited conditions.

Biomass production affected by forage species

Crop DM yield was influenced ($P < 0.05$) by site-year, treatment, and their interaction (analysis not shown). The highest yields were recorded at site-year 1 where near normal June precipitation (Table 2) allowed greater plant growth. The later seeding date of site-year 3 likely benefited the warm-season annuals by avoiding the below average temperatures of May 2019.

The site-year by treatment interaction for crop DM yield was attributed to differences in the relative magnitudes between treatments and not a change in rankings across site-years (Table 3). The crop DM yield ranking was sorghum-sudangrass > corn > millet > oat > winter triticale > annual ryegrass. The only exception was corn in site-year 1, when poor establishment required replanting resulting in a low yield. The relative difference between the yield of sorghum-sudangrass and annual ryegrass was 4285, 3763, and 6820 kg·ha^{-1} in site-years 1, 2, and 3, respectively. Among cool-season species, oat was always the highest yielding and annual ryegrass always the lowest. Among warm-season species, sorghum-sudangrass was always the highest and millet the lowest (with the exception of corn in site-year 1).

This study is among the first to provide Canadian organic yields for the forages tested. For comparison, conventionally-produced sorghum-sudangrass grown in Manitoba (Schoofs and Entz 2000) and millet grown in Saskatchewan (Rosser et al. 2013) yielded similar to our study, while yields for corn in Alberta (Baron et al. 2014), and oat and winter triticale in Saskatchewan (McCartney et al. 2004), were two times greater than those in our study. Notably, annual ryegrass yielded less than 10% of previous reports (McCartney et al. 2004). Where yield comparisons with similar forage systems (ie., annual forages grown organically) were available, production levels were slightly lower. Slightly lower biomass in the present study (eg. oat total average yield at 4687 kg·ha^{-1} vs approximately 5400 kg·ha^{-1} (Cicek et al. 2014)) may be due to the lack of legumes, which were included in the Cicek et al. (2014) study. This may have limited N supply in the present study. Crop N uptake averaged 32 kg N·ha^{-1} with oat and millet having the greatest uptake on average (Table 4). These N uptake

Table 3. Plant stand, crop dry matter (DM), weed DM, total DM and utilization for sheep of six annual forages over 3 site-years.

Plant species	Plant stand (plants·m^{-2})	DM (kg·ha^{-1}) Crop	Weeds	Combined	Utilization[a] (%)
Site-year 1					
Annual ryegrass	212	515C	4541A	5036AB	68A
Winter triticale	186	1769BC	1364B	3141B	62A
Oat	233	3753AB	2154B	5901AB	68A
Millet	224	4781A	1451B	6232AB	56A
Corn	14	2756AB	1551B	4310AB	65A
Sorghum-sudangrass	51	4800A	1994B	6760A	—
P>F	—	0.0001	<0.0001	0.0414	0.6261
Site-year 2					
Annual ryegrass	199	131B	3072A	3213B	40A
Winter triticale	232	1407A	1682B	3111B	69A
Oat	298	2127A	1453B	3597B	57A
Millet	205	2226A	1567B	3813B	38A
Corn	52	2803A	3042A	6096A	57A
Sorghum-sudangrass	99	3894A	2842A	6944A	—
P>F	—	<0.0001	0.0002	0.0008	0.1971
Site-year 3					
Annual ryegrass	265	40D	5566A	5603A	—
Winter triticale	266	1111C	1552C	2644C	—
Oat	324	1837BC	2690B	4564ABC	—
Millet	213	2949B	641C	3583BC	—
Corn	44	5045AB	991C	6112AB	—
Sorghum-sudangrass	118	6860A	884C	7774A	—
P>F	—	<0.0001	<0.0001	0.0010	—

Note: Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ with the Tukey test.
[a]% of pre-grazing DM.

Table 4. Total digestible nutrients (TDN) and crude protein (CP) of crop, weed, and total dry matter (DM) and crop nitrogen (N) uptake of six annual forages over 3 site-years.

	TDN (% DM) Crop	Weeds	Combined	N Uptake (kg N·ha^{-1})[a]	CP (% DM) Crop	Weeds	Combined
Site-year 1							
Annual ryegrass	65.8ABC	60.8A	61.4B	9	11.3A	8.4BC	8.6AB
Winter triticale	68.7AB	59.7AB	64.9AB	29	10.1AB	6.4C	8.6AB
Oat	64.4C	60.2A	62.7AB	59	9.8AB	10.2AB	9.9A
Millet	64.8BC	59.8A	63.6AB	61	8.0BC	10.4A	8.6AB
Corn	69.2A	60.1A	65.9A	30	6.7CD	10.9A	8.2B
Sorghum-sudangrass	64.3C	55.4B	61.7B	37	4.8D	6.5C	5.3C
P>F	0.0026	0.0117	0.0072	—	<0.0001	<0.0001	<0.0001
Site-year 2							
Annual ryegrass	61.2B	63.3AB	63.5ABC	3	15.5A	9.5B	10.8AB
Winter triticale	66.9A	63.9AB	65.2AB	31	13.6A	5.5C	9.2AB
Oat	62.3B	67.3A	64.4ABC	37	10.9B	12.0A	11.4A
Millet	67.3A	67.3A	67.3A	36	10.0B	12.0A	10.9A
Corn	65.1AB	60.8BC	62.9BC	27	6.0C	9.0B	7.4BC
Sorghum-sudangrass	63.3B	57.5C	60.9C	29	4.7C	7.4BC	5.9C
P>F	0.0003	<0.0001	0.0027	—	<0.0001	<0.0001	<0.0001

Note: Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ with the Tukey test
[a]Crop N uptake.

values are lower than previous studies where cereal crops were grown the year after a legume green manure (eg. 127 kg N·ha^{-1} on average, (Bullied et al. 2002) and 117 kg·ha^{-1} on average (Cicek et al. 2014)). In general, the average N uptake rankings were consistent with the crop DM yield rankings, with the exception of sorghum-sudangrass which had a lower N uptake.

Weeds contribute significantly to forage biomass

Weeds at each site-year consisted primarily of warm-season species (green foxtail, yellow foxtail, redroot pigweed), lamb's quarters, Canada thistle (*Cirsium arvense* (L.) Scop.), and wild buckwheat (*Polygonum convolvulus*). Weed DM ranged from 884 to 5566 kg·ha^{-1} across site-years. The average weed contribution to total DM was 95% for annual ryegrass, 52% for winter triticale, 45% for oat, 27% for millet, 34% for corn, and 27% for sorghum-sudangrass. Similar proportions of weed DM were reported in herbicide-free (Schoofs and Entz 2000) and organic (Cicek et al. 2015) experiments at the same research location.

The lower proportions of weed DM observed in the warm-season crop species compared with the cool-season crop species suggest an advantage of warm-season forages as they were able to produce higher crop yield with less weed growth than cool-season forages (Table 3). Two other points of interest regarding weed growth in different forage species were noted. First, annual ryegrass appeared to offer little competition to weeds despite having adequate plant population densities (average 225 plants·m^{-2}, Table 3). This was likely because annual ryegrass was not well-suited to the warm and dry conditions experienced during the study (Kunelius et al. 2004). Second, winter triticale had a low combined DM yield as a result of both low weed and low crop growth. Winter triticale is known to suppress redroot pigweed and green foxtail (Flood and Entz 2009), two common weed species in the current study, however, dry conditions likely limited the overall growth of winter triticale. Therefore, low combined DM yield in winter triticale may have been due to the combination of its weed suppressing allelopathy and low crop growth. These results suggest that both annual ryegrass and winter triticale have a very limited competitive ability for water particularly under warm conditions.

Corn and sorghum-sudangrass consistently had among the greatest combined forage yields whereas winter triticale had among the lowest (Table 3). In site-years 1 and 3, however, there were few statistically significant differences between the highest and lowest yielding crops. When averaged across site-years, combined forage and weed DM yields were 7159 kg·ha^{-1} for sorghum-sudangrass, 5506 kg·ha^{-1} for corn, 4687 kg·ha^{-1} for oat, 4618 kg·ha^{-1} for annual ryegrass, 4542 kg·ha^{-1} for millet, and 2965 kg·ha^{-1} for winter triticale. These production levels are similar to other organic annual forage yields (Cicek et al. 2015; Carkner et al. 2020), and indicate the potential for high yield forage production, even under water-limiting growing conditions. Sorghum-sudangrass and corn were frequently the highest yielding crops. Despite having a very low crop proportion, annual ryegrass had combined DM yields similar to most other forage treatments owing to the high proportion of weed biomass in the annual ryegrass crop.

Forage quality affected more by crop than weed presence

The crop TDN concentrations were affected by site-year. In site-year 1, winter triticale and corn had greater TDN concentrations than oat and sorghum-sudangrass (Table 4). In site-year 2, however, winter triticale and millet had greater TDN concentrations than annual ryegrass, oat, and sorghum-sudangrass. Winter triticale and corn had among the highest TDN concentrations in both site-years whereas oat, sorghum-sudangrass, and annual ryegrass had among the lowest.

The TDN concentrations of the weed biomass from each treatment were generally within 5% of the crop TDN concentrations. The weed TDN concentrations of sorghum-sudangrass were lower than all other crops with the exception of winter triticale in site-year 1 and corn in site-year 2. The later harvest date of the sorghum-sudangrass likely resulted in advanced weed maturity and therefore decreased weed digestibility compared with other treatments. For example, millet was harvested 28 d earlier than sorghum-sudangrass in site-year 1 because millet was a faster maturing crop (both crops were seeded on the same date). The millet weeds were therefore less mature than the sorghum-sudangrass weeds. Weed maturity, however, was not specifically measured and should be considered in future studies as well as weed species composition in each treatment.

When TDN concentrations were assessed for the entire plant biomass (crops and weeds), there were fewer significant differences between the treatments. For example, in site-year 1 the only differences were that the TDN concentration of corn was greater than annual ryegrass and sorghum-sudangrass. Similarly, in site-year 2 the differences were that the TDN concentration of millet was greater than that of corn and sorghum-sudangrass. Low quality for sorghum-sudangrass supports results reviewed by McGeough et al. (2018).

The crops in the current study were generally harvested at earlier developmental stages than commonly used for forages to ensure no grain was included in the forage samples (Table 1). This likely resulted in the higher total TDN concentrations compared with other forage studies. For example, TDN concentrations within Manitoba include 57%, 62%, and 65% for spring triticale, corn, and millet, respectively, when harvested as green feed which correspond to the dough, mature, and early heading stages for each crop, respectively (Manitoba Agriculture undated*b*). In the current study the winter triticale was vegetative and the corn was tasseling, however, the millet was at the early heading and milk development stages. Sorghum-sudangrass grown in Georgia, USA, had a TDN concentration of 59% (Harmon et al. 2019) and oat harvested at the milk stage in Alberta had a TDN concentration of 62% (Omokanye et al. 2019). The inclusion of the weed biomass in the current study, however, generally decreased the overall forage quality in terms of TDN concentrations. Future research should consider grazing at different crop maturities; especially for sorghum-sudangrass which had low quality partially based on the later harvest date.

The crop CP concentrations were lower for the warm-season crops than the cool-season crops with a CP concentration ranking of annual ryegrass > winter triticale > oat > millet > corn > sorghum-sudangrass. These rankings were consistent across site-years. The warm-season CP concentrations were lower than those reported in Saskatchewan, at 11%, 9%, and 11% for millet, corn, and sorghum-sudangrass, respectively (May et al. 2007). For cool-season species, however, the CP concentrations were more comparable to other Canadian Prairie studies, at 13% and 15% for annual ryegrass and winter triticale, respectively (McCartney et al. 2004) and 10% for oat (Omokanye et al. 2019). The CP concentrations were likely affected by the lower levels of N fertility in the current study. Crop N uptake was never higher than 61 $kg \cdot ha^{-1}$ (Table 4) indicating relatively low N availability; less than recorded in organic forage work by Cicek et al. (2015) at 98 $kg\ N \cdot ha^{-1}$ for wheat on average.

Under some conditions, weeds may improve the nutritive value of forages (Lenssen and Cash 2011). Weed CP concentrations ranged from 6% to 11% in site-year 1 and 6% to 12% in site-year 2. In both site-years, the weeds growing with sorghum-sudangrass had CP concentrations lower than all other treatments with the exception of winter triticale in site-year 1 and corn in site-year 2. The differences between the weed CP concentrations were likely dependant on the days to harvest of each crop, as maturity is the factor that influences forage quality to the greatest extent compared with other factors such as temperature, moisture, and soil fertility (Buxton 1996). For example, sorghum-sudangrass and winter triticale had the greatest days to harvest in site-year 1 while sorghum-sudangrass and corn did in site-year 2.

The combined crop and weed CP concentrations were greatest for millet at 9.9 and 11.4 in site-years 1 and 2, respectively, and lowest for sorghum-sudangrass at 5.3 and 5.9 in site-year 1 and 2, respectively. Differences in weed species composition across treatments may have also influenced the weed CP concentrations, however, species composition was not included in the study and should be considered in future work.

Forage utilization by sheep

Forages were grazed with sheep immediately after biomass sampling. The purpose of sheep grazing was to collect preliminary information on the utilization rates when summer forages were grown in an organic production system according to grass-fed protocols. Utilization varied widely between forage systems, but high experimental error limited treatment differences so that no significant differences were observed (Table 3). In general, utilization rates were in line with many other annual forage grazing studies (Cicek et al. 2014, 2015). It was notable that average utilization of millet by grazing sheep (47%), while not statistically different, was numerically less than utilization by the other forages: 54% for ryegrass, 65% for winter triticale, 62% for oat, and 61% for corn (Table 3). Similar to previous studies (Tracy et al. 2010; Cicek et al. 2015), our results demonstrate relatively high forage utilization rates even when forages are heavily inundated with weeds. This provides evidence that summer annual forages for grass-fed (or other) ruminant production appear to be well suited to organic production.

Application of results

Ruminant livestock nutritional requirements will vary throughout the production cycle. The following analysis applies the results from the present study to the most popular grass-fed livestock class in Canada, namely beef cattle. Beef cows require a diet with a TDN concentration corresponding to 55%, 60%, and 65% during mid-pregnancy, late pregnancy, and after calving, respectively (Manitoba Agriculture undated*c*). Based on these guidelines, all forage treatments (crops and weeds combined) could potentially provide adequate TDN requirements of mid-pregnancy and late pregnancy cows. However, only corn and winter triticale (64.9% TDN) reached the 65% TDN goal required for cows after calving in site-year 1, while only winter triticale and millet reached the 65% TDN goal in site-year 2 (Table 4).

An average beef calf requires 66% to 71% TDN to achieve a weight gain of 1 kg per day (Manitoba Agriculture undated*c*). Given this assumption, not all treatments would have been able to provide adequate TDN requirements for such a calf weight gain. When the crop alone was considered, winter triticale and corn had TDN levels above the 66% threshold in site-year 1 while triticale and millet had TDN levels above the 66% threshold in site-year 2. When the combined crop and weed forage was considered, only corn (65.9%, site-year 1) and millet (site-year 2) had TDN levels above this threshold (Table 4).

A ration with a CP concentration of 7%, 9%, and 11% is required for beef cows during mid-pregnancy, late pregnancy, and after calving, respectively, while an average beef calf requires 10% CP during the later stages of finishing (Manitoba Agriculture undated*c*). Based on these guidelines, sorghum-sudangrass never provided adequate CP for any development stage, while only oat and millet (10.9% CP) in site-year 2 provided a CP above the 11% threshold for cows after calving (Table 4).

All other forage treatments (crops and weeds combined) would be considered adequate for mid- to late-pregnancy cows.

Conclusion

This is the first Canadian study to test mid-summer forages in the context of grass-fed, organic production. Results demonstrated the potential that different forage species have for producing high quality mid-summer forage even in the presence of weeds.

Averaged across site-years, combined forage and weed DM yield was 7159 kg·ha^{-1} for sorghum-sudangrass (27% weeds), 5506 kg·ha^{-1} for corn (34% weeds), 4687 kg·ha^{-1} for oat (45% weeds), 4618 kg·ha^{-1} for annual ryegrass (95% weeds), 4542 kg·ha^{-1} for millet (27% weeds), and 2965 kg·ha^{-1} for winter triticale (52% weeds). Therefore, the highest combined biomass producing forages were two warm-season species, sorghum-sudangrass and corn, and the cool-season oat; however, sorghum-sudangrass was more consistent in its production across the site-years. We conclude that annual ryegrass is not a realistic candidate for summer grazing due to low weed competitiveness.

Utilization of forages by grazing sheep averaged 58% (range 38% to 69%), demonstrating that even with significant weed growth, annual forages were palatable to sheep.

Corn, winter triticale, and millet (crops and weeds combined) provided sufficient energy (TDN) for beef cows, whereas corn and millet provided sufficient TDN for calf target gains. Oat and millet provided sufficient CP for animal performance for grass-fed beef cows. Sorghum-sudangrass alone had protein levels under 5% CP; together with weeds the CP was still below 6%. We observed that the summer annual weeds which grew as intercrops with forage species did not compromise forage quality.

Future research should consider the optimum harvest time to achieve optimum quality for different forage-weed combinations, more rigorous weed management to reduce weed biomass, and animal performance when grazing various crop-weed mid-summer forage combinations.

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