Yield, nutrient composition, and horse condition in integrated crabgrass and cool-season grass rotational grazing pasture systems

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ABSTRACT: Integration of warm-season grasses into traditional cool-season pastures can increase summer forage for grazing cattle. The aim of this study was to determine impacts of this practice on yield and nutrient composition of equine rotational pasture systems as well as horse body condition. Two 1.5 ha rotational systems (6 to 0.25 ha sections/system) were evaluated: a control system (CON) (all sections mixed cool-season grass [CSG-CON]) and an integrated rotational grazing system (IRS) (three CSG sections [CSG-IRS] and three *Quick-N-Big* crabgrass [*Digitaria sanguinalis* (L.) Scop.; CRB-IRS]). Three horses per system grazed in three periods: EARLY (mid-May to mid-July), SLUMP (mid-July to mid-September), and LATE (mid-September to mid-November). Herbage mass (HM) was measured prior to each rotation and samples were collected (0800 to 1000 h) for nutrient analysis. Grazing days were tracked to calculate carrying capacity (CC). Horse condition measures were assessed monthly. Over the full grazing season, 9,125 kg of forage was available for grazing in IRS versus 6,335 kg in CON. The CC was 390 horse d for IRS, while only 276 horse d for CON. Total HM/section did not differ during EARLY when CRB was not available (CSG-IRS: 2,537 ± 605; CSG-CON: 3,783 ± 856 kg/ha), but CC was greater in CSG-IRS (220 ± 37 horse d/ha) than CSG-CON (92 ± 26 horse d/ha; $P = 0.03$). In SLUMP, both HM and CC were greater in CRB-IRS (HM: 4,758 ± 698 kg/ha; CC: 196 ± 31 horse d/ha) than CSG-IRS (HM: 1,086 ± 698 kg/ha; CC: 32 ± 31 horse d/ha) or CON (HM: 970 ± 493 kg/ha; CC: 46 ± 22 horse d/ha; $P < 0.02$). While HM did not differ by section type in LATE (1,284 ± 158 kg/ha), CC was greater in CSG-CON (84 ± 9 horse d/ha) versus CRB-IRS (32 ± 13 horse d/ha; $P = 0.03$) and CSG-IRS (40 ± 13 horse d/ha; $P = 0.06$). During SLUMP, water-soluble carbohydrates (WSC) were lower in CRB-IRS (4.46% ± 0.80%) than CSG-CON (7.92% ± 0.90%; $P < 0.04$), but not CSG-IRS (5.93% ± 1.04%); however, non-structural carbohydrates (NSC) did not differ (7.05% ± 0.62%). There were no differences in WSC (6.46% ± 0.54%) or NSC (7.65% ± 0.54%) by section type in LATE. Horses in IRS maintained a body condition score (BCS) of 5.78 ± 0.48, but BCS did not differ by system (CON: 6.11 ± 0.48). Thus, integrated grazing increased summer pasture yield and provided adequate nutrition to maintain horse condition, but further research is needed to improve late-season production. Integrated grazing may not, however, provide an advantage in limiting dietary NSC, as NSC remained low for all pasture sections.

Key words: integrated grazing system, non-structural carbohydrates, summer slump

Transl. Anim. Sci. 2021.5:1-18
https://doi.org/10.1093/tas/txab208

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Received March 30, 2021.
Accepted October 21, 2021.

INTRODUCTION

Traditional pasture forages in temperate regions of the United States are mainly perennial cool-season grasses (CSGs) well adapted for survival of cold winters and growth in periods of cooler temperatures during spring, early summer, and fall. However, these species are less tolerant of heat and drought, which leads to a period of low forage productivity often called the "summer slump" (Moore et al., 2004; Tracy et al., 2010).

The "summer slump" presents management challenges to horse producers, with implications for both economic and environmental sustainability of equine operations. Supplemental feed is often needed to meet the nutritional needs of horses during the "summer slump," resulting in higher feed costs during this period (McMeniman, 2000; McCormick et al., 2006). Often, producers will provide supplemental feed to horses in existing pastures. Leaving horses on low productivity pastures can result in overgrazing with potential for negative environmental impacts. If forage is overgrazed, over time vegetative cover (VC) will be reduced (Williams et al., 2020), increasing the potential for soil erosion and nutrient runoff (Butler et al., 2007). Furthermore, overgrazing may result in long-term decreased forage stand persistence and weed invasion (Weinert and Williams, 2018). This may necessitate more frequent pasture renovation, conferring additional cost to producers. Alternatively, producers may choose to confine horses to stress lots, allowing the pasture forage time to rest and regrow. Stress lots often lack adequate vegetative filtration, which in combination with increased manure accumulation may result in surface and groundwater contamination due to increased nutrient runoff (Baxter and Gilliliand, 1988; Parvage et al., 2013).

Due to differences in photosynthetic processes, warm-season grass (WSG) yields are greatest during the hot, dry months of the "summer slump" when cool-season species are less productive (Taiz and Zeiger, 2002). A grazing system that incorporates complementary cool- and warm-season forage varieties would potentially provide more uniform productivity over the grazing season, increasing overall yield and reducing costs associated with supplemental feeding during periods of summer drought.

This integrated cool- and warm-season pasture management strategy has been previously assessed for use in cattle grazing management. Studies using cattle have reported higher summer and/or season-long yield for warm-season species in integrated rotational grazing systems (IRSs), but lower forage nutritional quality of WSGs resulted in no advantages for milk production or growth performance (Tracy et al., 2010; Kallenbach et al., 2012; Ritz et al., 2021). However, integrated rotational grazing has not been evaluated in horses. Extrapolating data from studies in other livestock species is often of limited value in management decisions for horse operations (Schmitz and Isselstein, 2020). Forage preference, grazing behaviors, nutritional requirements, digestive physiology, animal management goals, and drivers of enterprise profitability are vastly different (NRC, 2007; Catalano et al., 2020; Schmitz and Isselstein, 2020).

An integrated rotational grazing strategy may be better suited to nutrition and management goals of horse operations. Horses are fed to maintain body weight (BW) and sustain athletic performance rather than to maximize growth. Weight management is often the focus of equine feeding programs, with 30% to 50% of horses classified as overweight (Fernandes et al., 2015; Robin et al., 2015; Jaqueth et al., 2018). Additionally, due to lower non-structural carbohydrate (NSC) content, WSGs have been suggested as an alternative source of pasture forage for obese horses and horses with metabolic dysfunction where limiting dietary NSC is recommended (Chatterton et al., 1989; Frank et al., 2010; DeBoer et al., 2017).

However, few studies have assessed warm-season annual (Glunk et al., 2013; DeBoer et al., 2017, 2018) or perennial (Aiken et al., 1989; Webb et al., 1990; Ghajar et al., 2021) grasses as horse pasture forages. Lack of suitability due to prussic acid production and forage-related disorders associated with many warm season annuals and cold-sensitivity of traditionally cultivated perennials are limiting factors in integration of WSGs into temperate horse grazing systems. Although common crabgrass (CRB) is traditionally thought of as a weed, high summer yields have been reported for improved forage varieties (Teutsch et al., 2005; Gelley et al., 2016; Bouton et al., 2019). Given a lack of forage-related disorders, CRB may represent a viable summer forage option for horse pastures (Teutsch, 2009).

Therefore, the objective of this study was to determine the impact of integrating CRB, a warm-season annual, on yield and nutrient composition of equine rotational grazing systems as well as body condition of grazing horses. We hypothesized that integrating CRB into a cool-season perennial rotational grazing system would increase pasture forage availability during summer months, thereby increasing season-long production. We also expected this management approach would provide lower soluble carbohydrates for grazing horses and adequate nutrition to maintain horse body condition.

MATERIALS AND METHODS

Grazing Systems

This study was conducted in 2019 at the Ryder's Lane Environmental Best Management Practices Demonstration Horse Farm (Rutgers, The State University of New Jersey; New Brunswick, NJ). Pasture soil was a silty clay loam comprised of FapA (Fallsingotn loams, 0% to 2% slopes, Northern Coastal Plain), NknB (Nixon loam, 2% to 5% slopes), and NkrA (Nixon moderately well-drained variant loam, 0% to 2% slopes) (Weinert and Williams, 2018; Williams et al., 2020). Bi-annual soil tests are conducted at the study site, and lime and fertilizers were applied to adjust soil fertility to optimum ranges based on soil test results, with the most recent applications preceding initiation of grazing in 2019. Weather data for the New Brunswick station nearest to the site was obtained from the Historical Monthly Station Data portal of the Office of the New Jersey State Climatologist website (Rutgers New Jersey Weather Network; https://www.njweather.org/data).

Two separate 1.5 ha rotational grazing systems, each consisting of six sections (0.25 ha/section), were utilized. All pasture sections within each system were connected to a stress lot, where shelter, automatic waterers, and hay feeders were located. In the control system (CON) all sections contained an established CSG mix; these sections were then designated (CSG-CON). The CSG mix contained *Inavale* orchardgrass (OG) [*Dactylis glomerata* (L.)], *Tower* tall fescue (endophyte-free) (TF) [*Lolium arundinaceum* (Schreb.) Darbysh.], and *Argyle* Kentucky bluegrass (KB) [*Poa pratensis* (L.)] (DLF Pickseed, Halsey, OR) planted in a 24-16-16 mix for a total seeding rate of 56 kg/ha. In the IRS, three sections contained the established CSG mix (CSG-IRS) and remaining three sections were planted with *Quick-N-Big* CRB [*Digitaria sanguinalis* (L.) Scop.; Dalrymple Farms, Thomas, OK], a warm-season annual, at a seeding rate of 13 kg/ha (sections designated CRB-IRS). The CSG mix was established in the fall of 2017 by no-till drilling following application of glyphosate to eliminate existing forage. After close grazing of two sections in the spring 2018, glyphosate was applied and CRB was planted. All pasture areas within both systems were used for a separate equine grazing study in 2018 with similar grazing pressure across systems. In 2019, the same procedure was followed for re-establishing CRB for the current study, with seeding completed on June 3. Nitrogen fertilizer was applied to all sections in three split applications at a rate of 33.6 kg/ha to support optimal forage growth. Timing of applications for CSG was the same for both systems. Application of nitrogen fertilizer for CRB was dependent on germination/initial growth and grazing management (i.e., timing of pasture rotations). One application of 2,4-D (2.33 L/ha) was required for control of broadleaf weeds in CRB-IRS. In the CSG sections of CON and IRS, triclopyr (2.33 L/ha) and 2,4-D (2.33 L/ha) were applied in two separate applications for weed control.

In 2019, horses began spring grazing of CSG sections when the forage reached a height of approximately 15.2 cm. Horses were allowed to graze a given section until forage was reduced to approximately 7.6 cm sward height, at which time horses were moved to a new section to begin grazing. Early growth of CSG-CON sections out-paced the grazing capacity of horses maintained in that system, and thus three sections of CSG-CON were mowed (to 7.6 cm) one time prior to grazing as forage was becoming overly mature. Similarly, first growth of CRB in July was vigorous. Observations from preliminary studies in 2018 indicated that CRB was prone to lodging when allowed to become too tall and mature. Therefore, one section of CRB-IRS was mowed (to 7.6 cm) once before first grazing to avoid issues with lodging. Previously grazed or mowed sections were then allowed to regrow to a minimum 15.2 cm sward height. Sequential grazing of CRB sections began once the planted forage reached at least 15.2 cm. All sections were then managed with the take-half, leave-half rule as described above (Crider, 1955). After horses were removed from a grazed section, any remaining tall weeds were mowed to a height of 7.6 cm. The CSG sections were then dragged to evenly spread-out manure from defecation areas. Observations from preliminary work had suggested that CRB may be less tolerant of mechanical dragging procedures, as it damaged residual plant stubble and root integrity, impairing regrowth and stand persistence. Thus, CRB sections were not dragged following mowing. Horses were allowed 24-hour ad libitum access to pasture forage. If adequate pasture forage was not available (at least one pasture section at 15.2 cm to begin the next rotation), horses were confined to a stress lot and supplemental grass hay was provided at 2.5% of BW on a dry-matter (DM) basis. Nutrient composition of hay fed to horses during periods of stress lot confinement is shown in Table 1.

Forage Measurements

To determine if integrated rotational grazing would increase forage availability during summer months, grazing days, yield, and persistence were compared between CON and IRS. The number of grazing days in each section of each system were tracked in order to calculate carrying capacity (CC). For each rotation, prior to grazing, herbage mass (HM) was measured to evaluate yield. VC and species composition were assessed as measures of forage species persistence. The HM was determined by hand-clipping random sub-quadrants of pasture forage to estimate yield. A 0.5 m wooden square was placed randomly at four sites in each 0.25 ha section of pasture, and forage in each square was clipped to 7.6 cm to represent minimum allowed grazing height. Forage clipped was placed in a paper bag and dried at 60 °C in a Thelco (Precision Scientific, Chicago, IL) oven to remove moisture content and obtain a DM weight, which was used to estimate HM yield (Williams et al, 2020). Twenty measurements were taken per section of pasture. Species composition and VC were evaluated using the Step Point method (Evans and Love, 1956; Kenny et al., 2018). Twenty observations per section were recorded. To evaluate pasture forage botanical composition, individual observations were classified as either a planted grass species (G), non-planted grass weed (GW), non-grass species of weed (W), or other (O) including observations such as bare ground, water, or dead plant matter. Observations classified as O were subtracted from 100 (%) to determine VC. For plants classified as G, individual species identifications were also recorded to determine the composition of planted grasses.

Forage nutrient composition was analyzed by collecting representative pre-grazing samples hand-clipped to a 7.6 cm height. Samples were collected by walking in a random zig zag pattern throughout the pasture section, clipping forage every 30 paces (Williams et al., 2020). All samples were collected between 0800 and 1000 h on the day of rotation. Samples were weighed before and after drying at 60 °C for at least 36 h in a Thelco to calculate DM. After drying, samples were ground to 1 mm using a Wiley Mill and submitted to Equi-Analytical Laboratories (Ithaca, NY) to be analyzed by wet chemistry.

Table 1. Nutrient composition[1] of cool-season grass hay fed to horses confined to stress lots during periods of low pasture forage productivity

Nutrient	Hay
Dry matter, %	91.5
Digestible energy, Mcal/kg	1.98
Crude protein, %	8.7
Acid detergent fiber, %	41.5
Neutral detergent fiber, %	66.5
Water-soluble carbohydrates, %	5.1
Ethanol-soluble carbohydrates, %	4.5
Starch, %	0.6
Non-structural carbohydrates, %[2]	5.7
Calcium, %	0.26
Phosphorus, %	0.23

Hay was fed at 2.5% body weight per day.

[1]Nutrient composition of forage samples was determined by wet chemistry (Equi-Analytical Laboratories, Ithaca, NY). Nutrients are presented on a dry-matter (DM) basis.

[2]Non-structural carbohydrates were calculated as the sum of water-soluble carbohydrates and starch.

Animal Management and Measurements

Use of animals in this study was approved by the Rutgers University Institutional Animal Care and Use Committee protocol #PROTO201800013. Six adult Standardbred mares with a body condition score (BCS) of 5 to 7 out of 9 were used for the study. Prior to grazing, horses were weighed and then grouped by BW. Groups of three horses were randomly assigned to each of the grazing systems. Mean age and initial BW and BCS for each group are as follows: IRS—17.7 ± 0.33 year, 517 ± 11 kg, 5.50 ± 0.14 (BCS); CON—16.7 ± 2.33 year, 538 ± 9 kg; 5.67 ± 0.22 (BCS). In addition to access to either pasture forage or hay, all horses were fed a daily ration balancer supplement formulated to meet micronutrient requirements of horses consuming all-forage diets (GRO N WIN, Buckeye Nutrition) at a rate of 1.25 kg/day per horse; horses in each system were group-fed, with each horse provided the ration balancer in a separate feed trough. Horses also had ad libitum access to a salt block.

Horse body condition was first assessed on May 15 and then monthly throughout the grazing season by measuring BW, percent body fat (FAT), and BCS. Horse BW was measured by using an electronic scale, and FAT was determined using the Westervelt method (Westervelt et al., 1976) which uses a regression equation to convert ultrasonographic measurement of subcutaneous rump fat to an overall body fat percentage. BCS was evaluated using the Henneke Body Condition Score scale; scores were assigned on a scale of 1 to 9, with 1 = emaciated and 9 = morbidly obese (Henneke et al., 1983).

Production Costs

To determine if any advantage in production cost exists in integrating CRB into a traditional cool-season grazing system, total production costs were calculated and compared for each system. Relevant costs include cost of establishment (herbicide, fertilizer, seed, equipment, and labor costs), pasture maintenance (mowing and dragging), and supplemental feeding (if any). As described above, in the event that pasture forage was inadequate for grazing, horses were confined to a stress lot and fed supplemental hay at 2.5% BW DM. Any hay provided was weighed, and the cost of that feed was calculated.

Statistical Analysis

Forage and horse data were grouped into EARLY (Mid-May to Mid-July), SLUMP (mid-July to mid-September), and LATE (mid-September to mid-November). Inherent differences in seasonal availability of grass types in each of these periods created an unbalanced dataset; thus, each grazing period was analyzed separately (Grev et al., 2017). The HM for each rotation was summed in each section to determine total HM (per section) in each period. Similarly, total grazing days per section were used to calculate the CC of each section. Mean total HM and CC (per section), as well as forage nutrients across section types (CSG-CON, CSG-IRS, and CRB-IRS) for each period were analyzed by analysis of variance (ANOVA) of a linear model in R (v. 4.0.2). Horse body condition data including means and percent change for all variables were analyzed using a MIXED model with system, period, and their interactions as fixed effects and horse as the random effect. Means were separated by Tukey's method where applicable. For all data, normality was assessed using a Shapiro-Wilk test, and log, square-root, or inverse transformations were applied as necessary to meet ANOVA assumptions. Transformed means were back-transformed after the Tukey's post-hoc adjustment with standard errors (SE) converted to the original variable scale with the delta method. Pasture forage and species composition frequency counts were analyzed using a Pearson's Chi Square Test of Association. If expected counts were <5 in >20% of cells or any cells had an expected count of <1, frequency count data were analyzed using Fishers exact test. Results were considered significant at $P \leq 0.05$; trends were considered at $P \leq 0.10$. Data are presented as means ± SE.

RESULTS AND DISCUSSION

Forage Production and Persistence

Grazing began on May 17, 2019, with horses in both IRS and CON having access to CSG pasture sections. For IRS, horses were removed from pasture for the final time on October 25. Horses in CON were removed from pasture on November 9. Initial growth of CRB was sufficient for grazing beginning on July 15, just 43 days after planting on June 3. This coincided with a decline in forage production in CSG sections of both systems entering the "summer slump." The CRB-IRS sections were grazed during the SLUMP period from mid-July to mid-September, when cooler temperatures began to slow the growth of CRB and allow for the CSG to once again be more productive. In late September through early October warmer temperatures returned, however, allowing for additional rotations to graze the forage remaining in CRB-IRS sections in Oct. Monthly average temperature and total precipitation in 2019 as well as historical averages are presented in Table 2. Monthly average temperatures were near historical averages except for in July and October, when temperatures were above the historical values. Precipitation totals were well above average early in the grazing season (May to July) and in October. However, precipitation in September was well below historical averages.

Of the full grazing season duration (May 17 to November 9), horses in IRS had pasture access for 122 d. Horses in CON had pasture access for 104 d. Therefore, the IRS system supported horses on pasture for 69% of the grazing season, while the CSG-CON allowed grazing for 59% of the season. For IRS, there were a total of 18 rotations, and for CON, there were 16 rotations. Due to land-size constraints on the experimental design of this study, no statistical analysis was possible on whole-system measures. However, the IRS system produced more total available forage over the course of the full grazing season than the CON system (IRS: 8729 kg; CON: 7602 kg). Total season-long yields of forage available for grazing were similar between CRB and CSG within the IRS system (CRB-IRS: 4,343; CSG-IRS: 4,386 kg) despite CRB being available only in SLUMP and LATE grazing (2 months

Table 2. Weather data from 2019 grazing season[1]

	Average temperature, °C		Total precipitation, cm	
Month	2019	Historical average	2019	Historical average
May	16.89	16.17	18.16	10.21
June	21.28	21.00	13.84	9.93
July	25.67	23.78	16.00	12.32
August	23.78	22.78	11.63	11.89
September	20.67	19.17	3.86	10.29
October	14.61	12.94	13.16	8.97
November	5.56	7.11	5.41	8.81

Data shown include monthly average temperature and total precipitation from 2019 as well as historical averages.

[1]Weather data were obtained for the New Brunswick Station through the Office of the New Jersey State Climatologist website (Rutgers New Jersey Weather Network; https://www.njweather.org/data).

less than CSG). Similarly, CC over the full grazing season for the IRS system (390 horse d) was also numerically greater than in CON (333 horse d). However, within IRS, total CC for CSG was 213 horse d, while CC was only 177 horse d for CRB. This discrepancy in CC and HM between CRB-IRS and CSG-IRS could reflect physical characteristics of the forage stands. In our study, we observed that CRB was more prone to lodging and trampling as it became more mature, which may have impacted the use efficiency of CRB and constrained CC in these sections. The HM measurements were collected pre-grazing and would not have accounted for these characteristics, potentially resulting in lowered CC relative to total HM.

The distribution of pasture forage botanical composition (as assessed by categories G, GW, W, and O) varied across section types (CSG-CON, CSG-IRS, CRB-IRS). There was an association between section type (CSG-CON, CSG-IRS, CRB-IRS) and pasture forage composition in all three grazing periods ($P < 0.002$; Figure 1a–c). In EARLY grazing, when only CSG was available for grazing, the prevalence of G in CSG-IRS was 85%, while it was 69% in CSG-CON. Conversely, the prevalence of GW was 24% in CSG-CON versus only 2% in CSG-IRS. In the SLUMP period, the percentage of G was 75% in CSG-IRS in comparison to 85% and 87% in CSG-CON and CRB-IRS, respectively. GW were more common in CSG sections of both CON (11%) and IRS (15%) than in CRB-IRS (1%), while W was more common in the IRS (CSG-IRS: 9%; CRB-IRS: 10%) compared to CSG-CON (2%). Similarly, in LATE grazing, the prevalence of G was 78% in CSG-IRS compared to 82% in both CSG-CON and CRB-IRS. GW prevalence was only 4% in CRB-IRS versus 18% in CSG-IRS and 14% in CSG-CON, while O was 14% in CRB-IRS versus 5% in CSG-IRS and 2% in CSG-CON. Pasture VC remained high throughout the grazing season in all sections. The lowest VC recorded was for CRB-IRS in the LATE period (84%) and VC was ≥95% in all other section types across all grazing periods. These values for VC are well above the 70% level recommended for preventing excess soil erosion and nutrient runoff (Costin, 1980).

The G values for CRB-IRS represent the establishment and persistence of *Quick-N-Big* CRB, as this species was established in monoculture in these pasture sections, and were 87% and 82% for SLUMP and LATE grazing. For the CSG sections in CON and IRS, there was an association between system and CSG grass species for the EARLY and SLUMP periods ($P < 0.05$), but not during LATE grazing (Figure 2a–c). In EARLY grazing, prevalence of KB was 32% in CON versus 21% in IRS, with 32% OG and 36% TF in CON compared to 63% OG and 16% TF in IRS. During the SLUMP period, KB prevalence was only 13% in CON and 8% in IRS, while OG and TF were more abundant, with 34% OG and 53% TF in CON versus 56% OG and 36% TF. During LATE grazing, prevalence of both KB and OG was relatively low in both systems (CON: 15% KB, 14% OG; IRS: 6% KB, 19% OG), while TF prevalence was high (CON: 71%; IRS: 74%). The CSG pasture sections of IRS and CON were planted on the same date in the fall of 2017 with an identical seeding rate. Additionally, pasture management practices and grazing pressure during 2018 were also similar. However, differences in species composition of CSG pasture sections was evident between systems in 2019 and should be considered when interpreting results presented for yield and forage nutrients as interspecies variance in these parameters have been documented in cool-season pasture grasses (Allen et al., 2012, 2013; Martinson et al., 2015). While establishment and management of all CSG sections were similar, other factors such as utilization and management prior to the re-establishment of CSG in these

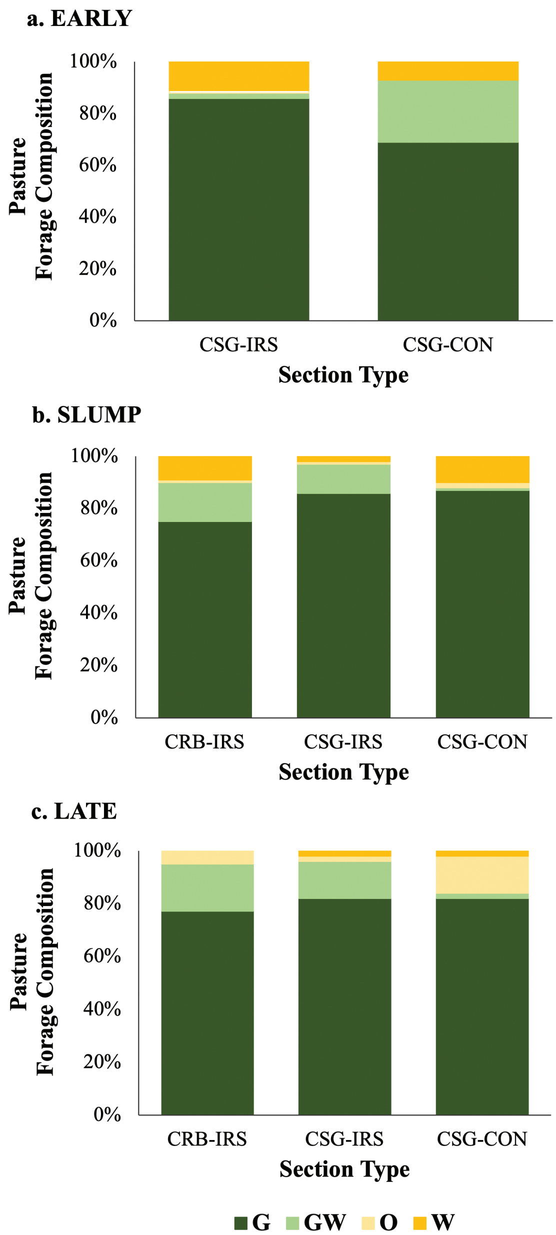

Figure 1. Pasture forage botanical composition (%) across pasture sections (crabgrass sections of integrated rotational grazing system [CRB-IRS], cool-season grass sections of integrated rotational grazing system [CSG-IRS], and the control cool-season grass system [CSG-CON]) during (a) EARLY (mid-May to mid-July), (b) SLUMP (mid-July to mid-September), and (c) LATE (mid-September to mid-November) grazing periods. Grass (G) included planted forage grasses (*Argyle* Kentucky bluegrass, *Inavale* orchardgrass, and *Tower* tall fescue in CSG sections and *Quick-N-Big* crabgrass in CRB sections. All other non-planted grass species were classified as grass weeds (GW), and any non-grass plants as Weeds (W). Other (O) includes observations including bare ground, dead plant material, manure, water, etc. There was an association between forage composition and section type in all three periods ($P < 0.002$).

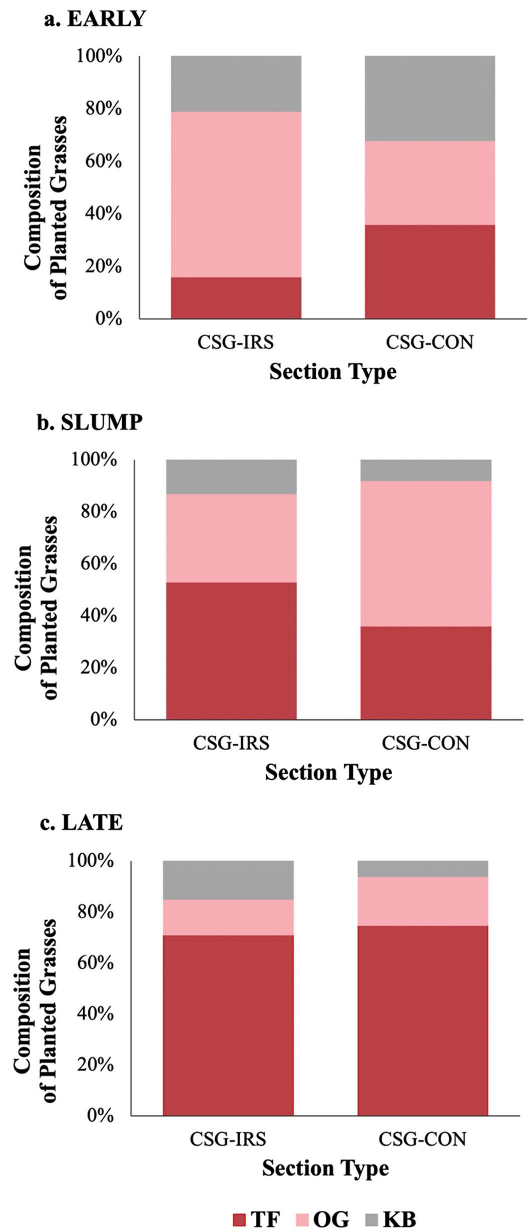

Figure 2. Species composition (%) of planted grasses in cool-season grass sections of the integrated rotational grazing system (CSG-IRS) and the cool-season grass control system (CSG-CON). (%) across (a) EARLY (mid-May to mid-July), (b) SLUMP (mid-July to mid-September), and (c) LATE (mid-September to mid-November) grazing. Cool-season grass species included *Argyle* Kentucky bluegrass, *Inavale* orchardgrass, and *Tower* tall fescue in CSG sections and *Quick-N-Big* crabgrass in CRB sections. There was an association between species composition and system in the EARLY and SLUMP periods ($P < 0.05$), but not during LATE grazing.

sections in 2017 could have impacted establishment and growth of CSG grasses in the current study. Other factors such as slight variation in topography or shade from trees along fence lines could have also influenced the composition of CSG observed in the IRS versus the CON pasture.

Horses in both systems had access to CSG pasture sections throughout the EARLY grazing period. Pasture yield was high during these months, and three sections of CON were mowed in mid-June, as they were becoming overly mature. Regrowth in these sections was subsequently grazed upon reaching an adequate height in July. The CC was greater in CSG-IRS (220 ± 37.4 horse d/ha) than CSG-CON (114 ± 26.5 horse d/ha; $P = 0.05$; Figure 3a), but HM did not differ by section type (CSG-CON: 2537 ± 605; CSG-IRS: 3783 ± 856 kg/ha; Figure 3b). The HM of CSG in the EARLY period are within ranges documented in previous equine grazing studies conducted in the Mid-Atlantic states by Jordan et al. (1995) (1,588–4,070 kg/ha) and McIntosh (2007) (2,612 kg/ha) for this period of the grazing season. These HM values are also similar to historical late-spring and early-summer yields reported in prior years for fields used in the current study (Williams et al., 2020).

During the SLUMP period, HM and CC were all greatest in CRB-IRS (HM: 4,758 ± 698 kg/ha; CC: 196 ± 31.0 horse d/ha; $P < 0.02$). The HM and CC did not differ between CSG-IRS (HM: 1,086 ± 698 kg/ha; CC: 32 ± 31.0 horse d/ha) and CSG-CON (HM: 970 ± 493 kg/ha; CC: 46 ± 21.9 horse d/ha). Conversely HM did not differ during LATE grazing (CRB-IRS: 1,033 ± 296; CSG-IRS: 979 ± 296; CSG-CON: 1,561 ± 209 kg/ha). However, CC was greater in CSG-CON (84 ± 9.43 horse d/ha) than CSG-IRS (32 ± 13.33 horse d/ha; $P = 0.03$) in the LATE period. There was also a trend for greater CC in CSG-CON than CRB-IRS (40 ± 13.33 horse d/ha; $P = 0.06$), but CC did not differ between CRB and CSG within IRS. The HM of CRB-IRS is within yields reported for *Quick-N-Big* CRB grown in Tennessee (1,888 to 7,501 kg/ha) and another CRB variety, *Red River*, in a Virginia trial, but near the lower end of yield ranges reported in Oklahoma (5,459 to 24,176 kg/ha) for *Quick-N-Big*, *Red River*, or *Impact* varieties (Teutsch et al., 2005; Gelley et al., 2016; Bouton et al., 2019). However, these prior studies utilized mechanical harvesting rather than grazing as the means of forage removal. Little research to date has been conducted for improved forage varieties of CRB in the Mid-Atlantic or Northeast United States or under stresses induced by grazing horses. In Maryland, reported yields of the *Red River* CRB variety (461 to 1,580 kg/ha) from forage plots subjected to a compaction simulation designed to mimic equine grazing pressure were well below those documented during the SLUMP period in the current study (Jaqueth et al., 2021).

Yield results for the EARLY and SLUMP periods should be interpreted with consideration of the need to mow multiple CSG-CON sections during the EARLY period and one CRB-IRS section in the SLUMP period prior to first grazing. Depending on stocking density, initial forage growth can out-pace the capacity for forage consumption in grazing animals (Burk et al., 2011). In the case of CSG-CON in the EARLY period, sections were mowed to avoid forage becoming over-mature and unpalatable for the grazing horses. For CRB-IRS, the concern was the potential for lodging of overly tall CRB, which had been observed in preliminary work at the study site. Thus, CSG-CON had un-used grazing capacity in the EARLY period. Had more horses been available to graze at a higher stocking rate, this would have resulted in greater recorded yield and CC in the CSG-CON sections that were mowed prior to grazing. The same is true of CRB-IRS during the SLUMP period. One option to prevent waste of forage without the need for increasing the stocking rate would be to harvest un-grazed forage as hay. This hay could then have been fed to horses during periods in which pasture was non-productive and horses were confined to stress lots, decreasing supplemental feed costs. This practice has been employed in prior studies (Burk et al., 2011), but is dependent upon the availability of resources for harvesting and storing hay. This approach was not attempted in the current study due to lack of such resources.

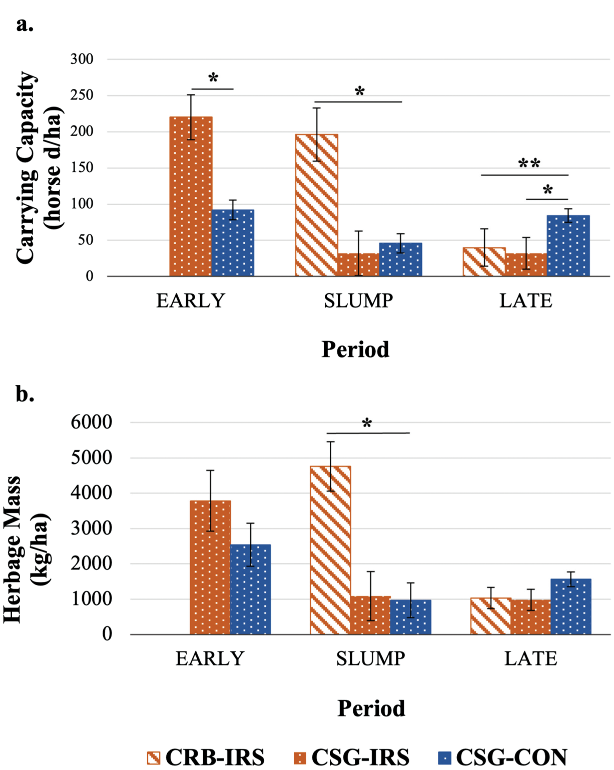

Figure 3. Pasture production by section type (crabgrass sections of integrated rotational grazing system [CRB-IRS], cool-season grass sections of integrated rotational grazing system [CSG-IRS] and the control cool-season grass system [CSG-CON]) including (a) carrying capacity and (b) herbage mass in EARLY (mid-May to mid-July), SLUMP (mid-July to mid-September), and LATE (mid-September to mid-November) grazing periods. A single asterisk indicates differences between section types within each grazing period at $P \le .05$. Double asterisks indicate a trend for differences $P \le 0.10$. Data are presented as the means ± SEM.

The difference in CC between CSG sections of CSG-CON and CSG-IRS during the LATE grazing period may have been, in part, attributable to the total number of rotations and the available land area in those pasture sections. Prior to the LATE grazing period, CSG sections of CRB-IRS averaged 2.67 rotations/section compared to only 1.67 rotations/section in CSG-CON. This was reflected in the results reported above for CC in the EARLY period, with CC in CSG-IRS more than two times that of CSG-CON sections. Because there were only three CSG sections in IRS compared with six CSG sections in the CON system, more frequent rotations were required in the EARLY period in order to maintain continuous pasture access for grazing horses and avoid feeding supplemental hay. While rotational grazing best management practices were followed to prevent over-grazing below an average 7.6 cm sward height and allow adequate regrowth prior to the next rotation, the greater number of rotations in the CSG-IRS sections during the EARLY period could have contributed to greater stress on pasture grasses and impaired productivity in later months. Additionally, the lower number of CSG sections in CRB-IRS resulted in fewer possible rotations in the LATE period. In the CON system, each section averaged 1.12 rotations, with 0.67 rotations per CSG-IRS section in the LATE period. However, because there were half as many CSG sections available in IRS, this slight difference in number of rotations per section was amplified into a large difference in grazing days and CC. Thus, there was more limited potential for the CRB-IRS system to take advantage of the secondary peak in production characteristic of CSG as cooler temperatures returned in the fall months.

Adjusting aerial proportions of CRB to CSG, utilizing variable stocking rates, or interseeding CRB into existing CSG (as an alternative to monoculture establishment) may improve season-long production of IRS. Studies in cattle have utilized a lower proportion of WSG pasture area in comparison to cool-season pasture area than the 1:1 ratio used in the current study (Hudson et al., 2010; Tracy et al., 2010; Ritz et al., 2020). Moore et al. (2004) and Hudson et al. (2010) varied stocking rate by season to maximize integrated pasture production. Interseeding CRB, as opposed to monoculture establishment, would allow for grazing of CSG in all pasture sections both in the spring prior to planting of CRB and later in the grazing season (Guretzky et al., 2020). These options could minimize grazing pressure in the spring and early summer before CRB is available for grazing and increase fall yields in CSG pasture sections. These strategies could also have some benefit for summer grazing of CRB. The *Quick-N-Big* variety used in the current study is fast-growing and reaches maturity quickly, which could lead to issues with lodging and could affect production and persistence over the full summer season. A smaller aerial proportion of CRB or adjustments in stocking rate could help prevent against such problems. However, future research is necessary to determine the proportion of CRB to CSG that would maximize season-long production, and the impact of stocking rate on production of CRB IRSs.

Alternatively, staggering planting of CRB or incorporating other improved CRB varieties may provide some benefit. Both *Red River* and *Impact* varieties have demonstrated higher late-season yields in comparison to *Quick-N-Big* (Bouton et al., 2019). Because the present study was conducted in the Northeast United States where the climate is more temperate than Southern areas of the United States where CRB is more commonly utilized for forage production, the *Quick-N-Big* variety was selected due to its rapid early-season growth. However, a mix of varieties with differing times of peak production may result in more uniform yields across the “summer slump” and sustain growth into the fall months in years such as 2019 when temperatures are above average and precipitation below average in fall months. This extension of CRB productivity would also allow for a longer period of rest and regrowth for CSG sections prior to fall grazing.

Environmental conditions during the current study likely also impacted pasture productivity during the SLUMP and LATE period. Prolonged drought conditions in September limited pasture production at the end of the SLUMP period and into later-season grazing. This could have further depressed regrowth in CSG-IRS sections that were already more stressed due to higher grazing pressures in earlier grazing. Cattle integrated grazing studies have reported data from multiple years. Production differences between years is often attributed to differences in environmental conditions (Moore et al., 2004; Tracy et al., 2010; Ritz et al., 2020). Studying equine integrated rotational systems over multiple years would be necessary in order to more fully determine the production potential of this approach and how to best manage these systems both in normal (or average) years as well as under conditions of environmental stress. Additionally, a larger study site area enabling additional replicates would provide more robust data on which to base integrated rotational grazing recommendations for equine operations.

Production Cost

Production costs may vary based on local hay, fertilizer, and service provider/labor pricing. In the current study, horses in the IRS system consumed 1,782 kg supplemental hay per horse over the full grazing season compared to 2,409 kg supplemental hay per horse in CON. At the local hay market price of $350/T, this corresponds to $229/horse to provide supplemental hay to horses in IRS and $309/horse in CON. Weed control expense was also greater in CON, as twice the amount of triclopyr was applied (six CSG-CON sections vs. three CSG-IRS sections). While the IRS required application of glyphosate to kill existing vegetation prior to establishing CRB, the cost of glyphosate is lower than that of triclopyr. Additionally, CRB sections required only one application of 2,4-D, whereas all CSG sections required two seasonal applications. Therefore, total herbicide costs (chemical and labor) for CON were $273, but were only $174 for IRS. The IRS system did also require additional costs for establishment of CRB, but these costs (seed + labor) were relatively minimal ($211). Total nitrogen fertilizer application was the same between the two systems, with three split applications of 33.6 kg/ha ($135/system). Mowing and dragging costs were similar (CON: $128; IRS: $117). Even though there were two more rotations in CON than IRS, CRB sections were not drug post-grazing lowering the post-rotation maintenance cost. This management decision was based on observations from previous studies in our lab, where it was observed that dragging damaged CRB root structure and plant integrity, impairing productivity in subsequent rotations. Thus, the final cost to maintain horses in IRS was $441/horse. In CON, this final cost was $488/horse. Alternatively, if horses had been maintained solely with a hay diet (no pasture access), estimated hay cost over this same period would have been $750/horse. Therefore, both grazing approaches were more cost effective than offering a hay diet.

For a producer implementing integrated rotational grazing, the expense margin compared to traditional cool-season rotational grazing would be heavily dependent upon the pricing structure of inputs and labor. For example, if a producer had access to a less expensive hay source, this margin would narrow. Availability and ownership of the equipment necessary for seeding, mowing/dragging, and applying herbicide/fertilizer could also impact producer costs. Furthermore, the cost analysis described above does not consider the initial cost of establishing the CSG sections (which could be allocated annually over the life of stand) or the fact that if managed properly, improved annual CRB varieties can reseed themselves, which could lower or eliminate annual reseeding costs. Similar to yield measures, no statistical analysis was possible on whole-system measures such as production costs. The above-noted differences in production costs represent numerical, rather than statistical, differences. Thus, further research would be necessary in order to draw definitive conclusions about the financial implications of this integrated rotational grazing approach at the producer level.

Forage Nutrients

Differences in soluble carbohydrates were found between CRB-IRS, CSG-IRS, and CSG-CON across all grazing periods (Table 3). In the EARLY period, NSC and water-soluble carbohydrate (WSC) concentrations were greater in CSG-CON than CSG-IRS ($P < 0.04$). Differences in NSC concentrations between the CSG sections of IRS and CON could reflect the above-noted differences in species composition. The percentage of KB was greater in CSG-CON versus CSG-IRS in the EARLY period, and the NSC concentration of KB has been previously reported to be greater than that of OG (Allen et al., 2013). There were no differences in NSC during the SLUMP period. While WSC was lower in CRB-IRS than CSG-CON ($P = 0.04$), there were no differences with CSG sections within IRS. However, there was a trend for lower ethanol-soluble carbohydrates in CRB-IRS versus CSG-IRS, but greater starch in CRB-IRS than CSG-CON ($P \leq 0.10$). In LATE grazing, starch was greater in CRB-IRS than CSG-CON ($P = 0.008$), but there were no differences in other soluble carbohydrate fractions. Inconsistencies in the differences between soluble carbohydrates in CRB-IRS and the CSG in either the CON or IRS systems may also be explained, in part, by differences in species composition of the CSG sections between the two systems.

Overall, the NSC concentrations were low for both CRB and CSG forages. Forage NSC levels were elevated above the 10% threshold established for obese horses and those with metabolic dysfunction (Frank, 2010) for several CSG rotations occurring earlier in the growing season and in November, but NSC levels never exceeded 15%. The NSC content of CRB did not exceed 10%

Table 3. Nutrient composition[1] by section type (crabgrass sections of integrated rotational grazing system [CRB-IRS], cool-season grass sections of integrated rotational grazing system [CSG-IRS], and the control cool-season grass system [CSG-CON]) across EARLY (mid-May to mid-July), SLUMP (mid-July to mid-September), and LATE (mid-September to mid-November) periods

	Section type[2]		
	CRB-IRS	CSG-IRS	CSG-CON
DM, %			
EARLY	—	27.5 ± 0.02[a]	26.6 ± 0.01[b]
SLUMP	22.4 ± 0.01[a]	23.6 ± 0.07[b]	25.2 ± 0.02[c]
LATE	31.4 ± 0.02[a]	24.5 ± 0.02[b]	20.1 ± 0.02[c]
Digestible energy, Mcal/kg			
EARLY	—	2.06 ± 0.05	2.13 ± 0.04
SLUMP	2.06 ± 0.50[ab]	2.23 ± 0.03[a]	2.10 ± 0.02[b]
LATE	2.19 ± 0.05	2.23 ± 0.07	2.20 ± 0.04
Crude protein, %			
EARLY	–	13.2 ± 1.84	12.5 ± 1.65
SLUMP	19.1 ± 1.09[ab]	21.8 ± 1.43[a]	16.1 ± 1.24[b]
LATE	17.6 ± 1.21[a]	20.3 ± 1.71[ab]	22.4 ± 1.91[b]
Acid detergent fiber, %			
EARLY	–	36.8 ± 1.19	35.9 ± 1.06
SLUMP	32.4 ± 0.75	29.4 ± 0.97	32.9 ± 0.84
LATE	33.9 ± 1.08[a]	29.4 ± 1.54[b]	29.2 ± 0.82[b]
Neutral detergent fiber, %			
EARLY	–	62.8 ± 2.11	60.5 ± 1.89
SLUMP	57.7 ± 1.09[ab]	54.2 ± 1.41[a]	60.7 ± 1.22[b]
LATE	56.4 ± 1.95	54.3 ± 2.76	55.3 ± 1.47
Water-soluble carbohydrate, %			
EARLY	–	7.8 ± 0.65[a]	10.5 ± 0.58[b]
SLUMP	4.46 ± 0.80[a]	5.93 ± 1.04[ab]	7.92 ± 0.90[b]
LATE	5.72 ± 0.92	4.17 ± 0.69	6.69 ± 0.95
Ethanol-soluble carbohydrate, %			
EARLY	–	3.75 ± 0.57	4.52 ± 0.51
SLUMP	2.50 ± 0.27	3.63 ± 0.36	3.42 ± 0.31
LATE	3.32 ± 0.57	2.86 ± 0.65	3.69 ± 0.53
Starch, %			
EARLY	–	1.45 ± 0.68	1.36 ± 0.60
SLUMP	1.58 ± 0.27	0.73 ± 0.36	0.68 ± 0.31
LATE	2.24 ± 0.92[a]	1.18 ± 0.65[ab]	0.31 ± 0.10[b]
Non-structural carbohydrate, %[3]			
EARLY	–	9.25 ± 0.76[a]	11.86 ± 0.68[b]
SLUMP	6.04 ± 0.89	6.67 ± 1.43	8.60 ± 0.99
LATE	8.09 ± 0.96	6.42 ± 0.85	7.16 ± 0.57
Calcium, %			
EARLY	–	0.37 ± 0.06	0.44 ± 0.05
SLUMP	0.49 ± 0.04	0.53 ± 0.05	0.49 ± 0.04
LATE	0.50 ± 0.04	0.54 ± 0.05	0.62 ± 0.04
Phosphorus, %			
EARLY	–	0.46 ± 0.05	0.37 ± 0.04
SLUMP	0.45± 0.04	0.56 ± 0.06	0.43 ± 0.05
LATE	0.34± 0.02	0.44 ± 0.04	0.39 ± 0.02

[1]Nutrient composition of forage samples was determined by wet chemistry (Equi-Analytical Laboratories, Ithaca, NY). Nutrient concentrations are presented on a dry-matter (DM) basis. Data are presented as the means ± SEM.

[2]Nutrient content across section types were analyzed separately for each grazing period, as CRB was not available for grazing during EARLY grazing due inherent temporal differences in establishment and growth.

[3]Non-structural carbohydrates were calculated as the sum of water-soluble carbohydrates and starch.

[a,b]Indicates significant difference within rows ($P \leq 0.05$).

for any rotation in either the SLUMP or LATE periods. The NSC concentrations for CRB in the current study are similar to those reported for other warm-season annual grasses evaluated in an equine grazing study in Minnesota (Deboer et al., 2017, 2018), but were slightly higher than NSC content of perennial native WSGs in Virginia (Ghajar et al., 2021). The NSC concentrations of the *Quick-N-Big* CRB in the current study were, however, lower than those found for *Red River* CRB in Maryland (Jaqueth et al., 2021). These results indicate that *Quick-N-Big* CRB may serve as a potential pasture forage source for horses requiring lower dietary NSC. However, with the exception of one CSG-CON rotational section, the NSC levels measured in CSG sections of both systems remained below 10% during the SLUMP period. It is also important to note that while statistically significant, the magnitude of differences in soluble carbohydrates reported in the present study is relatively small (<3.5% in all instances). Additional research is necessary to determine whether or not differences in NSC levels in the range found in these pasture forages would impact metabolism in the grazing horse.

Seasonality of NSC values in CSG forages, with lower NSC during summer months compared to spring and fall, has been previously documented (Jensen et al., 2014; Williams et al., 2019, 2020). As the SLUMP is the period during which horses in an integrated grazing system would spend the most time grazing CRB rather than CSG, results of this study indicate that benefits of this practice may be minimal if the nutritional management goal is to limit dietary NSC. However, many factors (i.e., species [or even variety within species], plant maturity, climate, and growing conditions) influence sugar metabolism and partitioning in growing plants (Taiz and Zeiger, 2002). Additionally, the forage processing protocols following sample collection can impact plant soluble carbohydrates (Pelletier et al., 2010). In other equine grazing studies, summer NSC concentrations above 10% have been reported, particularly in perennial ryegrass [*Lolium perenne* (L.)] pastures (Allen et al., 2013; Grev et al., 2017; Catalano et al., 2020). It is possible that integrated grazing with *Quick-N-Big* CRB could aid in limiting NSC intake in pasture systems with different species composition and/or under alternative growing conditions. Additionally, if CRB varieties with peak production later in the grazing season were used, perhaps a greater benefit could be realized during later-season grazing when NSC concentrations in CSG may be higher (Jensen et al., 2014; Williams et al., 2020).

There were no differences in any other forage nutrients during EARLY grazing. In the SLUMP period, differences in digestible energy (DE), neutral detergent fiber (NDF), and crude protein (CP) were found between CSG-CON and CSG-IRS ($P < 0.04$), but no differences in these nutrients were found with CRB-IRS. Forage CP and DE were greater and NDF lower in CSG-IRS than CSG-CON ($P < 0.05$), but there were no differences between either CSG-IRS or CSG-CON and CRB-IRS for these nutrients. There was also a trend for greater acid detergent fiber (ADF) in CSG-CON versus CSG-IRS ($P = 0.07$) during the SLUMP period. Forage DE and NDF did not differ by section type during LATE grazing. However, ADF was greater in CRB-IRS than CSG-CON ($P = 0.02$), and there was a trend for greater ADF in CRB-IRS versus CSG-IRS ($P = 0.09$). Conversely, CP was lower in CRB-IRS than in CSG-CON ($P = 0.02$). There was also a trend for lower phosphorus (P) in CRB-IRS than CSG-IRS ($P = 0.07$) in the LATE period. The nutrient concentrations reported for CSG sections are similar to those found in prior rotational grazing trials at the current study site (Weinert and Williams, 2018; Williams et al., 2020). The CP concentrations of CSG in this study are within to slightly above concentrations documented in studies evaluating KB, OG, and TF under equine grazing, while fiber concentrations were slightly greater (Allen et al., 2013; Jacqueth, 2018). The CP concentrations of CRB in the current study were greater and fiber concentrations lower than those reported in prior studies that have evaluated nutrient composition of *Quick-N-Big* CRB (Gelley et al., 2016; Bouton et al., 2019).

Mean DE values for CRB-IRS were 2.15 Mcal/kg and 2.17 Mcal/kg in SLUMP and LATE periods, respectively. At a consumption rate of 2.5% BW DM, horses grazing CRB would exceed dietary energy requirements for horses at maintenance (NRC, 2007). Similarly, CRB would provide excess CP, calcium (Ca), and P as well as exceeding requirements for other minerals including potassium, magnesium, iron, manganese, copper, and zinc (shown in Table 4). The CRB did not meet the sodium requirement, but low concentrations are typical in forages and other non-processed equine feedstuffs, with supplemental salt commonly required (NRC, 2007). Horses in the current study were fed a ration balancer pellet and had access to

Table 4. Mean mineral content[1] of *Quick-N-Big* crabgrass grazed by horses in CRB-IRS during SLUMP (mid-July to mid-September) and LATE (mid-September to mid-November) grazing periods

Mineral[2]	SLUMP	LATE
Mg, %	0.67 ± 0.048	0.89 ± 0.034
K, %	4.02 ± 0.454	2.19 ± 0.075
Na, %	0.04 ± 0.016	0.01 ± 0.002
Fe, ppm	243 ± 22	334 ± 29
Zn, ppm	67 ± 4	92 ± 12
Cu, ppm	13 ± 0.9	15 ± 0.5
Mn, ppm	61 ± 13	96 ± 27
Mo, ppm	1.9 ± 0.26	1.1 ± 0.39

[1]Analyses were performed by Equi-Analytical Laboratories (Ithaca, NY). Concentrations are reported on a dry-matter (DM) basis. Data are presented as the means ± SE.

[2]Mg, magnesium; K, potassium; Na, sodium; Fe, iron; Zn, zinc; Cu, copper; Mn, manganese; Mo, Molybdenum.

a salt block. Therefore, low Na in CRB was not of concern.

Accumulation of nitrates and an inverse Ca to P ratio have been noted as potential concerns for horses grazing other warm-season annual grasses (Deboer et al., 2017). While not considered common in horses, cases of nitrate toxicity have been documented (Burwash et al., 2005), and application of high levels of nitrogen fertilizer can lead to nitrate accumulation in grasses (Nicholson, et al. 2007). Teutsch and Tilson (2005) reported that nitrate levels in *Red River* CRB fertilized with nitrogen fertilizer did exceed the 5,000-ppm threshold considered dangerous to cattle when fertilized with a single application at rates above 94 or 160 kg/ha (variable by year). In the present study, nitrogen fertilizer was applied at a total rate of 100.8 kg/ha, but nitrate-nitrogen levels in the *Quick-N-Big* CRB ranged from 1,070 to 2,495 ppm, well below the recommended threshold in horses (Burwash et al., 2005). The nitrate-nitrogen concentrations in CRB-IRS were also below levels reported in other warm-season annuals evaluated as potential equine forages (Hansen et al., 2016; DeBoer et al., 2017). Deboer et al. (2017) also observed Ca:P ratios below 1:1, the lowest recommendation for horses (NRC, 2007), in other warm-season annuals including Teff, sorghum sudangrass, and Siberian millet. In the current study, the Ca:P ratio for CRB remained above 1:1 in both SLUMP and LATE periods. Thus, concerns over these factors noted for other WSG species should not prevent grazing of CRB by horses.

Horse Body Condition

Horse body condition variables including mean and percent change for BW, BCS, and FAT in each grazing period are shown in Table 4. Mean horse BW, BCS, and FAT did not vary by grazing system. Mean horse BW and FAT did differ across periods ($P < 0.04$; Table 5); BCS, however, did not differ by period. Mean horse BW was lower in LATE grazing than EARLY grazing ($P = 0.02$; Table 4). There was also a significant system by period interaction for mean BW ($P < 0.001$). In CON, mean BW was lower in the SLUMP than during EARLY grazing ($P = 0.01$), but BW of horses in IRS did not differ between these two periods. Mean BW of horses in IRS was also lower in the LATE grazing than in the SLUMP period ($P = 0.01$), with no difference between CON horses. There was a trend for greater mean BW in CON horses during LATE versus EARLY grazing ($P = 0.08$), but this was not seen in IRS horses. In contrast to BW, mean FAT was greater in the LATE period than during EARLY grazing ($P = 0.03$), but there was no interaction of system and period.

Changes in these horse condition variables during each grazing period, however, were not entirely consistent with results reported for mean BW, BCS, and FAT. The percent change in horse BW and BCS varied by period ($P < 0.04$). Percent change BW did not differ by grazing system, but there was a trend for difference for percent change in BCS ($P = 0.10$). There was also significant grazing system by period interactions for both percent change BW and BCS ($P = 0.0004$). Horses in both IRS and CON gained weight, with increased BCS during EARLY grazing. There was a trend for a difference in the percent change BW and BCS between systems during the SLUMP period, when horses in CON lost weight (with decreased BCS), but a slight weight gain (and increased BCS) was found four horses in IRS ($P = 0.08$). The percent change in horse BW and BCS also differed during the LATE period, as horses in CON gained weight and increased BCS, while horses in IRS lost weight and BCS decreased ($P = 0.03$). In IRS, the percent change in BW and BCS differed between EARLY and LATE grazing ($P = 0.007$), while there was a trend for a difference between EARLY and SLUMP periods for BW ($P = 0.10$) but not for BCS. Percent change BW and BCS also differed between the SLUMP period and LATE grazing in IRS ($P < 0.02$). Again, this reflects minimal weight gain in IRS horses through the SLUMP period, with weight loss and decreased BCS occurring during the LATE period.

Table 5. Body weight, body condition score (BCS), rump fat thickness, and body fat percentage[1] of horses grazing within the integrated rotational grazing system (IRS) versus the control cool-season grass grazing system CON across the three periods of the grazing season: EARLY (mid-May to mid-July), SLUMP (mid-July to mid-September), and LATE (mid-September to mid-November)

	Grazing period					
	EARLY		SLUMP		LATE	
	Mean	Percent change, %	Mean	Percent change, %	Mean	Percent change, %
Body weight, kg	555 ± 18[a]	+6.30 ± 0.8[x]	550 ± 18[ab]	−0.88 ± 0.81[y]	545 ± 18[b]	−1.87 ± 0.81[y]
CRS	544 ± 25[ab]	+6.67 ± 1.15[x]	556 ± 25[a]	+1.67 ± 1.15[x]	538 ± 25[b]	−5.29 ± 1.15[y]
CON	566 ± 25[a]	+5.94 ± 1.15[x]	545 ± 25[b]	−5.41 ± 1.15[y]	552 ± 25[b]	+3.55 ± 1.15[x]
BCS, scale: 1−9	6.00 ± 0.34	+5.85 ± 1.50[x]	5.92 ± 0.34	+0.04 ± 1.50[y]	5.92 ± 0.34	+0.15 ± 1.50[x]
CRS	5.83 ± 0.49	+2.78 ± 2.12[x]	5.83 ± 0.49	+5.90 ± 2.12[x]	5.67 ± 0.49	−8.44 ± 2.12[y]
CON	6.17 ± 0.49	+8.93 ± 2.12[x]	6.00 ± 0.49	−5.81 ± 2.12[y]	6.17 ± 0.49	+8.74 ± 2.12[x]
Rump fat thickness, cm	1.57 ± 0.11[a]	+8.94 ± 9.10	1.73 ± 0.11[ab]	+14.93 ± 9.10	1.86 ± 0.11[b]	+16.22 ± 9.10
CRS	1.35 ± 0.16	+5.66 ± 14.0	1.72 ± 0.16	+32.8 ± 14.0	1.69 ± 0.16	+1.39 ± 14.0
CON	1.78 ± 0.16	+12.22 ± 14.0	1.74 ± 0.87	−0.35 ± 14.0	2.03 ± 0.87	+28.47 ± 14.0
Body fat, %	16.3 ± 0.59[a]	+6.93 ± 4.49	17.4 ± 0.59[ab]	+2.66 ± 4.49	16.5 ± 0.59[b]	+6.53 ± 4.49
CRS	15.5 ± 0.87	+8.42 ± 6.34	16.2 ± 0.87	+6.08 ± 6.34	16.6 ± 0.87	−0.61 ± 6.34
CON	17.0 ± 0.87	+5.45 ± 6.34	16.8 ± 0.87	−0.78 ± 6.34	18.2 ± 0.87	+13.7 ± 6.34

[1]For mean BW, FAT and rump fat thickness, an effect of grazing period ($P < 0.03$) was observed. Interactions were also for system by period for body weight ($P < 0.0001$). Percent change in BW and BCS differed by period ($P < 0.04$). Percent change BW did not differ by grazing system, but there was a trend for difference in percent change BCS ($P = 0.10$). There was also significant grazing system by period interactions for both percent change BW and BCS ($P = 0.0004$). The percent change in FAT and rump fat thickness did not differ by grazing system or period, and there was no grazing system by period interaction.

[a,b]Indicates significant difference within rows for mean values ($P \leq 0.05$).

[x,y]Indicates a trend for a difference within rows for percent change values ($P \leq 0.05$).

Conversely, in CON, the percent change in BW and BCS differed between EARLY and SLUMP periods and between SLUMP and LATE periods ($P < 0.009$), but there was no difference between the percent change BW or BCS in EARLY versus LATE grazing. This reflects the previously reported weight loss (and lowered BCS) in CON horses during the SLUMP, and the subsequent weight gain (and increased BCS) during the LATE period. In contrast to BW and BCS, however, the percent change in FAT did not differ by grazing system or period, and there was no grazing system by period interaction.

These results were not unexpected given animal and grazing management practices utilized in the current study. Horses in each system were maintained on CSG pasture sections for the same number of grazing days during the EARLY period. Thus, it is logical that measures of animal condition would be similar between systems during these months. The almost unlimited access to CSG pasture sections during EARLY grazing also explains the increases in weight and BCS during this period. When ad libitum access is provided, intake of pasture forage can exceed 3% BW DM in horses, with ponies known to consume up to 5% BW DM (Smith et al., 2007; Longland et al., 2012). Thus, there is potential for pastured horses to greatly exceed dietary caloric requirements (Trieber et al., 2006; Goer and Harris, 2013). This impact of forage availability on weight and BCS is also evident in changes that occurred in the SLUMP and LATE periods. During these periods, horses in IRS were maintained on a mixture of CRB, CSG, and supplemental hay, with CON horses offered either CSG or hay, depending upon forage availability. Horses in IRS had almost unlimited pasture access throughout the SLUMP, with grazing split between CRB (48 days) and CSG (14 days), while adequate pasture forage was only available for 25 days in CON-CSG during this period. Horses in CON were thus confined to a stress lot for over half of the SLUMP period. When confined to the stress lot, horses were fed supplemental hay at the maintenance requirement of 2.5% BW DM, while horses on pasture were allowed to consume pasture forage ad libitum. Therefore, the finding that BW and BCS decreased in the SLUMP compared to EARLY grazing for horses in CON when slight gains were seen in IRS horses is likely attributable to differences in access to forage. Subsequent fall regrowth of CSG pasture forage in CON allowed for grazing throughout a majority of the LATE period (42 d), whereas in IRS horses had pasture access for only 23 d (CRB 15 d; CSG 8 d) and were maintained on hay for the remaining days of the LATE period. Accordingly, BW and BCS decreased in IRS horses from SLUMP to LATE, while increases were found for horses in CON.

These findings thus confirm the nutritive value analyses, with CRB pasture forage and IRS grazing providing adequate nutrition to maintain acceptable body condition in healthy nonobese horses. Differences found in means or percent changes for BW, BCS, and FAT represent only slight variances in actual horse condition and may be of limited physiological significance to the healthy grazing horse. Neither grazing approach resulted in under-weight or obese conditions in grazing horses. Minimal inter-system differences in horse condition may also be a result of the small sample size used in the current study, with land area constraints limiting group size to three horses. It is possible that a larger sample size would be required to more conclusively determine the impacts integrated rotational grazing may have on horse BW, BCS, and FAT.

Interestingly, while mean BW was greater in EARLY versus LATE grazing, the opposite was found for FAT. Percentage body fat was estimated using the Westervelt method (Westervelt et al., 1976). However, differences in mean FAT cannot be attributed to a reduction in BW in LATE versus EARLY periods (thereby increasing percentage body fat), as similar to results for FAT, the mean rump fat thickness itself was greater during the LATE period than in the EARLY period ($P = 0.04$; Table 5). Seasonal decreases in body weight of horses maintained on pasture are not uncommon in winter months (Williams et al., 2020). However, Dugdale et al. (2011) reported weight gains during winter months and also observed that increased weight could not alone account for corresponding greater increases in body fat mass. Argo et al. (2012) found a poor association between changes in BCS and weight, and also reported increases in subcutaneous adipose depots including measures of rump fat thickness in horses fed a restricted diet that induced marked weight loss. Furthermore, rump fat thickness increased despite an overall reduction in total body fat mass, which authors attributed to redistribution of stored fat depots to the subcutaneous layer to assist with thermoregulation in response to cooler temperatures in winter months during which the study was conducted (Argo et al., 2012). It should be noted that while rump fat thickness (and estimations of body fat based on rump fat thickness) have been widely utilized in equine research (Kearns et al., 2006; Gordon et al., 2007; Williams et al., 2020), other studies have suggested that rump fat thickness may not be the most accurate marker of total body fat (Dugdale et al., 2010, 2011; Argo et al., 2012). Thus, additional morphometric and ultrasonographic measurements to complement those collected in the current study could have provided a more comprehensive assessment of the effects of integrated rotational grazing management on horse body condition.

In conclusion, results of this study indicate that implementing an integrated rotational grazing approach incorporating the warm-season annual *Quick-N-Big* CRB may offer production advantages when compared to a traditional CGS rotational grazing system. Production variables including HM and CC were all greater in CRB versus cool-season pasture sections during the critical "summer slump" period from mid-July to mid-September. However, HM and CC were lower in the IRS during late-season grazing, and further research is needed to determine if adjusting aerial proportions of CRB to CSG, stocking rates, or CRB variety mixtures could improve season-long production in integrated rotational systems.

Finally, the integrated rotational grazing approach provided adequate nutrition to meet daily nutrient requirements and maintain body condition in grazing horses. Integrated rotational grazing did not, however, result in marked differences in forage nutritional composition or horse condition in comparison to a traditional cool-season system. The *Quick-N-Big* CRB grazed in the current study was low in soluble carbohydrates, and thus may serve as potential source of pasture forage for horses where dietary NSC levels are of concern. While WSC concentrations of *Quick-N-Big* CRB were lower than cool-season sections in the CON during the "summer slump," mean NSC remained below 10% for all forages during the slump and late grazing periods when both CRB and CSG were available to graze. Therefore, the primary benefit of integrated rotational grazing is more likely to be increased forage yield rather than limiting NSC intake of grazing horses.

ACKNOWLEDGMENTS

This work was supported by the United States Department of Agriculture National Institute of Food and Agriculture Hatch project 1003557 through the New Jersey Agricultural Experiment Station, Hatch project NJ06170 and the United States Department of Agriculture Northeast Sustainable Agriculture, Research, and Education project gne17-162. Additional funding was provided by the Rutgers University Equine Science Center

(57 US 1, New Brunswick, NJ 08901). Seed for this project was donated by DLF Pickseed (Halsey, OR) and Dalrymple Farms (Thomas, OK); ration balancer was donated by Mars Horsecare US, Buckeye Nutrition (Dalton, OH).

Conflict of interest statement. None declared.

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