Improved Nutritive Value of Kura Clover– and Birdsfoot Trefoil–Grass Mixtures Compared with Grass Monocultures

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Improved Nutritive Value of Kura Clover– and Birdsfoot Trefoil–Grass Mixtures Compared with Grass Monocultures

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ABSTRACT

Improved dry matter (DM) production of cool-season grass monocultures may result from either N fertilization or the addition of legumes such as kura clover (*Trifolium ambiguum* M. Bieb.) or birdsfoot trefoil (*Lotus corniculatus* L.). Such improvements could affect forage nutritive value and potential milk production from dairy cattle (*Bos taurus*). Laboratory estimates of forage nutritive value as well as potential milk production per unit mass and area were compared for six levels of N fertilizer on Kentucky bluegrass (KBG; *Poa pratensis* L.), smooth bromegrass (SBG; *Bromus inermis* Leyss.), and orchardgrass (OG; *Dactylis glomerata* L.) in monoculture or with either kura clover or birdsfoot trefoil in binary mixture with each grass. Experiments managed in a three-harvest system were conducted from 1994 through 1996 near Arlington and Lancaster, WI. Either legume reduced neutral detergent fiber and acid detergent fiber and increased crude protein when added to grass. These effects increased with greater mixture legume DM proportions. Compared with grass monocultures averaged across years and locations and for any N rate, mixtures had greater potential milk production per megagram of DM and followed KBG > SBG > OG. Similarly, potential milk production per hectare for kura clover–grass mixtures exceeded that of monocultures by at least 49% for KBG and 12% for SBG while birdsfoot trefoil–grass mixtures were greater by at least 28% for KBG and 20% for SBG. Orchardgrass required maximum N rates to match milk production per hectare of the mixtures. Adding either kura clover or birdsfoot trefoil will improve potential milk production of these grasses while reducing reliance on fertilizer N in the North-Central USA.

As balanced rations for lactating dairy cattle, managed grasslands of the North-Central USA are often too low yielding, deficient in protein and minerals, and excessively high in fiber. Producers may rely on fertilizer N in this environment to improve forage dry matter (DM) production and persistence of desirable grass species. However, for decades, the region's producers have used forage legumes as an alternative to fertilizer N to improve sward DM production and nutritive value. Populations of alfalfa (*Medicago sativa* L.), birdsfoot trefoil, red clover (*Trifolium pratense* L.), and white clover (*Trifolium repens* L.) intended to improve sward DM yield and dietary quality rarely persist more than a few years under frequent defoliation in this region because of disease, drought, mismanagement, competition, and winterkill.

Kura clover is a long-lived, perennial, rhizomatous legume (Bryant, 1974; Taylor and Smith, 1998) that tolerates frequent defoliation in monoculture (Peterson et al., 1994) or in binary mixture with grass (Kim, 1996) and is suitable for hay or pasture production in this region (Sheaffer and Marten, 1991; Sheaffer et al., 1992). Kura clover has been identified as a grass-compatible legume with excellent persistence in mechanically harvested production systems (Kim, 1996; Zemenchik et al., 2001). However, there is limited information available regarding laboratory estimates of forage quality or potential milk production changes that may result by adding kura clover to cool-season grass swards. Peterson et al. (1994) reported that kura clover leaf proportion of total harvested forage DM was positively correlated to crude protein (CP) and inversely correlated to concentrations of acid detergent fiber (ADF) and neutral detergent fiber (NDF). Kim (1996) related harvest frequency and height to legume composition of kura clover–grass mixtures and kura clover monoculture but did not include a grass monoculture as one of the control treatments. Zemenchik et al. (2001) estimated that kura clover grown in binary mixtures with Kentucky bluegrass (KBG) resulted in total-season DM yields equivalent to 251 kg N ha^{-1} split-applied to that grass in monoculture. Similarly, estimated N replacement value of kura clover with orchardgrass (OG) was 93 kg N ha^{-1} and for smooth bromegrass (SBG), ranged from 74 to 325 kg N ha^{-1}, depending on the year.

Birdsfoot trefoil is more widely used by forage producers and has been more extensively studied than kura clover. It is known to be bloat safe because it contains a relatively low concentration of tannins (Lees et al., 1984) and has thick cell walls compared with other forages (Lees et al., 1981). Moreover, it is a prolific seed producer that can persist in pastures by self seeding if the grazing or harvesting interval exceeds 60 d in midsummer (Sheaffer et al., 1984). Birdsfoot trefoil maintains its nutritive value longer than many other legumes as it matures (Buxton et al., 1985) and can be stockpiled in pastures for subsequent utilization by grazing animals (Marten and Jordan, 1979).

Birdsfoot trefoil and kura clover performance in forage production systems for lactating dairy cattle should be evaluated after considering changes in both forage DM yield and forage nutritive value because both of these parameters influence milk yield per unit land area (Mertens, 1973; Reid et al., 1988; Van Soest, 1994a). Optimum milk production from forages of different quality occurs at the point of maximum feed intake (Mertens, 1985). Intake of low-fiber, high-energy forage is regu-

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; KBG, Kentucky bluegrass; NDF, neutral detergent fiber; OG, orchardgrass; SBG, smooth bromegrass; TDN, total digestible nutrients.

lated by ruminant energy demand. Within natural constraints, feeding low-fiber, high-energy rations to lactating dairy cattle provides more energy for potential milk production once energy demands for weight gain, metabolism, and maintenance are met. Low-energy forage requires more supplemental grain to balance rations than if high-energy forage is included in the diet. Maximizing the proportion of a high-energy ration that can be comprised of forage will reduce the need to increase the energy density of the diet by adding costly processed grains. There are also biological limitations to feeding grain supplements because forage fiber must comprise a substantial portion of the diet to maintain rumen microbial populations, achieve high milk-fat concentration, and avoid rumen acidosis (Van Soest, 1994b).

Continued dependence on fertilizer N, regular sward renovation by seeding legumes to improve DM production and nutritive value, reliance on grain concentrates to balance rations, and a relatively short growing season contribute to reduced profit margins for the livestock operations in the North-Central USA. Identifying management practices and persistent, high quality legumes that will provide a long-term supply of high quality forage could improve profitability of livestock operations within temperate grass communities of the region. Computer software programs such as MILK91 (Undersander et al., 1993) have been developed during the last decade to help evaluate solutions to these problems. Accordingly, the objective of this research was to determine whether changes in nutritive value and potential milk production resulting from using either kura clover or birdsfoot trefoil in mixtures with KBG, SBG, or OG could reduce reliance on fertilizer N for dairy cattle producers in the North-Central USA.

MATERIALS AND METHODS

Experimental Design and Stand Establishment

Three separate, adjacent experiments with KBG, SBG, and OG were conducted from 1994 to 1996 at the University of Wisconsin Arlington Agricultural Research Station (43°18′ N, 89°21′ W) on Plano silt loam soil (well-drained, fine-silty, mixed, superactive, mesic Typic Argiudoll) and repeated at the University of Wisconsin Lancaster Agricultural Research Station (42°50′ N, 90°47′ W) on Rozetta silt loam soil (moderately well-drained, fine-silty, mixed, superactive, mesic Typic Hapludalf). On the experimental sites during 1991 and 1992, soybean [*Glycine max* (L.) Merr.] was grown at Arlington and no-till corn (*Zea mays* L.) was grown at Lancaster.

Eight treatments in each experiment consisting of six N levels and two mixtures were arranged in a randomized complete block design with four replications. Spring seedbed preparation was performed in 1993 and included moldboard plowing to 15 cm followed by disking and cultimulching. Plots that were 6.1 m long by 0.9 m wide were sown on 30 Apr. 1993 at Arlington and 14 May 1993 at Lancaster. Using a six-row Carter planter (Carter Manufacturing, Brookston, IN), six monoculture grass treatments in each experiment were sown with 'Park' KBG, 'Badger' SBG, and 'Orion' OG at 17.9, 17.9, and 9.0 kg ha^{-1}, respectively. In each experiment, there were also two treatments that were binary mixtures comprised of the respective grass along with either kura clover or birdsfoot trefoil. The two mixture treatments in each experiment were sown with grass at one-half the seeding rate of the grass monoculture treatments. The kura clover mixture treatment was established by oversowing with the same planting technique at 9.0 kg ha^{-1} appropriately inoculated 'Endura' kura clover. The birdsfoot trefoil–grass mixture treatment was similarly oversown at 6.7 kg ha^{-1} with appropriately inoculated 'Norcen' birdsfoot trefoil. Kentucky bluegrass was also sown at 17.9 kg ha^{-1} to establish a 2.0-m-wide grass border surrounding all the experiments and a 0.9-m-wide corridor between blocks.

Beginning in 1994, broadcast N fertilizer was split-applied as ammonium nitrate to the six grass monoculture treatments in each experiment at annual rates of 0, 56, 112, 168, 224, and 336 kg ha^{-1}, respectively, in early April and after the first two harvests in a three-harvest system. The two mixture treatments received no N fertilizer. All plots were harvested on approximately 1 July and 20 August during the establishment year using a small-plot flail harvester to remove forage and volunteer weeds. Dead residue resulting from late-autumn growth was clipped and discarded in early April each year. Volunteer white clover and broadleaf weeds were controlled in the grass monocultures with dicamba (3,6-dichloro-2-methoxybenzoic acid) applied at 0.6 kg ha^{-1} acid eqivalent. Fertilizer P and K were applied annually at both locations based on soil test recommendations for grass pasture (Kelling et al., 1991).

Harvest Techniques

Forage within each plot was harvested to a 7.0-cm height three times during each growing season (approximately 5 June, 15 July, and 1 September) using a small-plot flail harvester. This harvest schedule coincided with the early-heading to late-flower stage for grasses in the first harvest. This three-harvest schedule has been shown to maximize DM yields for these forages compared with systems that involve shorter harvest intervals and as many as four or five harvests annually (Zemenchik, 1998). The wet weight of the harvested vegetation was recorded, and a subsample of approximately 0.5 kg of fresh forage was oven-dried at 60°C for 72 h to determine forage DM. Plot yields were computed on a dry weight basis and summed across harvests in each year. Subsamples were ground using a Thomas-Wiley mill (A.H. Thomas Co., Philadelphia, PA) to pass a 1.0-mm screen.

Forage Quality and Milk Production

Laboratory estimates of forage nutritive value for each plot at each harvest were determined by analyzing the ground forage samples. Means were computed and weighted to reflect the contribution of each harvest to annual plot DM yield. Neutral detergent fiber and ADF concentrations were determined by the method of Robertson and Van Soest (1981), with modifications. Modifications included a reduction in sample size to 0.5 g and treating the samples with 0.1 mL of α-amylase (no. A1064, Sigma Chemical, St. Louis, MO) during refluxing in neutral detergent solution and again during sample filtration (Hintz et al., 1996). Sodium sulfite was used during the NDF refluxing process only. Kjeldahl N was determined using a semimicro-Kjeldahl procedure (Bremner and Breitenbeck, 1983) with a salicylic acid modification (Bremner, 1965) for NO_3 recovery. Kjeldahl N was multiplied by 6.25 to estimate CP. Milk production per megagram of DM and per hectare was estimated from forage nutritive value (i.e., NDF, ADF, and CP) and DM yield data entered into the model MILK91 (Undersander et al., 1993). The model approximates a balanced ration as defined by the National Research Council (NRC, 1989) that meets the energy, protein, and fiber requirements for a 700-kg cow producing

36 kg d^{-1} 3.8% fat-corrected milk. The model uses forage ADF and NDF concentrations to estimate forage total digestible nutrients (TDN) and DM intake, respectively. The model then subtracts the kilograms of TDN required for maintenance of the cow (NRC, 1989) from the kilograms of TDN consumed from the forage. The remaining kilograms of TDN from forage are then converted to potential milk yield according to NRC (1989) equations. The model then calculates potential milk production from forage per megagram of DM and per hectare.

Statistical Analysis

Analysis-of-variance procedures were applied using the GLM procedure of SAS (SAS Inst., 1990) within years and across years on all parameters, including concentrations of ADF, NDF, CP and milk production per megagram of DM and per hectare. The effects of year, location, treatment, and all interactions were tested in all models. Mean separation on all parameters was achieved via Fisher's protected LSD at $P < 0.05$. In all cases, the treatment × year interaction was tested using treatment × year × location as the error term. Similar treatment comparisons for forage DM yield and sward species composition were performed and are reported in Zemenchik et al. (2001).

RESULTS AND DISCUSSION

Significant treatment × year interactions were present in nearly all NDF, ADF, CP, and milk production models. Significant treatment × location interactions were also present in the OG milk-per-hectare and CP models as well as the SBG milk-per-hectare model. We attribute these interactions primarily to changes in sward composition of the mixtures that occurred from year to year, which are discussed in Zemenchik et al. (2001). Generally, birdsfoot trefoil comprises a greater proportion of the mixtures than kura clover during the first year after establishment. However, by the third year after establishment, the opposite is true, and kura clover becomes the more dominant legume, outperforming birdsfoot trefoil over the long term. Sheaffer et al. (1992) found similar trends 4 yr after establishment for kura clover and birdsfoot trefoil in monoculture under lamb (*Ovis aries*) grazing in Minnesota. They reported that after 4 yr, birdsfoot trefoil swards were dominated by weeds and that forage availability, in terms of lamb days per hectare, was <50% of that for kura clover swards. Therefore, the data in the present study were not combined across years (Table 1) and are presented separately for each year and each location.

Neutral Detergent Fiber

Concentrations of NDF were significantly lower for the grass–legume mixtures than the grass monocultures in most years and locations for KBG (Table 1), SBG (Table 2), and OG (Table 3). Though not compared across years and locations, mean NDF concentrations of kura clover–grass mixtures were 416 g kg^{-1} for KBG, 438 for SBG, and 470 for OG. Mean NDF concentrations of birdsfoot trefoil–grass mixtures were relatively similar: 448 g kg^{-1} for KBG, 435 for SBG, and 471 for OG. These values were much lower than those for all of the grass monocultures where NDF concentrations averaged across locations, years, and N rates were 564 g kg^{-1} for KGB, 534 for SBG, and 555 for OG. Kura clover seasonal forage DM proportions in mixtures reported by Zemenchik et al. (2001) were negatively correlated with NDF concentrations over all years at Arlington (r = 0.78) and at Lancaster (r = 0.78). This is consistent with observations made by Napitupulu and Smith (1979) for alfalfa–OG mixtures. Similarly, the proportion of birdsfoot trefoil in mixtures was negatively correlated to NDF concentrations over all years at Arlington (r = 0.85) and Lancaster (r = 0.71). Small differences in NDF concentration among grass monoculture treatments occurred for all three species. Greater NDF concentrations were associated with increased N fertilizer rates for all years and locations.

Acid Detergent Fiber

With only three exceptions, concentrations of ADF in kura clover–grass mixtures were lower than in any N-fertilized grass monoculture at either location in any year (Tables 1–3). Exceptions include the non-N-fertilized control in the OG experiment in 1994 at both locations and the same N rate for SBG at Arlington in 1994 where ADF concentrations were not significantly different from the kura clover–grass mixture (Tables 2 and 3). In most cases, concentrations of ADF for birdsfoot trefoil–grass mixtures were intermediate between those of kura clover–grass mixtures and monoculture grasses. Kura clover–grass mixtures had significantly lower ADF concentrations than birdsfoot trefoil–grass mixtures in all experiments and at both locations, except for SBG at Lancaster in 1996 (Table 2) and for OG at both locations in 1994 (Table 3) where they were similar.

The kura clover–grass mixture had an ADF concentration lower than that for grass monocultures when averaged across N rates by 40 g kg^{-1} for KBG, 25 for SBG, and 23 for OG at Arlington. Similarly, kura clover reduced ADF concentrations at Lancaster by 32 g kg^{-1} for KBG, 23 for SBG, and 23 for OG. The birdsfoot trefoil–grass mixture had an ADF concentration lower than that of grass monocultures by 12 g kg^{-1} for KBG, 8 for SBG, and 4 for OG at Arlington. Similarly, birdsfoot trefoil reduced ADF concentrations at Lancaster by 4 g kg^{-1} for KBG, 7 for SBG, and 12 for OG. Greater reduction in ADF concentration for the kura clover–grass mixture compared with the birdsfoot trefoil–grass mixture was less a factor of mixture legume proportion than legume ADF concentration. For example, mean annual kura clover DM proportion of the mixtures compared with the birdsfoot trefoil mixture proportion at Lancaster was 556 and 614 g kg^{-1} for KBG, 450 and 575 for SBG, and 398 and 411 for OG, respectively (Zemenchik et al., 2001). Even though kura clover tended to comprise a lower proportion of the total annual mixture DM than birdsfoot trefoil in each experiment at Lancaster, kura clover mixtures never had a greater ADF concentration than birdsfoot trefoil mix-

Table 1. Neutral detergent fiber, acid detergent fiber, crude protein concentrations, and estimated milk production of N-fertilized Kentucky bluegrass (KBG) monocultures and binary mixtures of KBG with either kura clover (KC) or birdsfoot trefoil (BFT) managed in a three-harvest system near Arlington and Lancaster, WI.

Treatment		Arlington				Lancaster			
Sward type	N rate	1994	1995	1996	Mean	1994	1995	1996	Mean
	kg ha^{-1}								
				Neutral detergent fiber, g kg^{-1}					
KBG + KC	0	406e†	384c	406d	399	469e	406e	421d	432
KBG + BFT	0	446d	417b	449c	437	458e	438d	482c	460
KBG	0	526c	535a	589ab	550	544d	538c	568b	550
KBG	56	539bc	552a	593ab	561	562c	547bc	585ab	565
KBG	112	540bc	536a	574b	550	565bc	554abc	579ab	566
KBG	168	554ab	536a	596a	562	573abc	568a	604a	581
KBG	224	568a	540a	586ab	565	584a	565ab	592ab	580
KBG	336	555ab	541a	577ab	557	580ab	563ab	584ab	576
				Acid detergent fiber, g kg^{-1}					
KBG + KC	0	248d	240d	253e	247	270d	252c	263c	262
KBG + BFT	0	283c	268bc	274d	275	285c	293a	292b	290
KBG	0	285bc	276ab	304ab	288	292bc	277b	297b	289
KBG	56	288bc	277a	303abc	289	295ab	275b	305ab	292
KBG	112	287bc	270abc	298bc	284	295ab	276b	304ab	292
KBG	168	291ab	267c	306a	288	297ab	278b	314a	297
KBG	224	296a	267bc	303abc	289	303a	279b	311a	298
KBG	336	290ab	268abc	296c	285	301a	280b	305ab	295
				Crude protein, g kg^{-1}					
KBG + KC	0	189a	195b	197a	194	170b	188a	194a	184
KBG + BFT	0	189a	199ab	189ab	192	185a	192a	180b	186
KBG	0	138de	138f	127ef	134	137de	142e	122f	134
KBG	56	137e	144f	124f	135	132e	144e	120f	132
KBG	112	140cde	154e	136de	143	137de	152d	138e	143
KBG	168	147c	170d	141d	152	139de	161c	147d	149
KBG	224	146cd	178c	162c	162	142d	169b	159c	157
KBG	336	170b	204a	181b	184	158c	189a	197a	181
				Potential milk production, kg milk Mg^{-1} DM‡					
KBG + KC	0	1060a	1177a	1000a	1112	926a	1100a	1045a	1023
KBG + BFT	0	945b	1044b	958b	982	914a	939b	847b	900
KBG	0	767c	768c	586cd	707	711b	758c	647c	705
KBG	56	733cd	729c	579cd	680	667bc	741cd	594cd	667
KBG	112	731cd	782c	632c	715	658cd	726cd	609cd	664
KBG	168	693de	786c	567d	682	638cde	691d	530d	620
KBG	224	650e	774c	596cd	673	600e	696d	563cd	619
KBG	336	691de	775c	631c	699	613de	699d	595cd	635
				Potential milk production, kg milk ha^{-1}					
KBG + KC	0	7052a	6379a	7440a	6957	2997b	5848a	7286a	5377
KBG + BFT	0	6365a	5371b	5198b	5645	3951a	6078a	4963b	4997
KBG	0	1914g	784e	1007e	1235	1266d	943f	1484d	1231
KBG	56	2624f	1427e	1549e	1866	1815cd	1335e	1834d	1661
KBG	112	3137e	2220d	2365d	2574	1949c	2124d	2758c	2277
KBG	168	3751d	3429c	2285d	3155	2859b	2493d	2883c	2745
KBG	224	3765d	3764c	3283c	3604	2994b	3210c	3108c	3104
KBG	336	5456c	4741b	3764c	4653	4047a	3881b	3029c	3652

†Within columns and forage quality parameters, values followed by the same letter are not significantly different at $P = 0.05$ by Fisher's protected LSD.
‡DM, dry matter.

tures, and in the case of KBG, was significantly lower every year.

As with NDF, ADF concentrations in general were lower at Arlington than at Lancaster and may have resulted from a greater proportion of legumes in both mixtures at Arlington during this study. In contrast, adding birdsfoot trefoil significantly reduced ADF concentrations only for KBG and OG experiments at Arlington in 1996. Surprisingly, the ADF concentration of birdsfoot trefoil–grass mixtures was significantly greater than that all treatments in 1995 for KBG and SBG at Lancaster. This suggests that in a three-harvest system, birdsfoot trefoil–grass mixtures will generally contain levels of ADF similar to grass monocultures and greater than kura clover–grass mixtures. However, because ADF concentrations for these treatments are all less than 300 g kg^{-1}, it may not be a limiting factor for potential milk production. In all experiments, there was very little difference in ADF among grass monocultures receiving different N rates at either location.

These forage fiber measures suggest that kura clover–grass mixtures may have greater potential ruminant forage intake based on NDF and better digestibility based on ADF than birdsfoot trefoil–grass mixtures in ruminant livestock rations. This is especially true with KBG, with which the greatest reductions in NDF and ADF by adding kura clover were observed.

Crude Protein

Crude protein concentrations of grass monocultures increased significantly with greater rates of N in all three

Table 2. Neutral detergent fiber, acid detergent fiber, crude protein concentrations, and estimated milk production of N-fertilized smooth bromegrass (SBG) monocultures and binary mixtures of SBG with either kura clover (KC) or birdsfoot trefoil (BFT) managed in a three-harvest system near Arlington and Lancaster, WI.

Treatment		Arlington				Lancaster			
Sward type	N rate	1994	1995	1996	Mean	1994	1995	1996	Mean
	kg ha^{-1}								
					Neutral detergent fiber, g kg^{-1}				
SBG + KC	0	445e†	417b	416c	426	478d	434b	441c	451
SBG + BFT	0	455e	409b	423c	429	450e	443b	443c	445
SBG	0	488d	509a	509b	502	526c	519a	525b	524
SBG	56	503c	520a	549a	524	528c	526a	547ab	534
SBG	112	528b	517a	550a	532	535bc	535a	559a	543
SBG	168	527b	517a	560a	535	550ab	527a	566a	548
SBG	224	536ab	518a	551a	535	556a	531a	564a	551
SBG	336	543a	509a	564a	539	551ab	529a	564a	548
					Acid detergent fiber, g kg^{-1}				
SBG + KC	0	261d	247c	255c	255	275e	259c	274d	269
SBG + BFT	0	282ab	264b	271b	272	283d	293a	280cd	285
SBG	0	268cd	272a	275b	272	285d	278b	289bc	284
SBG	56	275bc	273a	290a	279	288cd	277b	300ab	289
SBG	112	284a	272a	287a	281	292bc	282b	305a	293
SBG	168	284a	272a	293a	283	298ab	278b	308a	295
SBG	224	287a	269ab	286a	281	302a	280b	305a	296
SBG	336	288a	265b	292a	282	302a	278b	305a	295
					Crude protein, g kg^{-1}				
SBG + KC	0	189a	192bc	196a	191	162b	191b	194a	182
SBG + BFT	0	186a	199b	203a	196	180a	182c	187a	183
SBG	0	161c	149f	156c	155	143c	150e	148bc	147
SBG	56	151d	148f	138e	146	140c	155e	141c	145
SBG	112	150d	161e	143de	151	141c	166d	160b	156
SBG	168	155d	173d	153cd	160	140c	172d	155bc	155
SBG	224	161c	186c	158c	169	144c	179c	162b	162
SBG	336	172b	223a	181b	192	162b	215a	189a	188
					Potential milk production, kg milk Mg^{-1} DM‡				
SBG + KC	0	997a	12088a	12073a	12052	895a	12025a	976a	965
SBG + BFT	0	951a	1067a	1024a	1014	937a	929b	959a	942
SBG	0	879b	834bc	825b	846	767b	797c	760b	774
SBG	56	839b	807c	704c	783	754b	784c	686bc	741
SBG	112	765c	816bc	709c	763	731bc	755c	650c	712
SBG	168	768c	817bc	674c	753	686cd	781c	628c	698
SBG	224	739c	819bc	709c	755	663d	768c	639c	690
SBG	336	724c	848b	667c	746	676d	777c	639c	697
					Potential milk production, kg milk ha^{-1}				
SBG + KC	0	5797b	5808b	6592a	6065	3941c	6105b	5991a	5345
SBG + BFT	0	7234a	6854a	5628b	6572	5001a	6596a	5208b	5601
SBG	0	3240e	2279e	2039de	2519	2623d	2944g	2093e	2553
SBG	56	3647e	2930e	1876e	2817	3061d	3461f	2528e	3020
SBG	112	4201d	4034d	2567de	3601	3547c	4029e	3347d	3641
SBG	168	4751c	4376cd	2769d	3965	3922c	4234e	3439cd	3865
SBG	224	4986c	4969c	3726c	4560	3940c	4913d	3812cd	4222
SBG	336	5665b	5786b	4092c	5181	5097a	5746c	4080c	4974

†Within columns and forage quality parameters, values followed by the same letter are not significantly different at $P = 0.05$ by Fisher's protected LSD.
‡DM, dry matter.

grasses (Tables 1–3). For example, averaged across locations and years, grasses fertilized with 336 kg N ha^{-1} compared with 0 kg N ha^{-1} had CP concentrations that were 182 and 134 mg kg^{-1} for KBG, 190 and 151 for SBG, and 162 and 127 for OG, respectively. Similarly, grass monocultures fertilized with 336 kg N ha^{-1} compared with 224 kg N ha^{-1} had CP concentrations that were 182 and 160 mg kg^{-1} for KBG, 190 and 166 for SBG, and 162 and 139 for OG, respectively. The consistent significant increase in CP concentration from 224 to 336 kg N ha^{-1} illustrates that these species were always responsive to N fertilizer at rates $<$336 kg N ha^{-1}.

With three exceptions out of 90 cases, concentrations of CP in kura clover–grass mixtures were significantly greater than all but the 336 kg N ha^{-1} rate at either location (Tables 1–3). Although working with alfalfa, Carter and Scholl (1962) reported that it required 269 kg N ha^{-1} applied annually to SBG or OG to achieve the same CP concentration as alfalfa in mixture with those grasses. In 10 out of 18 cases, there was no difference in CP concentration between kura clover–grass mixtures and birdsfoot trefoil–grass mixtures. In the other eight cases where such differences did occur (e.g., KBG at Lancaster), it can be generally attributed to a positive correlation with the legume proportion of the mixture from 1994 to 1996, which was increasing for kura clover and decreasing for birdsfoot trefoil (Zemenchik et al., 2001). Kura clover proportions in all mixtures were positively correlated to CP concentrations over all years at Arlington ($r = 0.76$) and Lancaster ($r = 0.81$). Similarly, birdsfoot trefoil proportions in all mixtures were positively correlated to CP concentrations over all years at

Table 3. Neutral detergent fiber, acid detergent fiber, crude protein concentrations, and estimated milk production of N-fertilized orchardgrass (OG) monocultures and binary mixtures of OG with either kura clover (KC) or birdsfoot trefoil (BFT) managed in a three-harvest system near Arlington and Lancaster, WI.

Treatment		Arlington				Lancaster			
Sward type	N rate	1994	1995	1996	Mean	1994	1995	1996	Mean
	kg ha^{-1}								
					Neutral detergent fiber, g kg^{-1}				
OG + KC	0	487d†	462c	427e	456	538e	477c	440d	485
OG + BFT	0	473d	453c	455d	460	500f	471c	477c	483
OG	0	515c	514b	539c	523	559de	535b	544b	546
OG	56	543b	521ab	543bc	533	556cd	536b	542b	548
OG	112	544b	523ab	558ab	542	573bcd	556a	559ab	563
OG	168	555ab	536a	567a	553	588abc	560a	577a	575
OG	224	563a	537a	575a	558	593ab	563a	574a	577
OG	336	570a	535a	574a	560	599a	563a	569a	577
					Acid detergent fiber, g kg^{-1}				
OG + KC	0	281c	266d	263e	269	307de	275d	275d	285
OG + BFT	0	283c	275c	276d	278	303e	297abc	288c	296
OG	0	282c	275bc	286c	281	309cde	288c	298bc	298
OG	56	296ab	279bc	286bc	287	316cd	290bc	296bc	301
OG	112	296b	282ab	295ab	291	318bc	299a	306ab	308
OG	168	301ab	287a	300a	296	328ab	300a	315a	314
OG	224	307a	288a	304a	300	331a	301a	310a	314
OG	336	310a	287a	303a	300	335a	297ab	306ab	313
					Crude protein, g kg^{-1}				
OG + KC	0	146b	160bc	185a	165	125b	157b	176a	153
OG + BFT	0	156a	171b	174b	167	147a	171a	162ab	160
OG	0	120d	131d	128de	126	117cd	136d	130cd	127
OG	56	115d	128d	121e	121	108e	132d	119d	120
OG	112	114d	131d	122e	122	110de	135d	128cd	124
OG	168	117d	146c	133cd	133	111cde	145c	140c	132
OG	224	120d	154c	141c	139	117c	156b	145bc	139
OG	336	137c	189a	169b	165	132b	179a	168a	159
					Potential milk production, kg milk Mg^{-1} DM‡				
OG + KC	0	862a	949a	1031a	947	691b	896a	978a	855
OG + BFT	0	887a	950a	941b	926	783a	860a	865b	836
OG	0	795b	815b	737c	782	640bc	740b	699c	693
OG	56	705c	790bc	727cd	740	610c	733b	706c	683
OG	112	701c	778bc	673de	717	590cd	669c	647cd	635
OG	168	667cd	740c	643e	683	535de	658c	588d	593
OG	224	636d	735c	618e	663	518e	652c	605d	591
OG	336	616d	741c	622e	659	496e	659c	628d	594
					Potential milk production, kg milk ha^{-1}				
OG + KC	0	5010cd	5193bc	5921a	5374	3066c	4358b	5465a	4296
OG + BFT	0	5861ab	5349bc	4795b	5335	4047a	5336a	4627b	4670
OG	0	3028g	2416e	1703g	2382	2335d	2398e	2314f	2349
OG	56	3759f	3498d	2610f	3289	3080c	3122d	3005e	3069
OG	112	4170ef	4458c	3184ef	3937	3522b	3677cd	3572de	3590
OG	168	4732de	5308bc	3449de	4496	3738ab	4057bc	3750cd	3848
OG	224	5339bc	5587ab	3955cd	4960	3817ab	4083bc	4150bcd	4017
OG	336	5973a	6311a	4309bc	5531	3961ab	4427b	4332bc	4240

† Within columns and forage quality parameters, values followed by the same letter are not significantly different at $P = 0.05$ by Fisher's protected LSD.
‡ DM, dry matter.

Arlington ($r = 0.89$) and Lancaster ($r = 0.86$). These correlations are consistent with the work of Napitupulu and Smith (1979) for alfalfa and OG mixtures and Barnett and Posler (1983) for red clover in mixture with several perennial grasses, including KBG and SBG.

Milk Production per Megagram of Dry Matter and per Hectare

Sward production in terms of potential milk production for each megagram of forage DM consumed in a balanced ration (Undersander et al., 1993) dramatically improved with the addition of either legume to any of the monoculture grasses, regardless of N rate (Tables 1–3). When averaged over years and locations, kura clover–grass mixtures had greater potential milk production per megagram of DM than grass monocultures at any N rate by at least 51% for KBG, 43% for SBG, and 22% for OG. Similarly, birdsfoot trefoil–grass mixtures had greater potential milk production per megagram of DM than any grass monoculture by 33% for KBG, 39% for SBG, and 20% for OG. Kura clover mixtures had significantly greater potential milk production per megagram of DM than the birdsfoot trefoil mixtures in five out of six cases for the KBG experiment (Table 1), one out of six cases in the SBG experiment (Table 2), and two out of six cases in the OG experiment (Table 3). In all other cases but one, they were the same. The exception was at Lancaster in 1994 (Table 3) where the birdsfoot trefoil–OG mixture had significantly greater potential milk production per megagram of DM than the kura clover mixture. We attribute this to kura clover comprising only 26% of forage DM of the sward at that location in the year after establishment. By 1996, kura clover–grass mixtures had significantly greater potential milk production per megagram of DM at both locations compared with birdsfoot trefoil–grass mixtures for KBG and OG (Zemenchik et al., 2001). There was no significant difference in potential milk production per megagram of DM between legumes in mixture with SBG at any location in 1996.

Potential milk production per hectare was often increased with the addition of either legume to any of the monoculture grasses, regardless of N rate (Tables 1–3). As expected, increasing the fertilizer N rate on grass monocultures resulted in increased forage DM production over the entire range of N rates (Zemenchik et al., 2001). Because comparatively smaller changes in forage nutritive value occurred with increasing N rate, the improvement in milk production per hectare for grass monocultures was largely driven by the increase in grass DM production. In 1994, high rates of fertilizer N applied to the grass monocultures had similar potential milk production per hectare compared with the mixtures. However, by 1996, in all cases for kura clover, there was significantly greater milk production per hectare compared with any grass monoculture. The same was true for birdsfoot trefoil in mixtures with KBG and SBG, but there was no significant difference in potential milk production per hectare in 1996 between OG fertilized with 336 kg N ha^{-1} and birdsfoot trefoil–OG mixtures. When averaged over years and locations, kura clover–grass mixtures had at least 49% greater milk production per hectare than monoculture KBG, regardless of N rate, and at least 12% greater than similarly fertilized SBG. Birdsfoot trefoil–grass mixtures had at least 28% greater milk production per hectare than similarly fertilized monoculture KBG and at least 20% greater than SBG. Meanwhile, potential milk production per hectare for monoculture OG fertilized with 336 kg N ha^{-1} was only 1% greater than in mixture with kura clover and only 3% less than in mixture with birdsfoot trefoil.

Generally, mean milk production per hectare from 1994 to 1996 was greater for all mixtures at Arlington than at Lancaster. Additionally, potential milk production per hectare for both mixtures followed the trend KBG $>$ SBG $>$ OG at each location. In contrast, potential milk production per hectare for monoculture grasses followed the trend OG $>$ SBG $>$ KBG when averaged across locations and years. Potential milk production per hectare was greater for birdsfoot trefoil–grass mixtures than kura clover–grass mixtures in 1994, but the opposite was true by 1996. However, both legumes in mixture with any of the grasses had greater potential milk production than grass monocultures on a unit land area basis for all N rates up to 336 kg N ha^{-1}. Such trends in potential milk production per hectare for mixtures comprised of either legume with these grasses were primarily related to legume proportions of the mixtures during the study (Zemenchik et al., 2001).

SUMMARY AND CONCLUSIONS

Combining either legume with any of these cool-season grasses dramatically reduced concentrations of NDF and ADF compared with grass monocultures. By combining kura clover rather than birdsfoot trefoil with these cool-season grasses, kura clover–grass ADF concentrations were reduced more, by as much as 49 g kg^{-1} more in KBG. Legume proportions in mixtures were positively correlated to CP concentrations and negatively correlated to NDF concentrations over all years and locations. Improvements in forage nutritive value and potential milk production were substantially greater for mixtures than with N fertilization of grass monocultures. Additionally, if high rates of N were applied to grasses such as OG, it may cause NO_3 accumulation (Dougherty and Rhykerd, 1985), decrease water-soluble carbohydrate concentrations and ensilability, and reduce profit margins because of the high cost of fertilizer N and the added cost of application.

Based on increased forage DM production, nutritive value, and potential milk production, we recommend combining either kura clover or birdsfoot trefoil with these grasses to reduce reliance on fertilizer N in the North-Central USA. Unbalanced seasonal yield distribution and grass displacement by the third year of the experiment were exhibited in SBG mixtures and could present challenges in obtaining forage with consistent nutritive value from which to balance rations for lactating dairy cattle. High-yielding KBG varieties may be the grass best suited for the legumes evaluated in this study, particularly kura clover. In the first year after stand establishment, we would expect birdsfoot trefoil–grass mixtures to have greater potential milk production per land area than kura clover. Where stands are intended to be managed for 3 yr or more, we would expect the opposite to be true. Potential milk production per hectare for both mixtures followed the trend KBG $>$ SBG $>$ OG at each location. In contrast, potential milk production per hectare for monoculture grasses followed the trend OG $>$ SBG $>$ KBG when averaged across locations and years. Although some reduction in forage DM production is likely with the use of either legume as a substitute for up to 336 kg N ha^{-1}, it is more than offset by the increase in potential milk production calculated on either a forage mass or unit area basis. Further investigation is needed to determine how these results would be different under grazing, and with other grass species, including the risks for bloat that would accompany the use of kura clover.

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