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Species Composition Changes in Conservation Reserve Program (CRP) Grassland When Managed for Biomass Feedstock Production

Species Composition Changes in CRP...

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Abstract Grasslands enrolled in the Conservation Reserve Program (CRP) serve as one of the potential national herbaceous resources for use as a dedicated bioenergy feedstock. The goal of this project was to assess the yield potential and suitability of CRP grassland as a bioenergy feedstock source across the USA in regions with significant CRP land resources. In addition to that goal, one major objective of this project was to assess vegetation composition changes that also occurred on these different CRP grasslands over time with different harvest and fertilization management strategies. Three levels of nitrogen fertilization (0, 56, and 112 kg ha^{-1}) and two harvest timings [peak standing crop (PSC) or end of growing season (EGS)] were evaluated for effects on biomass production and resulting species composition changes. Three sites in regions containing concentrated tracts of CRP grassland and representing variable climatic parameters were analyzed for vegetation composition trends over the course of six growing seasons (2008–2013). Specifically, a mixture of warm-season perennial grasses was evaluated in Kansas (KS), while a cool-season mixture was evaluated in Missouri (MO). North Dakota (ND) contained a mixture of both warm- and cool-season grasses. At the MO and KS sites, nitrogen fertilization significantly altered the grass and legume composition over time by lowering the legume percentage in the stand. In KS and ND, the two sites with warm-season grasses, harvesting in mid-summer at PSC, greatly reduced warm-season grass composition over time in favor of annual cool-season grass invaders or perennial cool-season grasses. Any shift to less desirable or less productive species limits the ability of these lands to provide a sustainable or reliable feedstock for bioenergy production.

Keywords Warm-season grass · Cool-season grass · Harvest management · Nitrogen management · Legumes · Dry-weight-rank

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Introduction

Grasslands enrolled in the Conservation Reserve Program (CRP) were identified by the Sun Grant/US Department of Energy Regional Biomass Feedstock Partnership as one of the five main sources of herbaceous biomass that could be used as a potentially sustainable source of energy feedstocks. The partnership developed a research team that performed long-term replicated field trials on CRP lands in order to assess the effects of management strategies on yield potential and suitability of CRP grassland as a bioenergy feedstock source [1, 14]. The CRP research team included research locations across the major regions of CRP implementation, which also included major regions of differing climates.

In 1985, the USDA launched CRP through the Food Security Act to protect highly erodible lands, of which the majority were lands used for row crop production. The goal of the national CRP program was to establish a perennial grass cover on these lands to reduce the impacts of high winds and precipitation on the soil surface and to develop root structures to stabilize and hold soil in place. Early implementation of the CRP program was estimated to have saved 42.6 Mg ha^{-1} of soil annually [15]. Early reports also estimated that CRP lands reduced N and P losses each year by 28.8 and 7.2 kg ha^{-1}, respectively, compared to cropped land, and that nationally CRP increased carbon sequestration by 20.9 million Mg on an annual basis [4]. Moreover, CRP lands have benefitted water quantity and quality. In portions of the High Plains Aquifer located in Oklahoma, Kansas, and Colorado and in the most critical counties that had previously shown the greatest aquifer water draw down, aquifer levels were higher beneath CRP lands than beneath non-CRP lands [23]. More recently, over 2.1 million ha of CRP lands has also been enrolled for providing diversified valuable habitat and cover for many wildlife species and for conserving rare and declining habitat for wildlife [27]. Soil and water conservation and wildlife habitat are just a few examples of the goods and ecosystem services provided by this program. In the future, the biomass produced by some of these CRP lands may also provide a valuable fuel source as bioenergy feedstocks during the typical 10- to 15-year CRP contract time period or when the contracts expire without direct land use changes.

Current CRP lands have largely been unmanaged or received minimal management since establishment, and incorporating management strategies to optimize biomass production may alter the balance of vegetative structure and composition that had developed over time. Grasslands with mixed vegetation can have complex interactions, and trends seen in composition over short time periods may not be reflective of composition over longer time periods. For example, successful interseeding to develop mixed grass-legume swards may have significant dry matter contributions from both components in the first few years of stand life, but, over longer time periods, one component may have greater persistence and dominate and not be reflective of earlier composition [17].

Large differences in yield potential and biomass quality parameters are observed within and between the functional groups of cool-season grasses [10, 12], warm-season grasses [8, 25], and legumes [5, 19, 26] used in CRP vegetation mixtures. Therefore, management strategies that alter CRP mixed vegetation composition can lead to great differences in biomass production and quality [19, 21]. The research presented here reports the vegetative composition changes over time from different harvest and N management strategies of CRP grasslands with mixed vegetation when utilized as a bioenergy feedstock source across diverse regions of the USA. Specifically, vegetation trends were examined following field-scale agricultural practices of three different N fertilization rates and two times of harvest management across three diverse national CRP regions.

Materials and Methods

Six test locations were identified and established for biomass research based on known regions containing concentrated tracts of CRP grassland, and these sites represented diverse soils, climatic parameters, and production histories [1, 14]. Of these six previously established CRP study sites, only three were evaluated for vegetation composition and trends for all 6 years of the biomass study: Foster County, North Dakota (ND) (47.5° N 99.2° W); Ellis County, Kansas (KS) (38.8° N 99.4° W); and Boone County, Missouri (MO) (39°N 92.2°W).

The three sites included in the composition analysis were divided between warm- and cool-season grasses. Warm-season (C_4) grasses and a legume predominated in KS, while cool-season grasses (C_3) and a legume predominated in MO, and a mixture of warm- and cool-season grasses was found in ND (Table 1). Species not seeded in the CRP site establishment nor seeded as common forage or pasture species were considered to be weedy invaders. The selected soil characteristics and classification and CRP history are shown in Table 1. All locations were managed to meet CRP regulations, and no agronomic management practices, including fertilization or aboveground biomass harvest, had been imposed during the CRP contract before this study. All field sites were selected in spring 2008 and were mowed at a 10- to 15-cm height in the spring before imposing fertilization treatments. The temperature (°C) and precipitation (mm) for 2008–2013, and the long-term average, are listed for each site in Tables 2 and 3, respectively.

The experimental design was a factorial arrangement of three N rates and two harvest dates within a randomized complete block with three replicates at each of the three sites. The plot size for treatments was approximately 0.5 ha. Urea nitrogen fertilizer (46–0-0) was annually broadcasted at the rates of 0, 56, or 112 kg N ha^{-1} onto each plot using a farm-scale fertilizer spreader on the dates shown in Table 4. No other fertilizer was applied as a treatment. The fertilizer spreader was calibrated to deliver 56 kg N ha^{-1}. Thus, fertilizer was applied at this rate to the 56 kg N ha^{-1} treatment once and to the 112 kg N ha^{-1} treatment twice.

Species composition at each site was estimated annually, during June or July depending on the site, according to the dry-weight-rank procedures and weighted factors described by Gillen and Smith [7]. Vegetation within 25 sample frames, each 0.2 m^2, in each plot was assessed for the species that contributed the greatest to dry matter (DM) within the frames. The species estimated to provide the greatest amount of DM within the frame received a rank of 1; the species contributing the next greatest amounts of DM in decreasing order were ranked 2 and 3, respectively. These species within the frame were then assigned a weighted composition factor, 0.70, 0.21, and 0.09, for each rank in decreasing order. The composition for all frames was then averaged to calculate a final vegetation

Table 1 Location, Conservation Reserve Program (CRP) enrollment year, initial species composition, and selected soil chemical and physical properties in the top 15 cm of soil, for each of the three CRP research sites

State	Location	CRP Established	Soil pH	SOC (g kg^{-1})	T-N (g kg^{-1})	Soil classification	Predominant species
ND	47 N 99 W	2001	7.8	20.8	2.90	Haplobobolls	BB, SW, SB, QG
KS	38 N 99 W	1988	7.6	24.3	1.90	Argiustolls	SO, SW, LB, YS
MO	39 N 92 W	2004	5.0	19.0	2.12	Epiaqualfs	RC, TF

SOC soil organic carbon, *T-N* total nitrogen, *BB* big bluestem, *SW* switchgrass, *SB* smooth bromegrass, *QG* quackgrass, *SO* sideoats grama, *LB* little bluestem, *YS* yellow sweetclover, *RC* red clover, *TF* tall fescue

composition estimate for each plot. Calculated composition estimates for each species were proportion values ranging from 0 to 1 and thus were transformed by calculating the square root of the proportion and then calculating the arcsin of the square root value (*arcsin√proportion*). Transformed values were used for statistical analysis, while non-transformed values are given in the text and tables. Individual species were also pooled according to functional group. Both individual species and functional groups were analyzed.

Whole plots were harvested with a farm-scale harvester at a cutting height of 10 to 15 cm on the dates listed in Table 4. At sites with warm-season grass, CRP biomass was annually harvested either at anthesis [peak standing crop (PSC)] or at the end of growing season after a killing frost (KF). The PSC harvest timing was determined at each location by the predominant species (as listed in Table 1) reaching anthesis. For the MO site, the PSC treatment was harvested at anthesis of spring growth and again at the end of fall growth, while the end of growing season (EGS) treatment was harvested after mature seed set at the end of late spring growth and again at the end of fall growth. Harvest timing and frequency information is described in Table 4. Above ground biomass was baled with a large round baler and was removed and weighed. Biomass data for this project was previously reported by Lee et al. [14], and Anderson et al. [1].

The effect of harvest timing and nitrogen fertilization as well as their interactive effects on species composition was analyzed using the PROC MIXED procedure in SAS (SAS Institute, Cary, NC). Each site was analyzed independently due to differences in initial species composition, as well as distinct soil and climate characteristics at each site. Harvest timing and nitrogen fertilization were considered fixed variables, while year was used as a fixed repeated effect to test composition over time. Replication was the random effect in the model. Within a vegetative functional group or species, contrasts were performed to test for linearity of harvest timing across years and fertilization levels across years and also to test for differences in slope of linear trends between harvest timings across years and fertilization treatments across years. All comparisons were declared significant at the $P = 0.05$ level of probability unless stated otherwise.

Results

Missouri Fertilization treatments changed species composition over time in this environment. Plots treated with 0 and 56 kg N ha^{-1} started with a greater legume content than 112 kg N ha^{-1} plots, and both declined at a similar rate as years progressed, which was more rapid than the gradual decline for the 112 kg N ha^{-1} plots (Table 5). Averaged across N fertilization rates, EGS and PSC legume content averaged 25 and 27 %, respectively (data not shown). For legume composition, no interaction occurred between harvest timing and fertilization level or harvest timing and year. So, at both harvest timings, legume composition declined at the same rate as N level increased and as years progressed from 2008 to 2013 (data not shown). Over 66 % of the legume content was red clover (*Trifolium pratense* L.), so total legume trends closely

Table 2 Mean monthly temperature data (°C) averaged over the 6-year period (2008–2013) of the study and the 30-year mean for each of three selected CRP research sites

State	Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
ND	2008–2013	−13.1	−11.8	−4.5	4.2	11.5	17.4	20.8	19.8	14.9	7.4	−1.5	−12.0
	30-year mean	−14.0	−9.0	−3.0	6.0	14.0	18.0	21.0	20.0	14.0	7.0	−3.0	−11.0
KS	2008–2013	−1.4	0.2	6.9	11.9	17.9	24.7	27.3	25.4	20.0	12.2	6.1	−1.9
	30-year mean	−2.2	0.9	6.1	11.8	17.3	23.3	26.2	25.2	20.2	13.3	4.9	−0.5
MO	2008–2013	−2.3	0.4	7.4	12.8	17.8	23.6	25.6	24.1	19.4	13.1	7.5	0.1
	30-year mean	−2.3	0.9	6.7	12.2	17.6	22.6	25.3	24.3	19.6	13.4	6.2	0.0

Table 3 Mean monthly precipitation data (mm) for each of the three selected CRP research sites evaluating species composition from 2008 to 2013

State	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
ND	2008	5	13	4	12	32	136	54	45	85	79	39	49	553
	2009	26	18	31	45	45	47	40	59	57	91	3	13	475
	2010	31	3	116	40	42	21	15	12	18	27	26	27	378
	2011	27	25	27	27	28	30	32	31	28	27	25	26	333
	2012	26	26	26	27	28	29	27	29	26	28	26	26	323
	2013	11	10	33	39	100	23	41	24	50	48	1	3	383
	30 yrs	13	10	19	37	63	96	79	63	47	46	21	10	505
KS	2008	11	33	10	50	174	47	102	86	36	153	18	6	727
	2009	1	1	0	85	56	58	70	130	42	53	26	30	552
	2010	5	11	51	41	91	96	70	137	54	2	22	5	585
	2011	9	15	17	26	61	61	50	104	22	40	31	51	486
	2012	1	33	36	73	40	22	6	86	27	24	0	20	366
	2013	19	30	20	27	55	69	180	15	76	25	30	1	547
	30 yrs	14	16	50	55	80	67	96	74	41	36	31	17	577
MO	2008	57	73	97	94	145	147	242	64	272	32	20	54	1296
	2009	5	55	75	139	149	138	125	92	89	223	42	57	1188
	2010	46	58	75	196	108	84	204	105	176	11	47	39	1149
	2011	7	57	78	72	136	77	59	61	46	26	98	68	785
	2012	26	55	113	171	25	39	18	49	46	68	31	26	667
	2013	62	39	55	194	265	47	41	45	43	70	42	39	942
	30 yrs	44	56	82	106	124	102	97	95	87	81	88	63	1023

reflected red clover trends (Table 5). The remainder of the legume component was composed of white clover (*Trifolium repens L.*) and yellow sweetclover [*Melilotus officinalis* (L.) Lam.]. Red clover composition with EGS and PSC harvests was similar and declined with both harvest treatments as N rate increased and as time progressed from 2008 to 2013 (data not shown).

Cool-season grass dominated MO CRP. Grass composition was greatest at 112 kg N ha^{-1} and was unchanged from 2008 to 2013 near 76 % (Table 5). Grass composition in plots fertilized with 0 and 56 kg N ha^{-1} slowly increased at the same rate to 60 and 72 % (approximately 10 % increases), respectively, over the course of the experiment (Table 5). Grass composition with EGS and PSC harvests was similar and averaged 66 and 67 %, respectively, and increased at the same rate as N rate increased and as years progressed from 2008 to 2013 (data not shown). Tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] not only was the dominant grass in all plots, but also included a very small percentage of smooth bromegrass (*Bromus inermis* Leyss.).

Table 4 Mean harvest and fertilization dates for each CRP research site

State	N application	PSC harvest	KF/EGS harvest
ND	3 Jun	23 Aug	19 Oct
KS	13 Apr	4 Aug[a]	30 Oct
MO	21 Mar	23 May/24 Oct	27 Jun/24 Oct

PSC date at which the predominant species reached anthesis and peak standing crop (PSC), *KF/EGS* date which killing frost (KF) occurred at the sites with warm-season mixtures or the end of the growing season (EGS) at the cool-season sites

[a] Severe drought at the Kansas site in 2012 resulted in no harvestable forage for the typical PSC harvest time frame and was therefore only harvested at the time of KF

Total weed composition, annual grass, and broadleaf species combined increased as each year progressed. The greatest rate of increase to 15 % weed composition occurred with 0 kg N ha^{-1} (Table 5). Plots treated with 112 kg N ha^{-1} had lower average weed composition than 0 kg N ha^{-1} plots. In plots harvested at EGS and PSC, weed composition averaged 7 and 8 % and increased as years progressed but decreased as N rates increased (data not shown).

North Dakota The ND location was dominated by warm-season grasses in 2008, and grass composition responded to harvest treatment but not to fertilizer treatment. Warm-season grass composition harvested at KF did not change over years and averaged 62 %, while warm-season grass composition substantially declined from 57 to 27 % as years progressed when harvested at PSC (Table 6). Big bluestem (*Andropogon gerardii* Vitman) and switchgrass (*Panicum virgatum* L.) composition trends reflected the total warm-season grass composition trends. Big bluestem composition did not change

Table 5 Species and functional group vegetation composition in MO Conservation Reserve Program land harvested for biomass under three different fertilizer and two different harvest management regimes from 2008 to 2013

	kg N ha^{-1}	Mean[a]	Year						Linear slope[b]
		%	2008	2009	2010	2011	2012	2013	
Legumes	0	34 a	38	47	34	31	27	26	−3.7 a*
	56	26 b	26	35	28	28	24	13	−2.8 a*
	112	19 c	16	25	22	19	19	12	−1.2 b*
Red clover	0	22 a	24	27	21	22	19	17	−1.7 a*
	56	17 b	18	21	18	19	17	8	−1.8 a*
	112	11 c	10	13	12	11	12	8	−0.4 b*
Cool-season grass	0	56 c	56	45	58	60	57	60	1.6 ab*
	56	67 b	69	58	66	66	68	77	2.0 a*
	112	76 a	82	71	73	75	73	83	0.4 b
Total weeds	0	10 a	6	8	8	9	17	15	2.1 a*
	56	7 ab	5	7	6	6	9	10	0.8 b*
	112	5 b	2	4	5	6	8	5	0.8 b*

All values are averaged across peak standing crop and end of growing season harvest treatments

*Within the vegetation class or species and specific fertilizer rate combination, the linear trend across years was significant at $P < 0.05$, except for red clover at 112 kg ha^{-1}, which was significant at $P = 0.06$

[a] Within a vegetation class or species, different letters between fertilizer rates indicate that the mean species composition was different at $P < 0.05$

[b] Within the vegetation class or species, different letters following the slope value indicate that the linear slopes of the trends for the fertilizer rates were different at $P < 0.05$, except that for red clover, the linear slope trend across years was different between the 0 and 112 kg N ha^{-1} fertilizer rates at $P = 0.07$

Table 6 Species and functional group vegetation composition in ND Conservation Reserve Program land harvested for biomass under three different fertilizer and two different harvest management regimes [peak standing crop (PSC), killing frost (KF)] from 2008 to 2013

	Harvest	Mean[a]	Year						Linear slope[b]
		%	2008	2009	2010	2011	2012	2013	
Warm-season grass	PSC	43 b	57	53	55	40	23	27	−7.2 b*
	KF	62 a	65	52	61	67	54	73	1.5 a
Switchgrass	PSC	20 b	27	30	22	27	8	5	−4.9 b*
	KF	27 a	32	25	21	39	13	35	−0.1 a
Big bluestem[a]	PSC	22 b	29	23	32	13	14	21	−2.4 b*
	KF	32 a	33	27	38	26	36	35	0.7 a
Cool-season grass	PSC	57 a	42	47	45	60	77	73	7.4 a*
	KF	38 b	35	47	39	33	46	27	−1.4 b
Smooth brome	PSC	21 a	7	17	18	26	29	29	4.4 a*
	KF	13 b	8	16	20	13	10	11	−0.3 b
Kentucky bluegrass	PSC	12 a	6	7	11	16	15	17	2.4 a*
	KF	3 b	5	3	3	5	2	1	−0.7 b*
Quackgrass	PSC	19 a	28	18	13	15	19	18	−1.2 a
	KF	17 a	18	22	13	13	21	12	−0.9 a

All values are averaged across 0, 56, and 112 kg N ha^{-1} fertilizer treatments

*Within the vegetation class or species and specific harvest timing combination, the linear trend across years was significant at $P < 0.05$

[a] Within a vegetation class or species, different letters between harvest timing indicate that the mean species composition was different at $P < 0.05$, except that mean big bluestem composition for PSC and KF was statistically different at $P = 0.06$

[b] Within the vegetation class or species, different letters following the slope value indicate that the linear slopes of the trends for the two harvest timings were different at $P < 0.05$

over years with KF harvests, but big bluestem composition declined over time from 29 to 21 % with PSC harvests (Table 6). Likewise, switchgrass composition did not change over years with KF harvests but declined sharply from 27 to 5 % with PSC harvests (Table 6). Fertilizer rate did not affect average big bluestem or switchgrass composition (data not shown). Prairie cordgrass (*Spartina pectinata* Bosc ex Link) was present but did not contribute significantly to stands.

Cool-season grass harvested at KF did not change composition over years and averaged 38 %, but composition substantially increased over years from 42 to 73 % with PSC harvests (Table 6). Averaged across harvest dates, cool-season grass composition was similar at all fertilization rates (data not shown). Smooth bromegrass, Kentucky bluegrass (*Poa pratensis* L.), and quackgrass [*Elymus repens* (L.) Gould] comprised the majority of the cool-season grass component. Smooth bromegrass and Kentucky bluegrass generally had similar harvest treatment trends as total cool-season grass (Table 6). Smooth bromegrass and Kentucky bluegrass composition did not change or slightly declined over time with KF harvests but increased over time with PSC harvests (Table 6). Smooth bromegrass composition increased over time in all three fertilization treatments (data not shown). Quackgrass composition averaged 18 % and was similar between fertilizer treatments, harvest treatments, and years and responded similarly with all interactions over time and fertilizer rate (Table 6). Intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey] and reed canarygrass (*Phalaris arundinacea* L.) were found in minimal amounts and did not contribute significantly to the stand.

Kansas Yellow sweet clover, the only legume found at the KS site, responded differently to fertilizer treatments (Table 7). Sweetclover started at 23 % composition in all fertilization treatments. In the first 3 years, sweetclover increased to 59 % in the 0 kg N ha^{-1} treatment, increased to 32 % in the 56 kg N ha^{-1} treatment, and declined to 17 % in the 112 kg N ha^{-1} treatment. In the fourth year, drought limited sweetclover emergence and growth, and it was seldom found during the final 3 years of the study.

Warm-season grass composition responded somewhat differently to fertilization over time (Table 7). Composition started near 70 % in all three fertilization treatments, and all declined in composition over time. However, warm-season grass in plots fertilized with 112 kg N ha^{-1} declined at a greater rate and ended with 33 % composition. Warm-season grasses in the 0 and 56 kg N ha^{-1} treatments finished with 43 and 46 % composition, respectively. Individually, warm-season grass species declined at the same rate over time in all three fertilizer treatments, except for sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], which slightly increased in composition over time in the 56 kg N ha^{-1} treatment (data not shown).

Warm-season grass harvested at PSC and KF declined over time at the same rate (~30 %) and ended at 35 and 47 % composition, respectively (Table 7). Individually, warm-season grass species responded differently to harvest treatment, unlike their response to fertilizer treatment. Switchgrass composition did not change over time with KF harvests, but composition declined with PSC harvests (Table 7). Little bluestem [*Schizachyrium scoparium* (Michx.) Nash] started at 20 % composition in both the KF and PSC harvests but declined at a faster rate in the PSC harvest and finished at 2 % (Table 7). Indiangrass [*Sorghastrum nutans* (L.) Nash] composition declined similarly over time in both harvest treatments (Table 7). Sideoats grama was the only warm-season grass that slightly increased composition over time with PSC harvests (Table 7). Big bluestem was present but did not contribute significantly to the stand.

Grassy weed composition, namely the cool-season winter annual Japanese brome (*Bromus arvensis* L.), tended to be greater at PSC harvests than at KF harvests ($P = 0.09$, Table 7). Japanese brome composition increased over time at the same rate regardless of fertilizer or harvest treatment. Japanese brome started the study at 0 % composition and increased linearly over time to over 30 % composition in the last 2 years of the study.

Perennial cool-season grasses did not respond differently to fertilizer or harvest treatments and averaged 6 % composition. However, perennial cool-season grass composition increased linearly over time from 1 to 17 % (data not shown).

Discussion

The two locations with legume components, KS and MO, responded similarly to fertilization treatments, with greater legume composition at low N fertilization levels. The results agree with those of Mallarino and Wedin [16] and Mohammed et al. [19], both of which documented that N fertilization can greatly reduce legume species composition in the grass sward. Sweetclover in KS and red clover in MO were greatest in plots without added nitrogen. The ability to fix N gives legumes a persistence advantage in low N environments, but heavy N fertilization will enable grasses to re-gain a competitive advantage [20]. Legume composition was lower at the MO site after only one season of 112 kg N ha^{-1} fertilization. Maximum biomass feedstock yields of mixed CRP grasslands in MO and KS were produced with N fertilization [1, 14], but legumes in the stand declined as a result of N fertilization. With the loss of legumes in the stand from greater N fertilization, the breakeven cost for producing biomass with 112 kg N ha^{-1} was 19 and 175 % greater than the breakeven cost of fertilizing with 0 kg N ha^{-1} at MO and KS, respectively [1]. The drought conditions in KS during the last 3 years of the study, especially

Table 7 Species and functional group vegetation composition in KS Conservation Reserve Program land harvested for biomass under three different fertilizer and two different harvest management regimes [peak standing crop (PSC), killing frost (KF)] from 2008 to 2013

	kg N ha^{-1}	Mean[a]	Year						Linear slope[b]
		%	2008	2009	2010	2011	2012	2013	
Legumes	0	17 a	23	17	59	1	1	1	−6.2 a*
	56	11 b	24	8	32	0	0	0	−4.9 ab*
	112	8 b	23	5	17	0	0	0	−4.2 b*
Warm-season grass	0	57 a	74	75	32	75	41	43	−6.1 ab*
	56	62 a	69	82	53	79	46	46	−5.5 a*
	112	60 a	73	78	59	80	37	33	−8.7 b*
Warm-season grass	Harvest								
	PSC	55 b	69	76	44	72	34	35	−7.7 a*
	KF	65 a	75	81	53	83	49	47	−5.9 a*
Switchgrass	PSC	10 b	15	19	9	5	4	6	−2.8 a*
	KF	15 a	15	17	13	14	12	17	−0.1 b
Sideoats grama	PSC	25 a	20	24	15	41	24	24	1.3 a*
	KF	22 a	22	25	15	31	22	18	−0.3 b
Little bluestem	PSC	8 b	19	12	8	6	3	2	−2.1 a*
	KF	15 a	20	19	12	20	10	9	−3.3 b*
Indiangrass	PSC	9 a	10	16	9	17	2	2	−2.1 a*
	KF	9 a	14	13	9	14	3	3	−2.4 a*
Japanese brome	PSC	20 a	0	6	12	8	54	39	9.5 a*
	KF	14 b	0	1	9	3	41	31	7.7 a*

All values for fertilizer treatments are averaged across PSC and KF harvest treatments, and all values for harvest treatments are averaged across 0, 56, and 112 kg N ha^{-1} fertilizer treatments

*Within the vegetation class or species and specific harvest timing or fertilization combination, the linear trend across years was significant at $P < 0.05$

[a] Within a vegetation class or species, different letters between harvest timing or fertilizer rates indicate that the mean species composition was different at $P < 0.05$, except that average warm-season grass composition for PSC and KF harvests was different at $P = 0.07$, and average Japanese brome composition for PSC and KF harvests was different at $P = 0.09$

[b] Within the vegetation class or species, different letters following the slope value indicate that the linear slopes of the trends for the two harvest timings or three fertilizer rates were different at $P < 0.05$, except that warm-season grass slopes of linear composition trends of fertilizer rates across years were different at $P = 0.06$

during April, May, and June (Table 3), also significantly reduced legume composition and biomass production in all fertilization treatments, which contributed to the high breakeven costs at the KS location.

In KS and ND, the two locations with warm-season grasses, harvest timing was more important to maintain desirable individual species than was fertilizer treatment. Harvests at PSC were detrimental to individual grass species, especially switchgrass at both locations. Mulkey et al. [22] reported that an early harvest had a significant negative impact on switchgrass and Indiangrass, while big bluestem biomass yield was unaffected when harvested at anthesis during three consecutive years. Big bluestem had more vigorous spring growth and more biomass growth than switchgrass following single or multiple defoliations during the previous growing season [3]. In southeastern Kansas, defoliating tall fescue infested tallgrass rangelands after a KF increased the warm-season grass composition and suppressed the cool-season grass composition of the mixed sward [13], which was similar to our results, especially at the ND site. In the present study, even big bluestem composition declined with PSC harvests during the growing season, while composition had little change at KF harvests. In ND, low biomass yields for PSC harvests during the last 3 years of the study [1] coincided with years in which warm-season grass composition dropped below 50 %.

Harvests at PSC, as in this study, occur when most warm-season grasses are in reproductive stages of development. Non-maintenance photosynthate is allocated to the developing seed after reproductive stages begin and may be removed by PSC harvest along with much of the plant's photosynthetic capacity to produce more carbohydrate. Total non-structural carbohydrate concentrations of big bluestem aerial tillers are greatest in May shortly after the beginning growth and spike again in July near the time of reproductive development [18].

At the time of a KF harvest, most warm-season grasses have either reached dormancy or are entering dormancy. Before dormancy, most plant storable carbohydrate resources that are important for winter respiration and survival have been translocated to plant bases and below-ground rhizomes for storage. Big bluestem rhizome weights and carbohydrate reserves decline in the spring and remain low through mid-summer, eventually begin to increase during late summer, and are near maximum levels in October to begin the winter [18]. Similar responses are likely to be observed in grasses of other biomass feedstock production systems and have even been observed in non-structural carbohydrate status of grazed bluestem pasture [24].

During the first 3 years of the current study, the warm-season grass mixtures changed little in yield and species composition due to harvest, while warm-season grass and legume composition was significantly altered by fertilization at the Kansas site [14]. More years of varying environmental conditions were necessary for other trends to appear. Species composition changes from defoliation may occur slowly over time, even with wide gradients in defoliation timing. No change in species composition was detected in three Oklahoma CRP grasslands of mixed native species when harvested annually for 3 years at three widely varying time periods of either August, October, or December [28].

The increased weed composition at the Kansas site may be a typical response in the lifespan of newly seeded southern warm-season grass mixtures. In Oklahoma, increased N fertilization of a seeded mixed grass stand resulted in a decrease of tallgrass species and an increase of annual weed species [2]. In another seeded and N-fertilized mixture of tall and short warm-season grasses in Oklahoma that was grazed at mid-growing season, blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] increased, while pooled composition of tallgrasses decreased [6]. In addition, the cool-season annual downy brome (*Bromus tectorum* L.) became abundant, and the authors cautioned that annual cool-season grasses should be expected to increase in seeded and spring fertilized warm-season grass stands [6]. A similar decrease in the composition of tallgrass species and an increase in the composition of annual cool-season grass weed species occurred over time regardless of N fertilization at the Kansas site in the present study. A large part of this increase in the last 3 years could be attributed to late winter or early spring precipitation utilized by Japanese brome and a lack of warm-season grass growth from low May and June precipitation (Table 3). Low May and June precipitation results in low yields of native rangelands dominated by warm-season grasses in the region [11]. Defoliation in spring rather than mid-summer or after frost would likely reduce the cool-season grass composition in these seeded warm-season grass mixtures [9].

The CRP was originally established for soil and water conservation, not biomass production. However, CRP land is a potentially important land resource for sustainable biomass feedstocks. Accordingly, in order for CRP to be a reliable source of sustainable biofuel feedstock, management must favor production of desirable species and maintaining stands to provide ongoing conservation services. Species composition of mixed CRP grasslands will shift over time based on harvest and fertilization management of these lands. Shifts to less desirable or less productive species will hinder the ability of these lands to provide a sustainable or reliable resource for bioenergy feedstock production. For CRP stands with significant legume composition, N fertilizer should not be applied in order to maintain the desirable legume population and to reduce the cost of biomass production. Furthermore, biomass harvests should be conducted after KFs at the end of the growing season to maintain desirable and productive warm-season grass species composition in CRP, especially at more northerly latitudes of the Great Plains.

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