A Screening for Biofuel Feedstock Quality of Perennial Warm-Season Grasses in Semiarid Subtropical Environments

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ABSTRACT

Cellulosic biofuel crops have not been evaluated for semiarid, subtropical environments, but commonly grown, taller-growing, perennial warm-season grasses may have merit. Desirable quality components [low crude protein (CP; <3.3%), low ash, high neutral detergent fiber (NDF), and high *in vitro* true digestibility (IVTD)] were estimated by near infrared spectroscopy (NIRS) for two replicates of 16 perennial warm-season grasses collected in eastern New Mexico post-frost in 2007 and 2008. Switchgrass (*Panicum virgatum*), which is the model perennial warm-season grass crop for cellulosic biofuel production, averaged 0.98, 6.83, 76, and 56.7% CP, ash, NDF, and IVTD, respectively. When averaged across years, big, little, and silver bluestem [*Andropogon gerardii* Vitman, *Schizachyrium scoparium* (Michx.) Nash, and *Bothriochloa laguroides* D.C., respectively]; Indiangrass [*Sorghastrum nutans* (L.) Nash]; and switchgrass had observed values that were in a desirable range, with CP consistently below 3.3%. Cane and yellow bluestem [*B. barbinodis* (Lag.) Herter and *B. ischaemum,* respectively], giant spike dropseed (*Sporobolus contractus* Hitch. or *S. giganteus* Nash), Kleingrass (*P. coloratum*), vine mesquite (*P. obtusum* H.B.K), and weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees] had CP values both above and below 3.3%, but had desirable values for ash, NDF, and IVTD. Giant sacaton and sand dropseed (*S. wrightii* Scribn. and *S. cryptandrus* Torr., respectively) had high CP, but were acceptable for the other components. High average CP and ash in plains bristlegrass [*Setaria leucopila* (Scribn. & Merr.) K. Schum.], purple threeawn (*Aristida purpurea* Nutt.), and sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] and low NDF for plains bristlegrass and sideoats grama lessen their value for cellulosic biofuel feedstock despite their fairly high IVTD. Several perennial warm-season grasses commonly grown in semiarid, subtropical regions may have potential as cellulosic biofuel feedstock. Further testing is needed to evaluate yield potential and to formally compare biofuel feedstock quality components in low-input systems.

INTRODUCTION

A goal throughout much of the developed world is to replace a considerable portion of petroleum fuel with biofuels, including those from cellulosic biomass sources (U.S. Department of Energy, 2006). Plant species that are more water-use efficient are preferred, and biofuel crops will be needed for each specific environment (Shubert, 2006). Cellulosic biomass crops have been identified for most agro-ecoregions as defined by temperature, rainfall, and soil types, but few have been identified for semiarid, subtropical regions, such as the Southern High Plains of the USA, which is dominated by short, mixed, and tallgrass prairie (U.S. Department of Energy, 2006; Allen et al., 2008).

Perennial warm-season grasses are ideally suited for biomass production because they can generally be harvested after seed production and senescence to optimize yield and cellulosic biofuel feedstock quality. This strategy also reduces energy and labor costs for harvesting and curing (Muir et al., 2001; Xiong et al., 2008) and improves feedstock quality through nutrient redistribution from aboveground plant parts to belowground plant parts (Mulkey et al., 2006; Parrish et al., 2008; Xiong et al., 2008).

These grasses also tend to be lower than some other forage species in crude protein (CP) and ash and higher in fiber and digestibility, which are desirable for biofuel feedstock (Sanderson et al., 1999; Mulkey et al., 2006; Parrish et al., 2008) and are already measured as components of forage nutritive value for livestock feed (Geber, 2002). Wolfrum and Sluiter (2008) found that near infrared spectroscopy (NIRS) estimates of fiber were highly correlated with wet chemistry evaluations

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Table 1. Common and Scientific Names, Origins, and Collection Locations in 2007 and 2008 of Perennial Warm-Season Grasses Commonly Grown in the Southern High Plains of the USA Compared to Switchgrass for Cellulosic Biofuel Feedstock Quality

Common name	Scientific name	Origin	Approximate site on Figure 1
Big bluestem	*Andropogon gerardii* Vitman	Native	C, D
Cane bluestem	*Bothriochloa barbinodis* (Lag.) Herter	Native	E, F
Giant sacaton	*Sporobolus wrightii* Scribn.	Native	A
Giant spike dropseed	*Sporobolus contractus* Hitchc. or S. giganteus Nash	Native	E
Indiangrass	*Sorghastrum nutans* (L.) Nash	Native	C, D
Kleingrass	*Panicum coloratum* L.	Introduced	H
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	Native	H, I
Plains bristlegrass	*Setaria leucopila* (Scribn. & Merr.) K. Schum.	Native	G
Purple threeawn	*Aristida purpurea* Nutt.	Native	H
Sand dropseed	*Sporobolus cryptandrus* Torr.	Native	A, C
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.	Native	B, G
Silver bluestem	*Bothriochloa laguroides* D.C.	Native	C, D
Switchgrass	*Panicum virgatum* L.	Native	C, D
Vine mesquite	*Panicum obtusum* H.B.K.	Native	E
Weeping lovegrass	*Eragrostis curvula* (Schrad.) Nees	Introduced	B, F
Yellow bluestem	*Bothriochloa ischaemum* L.	Introduced	G, H

of specific carbohydrates of interest in biofuel production, and Shenk (1981) reported that NIRS provides a more accurate estimate of forage nutritive value than wet chemistry, especially for *in vitro* digestibility, due to the ease of calibration and the elimination of bias and nonrandom error.

Switchgrass (*Panicum virgatum*) is indigenous to the eastern two-thirds of the USA (Muir et al., 2001; Parrish et al., 2008) and is the model perennial warm-season grass for cellulosic biofuel production because of its yield and quality potential (Bouton, 2006; Parrish et al., 2008). Other perennial warm-season grasses meet the criteria upon which switchgrass was selected (Bouton, 2006; Boe and Bortnem, 2009), including tissue quality for forage (Wilsey and Polley, 2006) or bioenergy production (Tilman et al., 2006). Many of these species have more stable production in semiarid regions than switchgrass (Stritzler et al., 1996; Wilsey and Polley, 2006; Boe and Bortnem, 2009), and several have been evaluated for their yield potential under rainfed conditions in the Southern High Plains.

Buttrey et al. (2009) found that sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] yielded >2 Mg ha^{-1}, while the shorter-growing blue grama (*B. gracilis* L.) and buffalograss (*Buchloe dactyloides* L.) did not. Switchgrass yielded 3.1 Mg ha^{-1} in that study. From Conservation Reserve Program (CRP) fields, Kirksey et al. (1996) measured >5 Mg ha^{-1} yields from mixed grasses, 3.9 Mg ha^{-1} for Kleingrass (*P. coloratum* L.), as much as 7.9 Mg ha^{-1} for weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees], and 5.6 Mg ha^{-1} for yellow bluestem (*Bothriochloa ischaemum* L.), while mixed blue and sideoats grama swards yielded <2 Mg ha^{-1}. Silver bluestem (*B. laguroides* D.C.) is a native species that yields similarly to the introduced yellow bluestem (Coyne and Bradford, 1985; Wilsey and Polley, 2006). Other perennial warm-season grasses with similar stature and stand density would likely yield similarly, or more for taller-growing species.

Little information is available on variables affecting the cellulosic biofuel feedstock quality of perennial warm-season grasses in the Southern High Plains. Consequently, the objective of this study was to survey native and introduced perennial warm-season grasses adapted to semiarid, subtropical environments for biofuel feedstock quality potential by describing their NIRS-estimated CP, ash, neutral detergent fiber (NDF), and *in vitro* true digestibility (IVTD).

METHODS

Two samples of each species of perennial warm-season grass were collected at or very nearby New Mexico State University's Agricultural Science Center at Tucumcari (35° 12' 0.5" N, 103° 41' 12.0" W; elev. 1,247 m) from their natural habitat or where they thrived upon introduction with no further inputs. The grasses included in this study are given in Table 1 and approximate sampling locations are shown on Figure 1. The study area included an irrigation canal that afforded the presence of tallgrass prairie species, including switchgrass. Soil types were either Canez fine sandy loam (fine-loamy,

Figure 1. **Approximate sampling locations for perennial warm-season grasses at New Mexico State University's Agricultural Science Center at Tucumcari**.

mixed, thermic Ustollic Haplargid) or Redona fine sandy loam (fine-loamy, mixed, superactive, thermic Ustic Calciargids). Sampling was guided only by species availability; no attempt was made to control for soil type or any other attribute of the sampling location. Anderson et al. (1991) reported that quality components are little affected by location, which can also exert environmental influences. Species locations were known from past surveys of the area at and around the science center. Collections were made post-frost (-2.2°C) in 2007 (frost on 1 November; harvest 16-20 November) and 2008 (frost on 24 October; harvest 8-12 December) to permit natural curing of the standing crop (Muir et al., 2001; Xiong et al., 2008). Each year, all species had completed seed production prior to sampling.

Samples of each species were hand-clipped to approximately 7.5 cm, dried for 48 h at 60°C, ground to pass a 1-mm screen, and submitted to Ward Laboratories (Kearney, NE, USA) for estimation of CP, ash, NDF, and IVTD by NIRS. The equation used in these evaluations (07gh50-2.eqa) was developed by the NIRS Consortium (2009) for grass hay using warm- and cool-season grasses as an update to the previous equation with the addition of over 100 samples. The number of samples, mean, and standard deviation used in the calibration were 799, 12.61, and 6.51, respectively, for CP; 164, 8.26, and 2.97 for ash; and 531, 59.6, and 13.1 for NDF (NIRS Consortium, 2009). *In vitro* true digestibility was calculated as 100 – (NDF – digestibleNDF) (Paolo Berzaghi, NIRS Consortium, personal communication, 2 June 2010).

For a special case such as this, where n = 2 for each year, the mean minus the standard error (SE) is the minimum of the two data points and the mean plus SE is the maximum. A descriptive data analysis used graphs for each variable depicting the mean and range of values (or equivalently the mean and the mean ± SE) observed for each species within each year. No inferences were made beyond the data at hand.

RESULTS AND DISCUSSION

Estimates of biofuel feedstock quality in this study (Figures 2 through 5) are consistent with those measured by others using various methods, including wet chemistry (Pieper et al., 1978; Stritzler et al., 1996), *in sacco* digestibility (Stritzler et al., 1996), flash combustion (Wilsey and Polley, 2006), and NIRS (Sanderson et al., 1999; Mulkey et al., 2006) for Indiangrass (Wilsey and Polley, 2006), Kleingrass (Stritzler et al., 1996; Wilsey and Polley, 2006), little bluestem (Wilsey and Polley, 2006), sand dropseed (Pieper et al., 1978), sideoats grama (Pieper et al., 1978; Wilsey and Polley, 2006), switchgrass (Sanderson et al., 1999; Stritzler et al., 1996; Mulkey et al., 2006), vine mesquite (Pieper et al., 1978), weeping lovegrass (Stritzler et al., 1996), and yellow bluestem (Wilsey and Polley, 2006).

The CP of switchgrass and several other species was below that reported by Sanderson et al. (1999) in central Texas, while NDF was similar (2.0% CP and 79.0% NDF compared with Figures 2 and 4). Sanderson et al. (1999) applied as much as 134 kg N ha^{-1} yr^{-1}, which may have led to higher CP concentration. Nutrients were not applied to the plants collected for this study. For CP (Figure 2), with some exceptions, measurements for 2008 were lower than 2007. This may have been due to the longer period in 2008 between the first temperature below -2.2°C and sampling compared to 2007 (16 vs. 46 d for 2007 and 2008, respectively). Parrish et al. (2008) reported that lower N content (calculated as CP / 6.25) could reduce decomposition after frosts in the standing crop and was beneficial for some ethanol conversion technologies, and Mulkey et al. (2006) stated that the reduction in N content also would likely lead to an increase in the fiber component. Switchgrass CP content can drop to 3.3% after senescence (Parrish et al., 2008), setting that as a standard for concentrations of that component. This suggests that delayed harvest may have improved feedstock quality due to reduced N content (Xiong et al., 2008; Boe and Bortnem, 2009), which should be further explored in regions with dry winters, such as the Southern High Plains.

Otherwise, in the current survey, only big, little, and silver bluestem, Indiangrass, and switchgrass had CP consistently <3.3% across years (Figure 2). Kleingrass, vine mesquite, and yellow bluestem had >3.3% CP in 2007, but sufficiently less in 2008 to average <3.3%

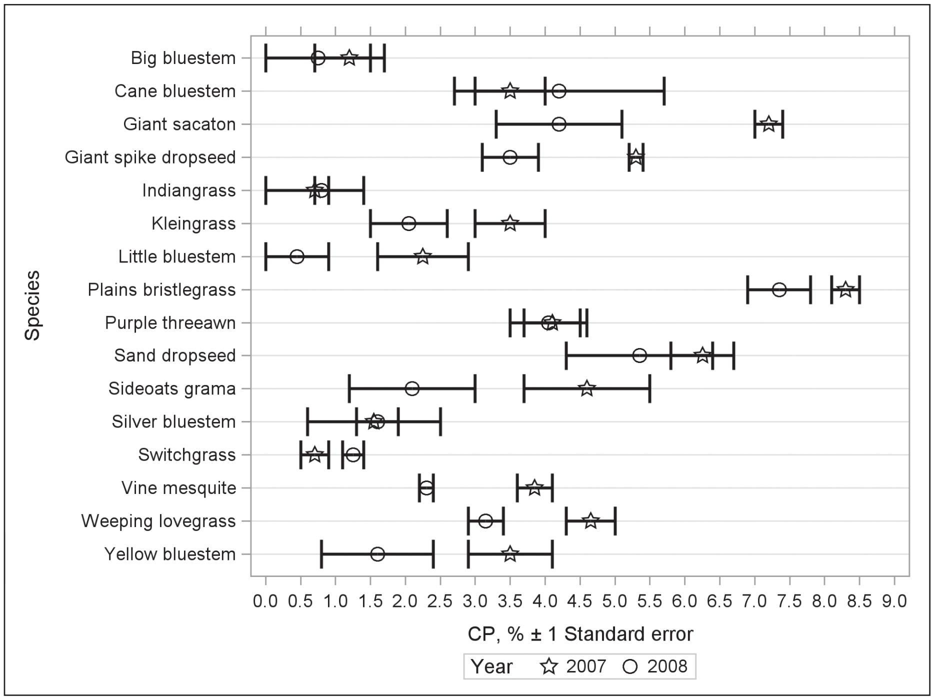

Figure 2. **Crude protein (CP) percentage means of two samples collected in 2007 and 2008 from perennial warm-season grasses near Tucumcari, NM. When n = 2, as in this case for each year, the mean – the standard error (SE) is the minimum of the two data points and the mean + SE is the maximum.**

across years. Sideoats grama and weeping lovegrass had <3.3% CP in 2008, but still averaged >3.3% across years, although only slightly (Figure 2). Cane bluestem averaged <4.0% CP across years and was one of the few grasses to not have a reduction from 2007 to 2008. Giant sacaton, giant spike dropseed, plains bristlegrass, and sand dropseed all averaged CP well above 3.3% across years (Figure 2).

Geber (2002) used digestible organic matter to evaluate cellulosic biofuel potential of reed canarygrass (*Phalaris arundinacea* L.) because the remaining plant components, such as ash, were largely insoluble. In addition to high CP, high mean ash concentrations in plains bristlegrass, sideoats grama, and purple threeawn lessen the value of these species (Figure 3) (Sanderson et al., 1999; Mulkey et al., 2006; Parrish et al., 2008). The other species tested had more acceptable mean ash percentages (Figure 3).

Low NDF content of plains bristlegrass and sideoats grama (Figure 4) also reduces their value as a biofuel (Sanderson et al., 1999; Mulkey et al., 2006; Parrish et al., 2008). All species had comparable or high IVTD (Figure 5). Despite exceptional digestibility, the high CP (Figure 2) and ash (Figure 3) and low NDF (Figure 4) of plains bristlegrass, purple threeawn, and sideoats grama make them less desirable as candidates for cellulosic biofuel production, as does the observation of low yield, particularly for plains bristlegrass and purple threeawn (L. Lauriault, personal observation).

Some of the species selected for use in this study are limited in distribution by environmental factors (L. Lauriault, personal observation). Prairies are often a blend of dominant and subdominant species (Pieper et al., 1978; Wilsey and Polley, 2006). Because cellulosic feedstock quality was comparable among most of the grasses in this study, a mid- or tallgrass prairie or a CRP field with a diversity of these grasses should have a fairly consistent feedstock quality even if the species are not uniformly distributed. Additionally, blends of cane, silver, and yellow bluestem, which are common to semiarid regions (350-600 mm precipitation; Wilsey and Polley, 2006; Allen et al., 2008) should also be consistent in terms of quality and yield (L. Lauriault, personal observation).

Tilman et al. (2006) reported that high-diversity, low-input grasslands produced greater bioenergy yields than monocultures and need not displace food production because they can be grown on marginal lands (Boe and Bortnem, 2009; Bouton, 2006). A considerable amount of the land in the semiarid, subtropical Southern High Plains is already established in high-diversity blends of perennial warm-season grasses (Allen et al., 2008) that could be used for biofuel production in low-input sys-

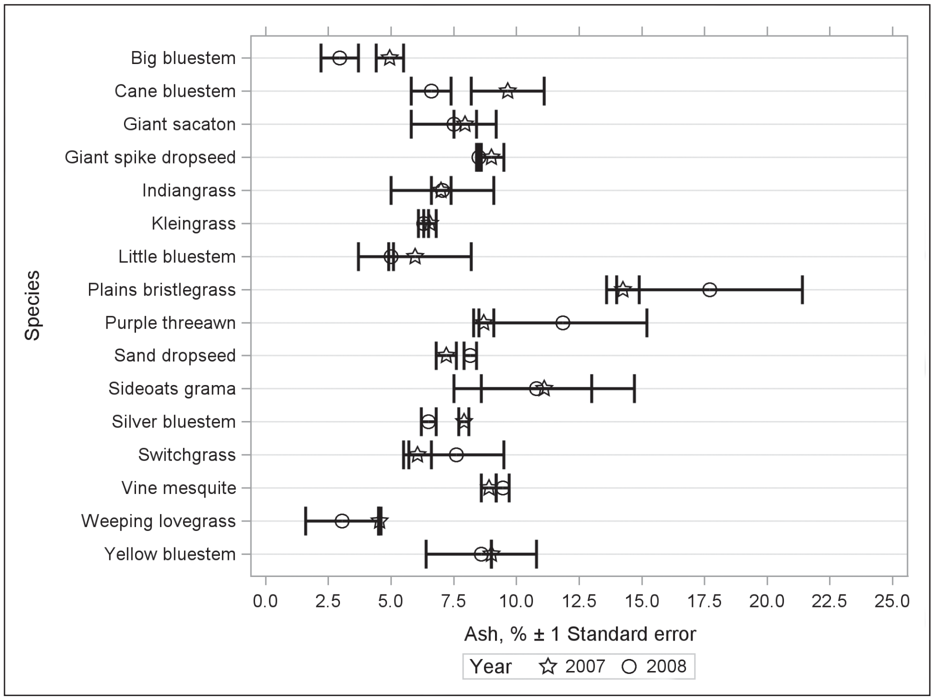

Figure 3. **Ash percentage means of two samples collected in 2007 and 2008 from perennial warm-season grasses near Tucumcari, NM. When n = 2, as in this case for each year, the mean – the standard error (SE) is the minimum of the two data points and the mean + SE is the maximum.**

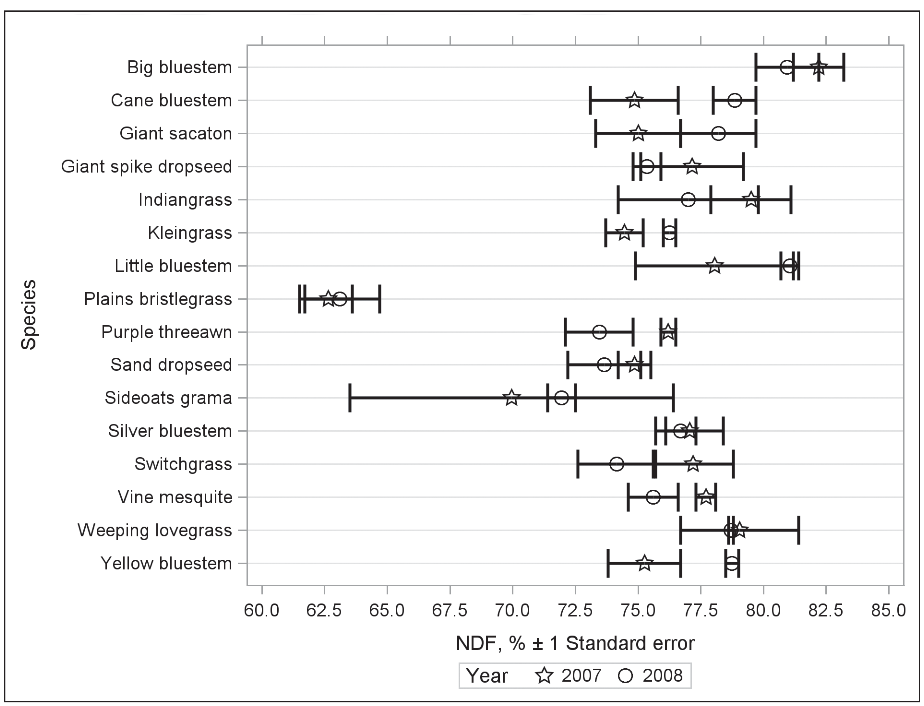

Figure 4. **Neutral detergent fiber (NDF) percentage means of two samples collected in 2007 and 2008 from perennial warm-season grasses near Tucumcari, NM. When n = 2, as in this case for each year, the mean – the standard error (SE) is the minimum of the two data points and the mean + SE is the maximum.**

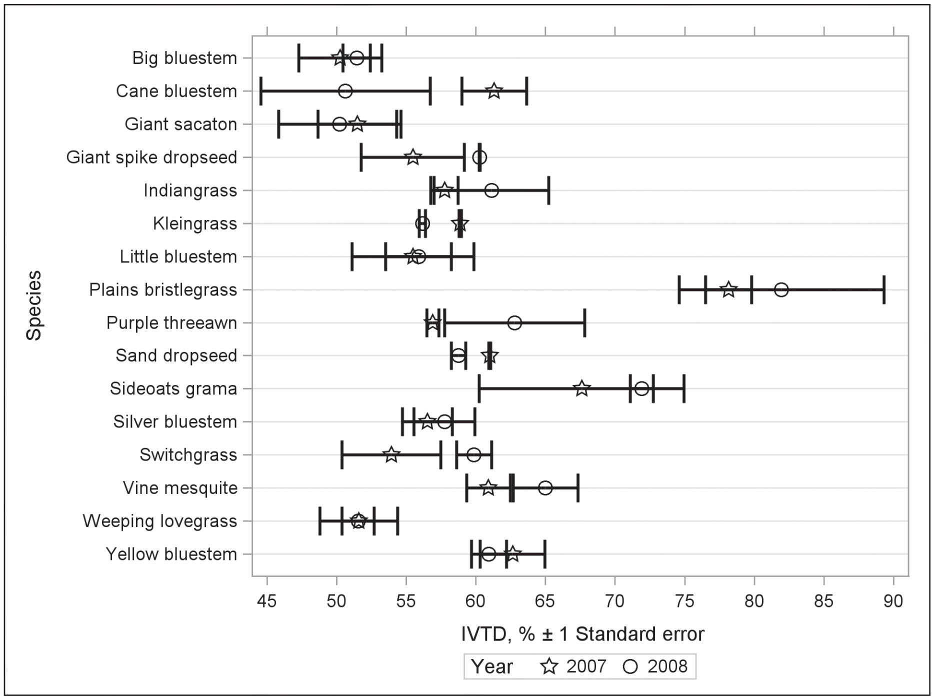

***Figure 5. In vitro* true digestibility (IVTD) percentage means of two samples collected in 2007 and 2008 from perennial warm-season grasses near Tucumcari, NM. When n = 2, as in this case for each year, the mean – the standard error (SE) is the minimum of the two data points and the mean + SE is the maximum.**

tems. Kirksey et al. (1996) reported >5 Mg ha^{-1} yields for mixed grass swards in CRP fields that likely were composed of a combination of several grasses included in this survey. Additionally, weeping lovegrass had consistently low ash (Figure 3), high NDF (Figure 4), and high IVTD (Figure 5), and <3.3% CP when harvest was delayed (2008) (Figure 2), which supports the proposition that CRP fields sown to weeping lovegrass can be maintained intact to produce biofuel rather than being reverted to annual cropping (Mulkey et al., 2006).

Further research is needed to evaluate the yield and cellulosic biofuel quality potential of these species compared to switchgrass under varied soil moisture conditions and nitrogen levels or interseeded with adapted legumes, in addition to the benefit of delayed harvest in this environment.

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