

## Ontogenesis and nutritive value of warm-season perennial bunch grasses

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### Abstract

Understanding the dynamics of nutritive values in warm-season perennial bunch grasses with change in ontogenesis is essential to managing their use as forage for livestock or cellulosic bioenergy feedstock. Accumulated growth (not previously harvested) of Alamo lowland and accession 9065018 upland switch grass (*Panicum virgatum*), Lometa Indian grass (*Sorghastrum nutans*), Earl big bluestem (*Andropogon gerardii*), San Marcos eastern gama grass (*Tripsacum dactyloides*) and Haskell sideoats grama (*Bouteloua curtipendula*), all native to the southern Great Plains of North America, as well as Selection 75 Klein grass (*Panicum coloratum*), originating in southern Africa but selected in North America, was harvested every 28 d for 3 yr, commencing 1 yr after establishment. Growth stage, crude protein (CP) and in vitro dry matter disappearance (IVDMD) over 48 h were evaluated at each date. Some entries, such as Haskell, San Marcos and Selection 75, initiated reproductive growth earlier in the growing season and had higher nutritive value [up to 119 g CP/kg dry matter (DM) and 630 g IVDMD/kg DM] at seed set than those reproducing later in the season. Nutritive value of San Marcos and Selection 75 responded to autumn rainfall with resurging nutritive value (over 100 g CP/kg DM and over 600 g IVDMD/kg DM), whereas others did not. These nuances in nutritive value may be useful in manipulating species composition and season of utilization for grazing bunch grasses, especially when incorporated into opportunistic harvests of bioenergy feedstock.

### Resumen

El conocimiento del valor nutritivo que acompaña la ontogénesis de una planta forrajera – cambios en el desarrollo durante su vida útil – es esencial para el manejo de las gramíneas perennes y de crecimiento en macollas (gramíneas cespitosas), para su uso como forraje en explotaciones ganaderas o como biomasa celulósica para producción de bioenergía. Para el estudio, durante 3 años y cada 28 días, se muestreó la biomasa acumulada (sin cosecha previa), después de 1 año de establecimiento, de las siguientes gramíneas subtropicales/de clima templado-cálido: switch grass, *Panicum virgatum* (‘Alamo’ para zonas bajas y ‘Accession 9065018’ para zonas altas); *Sorghastrum nutans* (‘Lometa’ Indian grass); *Andropogon gerardii* (‘Earl’ big bluestem); *Tripsacum dactyloides* (‘San Marcos’ eastern gama grass); y *Bouteloua curtipendula* (‘Haskell’ sideoats grama), todas ellas especies nativas de la región sur de las Grandes Planicies de América del Norte; y ‘Selection 75’ Klein grass (*Panicum coloratum*), originaria del sur de África pero mejorada en América del Norte. Se evaluaron la fase reproductiva, las concentraciones de proteína cruda (PC) y la digestibilidad in vitro de la materia seca (DIVMS). Algunos cultivares tales como Haskell, San Marcos y Selection 75 iniciaron sus fases reproductivas antes que las demás gramíneas en el estudio y presentaron el mayor valor nutritivo (hasta 119 g de PC/kg de MS y 630 g de DIVMS) al momento de la formación de semillas. Los valores nutritivos de los

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cvs. San Marcos y Selection 75 respondieron a las lluvias de otoño con valores de PC superiores a 100 g/kg de MS y 600 g de DIVMS. Estas diferencias en ontogénesis y valor nutritivo pueden ser de utilidad en el momento de seleccionar la composición de pasturas y la época para pastoreo, especialmente cuando estas gramíneas cespitosas se integran en sistemas con cosechas oportunistas de biomasa para producción de bioenergía.

## Sumário

O conhecimento do valor nutritivo que acompanha a ontogênese de gramíneas cespitosas perenes é essencial para o manejo destas como forragem ou bioenergia. Amostras da produção forrageira acumulada por 'Alamo' lowland e do acesso 9065018 de upland switch grass (*Panicum virgatum*), 'Lometa' Indian grass (*Sorghastrum nutans*), 'Earl' big bluestem (*Andropogon gerardii*), 'San Marcos' eastern gama grass (*Tripsacum dactyloides*), e 'Haskell' sideoats grama (*Bouteloua curtipendula*), todas espécies nativas do sul das Grandes Planícies da América do Norte, e 'Selection 75' Klein grass (*Panicum coloratum*) originária da África austral mas selecionada na América do Norte, foram colhidas cada 28 dias durante 3 anos após um ano de estabelecimento. Registraram-se as fases reprodutivas, proteína bruta e digestibilidade in vitro da matéria seca. Haskell, San Marcos e Selection 75 iniciaram a fase reprodutiva antes das outras e tiveram valor nutritivo superior (até 119 g de proteína bruta/kg de matéria seca e 630 g de digestibilidade in vitro) durante a formação de semente comparado com as restantes com floração mais tardia. Os valores nutritivos de San Marcos e Selection 75 também responderam às chuvas do outono com um crescimento no valor nutritivo (acima de 100 g de proteína bruta/kg de matéria seca e acima de 600 g digestibilidade in vitro) enquanto outras não tiveram esta resposta. Estas diferenças de ontogênese e valor nutritivo poderão ser úteis na seleção da composição específica da pastagem e na determinação da época de pastoreio de espécies cespitosas especialmente quando integrando com a colheita oportunística de forragem para bioenergia.

## Introduction

The design of low-input sustainable warm-season grassland systems, whether on reseeded rangeland or cultivated pasture, depends on identifying perennial grasses that provide ruminants with herbage of adequate nutritive value for as much of the growing season as possible, while still satisfying ancillary production goals such as bioenergy or wildlife. The limitation for perennial grasses, however, is that they quickly decline in nutritive value as they mature (White and Wight 1984), especially in conditions where close grazing does not constantly induce regrowth (Coleman et al. 2004). The appearance of reproductive structures in the grazed canopy, for example, results in reduced interspecific grass selection by cattle (Norton and Johnson 1983), but may not be as important as other factors in intraspecific grazing selection (Heitschmidt et al. 1990). These influences on intraspecific selection are even less well understood for more selective grazers or browsers. How soon these grasses, as they mature, lose their nutritive value for and palatability to grazing animals is an important management criterion.

Predicting forage quality by measuring nutritive value factors in the laboratory is a resource-saving tool. In vitro dry matter disappearance (IVDMD) is used to estimate relative digestibility of forages and is related to eventual animal performance (Stern et al. 1997). The

primary factor affecting digestibility is relative fiber concentrations, which tend to increase with plant maturity (Short et al. 1974; Andrighetto et al. 1992; Wilson 1994). Crude protein (CP) concentration is often used as a predictor of animal performance. A dietary CP concentration close to 70 g/kg DM is widely considered minimum for maintenance in beef cattle, with anything above that available for growth or other forms of production (Agricultural Research Council 1980; Van Soest 1994). Smaller ruminants have greater nutritional dietary requirements for the same performance than cattle, 92 g CP/kg DM considered minimum for maintenance of ewes (National Research Council 2007).

Our objectives were to monitor growth stage and evaluate nutritive value of 7 warm-season perennial bunch grasses during the 3 years immediately following an establishment year. We did this by registering phenological development of each species and measuring IVDMD and CP concentrations on accumulated herbage each month during the warm season. The relationships of nutritive value with morphological developmental stages should provide an understanding of how feed value of these species might change with maturity in other regions where they might be grown; this could reduce the number of laboratory analyses needed in these regions, saving both time and expense. It might also guide cellulosic bioenergy feedstock harvests, timed to remove lignified growth from swards.

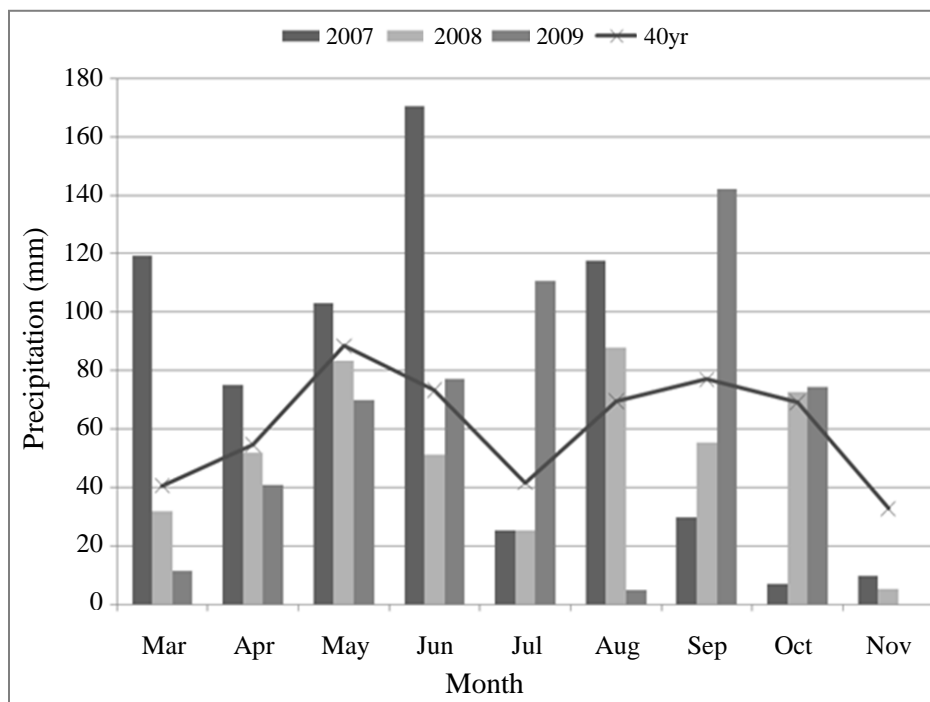
## Materials and Methods

The study was conducted in 2007–2009 at the USDA Natural Resources Conservation Service, James E. “Bud” Smith Plant Materials Center, Knox City, TX, USA (33°26′40.40” N, 99°51′53.89” W) on a Miles fine sandy loam soil (fine-loamy, mixed, superactive, thermic Typic Paleustalfs) (National Soil Survey 2002) with an initial soil pH of 6.9, 22 g P/kg, 139 g K/kg, 719 g Ca/kg and 251 g Mg/kg (Mehlich III). Alamo lowland and accession 9065018 upland switch grass (*Panicum virgatum*), Lometa Indian grass (*Sorghastrum nutans*), Earl big bluestem (*Andropogon gerardii*), San Marcos eastern gama grass (*Tripsacum dactyloides*), Haskell sideoats grama (*Bouteloua curtipendula*), all native to the southern Great Plains (Diggs Jr. et al. 1999), and Selection 75 Klein grass (*Panicum coloratum*), native to southern Africa but selected in North America (Tischler and Ocumpaugh 2004), were drilled at rates of 0.9, 2.7, 2.0, 0.7, 4.5, 0.9 and 2.0 kg pure live seed/ha, respectively, on 17 May 2006 in 2.1 x 9.6 m plots. Each of the 42 main plots (3 fertilized and 3 unfertilized per entry) was subdivided into eight 2.1 x 1.2 m subplots (total 336). The same subplots were used for each treatment combination during 3 years (2007, 2008 and 2009). Plots were irrigated in May and July 2006 to root-zone soil saturation to accelerate establishment and to guarantee seedling growth and development prior to

the first killing frost of that year. Forty-year average rainfall (March–November) for the site was 547 mm, while rainfall, as a percentage of that long-term average, was 120% in 2007, 85% in 2008 and 97% in 2009 (Figure 1).

No fertilizer was applied in 2006, but 40 kg P and 50 kg K were applied to all plots per Texas A&M AgriLife Extension Soil Analysis (College Station, TX, USA) recommendations in 2007 with the N application. In 2007, 2008 and 2009, half of the plots were fertilized with a single application of ammonium sulfate (21% N) at the 3<sup>rd</sup> leaf stage to provide 67 kg N/ha/yr. At the final forage sampling in 2009, analysis of soil samples indicated pH 6.8, 45 g P/kg, 282 g K/kg, 829 g Ca/kg and 382 g Mg/kg (Mehlich III).

Main plots were arranged in a randomized complete block design with 3 replications. Months (April–November) were randomly assigned to each subplot for harvest purposes. Each month morphological characteristics were recorded (simplified from Moore et al. 1991) for all subplots prior to harvest. Monthly samples, starting 19, 17 and 27 April in 2007, 2008 and 2009, respectively, were collected until November by harvesting growth accumulated to that date for that year from two 50 x 50 cm quadrats from within the 1.1 x 2.4 m interior of each subplot to a height of 3 cm. Frosts occurred every year between the October and November harvests.



**Figure 1.** Monthly precipitation during the 3 years of the trial and 40-year average at Knox City, TX, USA.

Representative herbage subsamples from material harvested from each subplot were dried in forced-air ovens at 55 °C, ground through a 1-mm screen and analyzed for N concentration and IVDMD. Nitrogen was determined using an Elementar Vario Macro C-N Analyzer (Mt Laurel, NJ, USA), following methods described by Burt (2004). The IVDMD rates were determined for 48 h using an ANKOM Daisy II Incubator (ANKOM Technologies, Macedon, NY, USA) inoculated with rumen liquid extracted from rumen-fistulated steers on a 12% CP sorghum-Sudan hybrid (*Sorghum bicolor* x *S. sudanense*) diet. This system emulates the Tilley and Terry (1963) 2-stage in vitro digestibility technique (Coblentz et al. 1997) but washes the sample in a neutral detergent (Van Soest et al. 1991) instead of a pepsin solution. Residues were corrected for residual ash and sodium sulphite was omitted.

Year (3), month (8), N fertilizer rate (2) and species (7) were independent variables in the model; all herbage component concentrations were dependent variables tested by analysis of variance for interactions and, if appropriate, simple effects. Nutritive values at the same phenological stages were tested for variance because these occurred in different months, depending on species. These were considered significant at  $P \leq 0.05$  and multiple mean separations were conducted where appropriate at the same level of probability using an LSD ( $P \leq 0.05$ ).

## Results

### *Phenological growth stages*

Lometa and 9065018 upland switch grass remained vegetative into June, at least 1 month longer than the other entries (Table 1). Stem elongation commenced in San Marcos and Selection 75 in May. Haskell was the first to flower (May), followed by San Marcos and Selection

75 in June, at least 1 month before the other entries. Lometa was the last to flower (September). Earl, Lometa and Alamo tended to be the latest to set seed, contrasting with San Marcos and Selection 75, which set seed as early as June every year.

### *Crude protein*

Phenological stage had the greatest effect on CP concentration, with highest values during the early vegetative stage and lowest in November for all species (Table 2; Figure 2). Species differences occurred within years but these were inconsistent among months. Crude protein concentration increased on average from 93 g/kg DM in plants receiving no N fertilizer to 98 g/kg DM in those that received 67 kg N/ha/yr, with responses similar for all species in all years and months of harvest.

Selection 75 was the only entry that maintained April CP concentrations until June in 2008 and May in 2009. San Marcos and Selection 75 were the only entries that maintained CP values above 70 g/kg DM until October of every year, while Earl and Lometa achieved this outcome in 2 of the 3 years. Unlike 9065018 upland switch grass, Alamo was among the first of the 7 entries whose CP concentration declined below 70 g/kg DM in all 3 years, i.e. July in 2007, September in 2008 and October in 2009.

Figure 2 shows CP concentration averages (pooled for fertilizer, which did not interact with the other factors) at each phenological growth stage for each species (averaged over years; years were also significant but are reported in Table 2). At the early stages of growth, Haskell, San Marcos and Selection 75 had consistently elevated CP concentrations relative to other entries; however, these 3 entries also initiated reproductive growth at least a month before other entries (Table 1). By the time November frost affected CP, however, only San Marcos was distinguishable from the other species.

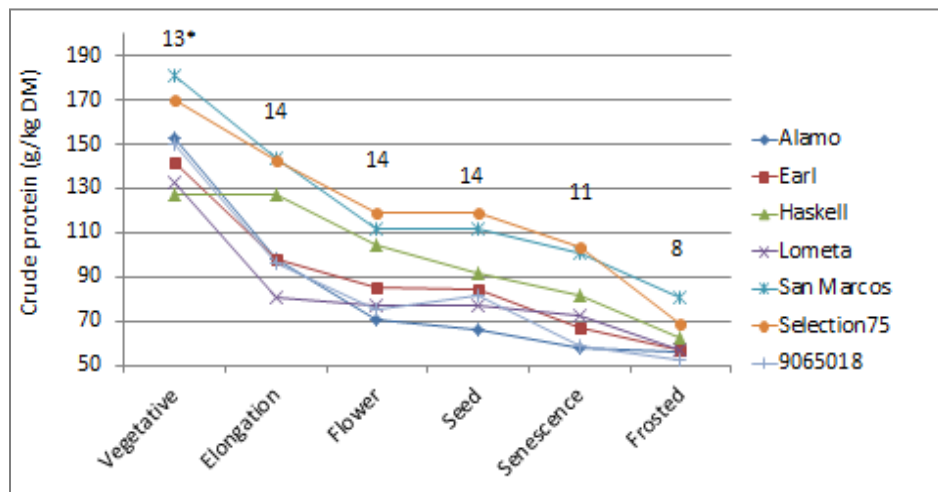
**Table 1.** Phenological growth stages (adapted from Moore et al. 1991) of 7 perennial warm-season grasses over 3 years at Knox City, TX, USA.

| Entry        | Vegetative | Stem elongation | Flowering | Seed set | Seed shatter |
|--------------|------------|-----------------|-----------|----------|--------------|
| Haskell      | Apr-May    | ---             | May       | Jun-Jul  | Jul-Aug      |
| San Marcos   | Apr        | May             | Jun       | Jun      | Jul-Aug      |
| Selection 75 | Apr        | May             | Jun       | Jun      | Jul-Aug      |
| Earl         | Apr-May    | Jun-Jul         | Aug       | Sep-Oct  | Oct-none     |
| Alamo        | Apr-May    | Jun-Jul         | Aug       | Sep      | Oct          |
| 9065018      | Apr-Jun    | Jun-Jul         | Aug       | Sep      | Oct          |
| Lometa       | Apr-Jun    | Jul-Aug         | Sep       | Sep-Oct  | Oct-none     |

**Table 2.** Crude protein concentrations (g/kg DM) of 7 perennial, warm-season grasses collected monthly over 3 years during the growing season (year x month x entry interaction  $P \leq 0.05$ ; pooled for fertilizer treatment).

| Year/Entry   | Apr                | May    | Jun     | Jul     | Aug    | Sep      | Oct    | Nov   |
|--------------|--------------------|--------|---------|---------|--------|----------|--------|-------|
| 2007         |                    |        |         |         |        |          |        |       |
| Haskell      | 145Ad <sup>1</sup> | 112Bc  | 95Cbc   | 87CDbc  | 78DEb  | 77DEb    | 68EFb  | 65Fb  |
| San Marcos   | 188Aa              | 153Ba  | 110Ca   | 102CDa  | 102CDa | 97Da     | 85Ea   | 77Ea  |
| Selection 75 | 193Aa              | 128Bb  | 102Cab  | 92CDEb  | 97CDa  | 95CDa    | 78Eab  | 83DEa |
| Earl         | 167Ab              | 120Bbc | 107Bab  | 90Cb    | 70Dbc  | 65Dc     | 52Dcd  | 57Dc  |
| Alamo        | 157Abcd            | 132Bb  | 83Ccd   | 63Dd    | 63Dc   | 55Dc     | 45Ed   | 52Dc  |
| 9065018      | 163Abc             | 127Bb  | 82Cd    | 70CDd   | 62DEc  | 57Ec     | 42Fd   | 53EFc |
| Lometa       | 147Acd             | 120Bbc | 97Cb    | 80Dc    | 72DEbc | 62EFc    | 57Fed  | 52Fc  |
| 2008         |                    |        |         |         |        |          |        |       |
| Haskell      | 113Ad              | 97Bd   | 95Bc    | 83BCd   | 83BCb  | 77CDbc   | 67DEe  | 54Eab |
| San Marcos   | 193Aa              | 148Ba  | 118CDb  | 103Db   | 110Da  | 113CDa   | 132BCa | 72Ea  |
| Selection 75 | 150Abc             | 152Aa  | 147Aa   | 127Ba   | 100Ca  | 103Cabc  | 103Cb  | 72Da  |
| Earl         | 133Acd             | 115Bc  | 92Dc    | 87DEd   | 103Ca  | 90Dabc   | 78Ecd  | 63Fab |
| Alamo        | 165Ab              | 125Bb  | 118Bc   | 98Cb    | 70Dc   | 67Dc     | 68Dde  | 50Eb  |
| 9065018      | 153Abc             | 125ABb | 112BCbc | 97BCDbc | 80CDbc | 98BCDabc | 67DEe  | 57Eab |
| Lometa       | 133Acd             | 107Bc  | 97BCc   | 88CDcd  | 78Dbc  | 78Dbc    | 82CDc  | 46Eb  |
| 2009         |                    |        |         |         |        |          |        |       |
| Haskell      | 123Ab              | 103Bd  | 87Cb    | 76CDbc  | 67Dd   | 87Cbc    | 72CDbc | 67Db  |
| San Marcos   | 162Aa              | 132Bb  | 107Ca   | 98Ca    | 100Ca  | 87Cbc    | 100Ca  | 93Ca  |
| Selection 75 | 167Aa              | 150Aa  | 107Ba   | 90BCab  | 88CDab | 88Cb     | 72DEbc | 60Eb  |
| Earl         | 127Ab              | 98Bd   | 95BCab  | 82CDbc  | 82CDbc | 128Aa    | 72Cbc  | 65Eb  |
| Alamo        | 135Ab              | 108Bcd | 93Cab   | 73Dc    | 80Dbcd | 75Dc     | 62Ec   | 60Eb  |
| 9065018      | 133Ab              | 117Bc  | 95Cab   | 83Cbc   | 82CDbc | 90Cb     | 68DEbc | 58Eb  |
| Lometa       | 118Ab              | 97Bd   | 80CDb   | 75DEc   | 72DEcd | 90BCb    | 77DEb  | 68Eb  |

<sup>1</sup>Coefficient of variation = 13.3; values within rows followed by different upper-case letters and within columns for each year followed by different lower-case letters differ ( $P \leq 0.05$ ).



\*LSD for comparison among grasses at each phenological stage.

**Figure 2.** Herbage crude protein concentration of 7 perennial warm-season bunch grasses in Texas, USA at different phenological growth stages (pooled over 3 growing seasons and 2 fertilizer treatments).

*In vitro* dry matter disappearance

There was an N fertilizer x year interaction on IVDMD over 48 h. *In vitro* DM disappearance (pooled over species and month of harvest) increased with fertilizer application from 536 to 553 g/kg in 2009, but there was no effect of fertilizer application in 2007 (562 vs. 566 g/kg) or 2008 (615 vs. 603 g/kg).

An entry x year x monthly harvest interaction of IVDMD over 48 h (Table 3) was observed. April IVDMD ranged up to 795 g/kg, while November values were as low as 400 g/kg. There were 5 entries whose IVDMD values did not decline in the low rainfall year (2008) from April to June, while upland switch grass had

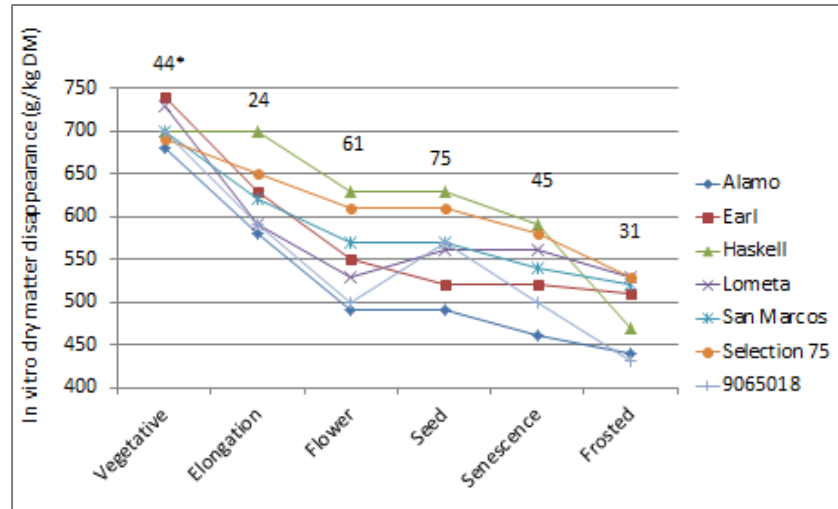
steady IVDMD through October, possibly as a result of slow growth due to low precipitation (Figure 1).

*In vitro* dry matter disappearance patterns varied among species, when compared at the same phenological development stage (Figure 3; averaged over years; years were also significant but are not reported here; pooled for N fertilizer treatment). Haskell and Selection 75 tended to have superior values relative to all other species from elongation through senescence. There were slight increases or at least a stabilization of IVDMD at seed set for some entries that set seed during autumn rainfall, especially visible in upland switch grass (9065018, selected from northern latitudes with shorter growing seasons) and Lometa.

**Table 3.** *In vitro* dry matter disappearance (g/kg DM) over 48 h of 7 perennial, warm-season grasses collected monthly over 3 years during the growing season. The year x month x entry interaction was significant ( $P \leq 0.05$ ). Values are pooled across fertilizer treatments.

| Year/Entry   | Apr    | May     | Jun     | Jul      | Aug      | Sep     | Oct      | Nov     |
|--------------|--------|---------|---------|----------|----------|---------|----------|---------|
| 2007         |        |         |         |          |          |         |          |         |
| Haskell      | 757Ab  | 638Bab  | 577Cbc  | 573Cab   | 532CDab  | 483DEa  | 480Eab   | 532CDab |
| San Marcos   | 730Abc | 612Bb   | 542Cc   | 533CDbc  | 487Dabc  | 525CDa  | 510CDa   | 500CDbc |
| Selection 75 | 760Aab | 603Bb   | 560BCc  | 553Cbc   | 535CDab  | 528CDa  | 493Dab   | 555Ca   |
| Earl         | 795Aa  | 683Ba   | 642BCa  | 605Ca    | 538Da    | 500Da   | 517Da    | 527Dab  |
| Alamo        | 720Ac  | 582Bb   | 542Cc   | 518Cc    | 483Dbc   | 458DEa  | 442Ebc   | 457DEd  |
| 9065018      | 732Abc | 612Bb   | 547Cc   | 558BCbc  | 462DEc   | 482Da   | 413Ec    | 482Dcd  |
| Lometa       | 765Aab | 633Bab  | 605BCab | 570BCDab | 538CDa   | 528Da   | 532Da    | 533Dab  |
| 2008         |        |         |         |          |          |         |          |         |
| Haskell      | 637ABb | 685Ab   | 657ABab | 607Bbc   | 475CDc   | 455Db   | 517Cc    | 468CDbc |
| San Marcos   | 717Aa  | 690ABb  | 640BCb  | 598CDc   | 535Eab   | 553DEab | 618Cab   | 557DEa  |
| Selection 75 | 633BCb | 740Aa   | 697Aa   | 685ABa   | 560Da    | 587CDab | 580CDabc | 555Da   |
| Earl         | 717ABa | 760Aa   | 702ABa  | 658Bab   | 525Cab   | 520Cab  | 558Cc    | 538Ca   |
| Alamo        | 725Aa  | 657Bb   | 663Bab  | 645Babc  | 477Dc    | 453Db   | 538Cc    | 447Dbc  |
| 9065018      | 715Aa  | 683ABb  | 660ABab | 667ABa   | 520ABabc | 658Aa   | 638ABa   | 417Bc   |
| Lometa       | 715ABa | 737Aa   | 688BCa  | 663Ca    | 485Fbc   | 525EFab | 572Dabc  | 540DEa  |
| 2009         |        |         |         |          |          |         |          |         |
| Haskell      | 698Aab | 557Bab  | 535BCa  | 480Dbc   | 493CDc   | 562Ba   | 465Dbc   | 415Ec   |
| San Marcos   | 658Ab  | 563Bab  | 540BCa  | 480Dbc   | 542BCab  | 625ABa  | 515BCDa  | 490CDab |
| Selection 75 | 685Aab | 597Ba   | 555BCa  | 504DEab  | 525CDabc | 593Ba   | 510CDEa  | 470Eb   |
| Earl         | 713Aa  | 545BCbc | 577Ba   | 520CDab  | 568BCa   | 542BCa  | 493DEab  | 457Eb   |
| Alamo        | 602Ac  | 517Bc   | 528Ba   | 465Cc    | 520Bbc   | 558ABa  | 422CDd   | 410Dc   |
| 9065018      | 652Ab  | 572Bab  | 562Ba   | 533BCa   | 517Cbc   | 560Ba   | 448Dcd   | 400Dc   |
| Lometa       | 710Aa  | 582Cab  | 577Ca   | 538CDa   | 537CDabc | 635Ba   | 515Da    | 523Da   |

<sup>1</sup>Coefficient of variation = 11.6; values within rows followed by different upper-case letters and within columns for each year followed by different lower-case letters differ ( $P \leq 0.05$ ).



\*LSD for comparison among grasses at each phenological stage.

**Figure 3.** Herbage in vitro dry matter disappearance over 48 h of 7 perennial warm-season bunch grasses in Texas, USA at different phenological growth stages (pooled over 3 growing seasons and 2 fertilizer treatments).

## Discussion

The results of this study provide an initial data set on the changes in nutritive value of 7 bunch grasses in Texas as the plants moved through successive stages of maturity. These should provide a basis for estimating the nutritive value of these species in areas with similar soils and climate without the need for detailed chemical analyses. The dynamics of season-long nutritive values, when combined with knowledge of phenological growth stages of these 7 grasses, may facilitate field estimation of forage value vis-à-vis cellulosic bioenergy feedstock value. However, sampling in other situations will add to the database and provide further evidence of how accurately these findings can be extrapolated more widely.

By using these data farmers could make informed decisions on the likely quality of material which could be harvested at different growth stages from fields restricted from grazing since the start of the growing season. The critical component that is missing for an accurate decision is the yield of material which might be expected at the different stages. A combination of both yield and quality is needed to make an informed decision on the best time to harvest or commence grazing of a pasture stand. In addition, by grazing plant tussocks and actively selecting for leaf, grazing animals can alter the growth dynamics of a pasture and the quality and quantity of available dry matter at any stage. Care should therefore be taken in extrapolating these findings from an ungrazed pasture to one which has been subjected to some level of grazing by livestock. The ontogenetic differ-

ences we observed between species may help explain why gains in cattle consuming perennial, warm-season bunch grasses vary between species at the same stage in the growing season.

Fertilizer application also has impacts on the quantity and quality of available pasture. Our data suggest that increases in CP concentration from applying N-fertilizer were much smaller than differences in CP concentrations among the different grass species. The small increases in CP concentrations from applying fertilizer could be a reflection of greater DM yields in the fertilized plots. We cannot confirm this, as we did not measure DM yields. Some research (Rehm et al. 1972) indicates that CP concentration of North American bunch grasses does not always increase when fertilized with N. However, the majority of research shows that amending soil N does result in a short-term increase in herbage CP (Gillen and Berg 1998; Lee et al. 2011) such as those we observed. The pattern of decreasing CP concentration as the grasses matured has been widely observed in warm-season bunch grasses (Sanderson and Wolf 1995; Coleman et al. 2004). Coleman et al. (2004) reported a CP concentration range in warm-season C4 grasses of 44–181 g/kg DM, similar to the 46–193 g/kg DM measured in this trial.

The indeterminate seed set of Klein grass (Tischler and Ocumpaugh 2004) prolonged its various reproductive stages compared with other entries with a single seed set. This species was also outstanding by maintaining higher CP concentration than most other species at all development stages. Intraspecific differences in tim-

ing of phenological development have also been observed and explained as adaptations to day length at regions of origin, for example between upland (9065018, selected from latitudes with shorter growing seasons) and lowland (Alamo, selected from latitudes with longer, drier growing seasons) switch grass ecotypes (Sanderson and Wolf 1995). Interspecific differences may also exist for the same reasons, especially for those species with a more limited distribution in latitude.

The two nutritive value parameters of CP and IVDMD paralleled each other, showing a marked decline for CP and increase for IVDMD between initiation of growth and flowering, minimal changes between flowering and seed set and steady deterioration during the senescence phase. This phenomenon is widely observed with warm-season C4 grasses and is termed “summer slump” (Coleman et al. 2004). The IVDMD extremes measured in our trial fall outside the 610–440 g/kg DM range reported in the literature for warm-season C4 grasses (Coleman et al. 2004). Agronomic forage trials rarely harvest very immature or senescent material because these are not usually of interest to forage production that endeavours to optimize both yield and nutritive value, usually around onset of inflorescence initiation (Burns et al. 1997).

Our results confirm that advancing herbage maturity will affect nutritive value across all species studied. Critical nuances in this general trend, however, may assist land managers as they balance grass stand dynamics with income from grazing early in the season and harvesting cellulosic bioenergy feedstock after growth stagnates due to the onset of dry or low temperature seasons. For example, understanding the ontogenesis of perennial grass species may allow increased seed set early or late in the growing season or knowing when to remove cattle from maturing stands in order to accumulate biomass intended for cellulosic bioenergy feedstock. The current approach is to protect perennial warm-season grasses from grazing late in the season as seed sets, thereby fostering seedling recruitment the following year and possible post-frost bioenergy harvest once seed has dropped. In the case of some species that flower earlier in the summer or exhibit indeterminate seed set (Haskell, San Marcos and Selection 75), this protection may need to start earlier, thereby curtailing grazing value of the stand, despite high nutritive values during flowering and seed set. Conversely, these species may be useful as late-season grazing once seed has set and, possibly, mature stems have been harvested as cellulosic bioenergy feedstock. Pasture and rangeland grass mixtures might also seek to balance better ruminant nutrition throughout

the season by mixing populations of early and late maturing species.

Results also indicate that some bunch grasses convert late-season autumn rainfall into regrowth with increased nutritive values, whereas others do not. Further research that measures DM yields along with leaf:stem ratios late in the growing season, as a reflection of the typically bimodal rainfall patterns similar to those of the southern North American Great Plains, may provide definitive conclusions. Such research, in conjunction with what we determined, could factor into the selection of warm-season dual-purpose grass species specifically for late summer bioenergy feedstock harvest, followed by autumn grazing in regions throughout the world with similar climates.

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