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## Research Papers

# The rise and fall of Siratro (*Macroptilium atropurpureum*) − what went wrong and some implications for legume breeding, evaluation and management

RICHARD M. JONES

**Keywords**: Long-term persistence, soil seed banks, seedling survival, stolon density, grazing pressure, Australia.

## Abstract

Siratro (*Macroptilium atropurpureum*) cv. Siratro was one of the first tropical legumes released for commercial use in the 1960s. It initially showed great promise in experiments and commercial sowings. Early research showed it was unproductive under heavy grazing, but after some 15 years there was increasing concern about its persistence, even under light to moderate grazing pressure. Commercial usage subsequently declined markedly although siratro, usually as cv. Aztec, is still sown to a very limited extent. This paper examines some reasons for this decline and then discusses some implications for research into improving tropical pastures through the use of legumes. In general, early pasture research, such as that on Siratro, failed to recognize that original plants of herbaceous legumes had a limited life span and that, for long-term persistence, new plants had to develop through vegetative or sexual reproduction. However, many studies over a 20-year time span showed that, although Siratro could form new plants, in most cases these replacements were insufficient to maintain an adequate plant density in the long term. Data on stolon density, plant longevity, soil seed banks and seedling survival, under different rainfall regimes and stocking rates, are presented to illustrate this. The major limitation was that soil seed banks were generally inadequate to ensure persistence, especially through a period of drier years, when there would be little or no seed set and possibly the death of all seedlings, which emerged from isolated falls of rain. Autumn spelling of pastures to enhance seed set improved persistence, but not reliably enough to be of widespread practical use. The major implication is that evaluation studies failed to adequately recognize the need for introduced legumes to form new plants after the original ones died. This has implications for future experiments, in terms of: duration; the management regime(s) imposed; the measurements or observations taken; and the need for a more ecological approach in evaluation.

## Resumen

Siratro (*Macroptilium atropurpureum*) cv. Siratro fue una de las primeras leguminosas forrajeras tropicales liberadas para uso comercial en Australia en la década de 1960. Inicialmente se mostró muy promisorio tanto a nivel de estación experimental como en siembras comerciales. Mientras al comienzo las investigaciones mostraron que pastoreo intensivo tuvo efecto negativo en la productividad de la leguminosa, 15 años después habían incrementado las dudas sobre su persistencia en condiciones de pastoreo aún con cargas animales ligeras a moderadas. Como consecuencia, el uso comercial de Siratro ha venido declinando en forma marcada, aunque en áreas muy reducidas todavía se encuentran algunas siembras del cv. Aztec. En este documento se analizan algunas de las razones de este descenso en el uso de Siratro y sus implicaciones en las investigaciones sobre mejoramiento de pasturas mediante la introducción de leguminosas. En general, la investigación inicial en pasturas tropicales, tal como es el caso de Siratro, no tuvo en cuenta que las plantas originales de leguminosas herbáceas tienen un ciclo de vida reducido y que para garantizar la persistencia de una población es necesario que se desarrollen nuevas plantas mediante reproducción vegetativa o a partir de semillas. En numerosos estudios realizados durante un lapso de 20 años se demostró que, aunque Siratro forma nuevas

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plántulas de reemplazo, en la mayoría de los casos éstas no son suficientes para mantener una adecuada densidad por un período prolongado de tiempo. Para ilustrar esto se presentan datos de estudios sobre densidad de estolones, longevidad de plantas, bancos de semilla en el suelo y sobrevivencia de plántulas en diferentes condiciones de pastoreo y clima. La principal limitante fue que los bancos de semillas en el suelo fueron generalmente inadecuados para asegurar la persistencia de la población, especialmente en años secos, cuando las plantas no alcanzaron a fructificar o solo muy poco, además del riesgo de muerte de todas las plántulas provenientes de semillas germinadas durante un evento de precipitación aislado. La interrupción del pastoreo en otoño para aumentar la producción de semillas en la pastura mejoró la persistencia de la leguminosa, pero no en una forma lo suficientemente confiable para un uso generalizado de esta práctica. La principal enseñanza es que los estudios de evaluación no reconocieron en forma adecuada que las leguminosas en una pastura tienen que formar plantas nuevas para reemplazar las plantas originales después de muertas. Esto tiene implicaciones para los futuros trabajos experimentales, en términos de duración de los experimentos, sistemas de manejo, mediciones y observaciones que se deben hacer, y la necesidad de un mayor enfoque ecológico en la evaluación.

## Introduction

Cultivar Siratro was bred from 2 introductions of *Macroptilium atropurpureum*; a description of the breeding program can be found in Hutton (1962). Siratro was one of the first legumes released for use in sown tropical pastures in Australia. As this species was new to cultivation, nothing was known about the agronomy, ecology or persistence of Siratro as a pasture legume, when it was released in 1960.

It was soon found that Siratro was relatively easy to establish and grew on a wide range of soil types (Jones and Jones 1978). Although it was affected by some pests and diseases, the main limitation, prior to about 1980, was that, in higher rainfall areas receiving in excess of 1,400 mm/yr, it was susceptible to foliar blight caused by *Rhizoctonia solani*. However, it was later affected by rust caused by the fungus *Uromyces appendiculatus*. This led to the release of the rust-resistant cv. Aztec, which is otherwise genetically similar to cv. Siratro (Bray and Woodroffe 1995). However, almost all the detailed studies described later have been done on cv. Siratro. Cutting trials in the 1960s showed that yield was depressed by close and frequent cutting (Jones 1974a; 1974b) and this depression in yield was soon noticed at high stocking rates on grazed pastures in the early 1970s (Jones and Jones 2003). However, if moderately or lightly grazed, Siratro showed great promise. It sometimes comprised about 30% of pasture yield at the end of the growing season, increased soil nitrogen levels plus the N% of the associated grass, and supported good animal production (Mannetje 1967; Bisset and Marlowe 1974; Mannetje and Jones 1990; RJ Jones 2003; Jones and Jones 2003; Tothill et al. 2008a, 2008b).

Thus, it appeared to have great potential and was well accepted by farmers and graziers; so a special issue of *Tropical Grasslands* in 1977 (Vol. 11, No. 1), restricted to papers on Siratro, recognized the retirement of Dr Hutton.

However, in the late 1970s, doubts began to surface about the long-term persistence of Siratro in commercial sowings; so QDPI (Queensland Department of Primary Industries) organized a symposium in 1982 to gather data on experiences with Siratro persistence. Divergent views were expressed at the symposium (Brown 1983), with most concerns being raised by QDPI staff, based mainly on experience with commercial sowings. Contributions from CSIRO (Commonwealth Scientific and Industrial Research Organisation) staff, primarily based on results from a large grazing trial at Samford (1,000 mm annual rainfall) and 2 experiments at Narayen (720 mm), were more positive, although they clearly recognized that Siratro was not suited to heavy grazing pressure. Siratro had persisted for 5 years in one of these trials (Tothill et al. 2008a) and for about 10 years in the other 2 (Mannetje and Jones 1990; Jones and Jones 2003); so this positive response was to be expected. However, persistence subsequently declined in all trials and, by the time the trials were terminated after 15−20 years, Siratro was a minor component. Thus, the serious problems with long-term persistence of Siratro reported in commercial pastures eventually occurred in lightly grazed experimental pastures. Despite a marked decline in its popularity with primary producers, about 20 t of siratro seed (presumably both cvv. Siratro and Aztec) were produced annually in the mid-1990s (Smith 1996). Siratro is still used to a limited extent in both long-term pastures and short-term leys, usually as part of a mixture of legume species (e.g. Clarke 2008; McCamley 2010).

This paper reviews the knowledge of Siratro persistence to give some reasons for the persistence problem and then looks at some wider implications.

**Persistence of Siratro**

With the early enthusiasm about Siratro and other herbaceous legumes, one basic principle was largely overlooked – herbaceous perennial plants do not persist forever. To maintain a legume of this type in a pasture in the long term, it must form new plants, either from stolons or rhizomes or from seed. Fortunately, some related measurements of Siratro persistence were made in several grazing trials. Almost all of these trials were carried out with fixed stocking rates, usually with continuous grazing.

*Life span of individual plants*

Siratro plants often have a half-life (time for half the population to die) of about 1.5–3 years (Gutteridge 1985; Jones and Mannetje 1986; Jones and Bunch 1988a; Jones et al. 1993), although this obviously varies with management, site and rainfall. As a typical Siratro sowing rate of 3 kg/ha could equate to 25 seeds being sown per $m^2$, 10 or more plants could establish per $m^2$. After 2 years there could still be more than 5 plants per $m^2$ and, as these plants are large, the loss of density might not be reflected in reduced dry matter yield. This could even apply after 4 years with a density of over 2.5 plants per $m^2$.

There are data from 4 sites on the effect of stocking rate on the half-life of original plants. At Samford (Jones and Bunch 1988a) and in Thailand (Gutteridge 1985), a higher grazing pressure reduced plant half-life, while in the 2 experiments at Narayen, there was little effect (Jones and Mannetje 1986; Jones et al. 1993). This difference between Samford and Narayen could be partly due to the wider range of stocking rates imposed at the wetter Samford site (1,000 mm rainfall compared with 700 mm), and to the overall lower grazing pressures (weight of animals per weight of herbage) during active summer growth periods at Narayen. Interestingly, in one experiment at Narayen, low soil phosphorus status also had little effect on plant longevity (Jones et al. 1993).

Thus, with time Siratro density must obviously decline to the point where yield is negligible – unless new plants establish. The following sections look at recruitment from both stolons and seed, and consider how this is affected by grazing pressure and climate.

*New plants from stolons*

Formation of new roots from stolons was mentioned in the initial description of Siratro (Hutton 1962). However, while small roots can develop from thin soft stolons on the soil surface, these do not persist. Under some situations, which appear to be restricted to sites receiving in excess of 1,000 mm rainfall and under light stocking (Bisset and Marlowe 1974; Walker 1981; Jones and Bunch 1988a), Siratro can form much firmer woodier stolons, which are often just under the soil surface. Growing points and roots can develop on these stolons. At a moderate stocking rate of 1.7 heifers/ha at Samford, the total length of these stolons was about 1 m per $m^2$ for about 10 years, but no stolons remained after 16 years. There were more stolons in a pasture lightly stocked at 1.1 heifers/ha, but none under heavy grazing. Further details about stolon length and size, and on the density and size of rooted points, are given by Jones and Bunch (1988a). Stolons were never observed at the drier Narayen site.

Overall, it seems that stolons are not the major pathway for Siratro persistence.

*New plants from seed*

Data from Samford (Jones and Bunch 1988a) and Narayen (Jones and Mannetje 1986; Jones et al. 1993) show that new plants can develop from soil seed reserves. In a moderately grazed pasture (1.7 heifers/ha) at Samford, seedling replacement maintained good densities of 6–13 plants/$m^2$ for 7 years after the density of the original plants had fallen below 1 plant/$m^2$ (Jones and Bunch 1988a; 1988b). Long-term persistence seemed assured. In contrast, density declined markedly under a higher grazing pressure, as crowns had a shorter life span and there were progressively fewer new plants. However, during the next 5 years, replacement in the moderately grazed pasture did not match plant death, and Siratro density fell to 1 plant/$m^2$. In part, this was due to less favorable rainfall conditions for seed set and to increased grazing pressure in generally dryer years. Siratro rust did not seem to be a major factor, but could have exacerbated the problem of poor persistence; it can reduce leaf and seed yields, but its biggest impact is in monospecific swards or pastures with a high Siratro component (RJ Jones 1982). Other unknown factors could also be involved.

Similarly, in 2 experiments at Narayen, although there was certainly some successful recruitment from seedlings, long-term plant density was not maintained (Jones and Mannetje 1986; Jones et al. 1993).

In summary, while there may be some instances where plant density can be adequately maintained after the original plants die out, in many or most instances this does not happen. This decline in successful recruitment must be largely related to fewer seedlings, thus to the size of the soil seed bank, which in turn relates to the amount of seed set.

*Seed set and soil seed banks*

Measurements of seed reserves in the soil have been made in medium- to long-term trials at Samford (Jones 1979; Jones et al. 1980; Jones and Bunch 1998b) and Narayen (Mannetje and Jones 1986; Mannetje and Jones 1990; Mannetje and Butler 1991; Jones et al. 1993, 2000), and in spot measurements in some other trials (Tothill and Jones 1977). In summary, seed reserves rarely exceeded 500/m$^2$ and were usually about 200 or below, even in pastures with a good Siratro content.

Poorer or overgrazed Siratro pastures have much lower or negligible seed levels. In the heavily grazed pasture at Samford, sown in 1968, no Siratro flowers or pods were recorded after 1972, whereas the moderately grazed pasture usually had above 20 flowers or pods/m$^2$ up to 1982. Not surprisingly, in 1983/85 there were 167 seeds/m$^2$ in the moderately grazed pasture but only 15 seeds/m$^2$ in the heavily grazed pasture (Jones and Bunch 1988b). Soil seed numbers were usually significantly reduced by higher stocking rates at Narayen (Jones and Mannetje 1986; Mannetje and Jones 1990; Jones et al. 1993) and were lower at a higher stocking rate in Thailand (Gutteridge 1985).

Although some slight moisture stress can aid initiation of flowering in Siratro, it appears that in dryer areas, such as Narayen, dry conditions in autumn, when seed set occurs, are a major factor contributing to low soil seed numbers. Under dry conditions, aerial stems on Siratro plants can even die back towards the crown and, if stems die, no flowering or seeding occurs. Paradoxically, there was a complete failure of seed set in one year at Samford with sustained wet conditions in autumn (author's unpublished data). There were many pods, but no hard seeds; all seeds were soft or rotten, or prematurely germinated in the pods.

The number of legume seeds measured in good Siratro pastures is about 5–25% of that found in good pastures of other persistent legumes in southeast Queensland, such as Wynn cassia (*Chamaecrista rotundifolia*) (Jones 1995; Jones et al. 2000), shrubby stylo (*Stylosanthes scabra*) (Jones et al. 1993; 2000), Bargoo joint vetch (*Aeschynomene falcata*) (Jones et al. 2000), fine stem stylo (*Stylosanthes hippocampoides*) (Orr 2008) and white clover (*Trifolium repens*) (Jones 1982; 1984). In a 1993 paper comparing the persistence of Wynn cassia, Verano stylo (*Stylosanthes hamata*), shrubby stylo and Siratro, there was a suggestion that, for any pasture legume, 'within reasonable ranges, there is a "trade off" between longevity and seed set. Perhaps a key weakness of Siratro is that the seed banks are outside this reasonable range and too low to ensure recruitment, even at moderate stocking rates' (McIvor et al. 1993).

*Seedling establishment*

Most seed set in pastures cannot subsequently be accounted for. In one experiment at Samford, hand-collected Siratro seed was broadcast into 2 sites in closely grazed Siratro-free pastures ideal for seedling emergence. Over the subsequent 6 years, only 21% of the seed was accounted for as seedlings and a further 15% as soil seed (Jones 1981). Similar low recoveries have been recorded with other species in similar experiments. Furthermore, most emerging seedlings, and in many instances all seedlings, will die. This is usually attributed to moisture stress, when the small seedling root system is competing with the established pasture for water (Cook and Ratcliff 1985; Jones and Mannetje 1986; Jones and Bunch 1988b; Mannetje and Jones 1990). Competition from associated grasses can greatly reduce Siratro density when compared with monospecific Siratro swards on clay soils (Keating and Mott 1987; Peake et al. 1990), but reduced half-life, lower seed set and increased seedling mortality could all be involved. Another source of seedling loss in high-yielding and lightly grazed pastures is that there can be almost complete death of emerging Siratro seedlings due to competition for light (Agishi 1974; Jones and Bunch 1988b).

*Effects of defoliation*

Because of the growth habit of Siratro, with its long twining aerial stems with long internodes, heavy grazing greatly reduces the number of growing points (Clements 1989b) and therefore forage yield. However, as outlined above, the reduction in Siratro persistence under heavy grazing must operate through the effects on plant half-life, seed set, soil seed banks and seedling recruitment, or, less importantly, on stolon development and persistence.

There are not enough data to make any specific comments about how rotational grazing systems could affect Siratro persistence. At Samford, results from a 4-year experiment suggested that Siratro yield and persistence were slightly better in a rotation with long rest periods, but that this would be obtained only at stocking rates where the pastures were probably overgrazed in terms of animal production (Jones 1979). At Narayen, there were only minor differences in Siratro yield and persistence when continuous grazing was compared with a 4 weeks on:4 weeks off rotation for 4 years (Mannetje and Jones 1990). There is no information about the effect of cell grazing on Siratro persistence. In any rotational system with lengthy periods of stay in each paddock, there is the possibility that the timing of grazing in relation to Siratro flowering and seeding may have a different effect on seed set in different paddocks.

*Effects of climate*

Siratro has a lower ability to set seed under dry conditions than other herbaceous legumes such as shrubby stylo, Wynn cassia and Bargoo joint vetch. This is illustrated by data from an experiment at Narayen (Jones et al. 2003), supported by data from a wider range of experiments. This is in part due to the growth habit of Siratro, where flowers are borne towards the ends of long aerial stems, and partly from its lower tolerance of moisture stress compared with shrubby stylo. In an experiment at Narayen, where soil seed reserves of Siratro were measured annually, the progressive annual levels were 42, 18, 285, 109, 62, 32, 13 and 11 seeds/$m^2$, averaged over all treatments (Jones et al. 1993). Clearly seed reserves increased in only one year and the impact of this one year's seeding on reserves lasted for only 3 years. Tothill et al. (2009) also commented on the effects of a series of years with below average rainfall on Siratro seeding and persistence. In a similar environment to that at Narayen, variation in rainfall had a greater effect on the population dynamics of fine stem stylo than stocking rate (Orr 2008).

Frosting is a feature of the climate in subtropical Queensland. In most years, Siratro flowering and seeding have ended before the onset of severe frosting, so frost is unlikely to have a major effect on size of soil seed banks. Limited evidence also suggests that, in terms of crown survival, Siratro is one of the more frost-tolerant tropical legumes (Jones 1969).

*Putting the pieces together*

As a result of the studies described above, we have a reasonable, but certainly not perfect, understanding of how the different components of Siratro persistence – plant survival, stolons, seed set, soil seed banks and seedling survival – are affected by grazing pressure and rainfall.

*How did this understanding of Siratro persistence develop?*

This understanding did not develop as a result of measurements made to validate a conceptual model. Rather, as described below, the understanding and model gradually evolved as more measurements were made. The first demographic measurements followed casual observations in 1969 of Siratro seedlings in a pasture established in 1966 (Rees et al. 1976) and from sheer curiosity about their survival. These very limited measurements led to more detailed work on seedling emergence and survival under contrasting stocking rates in an existing experiment at Samford, starting in 1970 (Jones and Bunch 1988a). It soon became obvious that, to understand how these measurements of seedlings fitted into the overall picture, there was a need to measure plant survival, stolons where present, and soil seed banks. These are the key measurements in simple conceptual models of persistence (Jones and Mott 1980; Jones 1985; McIvor et al. 1993) and helped to partly explain the effects of stocking rates on persistence.

These interesting results from Samford then led to some demographic measurements being taken in the later years of 2 existing grazing experiments at the drier Narayen site (Tothill and Tessel 1982; Mannetje and Jones 1990) and to more comprehensive measurements in 2 new Narayen trials that started around 1980 (Jones and Mannetje 1986; Jones et al. 1993). The Narayen measurements gave valuable insights into the role of moisture stress in limiting seed set and seedling recruitment, regardless of stocking rate. It is questionable if this gradual understanding of the mechanisms of Siratro persistence could be achieved under the current research trend to shorter-term and goal-specific experiments.

## Implications

*Implications for Siratro management*

The obvious implication from all studies on Siratro is that lighter grazing assists Siratro persistence through increasing seed set and, at times, longevity of crowns, as well as sometimes increasing stolon development. However, results from commercial experience and research indicated that this alone was not enough to reliably ensure persistence (Brown 1983). The next step was to examine the effects of resting in late summer and autumn on seed set in autumn, the main seeding period. Results have been equivocal. Resting can have a major impact on seed set; for example, in one year a 30- to 60-fold increase in seed set was recorded at Narayen with late season resting (Tessel 1983). However, in another study, although resting increased Siratro yield, there was no measureable effect on the soil seed bank (Jones and Jones 2003).

Most of the differences in seeding recorded in these studies could be attributed to differences in rainfall patterns and yield of Siratro. There have also been instances where light grazing or resting of commercial pastures, in conjunction with successive good rainfall years, substantially increased Siratro populations and yield (SJ Cook and CK McDonald personal communications). Other experiments examined the use of rough cultivation of established pastures to enhance Siratro seed germination and to aid seedling survival through reducing competition from established plants (Bishop et al. 1981; Jones and Jones 2003).

The findings from all the related studies are that both rough cultivation and late season resting, especially in years with good rainfall, can sometimes aid Siratro seed set, seedling recruitment and persistence (Hurford 1979; Jones 1979, 1988; Bishop et al. 1981; Tessel 1983; Jones and Jones 2003; Tothill et al. 2009). However, these practices are not sufficiently reliable to ensure confidence in the persistence of Siratro and hence widespread use in permanent pastures. Furthermore, there will always be some reluctance by many farmers or graziers to lightly graze good Siratro pastures in autumn, when grass quality is declining. This reluctance to graze lightly could even apply to the peak growth period in summer, although cattle usually prefer grass to Siratro during this period (Stobbs 1977).

*Implications for further selection or breeding*

Unfortunately, the objectives of the second breeding program on *Macroptilium atropurpureum* during the late 1960s and 1970s (Hutton and Beall 1977) were not related to enhancing the persistence mechanisms outlined above. However, following later characterization of 230 accessions of *M. atropurpureum*, a group of 45 lines was defined as having more branching and earlier flowering than Siratro (McDonald and Clements 2005). Seventeen of the 230 accessions, including some from this group, were compared for 5 years under farm grazing at 2 sites in southeast Queensland, but no single line maintained significantly higher densities than Siratro or Aztec at both sites (Bray et al. 2000).

If a clearly defined and important breeding target, which would obviously impact on plant survival and seed set, e.g. disease resistance in top growth or roots, can be identified, there is potential for breeding to assist legume persistence. A simple example is the improved persistence of *Medicago sativa* in southeast Queensland, produced by breeding for resistance to aphids and root diseases (Clements et al. 1984). Although Aztec, a rust-resistant cultivar of siratro, has been available for about 15 years, there is no feed-back that rust resistance is appreciably improving siratro persistence.

Disease or pest resistance apart, breeding for improved persistence in a legume, that persists in the long term through seedling recruitment, is very difficult – do you target longer crown life, more seed set, a higher level of hard seed or greater seedling vigor? The target has to be defined and then adequate variation found in plant collections. Furthermore, defining a target, such as higher seed set, is not enough. How much of an increase will you need in this attribute, before it will have an impact in commercial pastures? In addition, there is always the risk that selecting for an increase in one attribute may inadvertently lead to a decline in other desirable attributes of persistence, or even yield. Good advice on breeding for legume persistence has been presented elsewhere (Clements 1989a).

*Implications for weediness*

In some situations Siratro can be a weed, as it can climb over other plants and set considerable amounts of seed if not defoliated. The characteristics that imbue persistence are similar to those which contribute to weediness. This was not appreciated in the early research on tropical legumes, when Siratro was released, but the potential for weediness must now be considered in any introduction and evaluation program. Extreme conditions of weediness, either minimal or excessive, are relatively easily recognized. White clover, for example, can be a weed in lawns, but world-wide it has been a great asset for increasing animal production and soil fertility with minimal or negligible disadvantage as a weed. However, sometimes the boundary between desirable and undesirable persistence and spread is difficult to recognize and to relate to growth form. For example, glycine (*Neonotonia wightii*) and Siratro have somewhat similar growth habits, when grown with grass. Yet, in my experience in coastal southeast Queensland, glycine, with its much greater ability to climb, is a far more serious weed in open or disturbed forests.

*Implications for evaluation*

This is where the studies on Siratro persistence could have the greatest implications. Initial stages of evaluation of legumes for long-term pastures have often involved lightly defoliated trials lasting only 2–3 years and only yield has been measured. As a result of the factors outlined above, such trials can be potentially useless or at best misleading in assessing long-term persistence, especially if the legumes are grown in pure swards. Preferably, trials of this nature should be conducted under one or more defoliation treatments approximating commercial practice for at least 5 years. This is especially so if the site experiences wide variation in rainfall and, for example, can experience 2 or more consecutive years with well below average rainfall or infrequent periods of sustained heavy rainfall with potential for waterlogging. Longer trials will obviously involve more input of time and labor. However, the time and effort usually spent in cutting and measuring yield in screening trials can be reduced appreciably by using calibrated visual estimates of yield and composition. These are quite adequate to document the higher-yielding lines (Jones 2001). Very useful measurements of legume density, or at least legume frequency (Cameron et al. 1989; Jones 2001), could be made, even if only at the end of the trial.

Given the time-consuming nature of demographic measurements, such as survival of individual plants and soil seed reserves, it is pointless to make them in short-term assessments of a large number of lines. The important thing is to recognize the limitations of such trials and at least look for flowering, seed set, stolon/rhizome development, seedling recruitment and such like.

Management of evaluation trials should relate to the conditions in which the legumes are likely to be used. In commercial situations, farmers often stock according to average conditions, which means they are overstocked in below average rainfall years. They tend to focus more on the short-term forage needs of their stock than on the long-term survival of the pasture. Hence, evaluation methods need to reflect this. For example, a multi-site study in coastal Queensland evaluated legumes specifically for heavily grazed pastures (Cameron et al. 1989). The legumes were sown into cultivated strips in closely grazed grass swards. Management was controlled in the first year, to allow for legume establishment and seed set. However, in subsequent years, the experiments were just a small section in a pasture which, hopefully, was heavily grazed by the co-operating farmer. The emphasis was on persistence, which was easily measured by species frequency. The results in this experiment matched subsequent commercial experience with the same accessions. In contrast, the grazing or cutting regimes for legumes being evaluated for short-term ley pastures or cut-and-carry systems would be much more lenient.

There may be a case for specific demographic measurements to assist in understanding or extrapolation of the results of later-stage evaluation or management studies. For example, measurements of soil seed reserves of Siratro at the end of a 5-year study of rotational grazing aided prediction of the effects the treatments could have on Siratro persistence, if they had been continued for longer (Jones 1979). In longer-term grazing trials, perhaps with 1–3 accessions subjected to different grazing systems or stocking rates, demographic measurements may help to understand why species did or did not persist and how the results might be extrapolated to commercial conditions (Jones et al. 2000). They could lead to suggestions for improved management for persistence, based on seasonal changes in grazing pressure (Jones 1982, 1984; Orr 2008).

Thus, keeping demographic concepts in mind throughout the legume evaluation process may improve predictions of persistence. More comments about what demographic measurements to make, and why, when, and how to make them, can be found elsewhere (Jones and Mott 1980; Jones 1985; Jones and Carter 1989; Hay et al. 2000).

*Implications for thinking*

During the early years of "pasture improvement", I suggest we may have had a too simplistic view of what we were trying to do. In essence, we were trying to remove an existing plant community, or at least introduce a legume into it, to form a new and more productive community, which would be resilient over time. Perhaps we were too simplistic, thinking more like engineers rather than ecologists.

It was as if we were engineers erecting a new bridge to replace an existing bridge, which had load (animal production) limitations. All you had to do was to supply the seed and fertilizer (concrete and reinforcing), avoid gross mismanagement (exceeding the load limit) and behold the new bridge would be stronger (productive) than the old one, and last for decades. Our approach was somewhat mechanical rather than biological. Whereas concrete and steel reinforcing usually last for decades, regardless of external forces, herbaceous plants do not. Furthermore, they have widely varying tolerances of external forces such as rainfall, fire, frosting, weed invasion and, especially, grazing pressure and frequency.

Perhaps we should recognize that evaluation of pasture species is, by and large, not science. It is simply a measurement of one or more simple attributes (often yield is the only one), when a range of accessions is subjected to one or more ad hoc defoliation treatments. Even if the defoliation treatments and experimental duration are chosen to reflect particular farm management practices, this does not make evaluation into a science – albeit it is a worthwhile thing to do. Science in evaluation is where we are concerned with underlying processes and attempts to answer questions such as the following: What makes some plants more resistant to defoliation than others? Why does one species need more phosphorus than another? How does a species persist in a pasture after the original plants have died? Why does one species spread into adjacent plant communities and another does not?

## Some final personal comments

(1) In the 1950s and 1960s, when Siratro was developed and initially evaluated, very little was known about the potential, for good or bad, of incorporating tropical legumes in grazed pastures. At that time, the focus was on identifying legumes with high DM production. In retrospect, the development of Siratro was a good but imperfect start, but now the question is: "Are we learning from past shortcomings and doing things better?"

(2) Perhaps one of the surprising features of Siratro is that, given its growth habit, it was so successful and well accepted by graziers and scientists for more than a decade, and is still used to a limited extent. One possible reason for this relates to the climate of Queensland, which incorporates a cool season, usually dry, of 6 months or more. During this time, there is little or no pasture growth, which restricts animal numbers. Given an average or good warm season rainfall, growth is rapid and there is often plenty of forage, so the overall grazing pressure during the growing season is reduced, obviously favoring Siratro.

(3) In view of its ability to improve soil nitrogen status and N concentration in associated grasses (Mannetje and Jones 1990), Siratro may still have a useful role as part of a legume mixture for improving these characteristics in both long-term and ley pastures (McCamley 2010).

(4) Many of the early evaluation experiments were conducted for only 2–3 years, and measured yield only under light defoliation treatments. Unfortunately, they did not continue for long enough, ignored plant attributes related to persistence, and bore little relationship to commercial conditions as defoliation levels were too lenient.

(5) Having a "good" growth habit – prostrate stems that form roots, growing points that are largely protected from grazing, and a capability to set seed under close grazing – does not guarantee that a legume will persist in the long term. Both *Lotononis bainesii* cv. Miles and *Vigna parkeri* cv. Shaw have these attributes. However, despite early promise, lotononis has not persisted in the long term and no seed has been commercially produced in Queensland for about 10 years. *Vigna parkeri*, on the other hand, was rejected in early cutting experiments in favor of taller-growing species such as *Desmodium intortum* and its value was recognized only when it was seen invading and spreading under grazing at old trial sites (Jones 1984; Cook and Jones 1987). It has persisted well, seed is commercially available, and it is well regarded in the very limited area to which it is adapted.

(6) After having an interest in legume persistence for more than 40 years, I have recently revisited some former experimental sites to observe which legumes are persisting, and have received reports from others who have done likewise. In all cases, I had some experience with the species concerned and had made demographic measurements on many of them. Before looking at or learning about the sites, I formulated views on what the levels of persistence would be. In most instances, these predictions were quite accurate, but occasionally I was completely wrong. The message is: no matter how much experience or knowledge you have – be warned – predicting legume persistence, or botanical change generally, is often somewhat risky. The fewer years of experience, and the lower the demographic understanding, the greater the risk.

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# Village-based tropical pasture seed production in Thailand and Laos – a success story

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## Abstract

Seed of 6 forage species, Mulato II hybrid brachiaria (*Brachiaria ruziziensis* x *B. decumbens* x *B. brizantha*), Cayman hybrid brachiaria (*B. ruziziensis* x *B. decumbens* x *B. brizantha*), Mombasa guinea (*Panicum maximum*), Tanzania guinea (*P. maximum*), Ubon stylo (*Stylosanthes guianensis* var. *vulgaris* x var. *pauciflora*) and Ubon paspalum (*Paspalum atratum*), is currently being produced by more than 1,000 smallholder farmers in villages in northeast Thailand and northern Laos, under contract to Ubon Forage Seeds, Faculty of Agriculture, Ubon Ratchathani University, Thailand. The seed is mainly exported (95%), with the remainder sold within Thailand. Tropical Seeds LLC, a subsidiary of a Mexican seed company, Grupo Papalotla, employs Ubon Forage Seeds to manage seed production, seed sales and export, and to conduct research on new forage species. This paper details how the development of a smallholder-farmer seed-production program in Thailand and Laos produced positive social and economic outcomes for the village seed-growers. In addition, the strong emphasis on seed quality, high purity, high vigor and high germination enabled pasture growers in more than 20 tropical countries in Asia, Africa, the Pacific and Central and South America, to establish more than 20,000 ha of pastures over the past 3 years.

## Resumen

En aldeas de Tailandia y norte de Laos existen más de 1,000 pequeños agricultores dedicados a la producción de semillas de los híbridos de braquiaria (*Brachiaria ruziziensis* x *B. decumbens* x *B. brizantha*) cvs. Mulato II y Cayman; guinea (*Panicum maximum*) cvs. Mombasa y Tanzania; *Stylosanthes guianensis* cv. Ubon stylo y *Paspalum atratum* cv. Ubon paspalum, en contrato con Ubon Forage Seeds, Faculty of Agriculture, Ubon Ratchathani University, Tailandia. El 95% de las semillas producidas es exportado y el restante 5% vendido localmente. La Tropical Seeds LLC, una subsidiaria de la compañía mexicana de semillas del Grupo Papalotla, contrata a Ubon Forage Seeds para manejar la producción, venta y exportación de semilla y para conducir investigaciones en búsqueda de nuevos cultivares forrajeros. En este documento se presenta la forma cómo un programa de producción de semilla por productores aldeanos en Tailandia y Laos ha resultado en impactos positivos para los pequeños productores, desde el punto de vista social y económico. Adicionalmente, productores de forrajes en más de 20 países tropicales de Asia, Africa, la región del Pacífico y de Centro y Suramérica se han beneficiado de semilla de alta calidad, en términos de pureza, vigor y germinación, para el establecimiento de más de 20,000 ha en los últimos 3 años.

## Introduction

Seed of 6 forage species, Mulato II hybrid brachiaria (*B. ruziziensis* x *B. decumbens* x *B. brizantha*), Cayman hybrid brachiaria (*B. ruziziensis* x *B. decumbens* x *B. brizantha*), Mombasa guinea (*Panicum maximum*), Tanzania guinea (*P. maximum*), Ubon stylo (*Stylosanthes guianensis* var. *vulgaris* x var. *pauciflora*) and Ubon paspalum (*Paspalum atratum*), are currently produced by more than 1,000 smallholder farmers in villages in northeast Thailand and northern Lao PDR (subsequently referred to as Laos). The seed, over 130 t in 2012-13, is mainly exported (95%), with the remainder sold within Thailand.

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Tropical Seeds LLC, a subsidiary of a Mexican seed company, Grupo Papalotla, employs Ubon Forage Seeds in the Faculty of Agriculture, Ubon Ratchathani University, Thailand, to manage seed production, seed sales and export, and to conduct research on existing and new forage species. In 2003, Tropical Seeds LLC made the business decision to come to Thailand to produce brachiaria hybrid seed, because of high forage seed quality, smallholder experience and professionalism in Thailand (Hare 1993) and Ubon Ratchathani University's involvement in forage seed production (Hare and Horne 2004; Hare 2007). The company also wanted to access the Asian and Pacific markets for forage seed. In addition, there was an expectation that seed yields of brachiaria hybrids in Thailand, where agronomic management was intensive and seed was hand-harvested from small fields, might be higher than in Brazil and Mexico, where management was extensive and seed was swept from the ground in large fields.

The Ubon Forage Seeds group in the Faculty of Agriculture at Ubon Ratchathani University, had been involved in tropical forage seed research since 1995, and had built up an international reputation for excellence in forage seed production. A Memorandum of Understanding was signed in 2004 between Tropical Seeds LLC and the Faculty to produce, for export, tropical forage seed in villages in northeast Thailand. This Memorandum was further strengthened in 2008 and 2011, with the signing of 3-year contracts between the same parties.

In this joint venture, commercial seed production commenced with Mulato II hybrid brachiaria. However, with the development of a strong export market for seed, other species are now being produced commercially, including Cayman hybrid brachiaria, Mombasa guinea, Tanzania guinea, Ubon stylo and Ubon paspalum.

In 2007, Happy Farmers, an agricultural company in Laos, started producing seed of Mulato II hybrid brachiaria in northern Laos under contract to Ubon Forage Seeds and Tropical Seeds LLC. In 2012, Mulato 2 Co. Ltd took over production from Happy Farmers.

Ubon Forage Seeds is currently the major producer of forage seeds in Thailand and contracts the Mulato 2 Co. Ltd to manage seed production in Laos. Ubon Forage Seeds is the only enterprise exporting perennial forage seeds internationally from southeast Asia. The Thailand Department of Livestock Development, which for many years produced several hundred tonnes of forage seeds, has now reduced its production due to budget restrictions. It produces mainly on government stations and sells only within Thailand. Some agricultural trading companies in Thailand buy Tanzania guinea and ruzi grass (*Brachiaria ruziziensis*) from private farmers, but this seed is generally not cleaned, and while cheap, it usually has very low germination. In addition, some small Japanese companies contract farmers to produce foundation seed of several fine-stemmed guinea grass cultivars and other minor species for the Japanese market. In southern Thailand, there is regular annual seed production of puero (tropical kudzu, *Pueraria phaseoloides*), centro [*Centrosema molle* (syn. *C. pubescens*)] and calopo (*Calopogonium mucunoides*) for use as cover crops in the oil palm plantations in Thailand and Malaysia.

This paper discusses in detail seed production of the 6 forage species listed above, and how the development of a smallholder seed-production program produced positive social and economic outcomes for the village seed-growers and enabled many smallholder farmers in other countries to receive high quality forage seed. The strong emphasis on seed quality, high purity, high vigor and high germination impacted strongly on pasture development in more than 20 tropical countries in Asia, Africa, the Pacific and Central and South America, enabling pasture growers to establish more than 20,000 ha of pastures over the past 3 years.

## Mulato II and Cayman hybrid brachiaria

### *Seed research*

Good seed yields of Mulato II and Cayman have been very difficult to achieve, although both produce sufficient inflorescences, racemes and spikelets to indicate a potential for useful seed yields. By seed harvest, there is usually a massive failure of seed set, caryopsis maturation or both, with the cleaned seed coming from fewer than 9% of the spikelets formed by the crops. Weather conditions during seed maturation (October-November) in northeast Thailand are generally suitable for seed set, with bright sunshine and no rain. The failure of seed set is probably due to pollen sterility; Risso-Pascotto et al. (2005) showed that more than 65% of pollen grains of brachiaria hybrids were sterile and that this sterility was genetic.

A series of field experiments were conducted in Thailand to try to increase seed yields through agronomic management. The experiments were mainly with Mulato II, but the results can be applied to Cayman (Pizarro et al. 2013). While Cayman produces similar seed yields to Mulato II and flowers a month earlier, its release in 2011 resulted from its stronger tolerance of waterlogging than Mulato II (Pizarro et al. 2013).

Mulato II seed crops planted at the beginning of May and June produced more seed (mean of 124 kg/ha) when harvested in mid-November than crops planted in July and August (mean of 27 kg/ha) and harvested in late November (Hare et al. 2007a). If farmers want both forage and seed in the same year, we recommend using seedlings for planting Mulato II seed crops in Thailand as early as possible in the wet season (June), in order to produce a strong root system and to maximize the number of reproductive tillers. However, a closing date cut towards the end of July (cutting to between 5 and 10 cm above ground level) must be imposed on crops planted early (May-June), or severe lodging can occur in September before flowering. If the closing cut occurs in August and September, it will severely reduce seed yields (Hare et al. 2007b).

In practice, many Thai farmers find cutting difficult on their large areas (up to 3 ha), and there is too much forage for them to handle. These seed-producing farmers also do not need the forage, as many of them do not raise livestock. They prefer to plant in late June to mid-July as these crops do not have to be cut and do not lodge. Farmers in Laos, who plant smaller areas, have no problems in cutting their seed crops in July.

We also investigated various methods of seed harvesting. Tying light-weight nylon net bags over seed heads at anthesis to collect seed, yielded twice as much seed of Mulato II (508 kg/ha) as 3 methods of knocking seed from seed heads (252 kg/ha) without any reduction in viability (Hare et al. 2007c). Higher yields are achieved with nylon bags, because nylon bags catch all seeds as they mature and are shed from the seed heads. In contrast, with knocking, a lot of seed falls to the ground before farmers can harvest, especially if strong winds and heavy rain storms occur during the night.

*Farmer seed production*

Seed is produced in Nong Saeng village, Roi-et province (16° N; 130 masl) in Thailand and in several villages in Nga district, Oudomxay province (23° N; 500 masl) in Laos. The system used varies between the two countries. At the beginning of each wet season in Thailand and for the first year in Laos, each farmer receives 0.5−1.0 kg seed to plant a nursery. The farmers transplant 4- to 6-week-old seedlings into cultivated fields in Thailand in June and July. In Laos, the fields are on very steep hill slopes and so are not cultivated, and seedlings are directly planted in late May-June into small holes dug with a hoe. The time of planting in both countries depends mainly on available soil moisture. In Thailand, seedlings are planted in rows 80–90 cm apart and at spacings of 50−60 cm within the rows, while in Laos, farmers plant at wider spacings of 1−1.25 m between rows and 60−70 cm within rows. Farmers in Thailand replant Mulato II each year, because Mulato II seed crops in Thailand are grown on very poor soils and produce uneconomic seed yields in the second and subsequent years, even with fertilizer. In Laos, on richer soils without fertilizer, many farmers have produced consistently good yields (250−280 kg/ha) for 6 years.

For seed harvesting in Nong Saeng village, Thailand, the farmers allow the seed to fall to the ground. In late December-January, they cut all vegetation to ground level and remove it from the field. Seed on the ground is swept up, along with lots of sand, soil, leaves and other litter. The seed is firstly cleaned in the field through screens and then winnowed in cane trays back at their houses or cleaned through small seed cleaners provided by Ubon Forage Seeds.

In second-year and older seed crops in Nga district, Odumxay province, Laos, farmers cut Mulato II plants to ground level in July to prevent them growing too tall and lodging before flowering in October. In September, the leaves of each plant are tied together to make an upright bunch, and in late October the process is repeated with the stems just before anthesis to make living sheaves (Kowithayakorn and Phaikaew 1993). The seed is knocked into cane trays or baskets every 1−2 days, dried slowly in the shade for 1−2 weeks and then sun-dried for 4−5 days before cleaning and winnowing using cane trays. The seed is dried again prior to sale to reach 10% seed moisture.

In January, the Mulato 2 Co. Ltd purchases the seed from the Laos villages and trucks it through Laos, across the Mekong River, to Ubon Forage Seeds at Ubon Ratchathani University, Thailand, a distance of nearly 1,500 km. In February, the seed from Nong Saeng village, Thailand, is purchased. At the University, all seed is treated with sulfuric acid to remove the lemma and palea husks to improve seed germination, and is then washed, dried and re-cleaned before packaging for sale and export.

After acid-scarification, Mulato II and Cayman seeds average 88−91% viability (tetrazolium test), 70−90% germination and over 99.5% purity. Without acid-scarification, the seed fails to exceed 30% germination, and even long-term storage will not increase germination, owing to the physical dormancy imposed by the tightly bound lemma and palea husks (Hare et al. 2008).

In Thailand, production of Mulato II seed has increased steadily since first harvests in 2004 (Table 1). From 2004 to 2009, farmers harvested Mulato II seed by tying seed heads and knocking seeds out into large baskets. However, yields were low, averaging only 196 kg/ha. These farmers generally were disappointed with

**Table 1.** Mulato II seed production in Thailand.

| Year | No. farmers | No. villages | Province | Area (ha) | Production (kg)[1] | Seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| 2004-05 | 60 | 2 | Ubon | 11 | 2,070 | 188 |
| 2005-06 | 127 | 2 | Ubon | 16 | 1,292 | 81 |
| 2006-07 | 128 | 15 | Ubon, Amnart | 11 | 2,597 | 236 |
| 2007-08 | 200 | 20 | Ubon, Amnart Mukdahan, Lamphang | 48 | 12,202 | 254 |
| 2008-09 | 49 | 8 | Roi-et, Ubon, Amnart | 27 | 6,778 | 251 |
| 2009-10 | 45 | 1 | Roi-et | 26 | 9,959 | 383 |
| 2010-11 | 59 | 1 | Roi-et | 33 | 16,169 | 490 |
| 2011-12 | 58 | 1 | Roi-et | 33 | 10,829 | 328 |
| 2012-13 | 103 | 1 | Roi-et | 80 | 27,040 | 338 |

[1]Clean seed but not acid-scarified.

**Table 2.** Mulato II seed production in Laos.

| Year | No. farmers | No. villages | Province | Area (ha) | Production (kg)[1] | Seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| 2007-08 | 155 | 9 | Oudomxay | 16 | 2,205 | 138 |
| 2008-09 | 252 | 16 | Oudomxay | 25 | 4,492 | 180 |
| 2009-10 | 300 | 16 | Oudomxay | 40 | 7,437 | 186 |
| 2010-11 | 381 | 16 | Oudomxay | 50 | 12,073 | 242 |
| 2011-12 | 510 | 12 | Oudomxay | 90 | 21,595 | 240 |
| 2012-13 | 508 | 11 | Oudomxay | 84 | 23,381 | 278 |

[1]Clean seed but not acid-scarified.

the low yields, which they said did not cover their costs. In addition, harvesting of pasture seed coincided with rice harvesting, which taxed the labor force on the farm. As a result, many farmers ceased producing Mulato II seed altogether. Even though collecting seeds in nylon bags produced the highest seed yields in our trials, bags were considered too expensive by farmers (US$0.30−0.50/bag).

Since 2009 in Thailand, seed of Mulato II has been produced only in the village of Nong Saeng in Roi-et province, where farmers sweep the seed from the ground after the rice harvest is complete. Some farmers are now obtaining yields of more than 600 kg/ha, considerably better than yields from our research plots. Production has increased from about 10,000 kg in 2009/10 (45 farmers) to 27,040 kg in 2012/13 (103 farmers). The method of harvesting has been a major contributing factor towards increasing seed yields, with ground-harvesting producing far higher seed yields than knocking. The Roi-et farmers prefer ground-harvesting, but farmers in the other villages refuse to ground-harvest saying either it is too time-consuming for them or they cannot prepare even seed-beds because their land is on hill slopes.

In Laos, seed production has increased from 2,205 kg in 2007/8 (155 farmers, 9 villages) to 23,381 kg in 2012/13 (508 farmers, 11 villages) (Table 2).

Seed yields in Laos are lower than for Thailand, owing to plant and tiller death from rats eating the plants in the field, mice eating emerging seed heads, lack of fertilizer, wide row and plant spacings, and harvesting by tying and knocking seed heads. Average annual yields have ranged from 138 to 278 kg/ha (Table 2).

## Mombasa and Tanzania guinea grasses

### *Seed research*

Tanzania seed research conducted by the Department of Livestock Development studied flowering patterns, seed development and method of harvesting (Kowithyakorn and Phaikaew 1993). From these studies the hand-tying of seedheads into living sheaves and knocking the ripe seed out evolved. Current trials at Ubon Ratchathani University are studying the effects of crop age, plant spacing, fertilizer, liquid trace elements and seed storage on Mombasa and Tanzania seed production and seed quality.

### *Farmer seed production*

In 2008, Ubon Forage Seeds started producing Mombasa guinea seed for Tropical Seeds LLC, mainly for export back to Mexico, since Mombasa guinea seed produced in Central and South America was often contaminated with common varieties. Under the intensive management system in Thailand, farmers can remove any varieties that are not Mombasa guinea. As Mombasa is a large, leafy and very productive grass, a strong market has recently developed for Mombasa in Asia.

In 2010, Tropical Seeds asked Ubon Forage Seeds to produce Tanzania guinea seed for export to Central America, because they wanted seed of uncontaminated lines. We adopted the practices, developed by Phaikaew et al. (1995) and used by farmers for production of Mombasa seed, to produce Tanzania seed for several years. Tanzania is called Sri Muang (purple) in Thailand and TD58 in some other countries in Asia. For farmers in Mukdahan, Amnart Charoen and Ubon Ratchathani provinces, seed production of these 2 guinea cultivars is relatively easy. Activities fit in well with village management, as the seed crops can be planted quite late in the season (July-early August), and harvesting is in October before the rice harvest commences. Both cultivars are treated as annual crops and are replanted each year.

Farmers plant seed in nurseries in May-June, and transplant seedlings into their fields from July to early August, but different villages use different planting patterns. In Mukdahan, an inter-row spacing of 1 m is used, and within rows groups of 4 plants (50 cm apart) are planted at 1 m intervals. This planting pattern allows seed heads to be tied together in groups, enabling hand-knocking at seed harvesting. Some farmers plant only 3 plants per group. In Amnart Charoen and Ubon Ratchathani, the same inter-row spacing is used, but plants are 50 cm apart within the rows and the seed heads on each plant are tied together for harvesting.

Strong winds in October can be a major problem in all villages, blowing much good seed to the ground. It is estimated that nearly 40% of seed was lost from strong winds in 2009 and 2010. Farmers who produce guinea grass seed do not sweep fallen seed from the ground, because ground-sweeping requires thorough field preparation before planting to produce a relatively flat seed-bed, and it is difficult to separate the soil granules from the small guinea seeds. In the past, there has been a problem with too many empty seeds in guinea seed purchased by the University from farmers and re-cleaning at the University was necessary. In some instances, the trash removed amounted to 20% of the purchased weight. Farmers were not able to winnow strongly enough by hand to remove empty seeds. To overcome this problem, small seed cleaners with a strong air flow were manufactured in 2010 and provided free to the seed-growers. Farmers are now able to clean their seed to >99.5% purity, with a high thousand-seed weight (Mombasa 1.54 g; Tanzania 1.20 g). No further cleaning is required for sale and export.

Mean seed yields of Mombasa guinea ranged from 312 kg/ha in 2011 to nearly 500 kg/ha in 2012 (Table 3). The main factors preventing higher seed yields have been: strong winds during seed harvest knocking seed to the ground before harvest (2009); and wet, overcast weather during the growth phase before stem elongation preventing maximum tillering and inflorescence development (2011).

Tanzania seed yields are usually higher than those of Mombasa, averaging 766 kg/ha in 2009 (Table 4). However, bacterial leaf blight in 2010, wet weather during reproductive development in 2011, and low rainfall in 2012 substantially reduced seed yields.

**Table 3.** Mombasa guinea seed production in Thailand.

| Year | No. farmers | No. villages | Province | Area (ha) | Production (kg) | Seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| 2008 | 126 | 8 | Ubon, Mukdahan, Amnart | 23 | 7,318 | 318 |
| 2009 | 135 | 9 | Ubon, Mukdahan, Amnart | 64 | 28,570 | 446 |
| 2010 | 225 | 8 | Mukdahan, Amnart | 82 | 36,024 | 439 |
| 2011 | 166 | 7 | Mukdahan, Amnart | 68 | 21,269 | 313 |
| 2012 | 266 | 15 | Mukdahan, Amnart, Ubon | 116 | 57,137 | 493 |

**Table 4.** Tanzania guinea seed production in Thailand.

| Year | No. farmers | No. villages | Province | Area (ha) | Production (kg) | Seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| 2009 | 60 | 3 | Ubon, Mukdahan | 14 | 10,726 | 766 |
| 2010 | 56 | 4 | Ubon, Mukdahan | 13 | 7,050 | 542 |
| 2011 | 47 | 4 | Ubon, Mukdahan | 11 | 2,435 | 221 |
| 2012 | 125 | 11 | Mukdahan | 37 | 13,699 | 369 |

## Ubon paspalum

### *Seed research*

We first received seed of Ubon paspalum in 1994, and after research trials showed its tolerance of waterlogging (Hare et al. 1999a; 1999b), a demand for seed developed within Thailand. Immediately, we encountered problems with low seed yields and implemented a series of seed-production field trials.

Seed crops of Ubon paspalum established by sowing seed in mid-May produced no seed at all in the establishment year (Hare et al. 2001a). Planting rooted tillers, divided from second-year plants, or transplanting 2-month-old seedlings, grown in plastic bags, into the field also in mid-May, produced the highest seed yields in the establishment year, though not as high as yields of second-year crops. Seed crops, planted with rooted tillers at the beginning of May, produced 132 kg/ha seed 5 months after sowing in one trial and 331 kg/ha seed in a second trial. It is important to plant in May, as planting tillers or seedlings in June and July severely reduces seed yields.

Timing of the final closing cut is quite critical. Seed crops of Ubon paspalum cut in August and September produced little or no seed at all, and crops closed in May were susceptible to lodging (Hare et al. 1999c). Cutting and closing crops in June produced the highest seed yields.

To obtain an explanation for the poor seed yields from late plantings and late closing cuts, a plant growth chamber study on flowering was conducted at Ubon Ratchathani University. Ubon paspalum was confirmed as a long-short day plant exhibiting a quantitative response to long days followed by a qualitative response to short days (Hare et al. 2001b). In order to flower in September, plants must be at least 60 days of age before the summer solstice (June 22), explaining why crops sown with seed or planted late do not flower profusely in the year of establishment. Plants cut close to ground level after the summer solstice also do not receive enough long days subsequently to flower well and produce good seed yields in the same year. The study also confirmed that no juvenile phase exists in Ubon paspalum (Hare et al. 2001b).

While the correct planting time can ensure that good seed set occurs, the harvesting method can significantly affect recovery of seed. Hand-knocking mature Ubon paspalum seed from seed heads into bags each day produced 230 kg/ha, more than twice the amount produced by threshing or sweating seed heads (Hare et al. 1999c). Using this method, farmers in villages achieved yields in excess of 600 kg/ha (Hare *e*t al. 2001a). Even higher yields (1,108 kg/ha) were obtained on a research station by covering seed heads with nylon bags (Phaikaew et al. 2001).

### *Farmer seed production*

In March 1997, 20 farmers were contracted to grow Ubon paspalum seed. Each received 300 g of seed at that time and was instructed to sow the seed in a nursery and transplant strong plants to the field in May-June. The maximum area per farm was 1,600 $m^2$. Fields planted in May and June averaged 315 kg/ha and 65 kg/ha, respectively, whereas fields planted in July produced no seed at all (Hare et al. 2001a). Harvesting from the same fields in 1998 and 1999 produced mean seed yields of 632 kg/ha and 651 kg/ha, respectively (Hare et al. 2001a). Hand-knocking mature seed from tied seed heads into bags each day, followed by slow drying in the shade and winnowing on cane trays, produced high seed yields, with a purity of 99% and an average germination of 80%.

Even though seed production in Ubon paspalum is well synchronized, with flowering occurring predictably in September and hand-harvesting taking place over 7−10 days in early October, some difficulties can be experienced. Heavy thunderstorms frequently occur during the late September-early October flowering and harvesting period, causing seed to shed. Foraging birds may also dramatically reduce seed yields and farmers use nets to capture the birds for sale or install bird-scaring devices, such as scarecrows and tins filled with stones. Some farmers resort to sleeping in their fields in order to chase away birds, which usually forage in the early morning.

Seed production of Ubon paspalum has not expanded in recent years, because the market demand for seed is very small. We plan to produce no more than 10,000 kg per year.

## Ubon stylo

### *Seed research*

Perennial stylo cultivars have been harvested for seed in Thailand for over 30 years starting with Endeavour, Cook, Schofield and Graham. Anthracnose disease destroyed these cultivars, but fortunately cultivar CIAT 184 (called Tha Phra stylo in Thailand) became available and has been produced for seed by the Thailand Department of Livestock Development for more than 15 years. In 1999, Dr Bert Grof provided seed of a new stylo blend of lines derived from *S. guianensis* var. *vulgaris* x var. *pauciflora*, which had very strong resistance to anthracnose (Grof et al. 2001). This stylo has been released in Australia as cultivar Nina; however, in Thailand, farmers growing seed and forage call it "Ubon stylo" and we have continued to use this name. To identify optimum strategies for growing Ubon stylo, experiments were conducted in Thailand during 2004-5 to determine optimum times for cutting (Hare et al. 2007d).

Ubon stylo (959 kg/ha) produced 2.6 times the seed yield of Tha Phra stylo (365 kg/ha) in a field trial at Ubon Ratchathani University, and closing stylo seed crops in September doubled seed yield over closing in October (Hare et al. 2007d). We recommend cutting tall dense seed crops in September, but not crops which are sown late or are growing very slowly.

Germination tests on 1-year-old stored Ubon stylo seed (Hare 2007) showed that hot water and machine-scarification significantly increased germination and reduced the percentage of hard seed. Seed germination was less than 10% without scarification, while scarifying the seed 4 times through a machine significantly increased speed of germination at 7 days compared with hot water treatment (81.9 vs. 67.3%). However, after 14 days, there was no difference in total germination between hot water treatments and scarifying 4 times through a machine (88.0 vs. 89.9%).

Today, all Ubon stylo seed sold is acid-scarified because this operation is relatively easy to perform, and very high germination rates (99%) can be achieved (Table 5). Large quantities (over 1 t) can be scarified daily, and the resulting seed has far higher germination than machine-scarified seed.

*Farmer seed production*

In Thailand, Ubon stylo seed is produced in only a single village, Bark Kud Waay, in Ubon Ratchathani province. Farmers receive 500 g of seed in April to plant a nursery and in July plant seedlings into raised seed-beds in 1 m x 50 cm rows. They prefer to delay planting until July, because this precludes imposing a closing date defoliation. Seed crops flower and set seed from November to January. All crops are thoroughly hand-weeded during the growing season to remove any chance of weed-seed contamination during ground-sweeping of the Ubon stylo seed.

**Table 5.** Effect of sulfuric acid scarification on germination of Ubon stylo seed.

| Treatment | Germination (%) | | Hard seed (%) |
|---|---|---|---|
| | 7 day | 14 day | |
| No acid | 21 | 24 | 76 |
| Acid 5 minutes | 99 | 99 | 1 |

At seed harvest in late January, farmers use sticks to beat plants to dislodge any remaining seed that has not fallen from the seed heads, before the vegetation is cut to ground level and removed. Fallen seeds are swept from the ground and cleaned by farmers in the field.

In March the seed is purchased by the University. It is then acid-scarified to remove soil and seed coats, which improves seed purity and overcomes hard-seed dormancy, thereby improving seed germination. Farmers produce high seed yields (Table 6), and in March 2012, 17 farmers harvested average seed yields of 1,040 kg/ha.

## Profitability of smallholder forage seed production in Thailand and Laos

In Thailand, forage seed crops are grown on upland soils previously planted to cassava, or on upland rice paddies, which are only marginally productive for rice, because they are not inundated with water each year. Farmers usually hire contractors to plough their fields and hire additional labor for weeding, harvesting and cleaning. More and more rice is now machine-harvested and threshed by contractors.

**Table 6.** Ubon stylo seed production in Thailand.

| Year | No. farmers | No. villages | Province | Area (ha) | Production (kg)[1] | Seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| 2005-06 | 10 | 1 | Ubon | 3 | 2,070 | 690 |
| 2006-07 | 15 | 1 | Ubon | 9 | 5,590 | 621 |
| 2007-08 | 30 | 1 | Ubon | 12 | 7,500 | 625 |
| 2008-09 | 30 | 1 | Ubon | 9 | 6,400 | 711 |
| 2009-10 | 30 | 1 | Ubon | 3 | 1,950 | 650 |
| 2010-11 | 26 | 1 | Ubon | 9 | 6,265 | 696 |
| 2011-12 | 17 | 1 | Ubon | 7 | 7,290 | 1,041 |
| 2012-13 | 30 | 1 | Ubon | 12 | 9,000 | 750 |

[1]Before acid-scarification.

Costs of production were gathered from forage seed-producing farmers and rice farmers over 2 years (2011−2013) by holding informal discussions whenever possible. Further costs were obtained from data supplied by the agricultural economics division of the Ministry of Agriculture.

Forage seed crops are far more profitable than rice in Thailand (Table 7), but forage seed crops cannot be planted on the low-lying, waterlogged paddies, where only rice can be grown. Mulato II is the most profitable forage seed crop, but these yields and costs are from Roi-et, where high seed yields (500−650 kg/ha) are achieved using seed recovered from the ground. Roi-et farmers are the only farmers in Thailand and Laos who harvest Mulato II seed in this way.

Cassava is the main competitor with forage seeds for land in Thailand, particularly seed crops of Mombasa, Tanzania and Mulato II. Cassava is relatively easy to grow and, with the tubers in the soil, there is minimal risk of losing the crop from climate variations as with grass seed crops. Farmers usually look at the gross income they receive and not net income. If cassava prices increase to more than US$0.10/kg, many farmers would prefer to grow cassava. If the cassava price drops to US$0.08/kg, farmers will plant more forage seed crops. Decision making by farmers in our seed villages appears to be based on return to land ($/ha) and not on return to labor ($/hour).

Farmers in Mukdahan, Amnart Charoen and Ubon, who produce Mombasa and Tanzania guinea grass seed, currently harvest by tying seed heads and knocking, considering it is too difficult to ground-sweep seed, given the small seed size and the need to carefully prepare even seed-beds, which is difficult on hill slopes. On the other hand, the Roi-et farmers ground-sweep Mulato II, as they do not like tying seed heads and daily knocking seed into bags. Their fields are on flat land and it is not difficult for them to cultivate and produce even seed-beds. Another consideration is that Mulato II harvesting occurs at the same time as rice harvesting and farmers must harvest rice for their families for food security. With ground-sweeping Mulato II, they can let the seed fall to the ground during rice harvesting and after the rice harvest is completed, they can turn their attention to harvesting Mulato II seed. However, they will not consider growing guinea grass for seed, because they consider the seeds are too small to sweep and separate from the soil collected during harvest. If nylon net harvesting was introduced, the risk of losing seed from hand-knocking would be greatly reduced and seed yields could increase to over 700 kg/ha for Mombasa, over 800 kg/ha for Tanzania (Phaikaew et al. 1995) and over 800 kg/ha for Ubon paspalum (Phaikaew et al. 2001). In this situation, the price of nylon bags, currently deemed too expensive at US$0.30−0.50/bag, would need to be factored into the calculations.

In Thailand, additional benefits from forage seed crops can arise from the sale of fresh forage or its use to feed the farmer's own cattle and buffalo. However, farmers often do not seem to consider these aspects, when deciding which cash crop to plant.

Farmers in Nga district, Laos, do not hire outside labor for their agricultural production. Crops are sown by hand, seed is free, no fertilizers, insecticides or herbicides are used, cultivation is by hand and no machinery is hired or used. No costs are incurred except for family labor and time, which are common to all these crops. Seed production of Mulato II is very profitable

**Table 7.** Estimated costs and gross and net income* (US$/ha) from rice, cassava and forage seeds in northeast Thailand in 2013.

| | Rice | Cassava | Ubon paspalum | Mulato II | Ubon stylo | Mombasa |
|---|---|---|---|---|---|---|
| **Direct Costs** | | | | | | |
| Cultivation | 125 | 125 | 125 | 125 | 125 | 125 |
| Raising furrows | | 125 | | | 125 | |
| Fertilizer | 375 | 415 | 210 | 210 | 210 | 210 |
| Labor for weeding | | 125 | 65 | 125 | 125 | 65 |
| Labor for harvesting | 125 | 210 | 125 | 335 | 335 | 125 |
| Hire digger to dig up tubers | | 125 | | | | |
| Labor for cleaning/threshing | 125 | 125 | 65 | 335 | 335 | 65 |
| Transport | 80 | 105 | | | | |
| **Total Direct Costs** | 830 | 1,355 | 590 | 1,130 | 1,255 | 590 |
| Sale price (US$/kg) | 0.50 | 0.09 | 3.00 | 6.00 | 3.35 | 3.35 |
| Yield (kg/ha) | 2,500 | 25,000 | 565 | 500 | 810 | 500 |
| **Gross Income** | 1,250 | 2,250 | 1,695 | 3,000 | 2,714 | 1,675 |
| **Net Income*** | 420 | 895 | 1,105 | 1,870 | 1,459 | 1,085 |

*Net income: farm gate return.

**Table 8.** Estimated yield and net income from rice and Mulato II seed in Nga district, Oudumxay district, Laos.

| | Rice | Cassava | Maize + Soybean | | Mulato II |
|---|---|---|---|---|---|
| | | | Maize | Soybean | |
| Sale price (US$/kg) | 0.25 | 0.05 | 0.08 | 0.30 | 4.00 |
| Yield (kg/ha) | 1,500 | 25,000 | 3,500 | 1,500 | 278 |
| Net Income (US$/ha) | 375 | 1,250 | 280 | 450 | 1,112 |

compared with upland glutinous rice grown on steep hillsides, producing 6 times the income (Table 8). However, rice is produced mainly for household consumption and sales are rare.

Net incomes for upland rice, cassava and maize grown in Nga district can be increased, if other crops such as peanuts, soybeans and sesame are inter-row planted in the same fields. However, these crops are relatively bulky and villages producing Mulato II are remote and poorly serviced by roads, often having only walking tracks, which make transport expensive. Therefore, seed production of Mulato II is still the most profitable enterprise for village farmers. The major advantages of Mulato II seed are its relatively high value per kg and lower bulk, which reduce transport costs from remote areas like Nga district to Thailand. Some remote villages export Mulato II seed by boat, down the Mekong River to Luang Prabang, where Mulato 2 Co. Ltd loads the seed on to trucks to transport to Thailand.

In Laos, Mulato II is proving a sustainable and environmentally friendly agricultural crop in Nga district for the following reasons: it prevents erosion by providing a dense vegetative cover on the hill slopes; and it grows for many years, while upland rice and maize die after seed harvest and do not provide a ground cover. Some of the material cut after harvest of Mulato II and at closing is fed to cattle, while the rest is used as mulch, providing additional control against erosion and preventing weeds from growing. Mulato II seed crops planted in 2007 are still producing consistently good yields, averaging 278 kg/ha. How long these yields will be maintained is a matter for conjecture but, in Mexico, Mulato seed crops receiving 150 kg N/ha/yr produced 500 kg/ha of pure seed in year 5 and 900 kg/ha in year 8 but only 140 kg/ha in year 9 (Esteban Pizarro personal communication). On this basis, Mulato II seed crops in Nga district should continue to produce good seed yields for 10 years or longer.

## Export

Ubon Forage Seeds has achieved an international reputation for very high quality tropical forage seed, emphasizing high purity, high vigor and high germination.

Acid-scarification considerably improves seed germination of hybrid brachiaria cultivars and Ubon stylo and, to achieve high germinations in Mombasa, Tanzania and Ubon paspalum, the seed must be stored for at least 4−5 months to remove embryo dormancy before it is sold and exported (Hare et al. 1999c).

During the past 3 years, nearly 140,000 kg of seed has been exported to 22 countries and 6,000 kg has been sold within Thailand. The main markets have been in Central America (84,000 kg), Asia (32,000 kg) and the Pacific region (23,000 kg). Africa is becoming an emerging market. As 95% of seed produced is sold, the industry is highly dependent on maintaining and expanding these markets.

## Conclusion

Experience in northeast Thailand and northern Laos has shown that forage seed production can be an economically viable and sustainable cash crop for more than 1,000 smallholder village farmers. Over the past 5 years, production has increased exponentially, with 136 t of seed being produced by hand-harvesting and hand-cleaning methods in 2013. However, the future viability of this industry depends on reliable markets for the seed. To date, dairy and beef cattle smallholder farmers in other tropical countries in Asia, Africa, the Pacific and Central and South America have been the primary outlet. The future of the industry will depend on efforts to expand on export markets plus local sowings as well as the development of additional pasture species.

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# Developing a savanna burning emissions abatement methodology for tussock grasslands in high rainfall regions of northern Australia

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## Abstract

Fire-prone tropical savanna and grassland systems are a significant source of atmospheric emissions of greenhouse gases. In recent years, substantial research has been directed towards developing accounting methodologies for savanna burning emissions to be applied in Australia's National Greenhouse Gas Inventory, as well as for commercial carbon trading purposes. That work has focused on woody savanna systems. Here, we extend the methodological approach to include tussock grasslands and associated *Melaleuca*-dominated open woodlands (<10% foliage cover) in higher rainfall (>1,000 mm/annum) regions of northern Australia. Field assessments under dry season conditions focused on deriving fuel accumulation, fire patchiness and combustion relationships for key fuel types: fine fuels − grass and litter; coarse woody fuels − twigs <6 mm diameter; heavy woody fuels − ≥6 mm diameter; and shrubs. In contrast with previous savanna burning assessments, fire treatments undertaken under early dry season burning conditions resulted in negligible patchiness and very substantial consumption of fine fuels. In effect, burning in the early dry season provides no benefits in greenhouse gas emissions and emissions reductions in tussock grasslands can be achieved only through reducing the extent of burning. The practical implications of reduced burning in higher rainfall northern Australian grassland systems are discussed, indicating that there are significant constraints, including infrastructural, cultural and woody thickening issues. Similar opportunities and constraints are observed in other international contexts, but especially project implementation challenges associated with legislative, political and governance issues.

## Resumen

La quema de sabanas y pastizales tropicales es una fuente significativa de emisión de gases con efecto invernadero. En Australia, un número considerable de proyectos de investigación recientes ha sido orientado hacia el desarrollo de metodologías para cuantificar la emisión de gases ocasionada por las quemas, para el Inventario Nacional de Gases de Invernadero ('National Greenhouse Gas Inventory') y con propósitos de comercio de carbono. Esas investigaciones estaban enfocadas en sistemas de sabanas con presencia de especies leñosas en regiones con 500−700 mm de precipitación anual. En el presente trabajo extendimos la metodología para incluir tanto pastizales con especies de crecimiento en matojos ('tussocks grasslands') como los asociados bosques abiertos (<10% de dosel arbóreo), caracterizados por alta presencia de *Melaleuca*, los cuales predominan en regiones de pluviosidad más alta (>1,000 mm/año) en el norte de Australia. Las evaluaciones durante la estación seca se orientaron a la acumulación de material combustible, la heterogeneidad de sitios de fuego y las relaciones con combustión para 4 tipos clave de combustibles: combustibles finos (gramíneas y hojarasca); combustibles leñosos finos tales como chamizas y ramas pequeñas (trozos <6 mm de diámetro); combustibles leñosos gruesos (≥6 mm de diámetro); y arbustos. En contraste con evaluaciones previas de quemas en sabanas, en esta investigación los tratamientos de quema al comienzo de la época seca resultaron en una heterogeneidad insignificante de fuego y en un muy alto consumo de los combustibles finos. En consecuencia la quema en esta época no trae beneficios en la emisión de gases de invernadero; la reducción de gases por quemas en pastizales que crecen en matojos ('tussock grasslands') sólo es posible reduciendo la extensión de las quemas. Se discuten las

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implicaciones prácticas de la reducción de las quemas en áreas de mayor pluviosidad en el norte de Australia y se señala la existencia de importantes limitantes incluyendo infraestructura, la formación de matorrales espesos y aspectos culturales. Se señala, además, que similares oportunidades y limitantes existen en otros países tropicales donde, sin embargo, los retos para implementar proyectos de reducción de quemas son más que todo de índole legislativa, política y de gobernanza.

## Introduction

It is widely recognized that, together with interactions with seasonal moisture availability, nutrients and herbivory, fire regimes play a critical role in modifying the floristic composition, vegetation structure and dynamics of tropical savanna and associated grassland systems (Scholes and Archer 1997; Bond 2008; Lehmann et al. 2011). For example, reduced incidence and intensity of burning in northern Australian grazing management systems, as a result of either deliberate fire exclusion or a reduction in the capacity of grassy fuels to support intense fires through heavy grazing pressures, can allow woody plants to become firmly established in grasslands (Noble and Grice 2002; Myers et al. 2004). As a consequence, it is recognized that fire regimes in tropical savanna and grassland systems have substantial effects on carbon stocks and dynamics in living biomass components and associated dead fractions (e.g. Williams et al. 2004; Liedloff and Cook 2007; Bond 2008; Murphy et al. 2010; Smit et al. 2010; Ryan and Williams 2011), and possibly also in soils (Coetsee et al. 2010; Cook et al. 2010; Richards et al. 2011).

In addition to effects of fire regimes on biomass/carbon stocks, fire-prone savanna and grassland systems are a globally significant source of annual greenhouse gas (GHG) emissions. During 1997−2009, fires in savannas (incorporating grassland, open savanna and woodland) were estimated to account for 60% of total global fire emissions; estimates indicate such fires also accounted annually for 36% of methane ($CH_4$) and 58% of nitrous oxide ($N_2O$) emissions from fire sources globally (van der Werf et al. 2010). In recognition of the significance of this emissions source, the Kyoto Protocol requires participating Tier 1 (developed economy) countries, where pertinent, to account for emissions of GHGs (specifically $CH_4$ and $N_2O$) from "prescribed burning of savannas" (UNFCCC 1998: Article 3, Annex A). Australia, as the only Tier 1 country with substantial savanna coverage, includes savanna burning emissions in its National Greenhouse Gas Inventory (NGGI); typically accountable GHG emissions annually contribute ~3% of Australia's NGGI (ANGA 2011). In accord with international accounting rules, Australia's NGGI does not account for $CO_2$ emissions from savanna burning on the assumption that $CO_2$ emissions in one burning season are negated by growth of vegetation in subsequent growing seasons (IPCC 1997). Accountable greenhouse gas emissions from Australian savanna burning are predominantly associated with anthropogenic ignition sources (Russell-Smith et al. 2007).

In accord with other provisions of the Kyoto Protocol (Article 6), which establish a framework for developing market-based instruments to address anthropogenic sources and sinks of GHG emissions, Australia has also established a formal offsets mechanism, the Carbon Farming Initiative (CFI), which "allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land" (refer CFI website: www.climatechange.gov.au/cfi). One of the first GHG emissions reduction methodologies developed for the CFI has been a savanna burning methodology focusing on higher rainfall regions (>1,000 mm/annum) for fire-prone northern Australia (Russell-Smith et al. 2009; DCCEE 2012; Meyer et al. 2012). An essential premise underlying that methodology is that reductions in fire frequency and intensity result in reduced GHG emissions, because more of the fuel biomass (mostly grass and leaf litter) is decomposed biologically through pathways that, compared with savanna fires, produce lower relevant emissions per unit biomass consumed (Cook and Meyer 2009). The recently approved accounting methodology for savanna burning (DCCEE 2012) establishes strict accounting protocols, prescribing all methodological and calculation procedures, vegetation-fuel type and fire mapping requirements, and use of requisite parameter values, satellite imagery and acceptable data sources.

In this paper, we report research undertaken to extend the current savanna burning methodology (DCCEE 2012) to include an additional fuel type, and associated fuel accumulation (FA) and burning efficiency (BEF) parameters, relating to tropical tussock grasslands under higher rainfall (>1,000 mm/annum) conditions.

While tussock grasslands in northern Australia occur mostly on heavy-textured soils under lower seasonal rainfall conditions (generally ~500−700 mm/annum), and generally support highly productive grazing systems (especially for beef cattle production: Tothill and Gillies 1992; Noble and Grice 2002; Myers et al. 2004), extensive tussock grasslands occur in some higher rainfall savanna regions, especially on western Cape York Peninsula, Queensland. In these latter situations, beef cattle production is generally economically marginal, given mostly infertile soils, limited infrastructure, restricted seasonal access and remoteness from markets (e.g. refer to notes concerning Cape York pastoral industry on the Tropical Savannas Cooperative Research Centre's Savanna Explorer website at www.savanna.org.au/qld/cy/cygrazing.html). In such situations, and in combination with very frequent and extensive late dry season wildfires (Felderhof and Gillieson 2006), market opportunities afforded through savanna burning offsets may provide useful additional economic opportunities.

Tussock grassland (and *Melaleuca* open-woodland) communities occupy 48,600 $km^2$, or 10.6% of the 456,800 $km^2$ higher rainfall (>1,000 mm/annum) savanna region, based on Australian National Vegetation Information System (NVIS) mapping (National Vegetation Information System: www.environment.gov.au/erin/nvis/mvg/index.html#mvg30), with the great majority (76%, or 37,000 $km^2$) occurring on Cape York Peninsula (Figures 1A, 1B). When intersected with available annual fire extent mapping derived from MODIS imagery for the period 2000–2012, 74.7% of Cape York tussock grasslands had burnt at frequencies of 0.3 or greater (i.e. 4 or more times), 48.2% had burnt at frequencies of 0.58 or greater (i.e. 7 or more times) and 6.2% remained unburnt.

In this paper, we: (1) address parameter values required for developing a modified higher rainfall savanna burning abatement methodology addressing tussock grassland conditions; and (2) consider potential benefits and challenges for such a methodology to contribute to grazing and land management enterprises in Australia's higher rainfall savannas.

## Materials and Methods

### *Savanna burning methodology*

Components of the currently approved savanna burning methodology are set out in detail in Russell-Smith et al. (2009), DCCEE (2012) and Meyer et al. (2012). Essentially, savanna burning emissions are calculated as the product of the mass of pyrolized fuel and the emission factor (EF) of respective accountable GHGs ($CH_4$, $N_2O$). Pyrolized fuel is the product of: the area exposed to fire (derived from satellite mapping sources), taking into account spatial patchiness (calibrated from field studies), x the accumulated fuel load (FA) x the burning efficiency (BEF), defined as the mass of fuel exposed to fire that is pyrolized. Both FA and BEF are determined from field observations.

The methodology takes into account that, in savanna fires, different percentages of combustible fuels (grass, litter, twigs, logs, shrubs) are combusted in different major fuel types (e.g. open-forest, woodland) under different fire intensity conditions. In the current absence of available reliable fire intensity mapping surfaces for northern Australia, and as surrogate for fire intensity, the methodology differentiates between fires of generally lower severity, occurring in the early dry season (before August), and fires of generally higher severity, occurring in the late dry season (typically August−November) (Williams et al. 2003; Russell-Smith and Edwards 2006). A useful description of fire behavior in Australian grasslands is given in Cheney and Sullivan (2008).

The current burning methodology for higher rainfall savanna recognizes 4 major savanna fuel types: open-forest, with woody foliage cover (FC: sensu Specht 1970) of 30−70%; sandstone woodland (FC, 10−30%), typically over hummock (*Triodia* spp.) grasses; woodland (FC, 10−30%), typically over tussock grasses; and shrubby heath, typically with hummock grasses (FC, <30%).

This study addresses adding a fifth broad fuel type, tussock grassland, with woody FC <10%. Under higher rainfall northern Australian conditions, such grasslands may include scattered trees and shrubs, characteristically comprising *Melaleuca* spp. and allied myrtaceous taxa (e.g. *Asteromyrtus*). Under current fire and grazing situations in northern Australia, *Melaleuca* is recognized as being a significant invader of former open (non-woody) grasslands (Garnett and Crowley 1995; Myers et al. 2004; Crowley et al. 2009). The definition of 'tropical grassland' adopted here, allowing for a small component of woody cover (<10%) and recognizing that tropical grasslands occupy one end of the savanna vegetation continuum, is consistent with that used in other international settings (Olson et al. 1983; Scholes and Hall 1996; White et al. 2000; Lehmann et al. 2011).

### *Methods*

Extending the current higher rainfall savanna burning abatement methodology to include tussock grasslands essentially requires obtaining additional data specifically describing grassland pre-fire (FA: fuel accumulation with time) and post-fire (BEF: fire patchiness, combustion efficiency) relationships. Pertinent data for other requisite parameters (e.g. emission factors for $CH_4$ and $N_2O$ from combustion of fully cured grassy fuels) are already available from the literature.

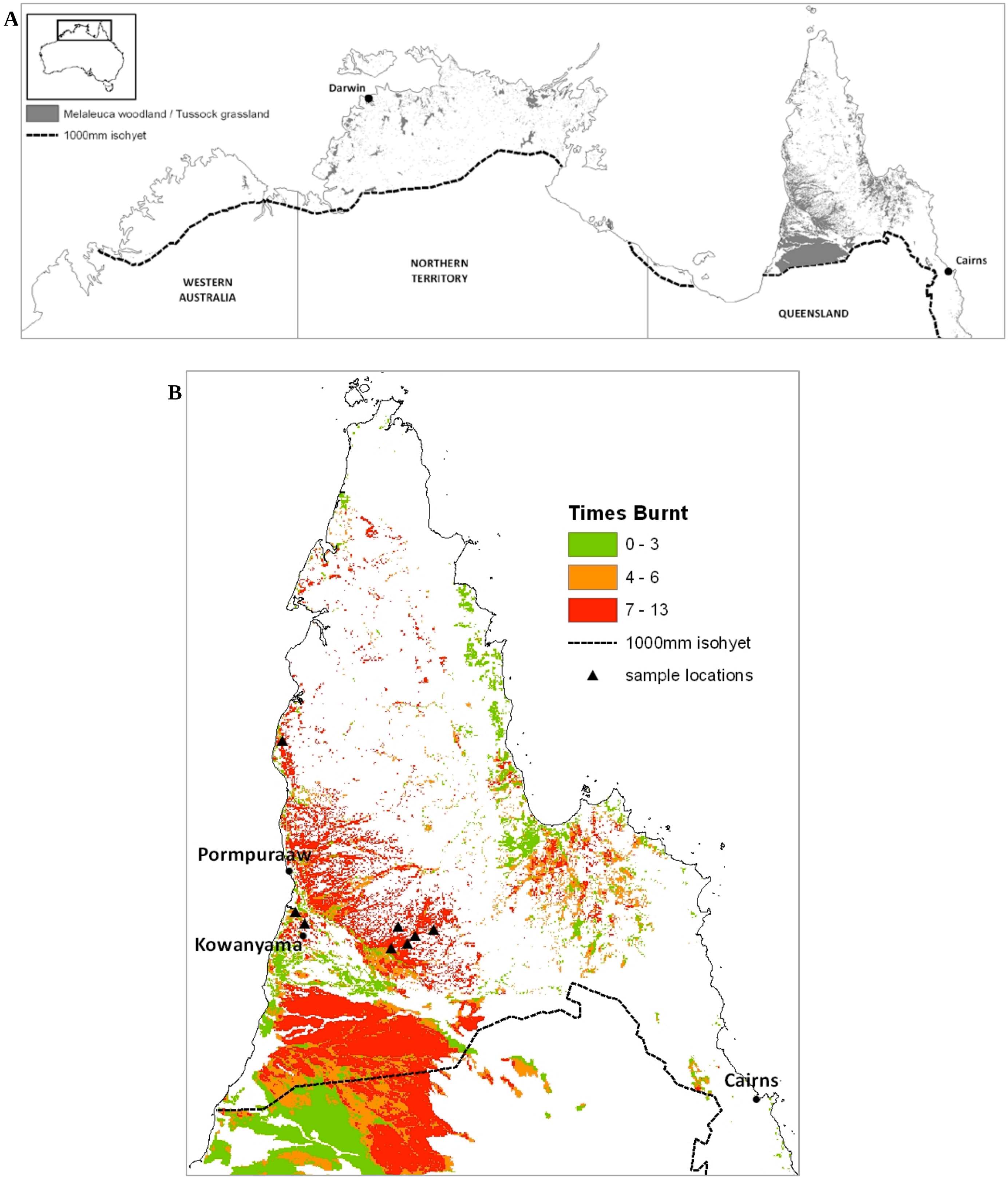


**Figure 1**. Distribution of tussock grassland (including *Melaleuca* open-woodland) communities: (A) in Australian higher annual rainfall (>1,000 mm) savanna region; and (B) on Cape York Peninsula, with recent fire frequency superimposed. Refer text for details concerning mapping surfaces.

Field sampling to assess pre- and post-fire conditions in typical higher rainfall (>1,000 mm/annum) grassland settings was undertaken at 2 sampling periods (see below) in the 2012 dry season, focusing on western Cape York Peninsula, given the significant extent of tussock grassland and open woodland in that region (Figure 1A). For consistency, applied field assessment methods followed, with noted exceptions, those described by Russell-Smith et al. (2009).

As a basis for sampling pre-fire fuel accumulation components, available fine-scale (1:100,000) vegetation mapping of grassland and associated open-woodland communities in the focal region (Queensland Herbarium 2009) was intersected using standard GIS (Geographic Information System) procedures with monthly/annual fire extent mapping derived from MODIS imagery (250 m pixels), for the period 2000−2012 (North Australia Fire Information website: [www.firenorth.org.au/nafi2](www.firenorth.org.au/nafi2)).

Given the very high fire frequencies prevalent in this region, including in target grassland and open-woodland communities (Figure 1B), accessing suitable areas that had remained unburnt for more than 1 or 2 years presented challenges. As such, the field program concentrated largely on a single region (in the vicinity of the township of Kowanyama: Figure 1B) with a mix of fuel ages (times-since-burnt) largely associated with fire-refugia − typically islands in braided stream channels. Identified suitable sites were accessed mostly by helicopter.

*Pre-fire assessments.* These were undertaken at 90 sites (transects of 10 m x 100 m) established in homogeneous tussock grassland or *Melaleuca* open-woodland communities, and homogeneous time-since-last-fire mapping units. Following the methodological approach outlined by Russell-Smith et al. (2009), time-since-fire (in years) was established for each site as identified through GIS analysis.

As well as information collected for descriptive purposes (e.g. tree stem density and height, species identification), sampling focused on assembling fuel accumulation data for the following classes: (a) fine fuel (grass plus litter <6 mm diameter); (b) coarse woody material (≥6 mm–5 cm diameter); (c) heavy fuel (≥5 cm diameter); and (d) shrub fuel with diameter at breast height (DBH) <5 cm, in 3 height classes per species (<50 cm, 50−200 cm and >200 cm). All field measurements and subsequent corrections for dry weight were undertaken using procedures as outlined in Russell-Smith et al. (2009).

Simple linear regression was used to examine relationships between accumulation of fuel load components (i.e. grass, litter, coarse fuels, heavy fuels, shrubs) and time-since-fire. Regressions for respective fuel components were expressed over the full 10-year time-since-fire sampling period, although, in many relatively long unburnt samples, no fuels were recorded for most fuel components. We note that, while this approach is consistent with Russell-Smith et al. (2009), under idealized experimental conditions fine fuel accumulation may be represented by a logarithmic function, which approaches a maximum value, theoretically reflecting a site-specific equilibrium between annual input and decay (Olson 1963). In northern Australian savanna woodlands with a tussock grass understory, the steady-state equilibrium for fine fuel accumulation may be attained within 5 years following fire (Cook 2003).

Given that savanna fires do not consume all available fuel components, for $t_0$ we included measurements of post-fire fuel components derived from fire treatments (see below). Following Russell-Smith et al. (2009), natural log-transformation was applied to both fuel load response (given strong positive skews for most observations) and time-since-fire (given apparent non-linearity). For time-since-fire, $t_0$ was given as the natural logarithm of 0 plus 1 day (i.e. 1/365). Where no coarse, heavy or shrub fuels were observed in sampling at respective plots, we assumed a small value (i.e. 0.001 t/ha) prior to natural log-transformation.

Following the methodology outlined in DCCEE (2012), we derived time-since-fire fuel component parameter values for years 1–5, and >5 years, as follows: Where significant ($P<0.01$) accumulation was observed for fuel load components with time-since-fire, we derived respective time-since-fire values for years 1–5, and maximum fuel load (>5 years) based on the derived regression value for year 6, utilizing the full 10-year expression equation. Truncating the maximum fuel component parameter value in this manner offers a conservative solution, as it fits with our observations (see Results), as well as partially addressing potential annual fire mapping errors, which compound over time (Russell-Smith et al. 1997). In other instances where non-significant relationships were observed between fuel load components and time-since-fire, we assumed that fuel load was best described by a simple mean, calculated using untransformed values, so as to not unduly weight the effects of large numbers of zero observations.

All plots were accessible to grazing by cattle and native herbivores (e.g. kangaroos and wallabies). In the field, sampling plots were located in fully cured grasslands, at sites away from intensively grazed or disturbed permanent watering points. We note that free surface water was very restricted at our study locations at the time of sampling; hence fuel loads were assessed under realistic ambient landscape-scale field conditions, including grazing utilization.

*Post-fire assessments.* These assessments comprised 2 components:

(1) Combustion efficiency: Immediately following the pre-fire assessments above, 24 plots were burnt under noon–early afternoon hot and typically gusty conditions in order to undertake measurements of post-fire fuel components. Post-fire measurements were undertaken within 6 h after the burn. Post-fire measurements generally followed the procedure given by Russell-Smith et al. (2009), with the exception that post-fire ash was sampled in each plot with 5 systematically placed quadrats, each 1 m x 1 m.

(2) Patchiness (percent burnt): Assessments of percent burnt were undertaken at both established plots at the time of post-fire assessments (above) on transect sections (1 m x 100 m) and at other recent extensive fires in tussock grassland and open-woodland vegetation types in random 1 m x 100 m areas within larger burnt patches as in Russell-Smith et al. (2009).

The applied methodology differed from that outlined in Russell-Smith et al. (2009), as separate assessments were not undertaken under both early dry season (EDS: pre-August) and relatively severe late dry season (LDS: post-August) fire-weather conditions. Russell-Smith et al. (2009) observed marked seasonal differences in fuel consumption and patchiness, while we observed that even EDS fires in tussock grasslands resulted in almost complete fine-fuel consumption and negligible patchiness, mitigating the need to undertake a separate LDS assessment. Additional sampling in the LDS was undertaken, however, specifically targeting pre-fire assessments of fuel accumulation at hitherto under-represented longer-unburnt sites.

## Results

### *Pre-fire assessments*

Commonly occurring graminoids in the 90 sample plots included the grasses *Eriachne* spp., *Aristida* spp., *Heteropogon triticeus*, *Panicum* spp. and *Whiteochloa airoides* and the sedges *Eleocharis* spp., *Fimbristylis* spp. and *Rhynchospora* sp. (Figure 2). Sample plots were dominated by perennial graminoids (Figure 2), characteristic of open grassland systems in Cape York Peninsula (Queensland Herbarium 2009). Shrubs (<5 cm DBH) occurred at 60 plots, and tree stems (≥5 cm DBH) at 41 plots, at overall (n = 90) mean densities of 99.9 shrubs/ha and 47.4 trees/ha. *Melaleuca* spp. comprised 78.2% of all shrubs, and 98.2% of all tree stems (Figure 3A). The great majority of tree stems were <20 cm DBH and <10 m tall (Figures 3A, 3B). These small stem sizes are indicative of relatively recent stand development/invasion within the last 2 decades. Even at highest sampled stem densities, tree foliage cover was <10%, given typically small crown sizes ≤2 m diameter.

Available fuels were dominated by fine fuels, which comprised a mean 88.3% of total fuel mass in years $t_0$–$t_{10}$ (n = 118). Mean (± s.e.; n = 118) fuel loads for respective components were: fine fuels, 2.6 ± 0.19 t/ha; coarse fuels, 0.12 ± 0.03 t/ha; heavy fuels, 0.17 ± 0.05 t/ha; and shrub fuels, 0.05 ± 0.01 t/ha. These values are much lower than the mean values for 219 fuel component samples for more wooded vegetation types during the early dry season under equivalent higher rainfall conditions: fine fuels, 4.16 t/ha; coarse fuels, 0.16 t/ha; heavy fuels, 1.35 t/ha; and shrub fuels, 0.62 t/ha (Russell-Smith et al. 2009). On average, under grassland/open-woodland conditions, 23 ± 7% of fine fuels was litter, and 18 ± 7% of litter was leaf and twig components.

Fuel accumulation relationships with time-since-fire are given for the 4 fuel classes in Figure 4. The linear regression [Ln(fuel component) with Ln(time-since-fire)] for fine fuel loads was highly significant ($P<0.001$, $R^2$(adj.)= 0.94). Modelled regression values for fine fuel accumulation with time, and mean values for coarse, heavy and shrub fuel components, are given in Table 1.

### *Post-fire assessments*

Fire treatments undertaken at 24 plots were generally of low-to-moderate severity, as evidenced by relatively low impacts on shrub size classes; consumption of shrub biomass at the 24 plots in the <0.5 m height class was 18.3%, and 8.2% in the 0.5–1.0 m height class.

Of the remnant post-fire debris, a mean of 21.3 ± 3.8% was ash. Mean consumption, corrected for remnant ash, which was applied equally to all fuel classes following Russell-Smith et al. (2009), was 99.9 ± 0.02% for fine fuels, 71.9 ± 12.6% for coarse fuels, 14.9 ± 9.8% for heavy fuels and 7.3 ± 3.2% for shrub fuels (Figure 5).

Based on assessments of post-fire patchiness undertaken at 112 transect segments (each 1 m x 100 m), the mean burnt proportion was 95.8 ± 1.3%.

## Discussion

This assessment provides a robust basis for parameterizing a savanna burning greenhouse gas emissions abatement methodology for Australian tropical tussock grasslands and *Melaleuca* open-woodland communities under relatively high rainfall conditions. The essential framework for that methodology is set out in DCCEE (2012). Key parameters and variable values required for propagating that framework, derived mostly from observations presented here but also from other pertinent studies, are summarized in Table 1.

By contrast with the earlier higher rainfall savanna burning abatement methodology focusing on woody systems (Russell-Smith et al. 2009; DCCEE 2012), particular features of the present study concern: (1) distinct differences in fuel accumulation and fuel consumption parameters for different fuel type components; and (2) the absence of seasonal variation in all parameters studied. While the latter issue (see below) somewhat clouds direct comparison between the 2 studies, suffice to say that, in grasslands, on average: (1) accumulation of fine fuels is less (given small leaf and twig litter inputs) than in woody systems, and accumulation of coarse, woody and shrub fuel components is much lower; (2) fuel consumption is greater for fine fuels, double that for coarse fuels, and substantially less for heavy and shrub fuel components; and (3) given these relationships and the much higher emission factors derived from woody fuel components (DCCEE 2012), resultant emissions per unit area burnt are substantially lower for grasslands than for woody savannas.

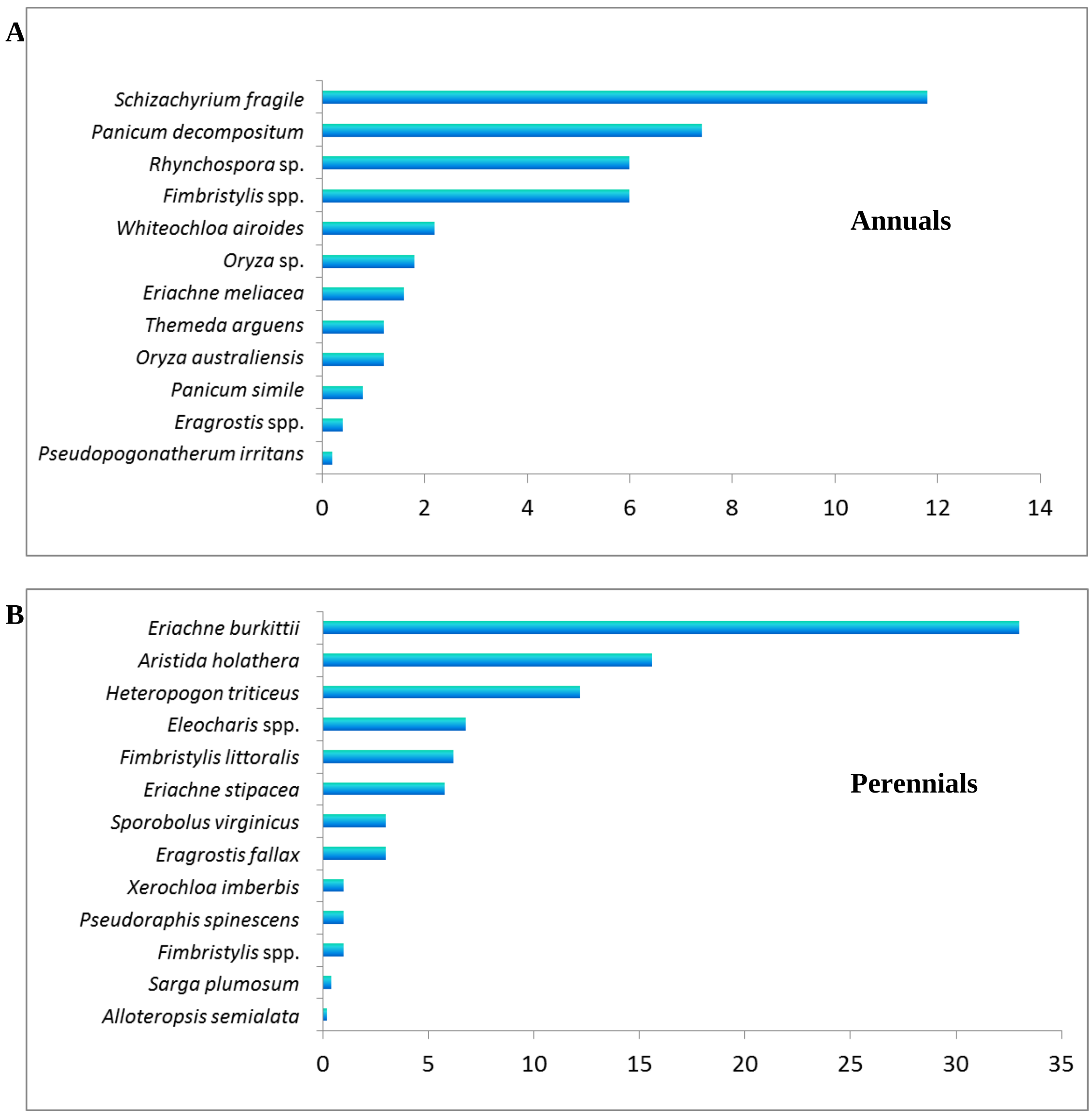


**Figure 2**. Sampled frequency of common graminoid taxa at 90 sample plots for: (A) annuals; and (B) perennials.

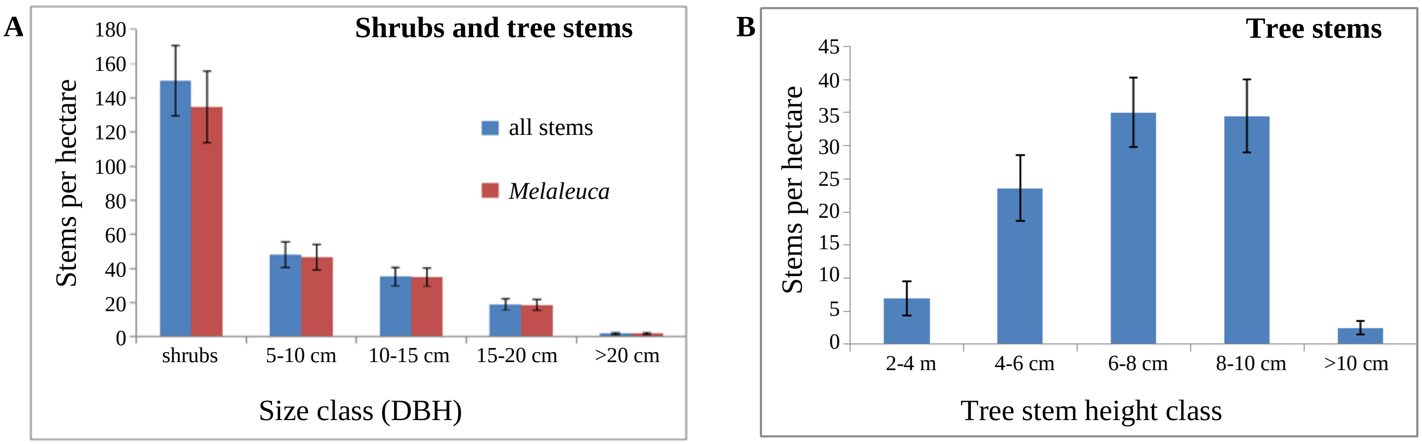


**Figure 3**. Mean density (± s.e.) of: (A) shrubs and tree stems in DBH classes; and (B) tree stems in height classes, where n = 60 for shrubs and n = 41 for tree stems.

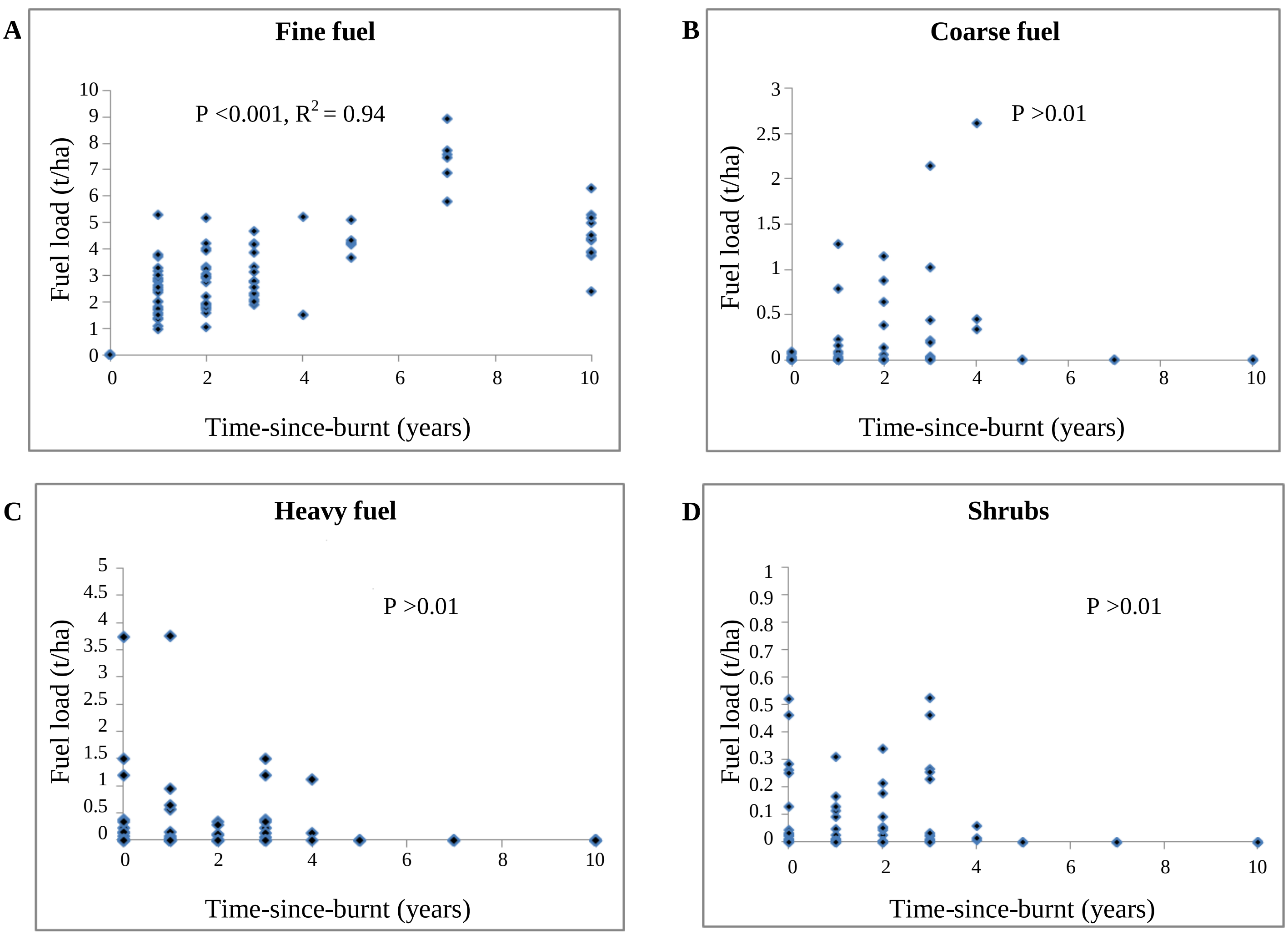


**Figure 4**. Relationship between accumulation of respective fuel components and time-since-fire. P and, where given, $R^2$ values, refer to the results of linear regressions of fuel load (natural log-transformed) vs. time-since-fire (natural log-transformed). Refer text for additional details.

**Table 1**. Summary of parameters required for deriving emission estimates from tussock grasslands under higher annual rainfall (>1,000 mm) conditions.

| Parameters and variables | Values | Comments | References |
|---|---|---|---|
| ***(a) Fuel accumulation* (n = 90)** | | Assumes insignificant seasonal (EDS vs. LDS) differentiation, especially of leaf and twig litter input, given small contributions of these components in litter (see below) | Refer Russell-Smith et al. (2009); this study |
| Fine fuels (t/ha) | Ln(fine fuels) = 0.06 + 1.027*Ln(time-since-fire, in years)<br>Yr 1 = 1.06 t/ha<br>Yr 2 = 2.16 t/ha<br>Yr 3 = 3.28 t/ha<br>Yr 4 = 4.41 t/ha<br>Yr 5 = 5.54 t/ha<br>Yr 5+ = 6.68 t/ha | Adequately described by this relationship | This study |
| - Proportion of litter (detached grass, leaves, twigs) in fine fuels | 23.7% | Adequately sampled | This study |
| - Proportion of leaves and twigs in litter | 18% | Small component, and highly variable depending on woody plant density | This study |
| Coarse fuels (t/ha) | 0.12 ± 0.03 | Relatively small component, and variable | This study |
| Heavy fuels (t/ha) | 0.17 ± 0.05 | Relatively small component, and variable | This study |
| Shrub fuels (t/ha) | 0.05 ± 0.01 | Relatively small component, and variable | This study |
| ***(b) Fire patchiness* (n = 112)** | | Assumes insignificant seasonal differentiation in cured grasslands, based on low fire patchiness (high % burnt) under EDS conditions | This study |
| Proportion of area burnt | 95.8% | | This study |
| ***(c) Burning efficiency factor (n = 24)*** | | | |
| *Pyrolysis efficiency (proportion of fuels pyrolized)* | | Assumes insignificant seasonal (EDS vs. LDS) differentiation in fuel consumption, especially given almost complete consumption of fine fuels (see below). Further work required to address possible effects of differential fire intensity | Refer Russell-Smith et al. (2009); this study |
| - Fine fuels (n = 24)[1] | 99.87% (99.84%)[2] | Adequately sampled | This study |
| - Coarse fuels (n = 12)[1] | 71.89% (71.88%)[2] | Adequately sampled | This study |
| - Heavy fuels (n = 12)[1] | 14.87% (14.87%)[2] | Adequately sampled | This study |
| - Shrub fuels (n = 12)[1] | 7.25% (7.24%)[2] | Adequately sampled | This study |
| *Residual ash − proportion of consumed biomass* | | | |
| Proportion of remnant fine fuel fraction comprising ash (n = 24)[1] | 21.3% | Adequately sampled | This study |
| ***(d) Emission factors*** | | Detailed studies already undertaken for high rainfall savannas, including grassland fuels. Note that no seasonal differentiation in emission factors is observed under fully cured conditions | Meyer and Cook (2011); DCCEE (2012); Meyer et al. (2012) |
| *Methane ($CH_4$)* | | | |
| Fine fuels | 0.0015 | Adequately sampled | Refer above |
| Coarse fuels | 0.0015 | Adequately sampled | Refer above |
| Heavy fuels | 0.01 | Adequately sampled | Refer above |
| Shrub fuels | 0.0015 | Adequately sampled | Refer above |
| *Nitrous oxide ($N_2O$)* | | | |
| Fine fuels | 0.0066 | Adequately sampled | Refer above |
| Coarse fuels | 0.0066 | Adequately sampled | Refer above |
| Heavy fuels | 0.0036 | Adequately sampled | Refer above |
| Shrub fuels | 0.0066 | Adequately sampled | Refer above |

[1]While total sample size = 24 plots, the number of plots referred to here relates to the number of observations made for respective fuel components, e.g. n = 12 refers to number of plots where coarse or heavy fuels were sampled both in pre- and post-fire treatments.
[2]Values given in parentheses are the proportion of fuels pyrolized (as measured in post-fire assessments), corrected for the proportion of ash remaining in situ. These corrected values are used for estimating emissions. In the absence of other data, we assumed that the in situ ash conversion rate was proportionately the same for all fuel components.

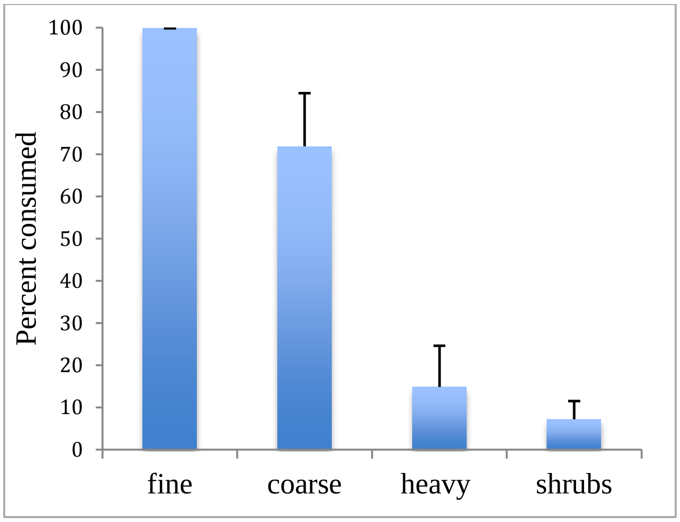


**Figure 5**. Mean consumption (± s.e.) of respective fuel components, from 24 post-fire assessments.

These observations imply that fire-related emissions characteristics in grassland systems differ fundamentally from those in more woody savannas. This applies particularly to seasonal characteristics. Considering fuel accumulation for example, while seasonal litter-fall in woody savannas can result in significantly greater availability of fine fuels in the LDS (Cook 2003; Williams et al. 2003), we contend that this is unlikely to be a significant factor in these grasslands, especially given that shrub fuels comprised only 1.1% of total available fuels.

At the outset of the program, we anticipated undertaking fire treatment assessments under both typical EDS and LDS conditions. However, under EDS conditions, where fine fuels were mostly to fully cured and continuous, and even where fire treatments were of low-to-moderate severity (sensu Williams et al. 2003; Russell-Smith and Edwards 2006), effectively full combustion of fine fuels and negligible patchiness resulted (Table 1). Any fire patchiness occurred typically in association with seasonal drainage features, and was thus applicable generally to both EDS and LDS conditions. On the basis of these observations, we considered it unwarranted to implement the potentially hazardous LDS fire treatment, or to apply differential seasonal parameters to our emissions estimates.

In woody savanna situations under LDS conditions, Russell-Smith et al. (2009) observed that consumption of heavy fuels was double, and shrub fuel components 5 times, those reported here for grasslands. Assuming that combustion of heavy and shrub fuel components in grasslands in LDS might reflect these differentials, as a sensitivity exercise it is useful to consider the net effect on emissions estimates. Thus, (1) taking into account data presented here describing untransformed mean fuel accumulation for all fuel components, and doubling that of heavy fuel consumption, and multiplying by 5 that for shrub fuel consumption, and (2) applying the methodological approach outlined in DCCEE (2012) for calculation of $CH_4$ and $N_2O$ emissions from equivalent grass-dominated fuel types, (3) we estimate that the resultant seasonal difference in LDS emissions would be 2.5% greater than that under EDS conditions. Use of natural log-transformed mean fuel accumulation data reduces the seasonal differential even more substantially.

*Management implications*

Fire mapping data for Cape York Peninsula indicate that, on average, 47.4% of tussock grasslands and *Melaleuca* open-woodlands was burnt annually over the period 2000−2012. Applying parameter values developed here to the emissions calculation framework outlined in DCCEE (2012), average annual GHG emissions from Cape York grassland communities for the 5-year period 2008–2012 would be 174,288 t $CO_2$-e (range: 136,340–204,180 t $CO_2$-e). Reducing mean annual fire extent by 30%, in line with conservative experience in savanna woodlands elsewhere (Russell-Smith et al. 2013), would reduce emissions by 52,290 t $CO_2$-e.

Such an emissions abatement project would be eligible under the CFI and would permit the sale of carbon credits into Australia's Carbon Pricing Mechanism (CPM). The CPM started in July 2012 with a fixed price of AU$23 per tonne, rising at 2.5% per year until 2014/15, when it will be linked with the European Union Emissions Trading Scheme and the price will be set by the market (see www.cleanenergyfuture.gov.au/clean-energy-future/carbon-price/). At the time of writing it is uncertain what policy direction will be taken in Australia concerning carbon pricing arrangements. The future European carbon price is also uncertain and, while there are some efforts to attempt to address recent price volatility, a stable future price to 2015 and beyond is unlikely to materialize for some time (see www.bloomberg.com/news/2013-03-28/carbon-in-worst-quarter-since-2011-set-for-rescue-vote.html).

Currently, most fires on Cape York Peninsula occur in the LDS period, typically as extensive wildfires (Felderhof and Gillieson 2006). As demonstrated by landscape-scale fire management projects currently being undertaken in various northern Australian regions, it is feasible to reduce the incidence of LDS fires and overall fire extent through strategic EDS fire management practices (e.g. Legge et al. 2011; Russell-Smith et al. 2013). However, whether such strategic fire management is practically transferable to relatively productive grassland settings is uncertain.

For example, in addition to infrastructural and capacity issues, there are significant constraints to implementing strategic EDS management programs in Cape York grasslands. There is potential for extensive woody thickening, especially *Melaleuca* invasion, associated with inappropriate fire regimes (Crowley 1995; Crowley et al. 2009). *Melaleuca* invasion can impact on both pastoral production and ecological values (Garnett and Crowley 1995; Myers et al. 2004; Crowley et al. 2009). Crowley et al. (2009) demonstrated that annual to triennial burning of grassland systems in the 'storm burning season' (i.e. after the first rains have commenced late in the year) can effectively control the height escape of suckers of *Melaleuca* and other woody species and hence maintain open-grassland conditions. On the negative side, undertaking burning under moist fuel conditions results in significantly elevated methane emissions per unit area burnt (Meyer et al. 2012).

In addition, most tussock grasslands on Cape York Peninsula and in other higher rainfall regions of northern Australia occur on lands owned and/or managed by Aboriginal people. In these situations, customary obligations and responsibilities typically involve requirements for implementing fire management extensively throughout the year, in essence, progressively burning the landscape as it dries (e.g. Thomson 1939; Chase and Sutton 1981; Yibarbuk 1998). Today, however, most Aboriginal land owners and managers have limited infrastructure (e.g. all-weather tracks) and means to access their lands, especially at appropriate times of the year, when it is feasible to implement effective fire management (see Altman and Kerins 2012 for detailed regional examples).

The potential carbon market benefits of applying strategic fire management in higher rainfall tropical grassland settings may thus seem small, when compared with contemporary infrastructural, cultural and land management tensions. At the enterprise level, however, strategic burning of grasslands may augment larger benefits realized through savanna burning activities undertaken in more woody settings, and by maintaining more pasture for cattle production purposes.

The emissions accounting methodology developed for northern Australia has general application in other tropical savanna regions, but substantial further work may be required to (a) access or develop reliable seasonal fire, and vegetation/fuel-type, mapping surfaces, (b) calibrate or determine appropriate parameter (e.g. fuel accumulation and combustion; emission factors for $CH_4$ and $N_2O$) estimates for regional conditions, (c) help develop technical capacity (remote sensing; Geographic Information System, GIS) and associated infrastructure. Particular methodological challenges are to ensure that the application is supportive of local cultural practices and requirements, and that mitigating early dry season fire management activities actually reduce emissions, i.e. are conducted when fuels are fully cured rather than still being moist, which would result in higher $CH_4$ emissions (Meyer et al. 2012). A first step therefore is to work with local communities to assess the applicability of, and where practicable appropriately modify, the model.

In a recent assessment focusing on savanna burning opportunities in southern African and South American savannas, where savannas occupy 10 $Mkm^2$ and 26.9 $Mkm^2$, respectively, Russell-Smith et al. (2014) observed that, although such projects are likely to be technically and operationally feasible, the associated legislative, political and governance issues typically are significantly more complex. Such opportunities include fire management projects in higher rainfall grassland/forest ecotonal settings, but with the caveat that carbon credits derived from (a) emissions abatement in fire-prone grasslands, and (b) associated biosequestration in adjoining woody vegetation, may be small in comparison with derived livelihood benefits (Bilbao et al. 2010).

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# 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 seleccionada na America 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 proteina 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 proteina 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 3rd 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.

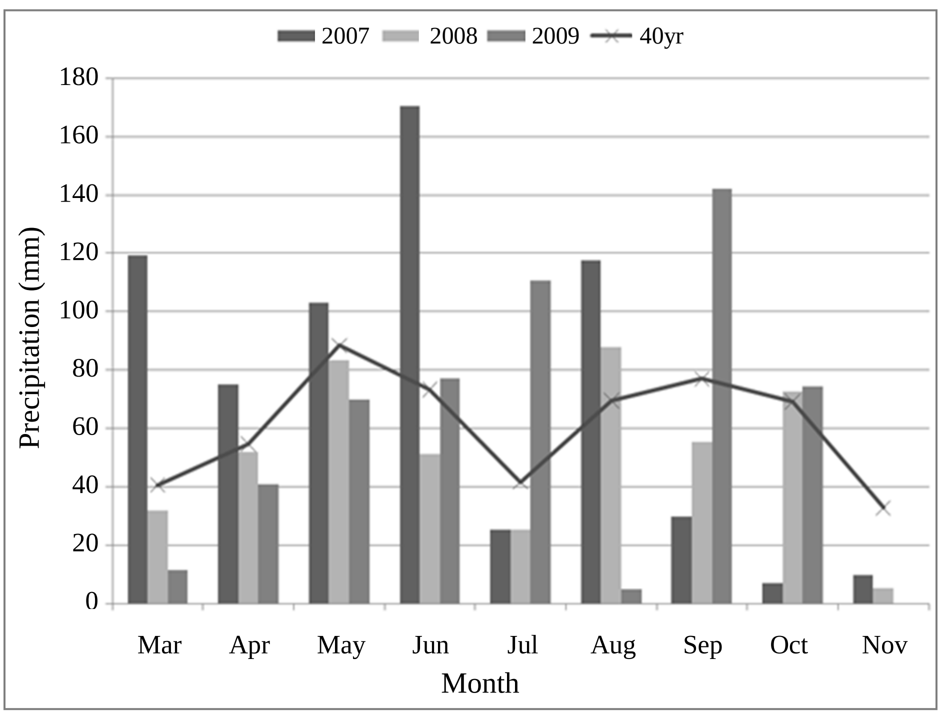



**Figure 1**. Monthly precipitation during the 3 years of the trial and 40-year average at Knox City, TX, USA.

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 $P\leq0.05$ and multiple mean separations were conducted where appropriate at the same level of probability using an LSD ($P\leq0.05$).

## 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.

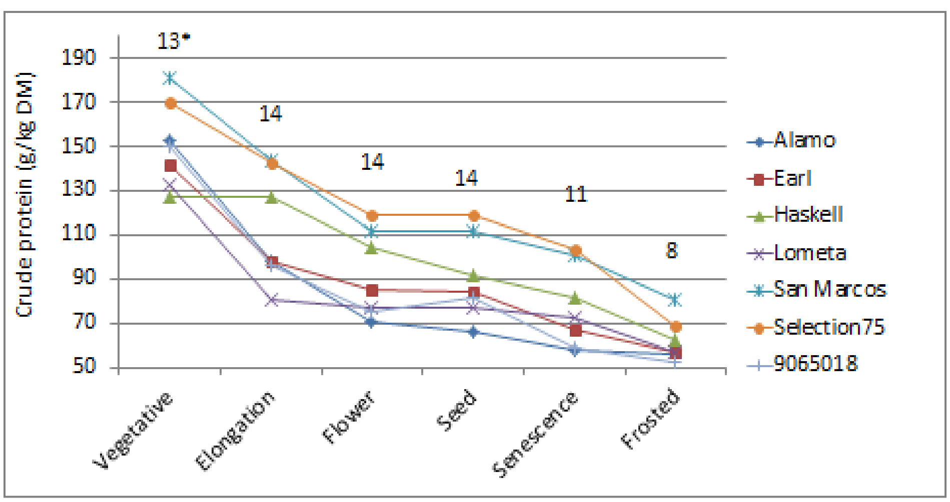
**Table 1**. Phenological growth stages (adapted from Moore et al. 1991) of 7 perennial warm-season grasses over 3 years at Knox City, TX, USA.

| 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≤0.05; pooled for fertilizer treatment).

| Year/Entry | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
|---|---|---|---|---|---|---|---|---|
| 2007 | | | | | | | | |
| Haskell | 145Ad[1] | 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 | 57Fcd | 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 |

[1]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≤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).

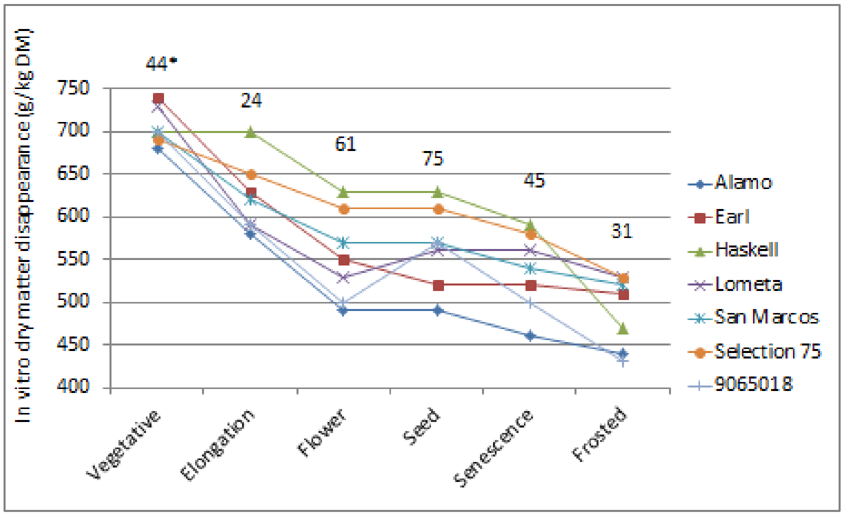
An entry x year x monthly harvest interaction of IVDMD over 48 h (Table 3) was observed. April IVDMD ranged up to 795 g/kg, while November values were as low as 400 g/kg. There were 5 entries whose IVDMD values did not decline in the low rainfall year (2008) from April to June, while upland switch grass 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≤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 | 525Cabc | 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 |

[1]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≤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 differences 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 timing 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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# Harvest frequency affects herbage accumulation and nutritive value of brachiaria grass hybrids in Florida

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**Keywords**: Warm-season grass, Mulato II, BR02/1794, BR02/1752, Cayman, pasture production.

## Abstract

*Brachiaria* 'Mulato II' is a hybrid brachiaria grass with superior nutritive value when compared with other warm-season grasses. The performance of 2 new brachiaria grass hybrids was compared with that of Mulato II in terms of herbage accumulation, nutritive value and ground cover in a series of experiments. In Experiment 1, Mulato II and lines BR02/1752 (now cv. Cayman) and BR02/1794 were harvested at 3- and 6-wk regrowth intervals in South Florida. Mulato II had greater herbage accumulation and ground cover than Cayman and BR02/1794, while Mulato II and Cayman had greater in vitro digestible organic matter (IVDOM) concentration than BR02/1794. Regrowth interval did not affect herbage accumulation and ground cover but herbage harvested at 3-wk intervals had greater nutritive value than 6-wk regrowth. In Experiment 2, Mulato II had similar IVDOM and CP concentrations to but greater herbage accumulation, ground cover and plant density than Cayman in North-Central Florida. In Experiment 3, Mulato II and Cayman plots were grazed at 2-, 4- or 6-wk intervals, and herbage accumulation and nutritive value were similar for both cultivars. Herbage nutritive value decreased and ground cover increased linearly as regrowth interval increased from 2 to 6 wk, and Mulato II had greater ground cover than Cayman. The new hybrids displayed no production or nutritive value advantages over Mulato II; regrowth intervals of less than 3 wk should be avoided to maintain *Brachiaria* hybrid stands in this subtropical environment.

## Resumen

El híbrido de braquiaria Mulato II es un cultivar (cv.) con valor nutritivo superior al de otras gramíneas de clima cálido. En la Florida se compararon, en 3 experimentos, 2 nuevos híbridos de braquiaria: las líneas BR02/1752 (ahora: cv. Cayman) y BR02/1794, con cv. Mulato II, en términos de producción de forraje, valor nutritivo y cobertura del suelo. En el primer ensayo, conducido en el sur de la Florida y con intervalos de corte de 3 y 6 semanas, el cv. Mulato II presentó mayor producción de forraje y cobertura que el cv. Cayman y la línea BR02/1794, mientras que los cvs. Mulato II y Cayman presentaron mayor digestibilidad in vitro de la materia orgánica (DIVMO) que la línea BR02/1794. El intervalo de corte no afectó la producción de forraje y la cobertura pero en los cortes cada 3 semanas el valor nutritivo fue mayor que en los cortes cada 6 semanas. En el segundo ensayo, conducido en el centro-norte de la Florida, Mulato II presentó valores de IVDMO y concentración de proteína cruda similares a cv. Cayman, pero mayor producción de forraje, cobertura y densidad de plantas. En un tercer ensayo, también en el centro-norte de la Florida, los cvs. Mulato II y Cayman fueron sometidos a pastoreo cada 2, 4 y 6 semanas. Aquí, la producción de forraje y el valor nutritivo de ambos cultivares fueron similares. El valor nutritivo disminuyó mientras que la cobertura aumentó en forma lineal a medida que el intervalo de pastoreo aumentó de 2 a 6 semanas; el cv. Mulato II tuvo mayor cobertura que el cv. Cayman. Los nuevos híbridos no presentaron niveles de producción y calidad nutritiva más altos que cv. Mulato II; para garantizar la persistencia de los híbridos es necesario evitar intervalos de pastoreo inferiores a 3 semanas.

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## Introduction

'Mulato' was the first hybrid to be released in the *Brachiaria* genus; it stems from an original cross of ruzi grass (*Brachiaria ruziziensis* clone 44-6) and palisade grass (*Brachiaria brizantha* cv. Marandu) (Argel et al. 2006). Subsequently, Mulato II was released because it had greater seed production than and similar forage production and nutritive value to Mulato. Mulato II is the result of 3 generations of crosses and screening conducted by the International Center for Tropical Agriculture (CIAT) in Colombia, including original crosses between ruzi grass and signal grass (*Brachiaria decumbens* cv. Basilisk; apomictic tetraploid) (Argel et al. 2007).

Mulato II has been a productive warm-season perennial grass in South Florida, with superior nutritive value to other warm-season grasses, and can be used for grazing (Inyang et al. 2010a) or harvested and conserved for feeding when needed (Vendramini et al. 2010). Following comparisons of herbage accumulation and nutritive value of 10 different species and cultivars of warm-season grasses in South Florida, Vendramini et al. (2010) concluded that Mulato II was among the species with greatest in vitro true digestibility (67%). Vendramini et al. (2012) compared animal performance, herbage accumulation and nutritive value of Mulato II, 'Tifton 85' bermuda grass (*Cynodon* spp.), pearl millet (*Pennisetum glaucum*) and sorghum-sudan grass (*Sorghum bicolor*) in North and North-Central Florida. Beef heifers grazing Mulato II, pearl millet and sorghum sudan grass had similar animal performance. Mulato II and Tifton 85 had similar herbage accumulation and crude protein (CP) concentrations, but Mulato II had greater in vitro digestible organic matter (IVDOM) concentration than the other species.

New *Brachiaria* hybrids were recently released by CIAT (Anon. 2011a, 2011b; Pizarro et al. 2013). Lines BR02/1794 and BR02/1752 (now released as cv. Cayman) were the result of a synthetic sexual breeding of palisade grass (*B. brizantha* CIAT 16320), ruzi grass and signal grass. Hare et al. (2013) compared Mulato II, Cayman and BR02/1794 in Thailand and concluded that cutting at 30-day intervals would produce CP levels 3−4 percentage units greater than cutting at 45- and 60-day intervals, but herbage accumulation would be 20% lower than cutting at the longer intervals. However, there is little information on herbage accumulation and nutritive value of these new hybrids in subtropical regions.

Regrowth interval is an important management practice that affects herbage accumulation, nutritive value and persistence of warm-season grasses. Inyang et al. (2010b) studied the effects of regrowth interval and stubble height on herbage accumulation, nutritive value and persistence of Mulato II. While herbage harvested at 2-wk regrowth intervals had greater nutritive value, herbage accumulation was less than observed for longer regrowth intervals, supporting results reported with other warm-season grasses. Vendramini et al. (2013) observed that bahia grass (*Paspalum notatum*) grazed at a 4-wk regrowth interval had greater herbage accumulation and persistence than pasture grazed at a 2-wk interval. These authors noted that the impact of regrowth interval on persistence was dependent on the bahia grass cultivar, with 'Argentine' more persistent than 'UF Riata', when grazed at a 2-wk regrowth interval.

Although it is crucial to understand the effects of regrowth interval on performance of warm-season grass species and cultivars, there are no reports in the literature about those effects on the new *Brachiaria* hybrids in Florida. The objective of this study was to compare herbage accumulation and nutritive value of Mulato II, Cayman and BR02/1794 under different regrowth intervals in Florida.

## Materials and Methods

### *Experiment 1*

This experiment was conducted at the University of Florida Range Cattle Research and Education Center, Ona, FL (27°26' N, 82°55' W) from July to November in both 2011 and 2012. The soil at the research site was classified as sandy siliceous, hyperthermic Alfic Alaquod (EauGallie sand). These sandy soils are poorly drained with slow permeability. Prior to initiation of the clipping study, mean soil pH (in water) was 5.9. Mehlich-I (0.05M HCl + 0.0125M $H_2SO_4$) extractable P, K, Mg and Ca concentrations in the Ap1 horizon (0 to 15-cm depth) were 33, 47, 246 and 1,323 ppm, respectively.

Treatments were the factorial combinations of 3 *Brachiaria* hybrids (Mulato II, Cayman and BR02/1794) x 2 regrowth intervals (3- and 6-wk) in a randomized complete block design with 4 replicates. The plots were established in April 2011 using a seeding rate of 13 kg/ha. The plots were irrigated 3 times weekly from April to June 2011 (total of 25 mm/wk), to ensure adequate establishment. In July 2011 and 2012, the plots received 35 kg N, 17 kg P and 64 kg K/ha to stimulate growth and provide maintenance P and K. An additional 80 kg N/ha was applied thereafter on 2 occasions at 6-wk intervals to provide a seasonal total of 195 kg N/ha.

Plot size was 3 m x 2 m with 1 m alleys between plots. In July 2011 and 2012, the plots were clipped at 7.5-cm stubble height and subsequently harvested at 3- or 6-wk regrowth intervals at the same height. Plots were harvested for 2 periods of 6 weeks in 2011 and 2012 (referred to as Periods 1 and 2 in the text). At harvest dates, herbage was harvested to a 7.5-cm stubble height from a 1.35 $m^2$ area at the center of the plot with a rotary blade mower (Sensation Mow-Blo Model 11F4-0) to determine herbage accumulation and nutritive value. Remaining herbage was clipped to the same stubble height and removed from the plots. Herbage accumulation, CP and IVDOM concentration data are presented by 6-wk periods and data from a given 6 wk reflect the total of one 6-wk or two 3-wk harvests within that period. The plots were not harvested from October 2011 to June 2012 and the forage accumulated during the period was clipped at 7.5-cm stubble height and removed from the plots to start the 2012 experimental period.

At harvest, total fresh weight was determined and 2 subsamples taken for determination of DM concentration and nutritive value. Subsamples were dried at 60 ºC for 48 h and ground to pass a 1-mm screen in a Wiley mill (Udy Corporation, Fort Collins, CO). Samples were analyzed for IVDOM using the 2-stage technique described by Tilley and Terry (1963) and modified by Moore and Mott (1974). Nitrogen concentration was determined using a micro-Kjeldahl method, a modification of the aluminum block digestion technique described by Gallaher et al. (1975). Crude protein was determined by multiplying N concentration by 6.25.

Ground cover was determined visually at the end of the 2012 experimental period using a 1-$m^2$ quadrat divided into 100, 10-cm x 10-cm squares. One quadrat was assessed per experimental unit. The proportion of squares with the sown species was reported.

Response variables were herbage accumulation, ground cover, CP and IVDOM concentration. The data were analyzed using PROC MIXED of SAS (SAS Institute Inc. 1996) with cultivar, regrowth interval, year and their interactions as fixed effects. Period was analyzed as a repeated measure using the unstructured covariance structure (UN). Block and its interactions were random effects. Treatments were considered different when $P<0.05$. Interactions not mentioned in the text were not significant ($P>0.05$). The means reported are least squares means, and means for month and year effects were separated by Fisher's protected least significant difference (LSD) at $P<0.05$.

### *Experiment 2*

The study was located at the University of Florida Beef Research Unit, Gainesville, FL (29°44' N, 82°16' W; 48 m asl). The experiment was conducted from July to October 2010 and May to November 2011. Soils at the research site are Adamsville fine sand (uncoated, hyperthermic, Aquic Quartzipsamments). Prior to initiation of the study, mean soil pH (in water) was 6.1. Mehlich-I extractable P, K, Mg and Ca concentrations in the Ap1 horizon (0 to 15-cm depth) were 82, 49, 72 and 473 ppm, respectively.

Treatments were 2 *Brachiaria* hybrid cultivars Mulato II and line BR02/1752 (now cv. Cayman) distributed in a randomized complete block design with 4 replicates. Plots were 5 m x 5 m. Seed of Mulato II and Cayman was broadcast on a prepared seedbed at 20 kg/ha and rolled to ensure good seed-soil contact on 25 May 2010. In 2010, the plots were fertilized with 80 kg N/ha, as applications of 40 kg N/ha in July and August. In 2011, 160 kg N/ha was applied as 40 kg N/ha in April, June, July and September. In addition, the plots were fertilized with 42 kg K/ha in April 2011. The herbicide 2, 4-D [(2, 4-dichlorophenoxy) acetic acid] was applied to all plots at 1.0 kg a.i./ha on 20 July 2010 and 11 April 2011 for control of broadleaf weeds.

Plots were harvested on 27 August and 22 October 2010, and 21 June, 25 July, 7 September and 7 November 2011. An area of 3 $m^2$ at the center of the plot was harvested with a sickle bar mower at 10-cm stubble height. The harvested material was separated into species by hand and the proportion of the sown grass in the harvested material reported as a proportion of the total forage harvested. The herbage accumulation reported is the herbage accumulation of the sown species. The remaining herbage in the plot was cut to the same stubble height and the harvested material removed from the plot. Forage samples were processed and analyzed for CP and IVDOM concentrations according to the procedures described in Experiment 1.

Two observers estimated ground cover visually as the proportion of the experimental unit covered by the sown species on 17 April 2012. Plant density was determined by counting the numbers of plants/$m^2$.

Response variables were total herbage accumulation, sown grass herbage accumulation, CP, IVDOM, ground cover and plant density. The data were analyzed using PROC MIXED of SAS (SAS Institute Inc. 1996). Cultivar and year were considered fixed effects. Block and its interactions were random effects. Harvests were analyzed as repeated measures using the unstructured covariance structure (UN). Treatments were considered different when P<0.05. Interactions not discussed were not significant (P>0.05). Data are reported as least squares means and were compared using PDIFF (SAS Institute Inc. 1996).

*Experiment 3*

The study was located at the University of Florida Beef Research Unit, Gainesville, FL (29°44' N, 82°16' W; 48 m asl) on Adamsville fine sand (uncoated, hyperthermic, Aquic Quartzipsamments). Prior to initiation of the study, mean soil pH (in water) was 6.0. Mehlich-I extractable P, K, Mg and Ca concentrations in the Ap1 horizon (0 to 15-cm depth) were 70, 53, 101 and 583 ppm, respectively. The experiment was conducted from July to October 2010.

Treatments were the factorial combinations of 2 *Brachiaria* hybrid cultivars (Mulato II and Cayman) x 3 grazing frequency treatments (2-, 4- and 6-wk) arranged in a randomized complete block design with 3 replicates. Plots were 4 m x 4 m with a 1.5 m alley between plots. Seed of Mulato II and Cayman was broadcast on a prepared seedbed and rolled to ensure good seed-soil contact on 10 June 2010. The plots were irrigated to provide ~20 mm water/wk for 4 weeks after planting. The plots were fertilized with 112 kg K and 144 kg N/ha divided into 3 equal applications in May, June and July. Before sowing seed, the herbicide 2, 4-D [(2, 4-dichlorophenoxy) acetic acid] was applied to all plots at 1.0 kg a.i./ha on 28 May for control of broadleaf weeds. On 10 June, a 4% glyphosate [isopropylamine salt (10 g/kg) of N-phosphonomethyl glycine] solution was spot-sprayed on the remaining weeds in the experimental area.

Mean pre- and post-grazing herbage heights were estimated from 20 measurements per experimental unit. Before the grazing events, 2 samples of an area of 0.25 $m^2$ per plot were harvested with hand shears to a 15-cm stubble height to determine herbage mass and nutritive value. Forage samples were processed and analyzed for CP and IVDOM concentrations according to the procedures described in Experiment 1.

A subsample of the fresh herbage mass was separated into leaf, stem and dead material, dried at 60 ºC until constant weight, and the proportions of leaf and stem in the sward determined. Herbage accumulation was calculated as the sum of pre-grazing herbage mass across grazing events. Leaf and stem proportions, and CP and IVDOM concentrations are presented as the weighted averages of the grazing events. Ground cover was determined at the end of the grazing season by visual estimation by 2 observers as the proportion of the experimental unit covered by the sown species.

The plots were grazed by beef heifers (320 kg live weight) using the mob stocking technique (Mislevy et al. 1981). The plots were separated with an electric fence and grazed individually. The animals were removed when the forage reached the target stubble height (15 cm), which did not exceed 12 h occupation. Dates for the grazing events are reported in Table 1.

Response variables were herbage accumulation, canopy height, CP, IVDOM and ground cover. The data were analyzed using PROC MIXED of SAS (SAS Institute Inc. 1996). Cultivar and grazing frequency were considered fixed effects. Block and its interactions were random effects. Single degree of freedom orthogonal polynomial contrasts were used to test grazing interval effects. Treatments were considered different when P<0.05. Interactions not discussed were not significant (P>0.05). Data are reported as least squares means and were compared using PDIFF (SAS Institute Inc. 1996).

## Results

*Experiment 1*

Mulato II accumulated more herbage than Cayman and BR02/1794 (P<0.05) (Table 2). There was a regrowth interval x period interaction on herbage accumulation (Table 3), with no difference in herbage accumulation between 3- and 6-wk regrowth intervals in the first period, but greater herbage accumulation for 3-wk than 6-wk regrowth interval in the second period. Total herbage accumulation was similar in 2011 and 2012 (mean = 2,750 kg DM/ha).

Mulato II, Cayman and BR02/1794 had similar CP concentrations (mean = 13.7%, s.e. = 0.7, P=0.45), while herbage harvested at 3-wk intervals had greater CP than that at 6-wk intervals (15.0 vs. 12.7%, s.e. = 0.5, P<0.01). In addition, there was a significant effect of period on CP concentration. Herbage harvested in Period 2 had greater CP concentration than that from Period 1 (16.0 vs. 11.6%, s.e. = 1, P<0.01). Crude protein concentration was greater (P<0.05, s.e. = 1) for herbage harvested in 2012 (14.6%) than in 2011 (13.0%).

Conversely, there was a cultivar effect on IVDOM concentration with Mulato II and Cayman having greater

IVDOM than BR02/1794 (P<0.05) (Table 2). There was a regrowth interval x period interaction on IVDOM concentration; while herbage harvested at 3-wk intervals had greater IVDOM than 6-wk material in both Periods 1 and 2, the magnitude of the difference was greater in Period 1 than Period 2 (Table 3). Corroborating the CP results, forage harvested in 2012 had greater (P<0.05, s.e. = 1) IVDOM concentration (63%) than that for 2011 (60%).

At the end of the experimental period in 2011, Mulato II had greater ground cover than Cayman (88 vs. 61%, s.e. = 6, P<0.02), with BR02/1794 intermediate (74%). There was no effect of regrowth interval on ground cover of the different cultivars.

*Experiment 2*

There was a year x cultivar x harvest interaction effect on herbage accumulation (Table 4). Herbage accumulation in 2010 was similar for Mulato II and Cayman, but herbage accumulation at July and November 2011 harvests and total herbage in 2011 were greater for Mulato II than for Cayman. There was no cultivar effect (P=0.45, s.e. = 3) on the proportion of the sown grass in the harvested forage; however, the proportion was greater (P<0.01, s.e. = 3) in 2011 (96%) than in 2010 (62%).

There was a harvest x year interaction on CP and IVDOM concentrations (Table 5). Crude protein concentrations in August and October 2010 were similar, but concentration in June 2011 exceeded those in July, September and November 2011. Conversely, IVDOM concentration in October was greater than in August 2010. In 2011, IVDOM concentration in June exceeded those in July and September (P<0.05) with concentration in November intermediate.

Mulato II had greater ground cover (43 vs. 8%) and plant density (8.3 vs. 1.0 plants/m$^2$) than Cayman in April 2012. These results may imply that Mulato II had greater cold tolerance than Cayman after experiencing 2 winters in Florida under the harvest management applied in this experiment.

*Experiment 3*

There was no effect of cultivar (P=0.81) or regrowth interval (P=0.69) on herbage accumulation, which averaged 9,200 kg DM/ha/annum across treatments.

Pre- and post-grazing sward canopy height increased linearly with increasing regrowth interval (Table 6), although the range in post-grazing height was only 4 cm. Cayman had greater pre-grazing canopy height than Mulato II (54 vs. 48 cm, s.e. = 1.5, P<0.01), greater proportion of stem (31 vs. 22%, s.e. = 3, P<0.01) and lesser proportion of leaf (63 vs. 74%, s.e. = 4, P<0.01). There was no difference between cultivars in percentage of dead material (6 vs. 4%, s.e. = 1, P=0.45).

**Table 1**. Dates of grazing events for Mulato II and Cayman grazed at different grazing frequencies (Experiment 3).

| Grazing frequency (wk) | Date 14 Jul | 28 Jul | 11 Aug | 25 Aug | 8 Sep | 22 Sep | 6 Oct |
|---|---|---|---|---|---|---|---|
| 2 | X | X | X | X | X | X | X |
| 4 | X | | X | | X | | X |
| 6 | X | | | X | | | X |

**Table 2.** Herbage accumulation and in vitro digestible organic matter (IVDOM) concentration (average of Periods 1 and 2) in brachiaria grass hybrid cultivars (Mulato II, Cayman and BR02/1794) in Ona, FL (Experiment 1).

| Response variable | Cultivar | | | s.e. |
|---|---|---|---|---|
| | Mulato II | Cayman | BR02/1794 | |
| Herbage accumulation (kg DM/ha) | 1,740a[1] | 1,200b | 1, 200b | 70 |
| IVDOM (%) | 63a | 62a | 59b | 1 |

[1]Means within rows followed by the same letter are not different (P>0.05).

**Table 3.** Regrowth interval x period interaction on herbage accumulation and in vitro digestible organic matter (IVDOM) concentration of brachiaria grass hybrid cultivars (Mulato II, Cayman and BR02/1794) in Ona, FL (Experiment 1).

| Regrowth interval (wk) | Period 1[1] | Period 2 |
|---|---|---|
| | Herbage accumulation (kg/ha) | |
| 3 | 2,180a[2] | 760a |
| 6 | 2,200a | 360b |
| s.e. | 70 | |
| | IVDOM (%) | |
| 3 | 63a | 67a |
| 6 | 53b | 63b |
| s.e. | 1 | |

[1]Data are presented by 6-wk periods and reflect the total of one 6-wk or two 3-wk harvests within that period.
[2]Means within columns and parameters followed by the same letter are not different (P>0.05).

Herbage CP and IVDOM decreased linearly with increasing regrowth interval (Table 6), but there was no difference between Mulato II and Cayman in either parameter. The proportion of leaf in available forage decreased linearly with increasing regrowth interval, while the proportion of stem increased linearly. Average CP concentrations of leaves and stems were 17.2 and 9.7%, respectively, and corresponding IVDOM values were 70.9% and 57.3%.

Both regrowth interval and cultivar had significant effects on ground cover, with ground cover increasing linearly as regrowth interval increased from 2 to 6 wk (Table 6), and Mulato II having greater ground cover than Cayman (61 vs. 47%).

## Discussion

This study has shown that Mulato II is better adapted for herbage production in the South Florida region than Cayman and BR02/1794. This contrasts with results obtained by Pizarro et al. (2013) in Thailand, where Cayman had greater herbage accumulation than Mulato II and BR02/1794 from 2005 to 2008.

The herbage accumulation observed in Experiment 1 was less than the 3,200 kg DM/ha recorded by Vendramini et al. (2010) for Mulato II with a 6-wk regrowth interval in summer in South Florida. Reduced herbage accumulation in the current experiment was possibly due to later planting and reduced soil fertility.

**Table 4.** Year x cultivar x harvest interaction effects on herbage accumulation (kg/ha) of brachiaria grass hybrid cultivars (Mulato and Cayman) in Gainesville, FL (Experiment 2).

| Year | Cultivar | Month | | | | | | Total | s.e. |
|---|---|---|---|---|---|---|---|---|---|
| | | Jun | Jul | Aug | Sep | Oct | Nov | | |
| 2010 | Mulato II | | | 1,200a[1] | | 300b | | 1,500 | 200 |
| | Cayman | | | 1,500a | | 300b | | 1,800 | |
| | P[2] | | | 0.32 | | 0.78 | | 0.41 | |
| | s.e. | | | 200 | | | | | |
| 2011 | Mulato II | 1,000c | 4,800a | | 3,400b | | 3,400b | 12,600 | 200 |
| | Cayman | 1,300b | 3,000a | | 3,200a | | 2,800a | 10,300 | |
| | P | 0.37 | <0.01 | | 0.42 | | 0.04 | <0.01 | |
| | s.e. | | | 200 | | | | | |

[1]Means followed by the same letter within rows are not different (P>0.05).
[2]Significance of cultivar effect within harvests.

**Table 5.** Harvest x year interaction on crude protein (CP) and in vitro digestible organic matter (IVDOM) concentrations of brachiaria grass hybrid cultivars (Mulato II and Cayman) in Gainesville, FL (Experiment 2).

| Response variable | Year | Month | | | | | | s.e. |
|---|---|---|---|---|---|---|---|---|
| | | Jun | Jul | Aug | Sep | Oct | Nov | |
| CP (%) | 2010 | | | 9.9a[1] | | 10.4a | | 0.7 |
| | 2011 | 15.5a | 10.6b | | 10.5b | | 11.2b | |
| IVDOM (%) | 2010 | | | 64.3b | | 71.5a | | |
| | 2011 | 66.0a | 63.2b | | 62.2b | | 64.1ab | 1.5 |

[1]Means followed by the same letter within rows are not different (P>0.05). Values presented are averages across cultivars.

**Table 6.** Pre- and post-grazing canopy heights, crude protein (CP) and in vitro digestible organic matter (IVDOM) concentrations and ground cover of Mulato II and Cayman grazed at 2-, 4- and 6-wk grazing frequencies in Gainesville, FL (Experiment 3).

| Response variable | Grazing frequency (wk) | | | P-value contrast | s.e. |
|---|---|---|---|---|---|
| | 2 | 4 | 6 | | |
| Canopy height (cm) | | | | | |
| pre-grazing | 38 | 52 | 63 | <0.01 Linear | 1.7 |
| post-grazing | 17 | 18 | 21 | <0.01 Linear | 0.5 |
| CP (%) | 17.2 | 14.2 | 11.8 | <0.01 Linear | 1.0 |
| IVDOM (%) | 71.4 | 67.2 | 64.4 | <0.01 Linear | 1.5 |
| Ground cover (%) | 42 | 51 | 69 | 0.02 Linear | 2 |

For many grasses, longer regrowth intervals result in greater herbage accumulation (Interrante et al. 2009), but in this experiment and that conducted with Mulato II by Inyang et al. (2010b), there was no advantage in herbage accumulation for the 6- vs. 3-wk regrowth interval. It seems that 3-wk regrowth interval is sufficient for the brachiaria hybrids to optimize light interception and herbage accumulation without exacerbating reserve structures. On the other hand, the plants harvested at a 6-wk regrowth interval probably reached the maximum light interception before the growth period expired, with a resultant decrease in herbage accumulation due to self-shading and appearance of senescent leaves.

In Experiment 2, herbage accumulation by Mulato II and Cayman in 2010 (the establishment year) was lower than observed in a previous study conducted at the same location (Vendramini et al. 2012). The below average rainfall in September 2010 (38 mm vs. the 30-yr average of 135 mm) and October 2010 (0.2 mm vs. the 30-yr mean of 64 mm) may have negatively affected herbage accumulation of the brachiaria grass cultivars in late summer and early autumn. However, herbage accumulation in 2011 was similar to those for established Mulato II stands in the same location (Vendramini et al. 2012). In addition, the total Mulato II herbage accumulation in 2011 was similar to the annual herbage accumulation of Mulato II observed by Hare et al. (2009) in northeast Thailand of 10,200 kg DM/ha. Herbage accumulation in June was lower than at the other harvests in 2011 because there was an unexpected below 0 $^{o}$C temperature event in April, followed by below average April rainfall (20 mm vs. the 30-yr average of 75 mm). The increase in proportion of the sown grass in the stand from 2010 to 2011 indicated that a period of 12 months after establishment may be necessary for the brachiaria grass hybrids to express their full herbage accumulation potential in South Florida.

In Experiment 3, total herbage accumulation during the entire season was similar to yields reported by Vendramini et al. (2012) in Central Florida, and in contrast with Experiments 1 and 2, Mulato II and Cayman had similar herbage accumulation. As harvest intervals were different, the herbage accumulation data in Experiment 3 were presented as the total for the growing season; in line with results for Experiment 1, no effects of harvest interval were observed. This finding contrasts with that of Inyang et al. (2010b), where cutting Mulato II at 2-wk intervals significantly reduced forage yields relative to longer regrowth intervals. In addition, Hare et al. (2013) observed that herbage accumulation in Mulato II, Cayman and BR02/1794 increased from approximately 11,000 kg/ha to 20,000 kg/ha in Thailand as regrowth interval was increased from 30 to 90 days. It is worth mentioning that these authors compared individual harvests at the target regrowth interval, whereas this research compared a single harvest of 6 wk with 2 harvests of 3-wk regrowth interval. The greater herbage accumulation presented by Hare et al. (2013) than in these projects in Florida was probably due to better soil characteristics, improved climatic conditions and N fertilization.

Pre-grazing canopy height increased linearly with increased regrowth interval and the pre-grazing heights observed in all treatments were above the 30 cm pre-grazing height suggested by da Silva and Nascimento (2007) as the target height for initiation of grazing on palisade grass. However, these authors suggested that the post-grazing height should be 15 cm and the heights found in our study were slightly above 15 cm. Although herbage accumulation was similar for both cultivars, Cayman had greater pre-grazing canopy height than Mulato II. This greater height possibly reflected the greater proportion of stem biomass in Cayman than in Mulato II, resulting in more upright plants.

Overall, the data suggest little difference in CP concentrations between cultivars but greater IVDOM in Mulato II and Cayman than in BR02/1794. The decrease in CP and IVDOM of all cultivars in Experiments 1 and 3 with increasing regrowth interval was not unexpected. The effects of regrowth interval on nutritive value of warm-season grasses are well documented in the literature and show that forage with greater maturity has greater proportions of cell wall and lignified tissue with lesser nutritive value (Johnson et al. 2001; Vendramini et al. 2008; Inyang et al. 2010b). Hare et al. (2013) observed that increasing cutting interval significantly reduced CP concentrations and increased ADF and NDF concentrations in stems and leaves of Mulato II, Cayman and BR02/1794 in Thailand. It is of interest that Cayman and BR02/1794 had higher stem CP levels than Mulato II at 30- and 45-day cutting intervals, while both had lower levels than Mulato II at the 60-day cutting interval. BR02/1794 had lower leaf CP levels than both Cayman and Mulato II at most cutting intervals.

The higher herbage CP and IVDOM concentrations later in the season reported in Experiment 1 reflect lesser herbage accumulation in the autumn resulting in less dilution of CP. Reduced growth temperatures like those observed in autumn have also been associated with greater herbage digestibility (Pitman and Holt 1982; Newman et al. 2005). Inyang et al. (2010b) reported that Mulato II in November had lesser herbage accumulation and greater nutritive value than in October.

The greater ground cover in Mulato II than in Cayman and BR02/1794 in Experiment 1 suggests that Mulato II is more persistent under defoliation than the other lines in subtropical areas. According to Beaty et al. (1970), frequent harvests reduce root, stolon and rhizome mass and the non-structural carbohydrates available for plant regrowth. There was no effect of regrowth interval on ground cover in Experiment 1 because the shortest regrowth interval was 3 wk, which allowed the plants to restore leaf area and possibly carbohydrate reserves before the subsequent harvest. Conversely, there was a linear decrease in ground cover as regrowth interval decreased in Experiment 3. Mislevy et al. (1991) observed that bahia grass harvested at 3-, 5-, and 7-wk regrowth intervals had greater concentration of total non-structural carbohydrates than at 2-wk intervals, and greater carbohydrate levels were associated with greater persistence. Inyang et al. (2010b) observed that shorter regrowth intervals (2 wk) may decrease ground cover of Mulato II, with harvesting every 4 wk resulting in greater cover than harvesting every 2 wk (87 vs. 83%, respectively).

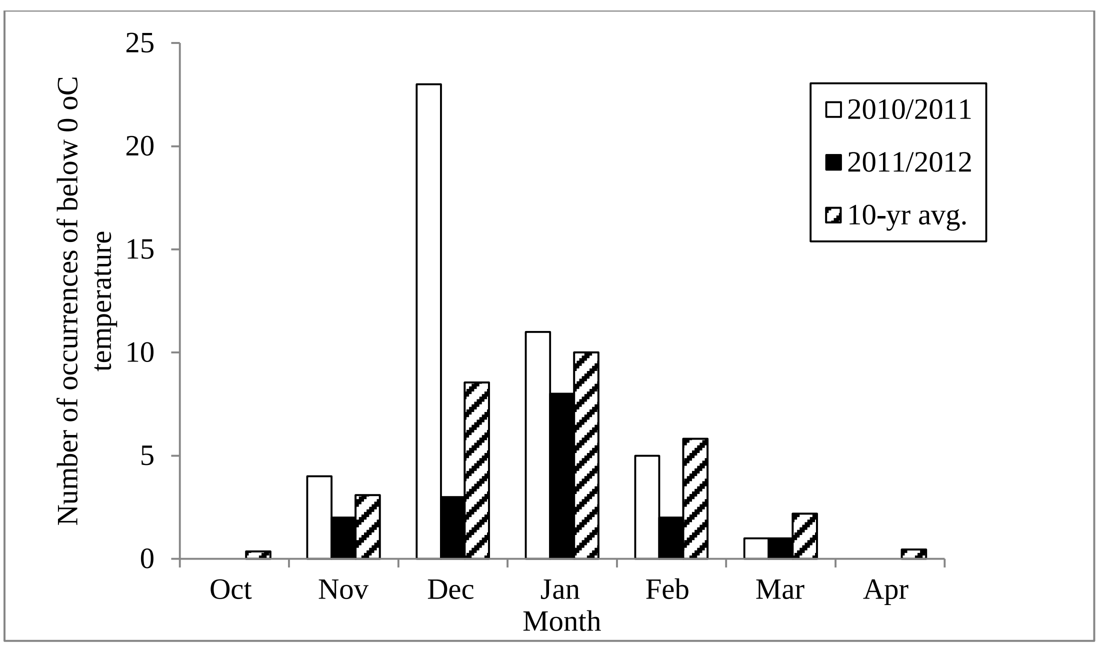


**Figure 1.** Number of days with one or more occurrences of below 0 $^{o}$C temperature in Gainesville, FL during the winters of 2010/2011 and 2011/2012 plus the 10-yr average figures.

However, weather conditions might also have played a part. Vendramini et al. (2012) observed that ground cover of Mulato II in Gainesville, FL decreased after a severe cold period with several consecutive days with minimum temperatures reaching below 0 °C. The reduced ground cover and plant density of Cayman after 2 years indicates that this cultivar may not be a perennial forage in North-Central Florida. Conversely, ground cover and plant density of Mulato II exceeded those reported by Vendramini et al. (2012). Despite an above average number of below 0 °C events in December 2010 (Figure 1), Mulato II persisted well through the remainder of 2010/2011 and then the winter of 2011/2012 with more normal numbers of freezing mornings, indicating that this cultivar may be a warm-season perennial grass suited to locations with greater latitudes (30° N), provided the number of below 0 °C temperature events is approximately 10 events/yr.

Since the new brachiaria hybrids displayed no advantages over Mulato II in Florida and in many instances were inferior, we conclude that Mulato II appears a better adapted brachiaria grass hybrid for the subtropical conditions in this region. The 3-wk regrowth interval may be recommended to produce forage with greater nutritive value with no detrimental effects on herbage accumulation and ground cover. While shorter regrowth intervals promoted greater nutritive value in all hybrids, regrowth intervals of shorter than 3 wk should be avoided because of decreased plant persistence and ground cover.

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# Ruminal in situ degradability of dry matter and neutral detergent fiber of sugarcane silage

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## Abstract

The ruminal degradability of dry matter (DM) and neutral detergent fiber (NDF) of 9 sugarcane varieties ensiled 15 months after planting was evaluated, using 3 fistulated Holstein x Zebu cows and incubation periods of 0, 6, 12, 24, 72 and 96 h in a randomized complete block design. Dry matter, crude protein (CP), mineral matter (MM), NDF, pH and in-situ degradability levels were determined. There were significant differences in composition of all evaluated parameters in the silages, except for CP, with the following variations: DM (19.7–23.2%), CP (2.70–3.47%), MM (3.2–5.2%), NDF (67.6–73.8%) and pH (3.8–4.2). The DM fraction ‘a’ differed among sugarcane varieties, with SP 801816 presenting the highest soluble fraction (26.83%). Effective degradability (ED) of DM (32.7–40.9%) and degradation rate ‘c’ did not differ among varieties. The ED of NDF and fraction ‘a’ did not differ among silages, but there were significant differences in fraction ‘b’, with a variation from 36.4 to 41.2%. Highest NDF ED occurred for the varieties RB 835486 (22%) and SP 791011 (21.1%). Further studies with these two varieties with the addition of inoculants and additives at ensiling are needed along with feeding studies to determine animal performance data.

## Resumen

Se evaluó la degradabilidad de la materia seca (MS) y la fibra detergente neutra (FDN) de ensilajes de 9 variedades de caña de azúcar, ensiladas 15 meses después de la siembra, utilizando 3 vacas (Holstein x Cebú) con cánula ruminal. Las muestras se incubaron durante 0, 6, 12, 24, 72 y 96 h y se determinaron los niveles de MS, FDN, proteína cruda (PC), materia mineral (MM), pH y la degradabilidad in situ. El diseño experimental fue bloques al azar con 9 tratamientos y 3 repeticiones. Los resultados mostraron diferencias (P<0.05) en la composición química de los ensilajes, excepto para PC, con las variaciones siguientes: MS (19.7–23.2%), PC (2.70–3.47%), MM (3.2−5.2%), FDN (67.6–73.8%) y pH (3.8–4.2). La fracción soluble (‘a’) de la MS varió entre las variedades de caña, entre ellas la SP 801816 que presentó el valor más alto (26.83%). La degradabilidad efectiva (DE) de la MS (32.7–40.9%) y la tasa de degradación (‘c’) no difirieron entre variedades. La DE de la FDN y la fracción ‘a’ no difirieron entre ensilajes, pero se encontraron diferencias en la fracción potencialmente degradable (‘b’) con variaciones desde 36.4 hasta 41.2%. Los valores más altos de la DE de la FDN ocurrieron con las variedades RB 835486 (22%) y SP 791011 (21.1%). Se sugiere la realización de estudios con estas 2 variedades usando inoculantes y aditivos al ensilar y determinando el desempeño animal.

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## Introduction

Sugarcane (*Saccharum officinarum)* is grown in the tropical areas of Brazil, where it is processed into sugar and/or alcohol. Increasingly, because of its high growth rate, it is viewed as a forage source for cattle. However, there are aspects of quality that must be considered before offering it to livestock, as its slow cell-wall digestion results in low metabolizable energy available to the animal, and limits its nutritive value. Due to difficulties presented by the use of freshly cut sugarcane, its conservation as silage is generally necessary to make it useful.

Although sugarcane has a high sugar fraction, which would support rapid microbial growth in the rumen, especially of bacteria, the microflora have a lesser capacity to degrade the potentially degradable fiber (Pereira et al. 2001). The rapid breakdown and loss of soluble carbohydrate fractions in sugarcane silages cause a slight increase in cell-wall components relative to other forage fractions (Schmidt et al. 2007b). The nylon bag technique has been adapted by researchers to estimate these losses. This technique has the advantages of speed, low cost and ease of execution.

As numerous sugarcane varieties are now available, each with certain enhanced characteristics aiming to meet the needs of the sugar/alcohol industry, it is essential to know the quality of these different varieties with respect to fiber content and degradation kinetics for the livestock industry. Further, these factors can be related to animal performance to allow selection of those varieties that can increase production (Azevêdo et al. 2003a).

It is customary to include additives during ensiling to enhance the fermentation process (Schmidt et al. 2007a). In this study, no additives or inoculants were used so that differences between the sugarcane varieties would not be masked. In a later study these same varieties will be assessed along with the use of inoculants and additives.

Therefore, the aim of this study was to assess silages made from different sugarcane varieties by determining the degradation profiles of dry matter and neutral detergent fiber, to help in choosing appropriate varieties for use as animal feed.

## Materials and Methods

The experiment was conducted at the Model Dairy Farm belonging to the Animal Production Department of the Veterinary and Animal Science School of the Federal University of Goiás, Goiânia, Goiás state, Brazil. The Model Farm is located in the Cerrado (savanna) biome (16º36' S, 49º16' W; 727 m asl). The climate in the region is Aw according to the Köppen classification (hot semi-humid, with a well-defined dry season from May to October), with average yearly temperature of 23.2 ºC, minimum average temperature of 17.9 ºC and mean annual rainfall of 1,760 mm (INMET 2010).

To assess the in-situ degradability of the ensiled forage, 3 crossbred (Holstein x Zebu) cows were used, each with a rumen fistula, and weighing approximately 450 kg. Animals were kept in individual paddocks with access to shade, water and feed troughs. The animals were fed with chopped sugarcane and a concentrate containing 20% crude protein, in the proportion of 60:40, at 8.00 and 15.00 h each day.

The experimental design was randomized blocks, with 9 treatments and 3 replicates. Nine sugarcane varieties were evaluated as silage: RB 72454, RB 835486, RB 845257, RB 855536, SP 813250, SP 835073, SP 801842, SP 801816 and SP 791011. The cane was ensiled 15 months after planting. Whole cane plants were chopped in a forage shredder into 2-cm pieces and ensiled, using experimental silos consisting of sealed plastic buckets, each with a capacity of 4 kg of forage. The material was compacted by hand and wooden clubs, to obtain a density of approximately 700 $kg/m^3$. The silos were opened after 45 days, when a 10-g sample was taken to measure pH according to Silva and Queiroz (2002) and a 500-g sample was removed for evaluations. Samples were placed in a forced-air oven at 65 ºC for 72 h. Then a sub-sample was taken, ground and passed through a 5-mm sieve for the degradability tests.

A second sub-sample was prepared to determine the levels of dry matter (DM), crude protein (CP), mineral matter (MM) and neutral detergent fiber (NDF), according to the methods described by Silva and Queiroz (2002).

To assess the ruminal degradability of DM and NDF, we used the nylon bag method as proposed by Meherez and Ørskov (1977). Bags measuring 7 x 14 cm of free area with a mesh size of 50 μm were identified and weighed. Samples of 4.0 g DM of each silage variety were placed in separate bags for incubation.

The nylon bags were closed with small metal rings, tied with elastic bands and affixed to a chain for placement in the rumen of each cow. Incubation times were 0, 6, 12, 24, 72 and 96 h. In each cow, 90 bags were incubated (2 samples of each cultivar for each assessment time – samples of time 0 h were simply immersed and immediately removed from the rumen of animals). The bags were placed in the rumen in reverse order of incubation time but were all removed simultaneously. After retrieval, the bags were placed in buckets containing cold water to stop microbial activity and then were sent to the laboratory for washing. After thorough washing in distilled water, the bags were dried in a forced-air oven at 60 ºC for 72 h and weighed. All residual material was ground in a Willey mill with 1-mm mesh for measurement of DM and NDF, according to the methodology described by Silva and Queiroz (2002).

DM and NDF degradabilities were calculated using the mathematical model proposed by Mehrez and Ørskov (1977). Once the values of fractions 'a', 'b' and 'c' were obtained, they were applied in the equation proposed by Ørskov and McDonald (1979): ED = a + [(b x c)/c + k], where ED is the effective ruminal degradability of the component analyzed and k is the rate of ruminal passage of the food (5%/h), according to ARC (1984).

Variables were submitted to analysis of variance and the means were compared by the Tukey test at 5% probability, using the Sisvar 4.6 program (Ferreira 2008).

## Results

Chemical composition and pH of the silage made from the 9 sugarcane varieties are shown in Table 1. There were significant differences ($P<0.05$) among varieties for all characteristics evaluated except for CP.

The CP concentrations ranged from 2.70 to 3.47% ($P>0.05$), MM levels from 3.25 to 5.24% ($P<0.05$) and pH from 3.80 to 4.30 ($P<0.05$). Variety RB 845257 had the highest NDF concentration and SP 801816 had the lowest ($P<0.05$).

The results for the soluble fraction ('a'), potentially degradable fraction ('b'), degradation rate of the potentially degradable fraction ('c') and effective degradability (ED) of DM estimated for the 5%/h passage rate of the silages made from the different sugarcane varieties are shown in Table 2. Soluble fraction 'a' for DM differed ($P<0.05$) among sugarcane silages, with SP 801816 presenting the highest soluble fraction (26.8%). Dry matter fractions 'b' and 'c' and ED of DM did not vary significantly ($P>0.05$) among the silages, with the potentially degradable DM fraction ('b') ranging from 26.7 (SP 801816) to 32.8% (SP 835073) and the degradation rate ('c') having an overall average of 3.64%/h. There was no statistically significant difference in ED of DM ($P>0.05$) among tested silages, with a range of 32.7 to 40.9%.

For NDF, fractions 'a' and 'b' and the degradation rate 'c', as well as effective degradability (ED) of NDF of the silages, are shown in Table 3. There was no significant difference ($P>0.05$) in the values of fraction 'a' among the varieties, which ranged from 0.63 to 2.22%. The potentially degradable fraction 'b' varied ($P<0.05$) from 35.5 to 41.2%, as did the degradation rate (range 2.46 to 5.23%/h; $P>0.05$). Effective degradability varied ($P<0.05$) from 15.3 to 22.0%.

## Discussion

This study has provided useful information on the quality of silage made from a range of sugarcane varieties for feeding to cattle. All varieties produced silage with low crude protein and high crude fiber levels plus dry matter degradability of less than 40%, indicating limited nutritive value for livestock unless nitrogen supplements are included to increase rate of passage and hence feed intake.

**Table 1.** Dry matter (DM), crude protein (CP), mineral matter (MM), and neutral detergent fiber (NDF) concentrations and pH of silages made from 9 sugarcane varieties.

| Variety | DM (%) | CP (% DM) | MM (% DM) | NDF (% DM) | pH |
|---|---|---|---|---|---|
| RB 72454 | 21.4b[1] | 3.03a | 5.07a | 73.9ab | 4.21a |
| RB 835486 | 21.6b | 2.91a | 3.25c | 73.2bc | 4.25a |
| RB 845257 | 23.2a | 3.00a | 3.60bc | 75.4a | 4.30a |
| RB 855536 | 22.3ab | 2.97a | 4.13b | 72.3bc | 4.20ab |
| SP 813250 | 22.1ab | 2.91a | 5.17a | 72.0c | 4.11b |
| SP 835073 | 21.6b | 2.70a | 3.74bc | 73.4bc | 4.10bc |
| SP 801842 | 19.7c | 3.47a | 5.24a | 70.3d | 3.96bcd |
| SP 801816 | 19.7c | 3.35a | 4.74a | 67.6e | 3.80d |
| SP 791011 | 18.7c | 2.71a | 3.74bc | 68.5de | 3.86cd |

[1]Means followed by different letters within columns differ ($P<0.05$) by the Tukey test.

**Table 2.** Soluble fraction (a), potentially degradable fraction (b), degradation rate of fraction 'b' (c) and effective degradability (ED) of dry matter, with their respective coefficients of determination ($R^2$), of silages made from 9 sugarcane varieties.

| Variety | a (%) | b (%) | c (%/h) | ED (%) | $R^2$ |
|---|---|---|---|---|---|
| RB 72454 | 22.0bc[1] | 30.3a | 4.35a | 35.9a | 0.98 |
| RB 835486 | 23.6abc | 31.8a | 3.71a | 37.7a | 0.98 |
| RB 845257 | 19.6c | 31.9a | 3.69a | 33.1a | 0.97 |
| RB 855536 | 21.9bc | 31.3a | 3.30a | 35.3a | 0.99 |
| SP 813250 | 21.3c | 29.5a | 3.25a | 32.7a | 0.99 |
| SP 835073 | 21.9bc | 32.8a | 3.39a | 35.0a | 0.98 |
| SP 801842 | 22.8abc | 28.8a | 3.35a | 35.8a | 0.98 |
| SP 801816 | 26.8a | 26.7a | 3.30a | 37.3a | 0.99 |
| SP 791011 | 26.4ab | 30.3a | 4.46a | 40.9a | 0.99 |

[1]Means followed by different letters within columns differ ($P<0.05$) by the Tukey test.

**Table 3.** Soluble fraction (a), potentially degradable fraction (b), degradation rate of fraction 'b' (c) and effective degradability (ED) of neutral detergent fiber, with their respective coefficients of determination ($R^2$), of silages made from 9 sugarcane cultivars.

| Variety | a (%) | b (%) | c (%/h) | ED (%) | $R^2$ |
|---|---|---|---|---|---|
| RB 72454 | 1.54a[1] | 37.2bcd | 4.71a | 19.2ab | 0.98 |
| RB 835486 | 2.22a | 40.8a | 5.23a | 22.0a | 0.98 |
| RB 845257 | 1.55a | 38.8abcd | 3.43a | 17.0ab | 0.98 |
| RB 855536 | 1.32a | 39.7abc | 3.40a | 17.3ab | 0.99 |
| SP 813250 | 0.63a | 36.4cd | 2.46a | 15.3b | 0.99 |
| SP 835073 | 1.12a | 41.2a | 3.62a | 18.3ab | 0.98 |
| SP 801842 | 0.70a | 35.5d | 4.86a | 17.7ab | 0.97 |
| SP 801816 | 0.70a | 37.2bcd | 3.35a | 15.6b | 0.99 |
| SP 791011 | 1.91a | 40.4ab | 4.66a | 21.1a | 0.98 |

[1]Means followed by different letters within columns differ ($P<0.05$) by the Tukey test.

The dry matter (DM) contents in the silages (18.7–23.2%) were similar to the 22.4 and 20.7% found by Freitas et al. (2006b) in an experiment involving sugarcane ensiled 11 and 13 months after planting, respectively, and lower than the 28.6% found by Freitas et al. (2006a) in sugarcane ensiled 16 months after planting, and the 25.2% reported by Santos et al. (2011). According to McCullough (1977), desirable DM levels for ensilage are between 28 and 34%. Above 28% DM, the proliferation of yeasts is reduced by raising the osmotic pressure (Van Soest 1994), while a DM content above 35% favors the growth of bacteria of the *Clostridium* genus, which produce butyric acid and reduce silage quality.

While stage of maturity and soil moisture levels can affect plant moisture levels, a contributing factor to the low DM levels found in our silages was the failure to use additives in the ensiling process, since effective ensiling of sugarcane requires large amounts of additives (Siqueira et al. 2007). These authors evaluated additives and inoculants for ensiling sugarcane and showed that the inclusion of inoculants increased DM content of silage by more than 4 units (from 27.4 to 31.9%), when *Lactobacillus buchneri* was added.

The low DM levels measured in varieties SP 801842, SP 801816 and SP 791011 were a reflection of the intermediate and late ripening cycles of these varieties, which were less mature than the others at harvest. McDonald et al. (1991) indicated that DM loss in sugarcane silages can exceed 35% of the original level due to alcoholic fermentation caused by epiphytic yeasts in the forage, which are a feature of some varieties. Freitas et al. (2006a) reported a DM reduction of 19.5% relative to the original DM level, when evaluating sugarcane silage with different forms of additives (soybean crop residue, *Lactobacillus plantarum* and *L. buchneri*).

According to Preston and Leng (1978), the crude protein (CP) concentration in sugarcane varieties is naturally low, as we have also shown, a strong case against its use as the sole feed for cattle. This low protein content can be remedied, at low cost, by adding a source of non-protein nitrogen to the diet. Some cattle herders routinely add low levels of urea, following a period of adaptation to its inclusion in the sugarcane forage diet. Without additional N or protein, low CP levels in sugarcane forage can impair the functioning of the ruminal microbiota; as Van Soest (1994) stated, the minimum CP level should be 7% for adequate rumen functioning. Azevêdo et al. (2003b) analyzed sugarcane varieties with different ripening cycles and found CP levels similar to those of our study, with mean values of 2.8, 2.4 and 2.4% for varieties SP 801842, RB 845257 and SP 791011, respectively, levels well below that suggested by Van Soest (1994) as optimal for rumen microbiota.

While sugarcane produces large quantities of DM, it is considered to be poor in minerals. For example, Pinto et al. (2003) reviewed several cultivars and the mineral concentrations ranged from 1.2% DM (cultivar SP 801842) to 3.4% DM (cultivar RB 72454). Therefore, it is necessary to improve the quality through physical and/or chemical techniques, since mineral deficiencies can occur, if sugarcane is the sole feed for livestock. Levels of particular minerals in the silage must be determined, so that appropriate mineral supplements can be fed to the particular class of animals. The mineral matter (MM) levels we recorded (3.25–5.24%) were lower than values reported by Pedroso et al. (2006) of 6.59% and Schmidt et al. (2007b) of 8.10%. A range of factors can affect mineral composition of forages, especially type of soil, level and type of fertilizer applied and species and variety. Lopes and Evangelista (2010), in an experiment conducted to assess the effect of additives on sugarcane silage, reported average ash levels of 4.26% after opening the silos, with no significant differences in this parameter attributed to different additives.

The neutral detergent fiber (NDF) values in this study were higher than those found by Freitas et al. (2006b) (66.3%), Balieiro Neto et al. (2007) (63.3%), Schmidt et al. (2007b) (66.0%) and Queiroz et al. (2008) (53.5%). This is quite significant as Van Soest (1965) indicated that cell-wall constituents above 55–60% in the DM are negatively correlated with the consumption of forage by animals, since rate of digestion is slower and retention time in the rumen is increased. Higher NDF levels in sugarcane silage than in the original green material occur due to the loss of cell contents caused by microorganisms that produce organic acids and alcohol, raising the proportion of fibrous matter, and reducing the nutritive value of the forage (McDonald et al. 1991).

The pH values in this experiment (3.8–4.3) are similar to the figures found by Freitas et al. (2006a) (3.5), Schmidt et al. (2007b) (3.31) and Siqueira et al. (2007) (3.7). According to McDonald et al. (1991), pH of silage should be lower than 4.2, to inhibit development of microorganisms that produce butyric acid, which lowers acceptability and quality of silage.

Compared with silage made from other tropical grasses, sugarcane dry matter's fraction 'a' in this research presented medium values. Pires et al. (2010) evaluated silage from corn (AG 7575), sorghum (BR 700) and *Brachiaria brizantha* and found DM fraction 'a' values of 38.5, 21.4 and 12.5%, respectively. Resende et al. (2003) evaluated forage sorghum and grain sorghum and the DM fraction 'a' values were, respectively, 26.8 and 29.2%. Rossi Jr. and Schogor (2006), in an experiment with silage made of sugarcane variety RB 72474, found a fraction 'a' value of 23.4% in silage without additives, 33.5% when urea was added (1% of silage fresh matter) and 35.3% when urea (1% of silage fresh matter) and corn grain (2.5% of silage fresh matter) were added. Since the fraction 'a' values did not differ between the urea treatment and the urea + corn grain treatment, the increase was possibly due to an increase in available nitrogen for the microbes. The higher soluble sugars fraction (26.8%) in SP 801816 in our study suggests that this would promote greater microbial growth in the rumen than the other cultivars.

It is of interest that fraction 'b' and its degradation rate 'c' and the effective degradability (ED) of DM did not differ among varieties. Values for the potentially degradable fraction (26.7–32.8%) were similar to those reported by Rossi Jr. and Schogor (2006) (31.4%) and Schmidt et al. (2007b) (27.5%). In silages such as corn and sorghum, which contain large quantities of starch because of the grain content, values for this fraction are substantially higher, averaging around 50%; thus they are potentially better feed sources for livestock. The overall average figure (3.64%/h) for degradation rate 'c', which represents the fermentation rate of fraction 'b', was similar to the rates observed by Rossi Jr. and Schogor (2006) of 3.29%/h (sugarcane cultivar RB 72-474), and Schmidt et al. (2007b) of 3.27%/h (sugarcane cultivar RB78-5841).

According to Martins and Loyola (1999), factors such as DM, type of fermentation and concentration of soluble carbohydrates can affect the ruminal degradability rates of silages. Schmidt et al. (2007b), in an experiment with sugarcane (cultivar RB78-5841), found the ED of DM to be 41.2%, compared with our findings of 33.1–40.9%. Balieiro Neto et al. (2007) found in vitro digestible DM concentrations in pure sugarcane silage (cultivar IAC86-2480) of 62.1%.

Our values of NDF fraction 'a' (0.63–2.22%) were much lower than the 10.9% for fraction 'a' for sugarcane (variety RB78-5841) silage reported by Schmidt et al. (2007b). They did not state the age of the cane at ensiling, so there is no way to judge whether the lower value for 'a' in our experiment was due to the increase in the fibrous fraction caused by greater age of the cane at ensiling.

The low values for the ED of NDF (15.3–22.0%) were similar to the 14.1 to 17.3% for sugarcane silage (variety not mentioned) without additives reported by (Santos et al. 2008) and 13.8% for silage of cultivar SP 801816 without additives (Santos et al. 2011).

## Conclusions

Effective degradability of DM of all analyzed varieties ranged around 35.9%, indicating that the silage would be of limited value for feeding to livestock as the sole diet. The results of this study suggest that varieties SP 791011 and RB 835486 are more suitable for animal feed due to higher NDF degradability. As a preliminary study, these two varieties should be evaluated under laboratory conditions with the use of additives and inoculants and evaluation of in vitro digestibility. This should be followed by assessment of animal performance with nitrogen supplements. Other factors such as DM yield, susceptibility to lodging and time to maturity of all evaluated varieties should be investigated in further studies to provide sufficient data for decision making.

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# Agronomic, morphogenic and structural characteristics of tropical forage grasses in northeast Brazil

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**Abstract**

The objective of this study was to assess the agronomic, morphogenic and structural characteristics of tropical forage grasses during the establishment phase and throughout the second year in northeast Brazil. The treatments included 9 grasses: *Brachiaria humidicola* (koronivia grass), *Brachiaria* hybrid cv. Mulato, *Brachiaria brizantha* cvv. Piatã, Xaraés and Marandu, *Brachiaria ruziziensis* (ruzi grass), *Brachiaria decumbens* (signal grass), *Panicum* hybrid cv. Massai and *Andropogon gayanus* (gamba grass). The grasses were planted in a randomized complete block design with 4 replications. The following parameters were measured: total forage production, leaf:stem ratio, tiller population density, number of dead tillers, leaf emergence rate, phyllochron, leaf elongation rate, stem elongation rate, rate of leaf senescence, final length of leaf blade and life-span of leaves. In the establishment year, cv. Mulato produced the highest forage yields, followed by cvv. Xaraés and Massai, with gamba grass and koronivia grass worst. In the second year, cvv. Mulato, Xaraés and Marandu, and gamba grass showed highest forage production, while cvv. Massai and Piatã produced the least. All grasses showed a marked drop in production during the dry season. Cultivar Massai consistently had the highest leaf:stem ratio. The morphogenic and structural characteristics differed according to cultivar and season of the year. In general, leaf emergence rate, leaf elongation rate, stem elongation rate, rate of leaf senescence, final length of the leaf blade, number of live leaves per tiller and density of living tillers were higher in the rainy season, while the phyllochron and life-span of leaves were higher in the dry season. The results of this research highlight the potential of the *Brachiaria* cultivars Mulato and Xaraés, gamba grass and *Panicum* cv. Massai in subhumid Maranhão, northeast Brazil.

**Resumen**

El estudio se realizó en el nordeste de Brasil con el objetivo de evaluar las características agronómicas, morfogénicas y estructurales de 9 gramíneas forrajeras tropicales durante la fase de establecimiento y el primer año de producción. Los tratamientos incluyeron: *Brachiaria humidicola*, *Brachiaria* híbrido cv. Mulato, *Brachiaria brizantha* cvs. Piatã, Xaraés y Marandu, *Brachiaria ruziziensis*, *Brachiaria decumbens*, *Panicum* híbrido cv. Massai y *Andropogon gayanus*. Las gramíneas fueron sembradas en un diseño de bloques completos al azar con 4 repeticiones. Se midieron los parámetros siguientes: producción total de forraje; relación hoja:tallo; densidad populacional de rebrotes; número de rebrotes muertos; tasa de aparición foliar; filocrono; tasas de elongación de hojas y tallos; tasa de senescencia foliar; longitud final de la lámina foliar; y duración de la vida útil de las hojas. En el año de establecimiento, *Brachiaria* híbrido cv. Mulato produjo los mayores rendimientos de forraje, seguido por *B. brizantha* cv. Xaraés y *Panicum* híbrido cv. Massai, siendo *A. gayanus* y *B. humidicola* los de peor desempeño. En el segundo año, los cvs. Mulato, Xaraés,

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Marandu y *A. gayanus* presentaron las mayores producciones de forraje, mientras que los cvs. Massai y Piatã fueron los menos productivos. Todas las gramíneas evaluadas presentaron una marcada reducción de la producción durante la estación seca. *Panicum* híbrido cv. Massai presentó consistentemente la mayor relación hoja:tallo. Las características morfogénicas y estructurales difirieron según la variedad y la época del año. En general, la tasa de aparición foliar, las tasas de elongación de hojas y tallos, la tasa de senescencia foliar, la longitud final de la lámina foliar, el número de hojas vivas por rebrote y la densidad de rebrotes vivos fueron mayores en la época de lluvias, mientras que el filocrono y la vida útil de las hojas fueron mayores en la época seca. Los resultados de esta investigación muestran el potencial de *Brachiaria* híbrido cv. Mulato, *B. brizantha* cv. Xaraés, *Panicum* cv. Massai y *A. gayanus* en la parte subhúmeda del estado Maranhão en el nordeste de Brasil.

## Introduction

Brazil has an area of more than 220 Mha of pastures, and at least 100 Mha of these are sown pastures (IBGE 2004). Thus, tropical grasslands represent an important resource for the Brazilian cattle industry, which is heavily dependent on grazed pastures (Faria et al. 2013).

Sown pasture grasses in Brazil differ in growth rate, nutrient requirements and sensitivity to water stress. Grasses in the genus *Brachiaria* have advantages over those in other genera, including good adaptation to acidic soils, tolerance of infertile soils and high dry matter yield. As a result, *Brachiaria* spp. are the most commonly used grasses in Brazilian pastures (Macedo 2005), and it is estimated that in the mid-western region of Brazil, 50% of sown pastures are *B. brizantha* cv. Marandu. Recently, 2 new cultivars of *B. brizantha* (cvv. Xaraés and Piatã) were introduced. Cultivar Piatã has the advantage of promoting slightly higher animal performance in the dry season. These cultivars, released by EMBRAPA (Brazilian Agricultural Research Corporation), flower at different seasons of the year (cv. Piatã in early summer, cv. Marandu in late summer and cv. Xaraés in autumn). This difference favors the strategic use of these grasses, taking advantage of the higher nutritional value and productivity of each cultivar in different periods.

*Andropogon gayanus* (gamba grass) is used widely in Brazil. It is tolerant of pests, and has high adaptation to arid conditions, high palatability and great potential for producing dry matter in sandy, acidic and infertile soils (Nascimento and Renvoize 2001).

Cultivar Massai, a natural hybrid of *Panicum maximum* and *Panicum infestum*, originates from Tanzania, Africa, and was released by CNPGC/EMBRAPA (Vilela 2012). This grass exhibits rapid establishment and regrowth and excellent forage production. Massai is better adapted to infertile soils than other cultivars of *P. maximum*, and has good resistance to leafhopper infestations. Brâncio et al. (2003) showed that Massai was as productive under rotational grazing as cvv. Mombaça and Tanzânia.

Owing to the range of species and environments, knowledge of the morphophysiological characteristics of these grasses is urgently needed to assist in the formulation of management practices. In tropical forage grasses, the morphogenic and structural characteristics can be expressed by leaf emergence rate, leaf elongation rate, stem elongation rate, life-span of leaves, leaf:stem ratio, final length of the leaf blade, number of live leaves per tiller and density of living tillers.

As these grasses were introduced relatively recently and the majority of research has been done in regions that differ significantly from the northeast region, this work aimed to compare the agronomic, morphogenic and structural characteristics of 9 tropical forage grasses during the establishment phase over 2 years in northeast Brazil.

## Materials and Methods

### *The study site*

The experiment was conducted in an area of the Forage Production Sector belonging to the Center for Agronomical and Environmental Sciences of the Federal University of Maranhão, in the lower Parnaíba river region, Maranhão, northeast Brazil (03°44'33" S, 43°21'21" W). The climate in the studied region has 2 well-defined seasons: a dry season (July–December) and a rainy season (January–June). The soil was a Yellow Latosol, with chemical properties of: pH($CaCl_2$) = 4.2; organic matter = 19 g/dm³; P, S, B, Cu, Fe, Mn and Zn = 5, 9, 1.43, 0.2, 55, 0.4 and 0.3 mg/dm³, respectively; K, Ca, H+L (potential acidity), aluminum, CEC (cation exchange capacity) and SB (sum of bases) = 0.4, 5, 2, 29, 8, 36 and 7 mmolc/dm³, respectively; V (base saturation) = 20%; and m (aluminum saturation) = 52%.

### *Experimental setup*

The area where the experiment was carried out was covered by Cerrado, the typical native vegetation. In February–March of 2010, the area was cleared and treated with limestone with reactive power of 94% of the total neutralization to give a base saturation of 60%. The experimental area was 430 $m^2$, divided into 36 plots of 3 x 2 m, separated by 1.0 m buffers.

Treatments included the following 9 tropical forage grasses: *Brachiaria humidicola* (koronivia grass); *Brachiaria* hybrid cv. Mulato (Mulato); *Andropogon gayanus* (gamba grass); *Brachiaria brizantha* cvv. Piatã (Piatã), Xaraés (Xaraés) and Marandu (Marandu); *Panicum* hybrid cv. Massai (Massai); *Brachiaria ruziziensis* (ruzi grass); and *Brachiaria decumbens* (signal grass). The treatments were allotted to a randomized complete block design with split plot, grasses in plots and season of year (dry and rainy) in subplots, with 4 replications.

Seed of the grasses was broadcast at 2 kg pure viable seed/ha on to the appropriate plots, except for *B. humidicola*, which was vegetatively planted in furrows, on 24 April 2010. At sowing, simple superphosphate and potassium chloride were broadcast on to plots at rates of 500 kg P/ha and 67 kg K/ha.

### *Sward management*

In 2010, plots were cut at 20 cm above ground level on 2 occasions (a standardization cut 105 days after sowing and a second cut to evaluate grass establishment on 28 August 2010). Plots were fertilized with urea at 50 kg N/ha on each occasion.

In 2011, another standardization cut was performed on 4 January, followed by maintenance fertilization with 333 kg P/ha and 67 kg K/ha. N was applied as urea at 150 kg N/ha/yr as equal split dressings after each harvest.

### *Measurements*

Total forage production was measured by cutting plots at 28-day intervals during the rainy season and 60-day intervals during the dry season. Material from a square quadrat of 0.25 $m^2$ in the center of each plot was cut to 20 cm for all cultivars except koronivia grass, which was cut to 15 cm, and was sorted into leaf blade, stem + sheath and dead material to determine the percentage of each morphological component and leaf:stem ratio (LSR) after drying in a forced-draught oven. After weighing the harvested forage, samples were taken to determine the dry matter (DM) content for calculation of DM yield.

Tiller population density (TPD) and number of dead tillers (NDT) within the quadrat were recorded immediately before harvesting. Ten vegetative tillers were marked in each quadrat and measured on a weekly basis, and new tillers were marked after each cut. The following variables were calculated: stem elongation rate (SER, the difference between the initial and final stem lengths, divided by the number of days in the evaluation period); number of live leaves per tiller (NFLT, number of live leaves present at the end of each evaluation period divided by the number of living tillers); density of living tillers (DLT, number of living tillers at the end of each evaluation period); final length of the leaf blade (FLLB, length from the apex to the ligule of fully expanded leaves); leaf elongation rate (LElR, the difference between the initial and final lengths of the leaf blades, divided by the number of days in the trial period); life span of leaves (LSL, the time during which the leaf remained alive after complete exposure of the ligule); leaf emergence rate (LEmR, number of leaves on the tillers marked in each parcel, divided by the number of days in the trial period); rate of leaf senescence (RLS, the area of senescent leaf blades on the marked tillers); and phyllochron (FYLL, the time between the appearance of successive leaves on a tiller).

### *Data analysis*

The data were grouped based on whether they were from the rainy (January–June) or dry (July–December) season and were submitted to an analysis of variance F-test; in the case of a significant difference, a comparison of averages with Student's t-test at 5% probability was performed.

In the case of variables with a coefficient of variation (CV) of more than 50%, such as DLT, NDT, RLS, LSL, FYLL and LEmR, a Kruskal Wallis non-parametric analysis was performed and data are represented by medians. In the case of a difference, Student's t-test at 5% probability was performed. InfoStat® (InfoStat Statistical Software, Universidad Nacional de Córdoba, Argentina, version 2004) was used for all computations.

## Results

### *Climatic conditions*

In 2010, when the data were collected during the dry season, average temperature varied from 27.0 °C (July) to 29.0 °C (December). In the 2011 rainy season, average temperature ranged from 26.3 °C (January) to 26.7 °C (June). Rainfall in 2010 was much lower than in 2011 (Figure 1). In the rainy season of the second experimental year, the accumulated rainfall was 1,900 mm (18.7% above 10-year mean), with 300 mm (36.9% above 10-year mean) in the dry season, and no rainfall during August–September.

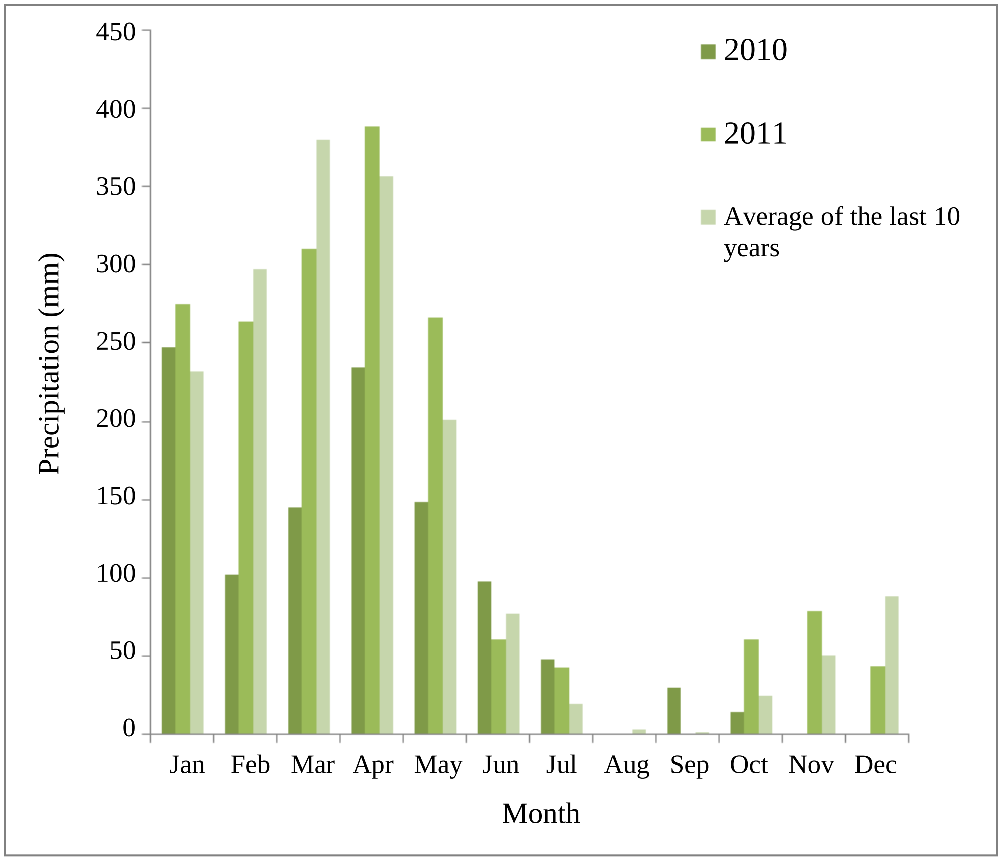


**Figure 1.** Precipitation during the experimental period and the average of the last 10 years.

*Sward variables in the establishment year*

During pasture establishment, forage production, leaf: stem ratio, tiller population density and number of dead tillers differed among the grasses (Table 1). In absolute terms, Mulato produced the most forage and koronivia grass and gamba grass the least, but only some differences between cultivars were significant. Leaf:stem ratio for Massai (13.5) was greater than for all other cultivars (range 1.0–3.7) (Table 1). The same pattern was displayed for tiller population density, with Massai (103) producing more than other cultivars (range 28.6–48.7).

**Table 1.** Total forage production, leaf:stem ratio, tiller population density and number of dead tillers of 9 tropical forage grasses during the establishment phase.

| Cultivar | Total forage production (kg DM/ha) | Leaf:stem ratio | Tiller population density (tillers/m$^2$) | Number of dead tillers (No./m$^2$) |
|---|---|---|---|---|
| Koronivia grass | 4,745d[1] | 1.04b | 28.63b | 0.56c |
| Marandu | 8,478bc | 2.75b | 36.57b | 1.43bc |
| Xaraés | 11,636b | 1.01b | 41.54b | 2.99abc |
| Piatã | 6,708cd | 2.83b | 48.72b | 2.46abc |
| Mulato | 18,620a | 1.33b | 33.84b | 0.00c |
| Signal grass | 8,940bc | 0.63b | 28.78b | 4.75abc |
| Ruzi grass | 6,972cd | 3.68b | 46.53b | 25.88a |
| Massai | 10,135bc | 13.51a | 103.50a | 8.95abc |
| Gamba grass | 4,782d | 3.26b | 31.58b | 22.38abc |

[1]Means within columns followed by the same letter do not differ by Student's t-test (P>0.05).

*Sward variables in the second year*

Cultivars Mulato and Xaraés had the highest annual forage production, which did not differ from Marandu, gamba grass and koronivia grass, although yields were 17.3, 17.7 and 23.2% lower than the average production of the former 2 cultivars, respectively. Signal grass, ruzi grass and Piatã had intermediate performance, while Massai had the worst performance (Table 2).

In the rainy season of 2011, there was a gradation in yield from Mulato (20,850 kg/ha) to Massai (8,939 kg/ha) (P<0.05). In the dry season, yields ranged from 5,180 kg/ha (Mulato) to 1,803 kg/ha (ruzi grass) (P>0.05), with significant (P<0.05) difference between seasons for all cultivars.

Massai had the highest leaf:stem ratio (LSR) in both wet and dry seasons, but differences between cultivars were rarely significant. Again LSR was higher in all cultivars in the dry season than in the wet season, but differences were generally not significant (P>0.05).

Koronivia grass and Massai produced more tillers in the rainy season than the other cultivars, but differences were rarely significant. Number of dead tillers was also higher in koronivia grass and Massai in the wet season, but differences were not so marked in the dry season.

In the rainy season, leaf emergence rate (LEmR) did not differ (P>0.05) among cultivars (Table 3). However, there was variation between periods, with lower values in the dry season (P<0.05) for most cultivars. Massai presented the smallest LEmR, and koronivia grass the largest.

For all cultivars, phyllochron was greater (P<0.05) in the dry than in the rainy season (Table 3) and there were differences between cultivars during the dry season (P<0.05). Xaraés and Massai had greater phyllochron and took longer to exhibit 2 consecutive leaves, 48 and 61 days, respectively, than koronivia grass (20.3 days). This may be because the sheath needed to go further between the apical meristem and the end of the pseudostem, as Xaraés presented one of the largest final leaf blade lengths (see Table 4). Koronivia grass required less time for the emergence of 2 consecutive sheaths, possibly due to the smaller size of the leaf blade observed in this species.

Leaf elongation rate (LElR) during the rainy season varied from 6.02 cm/tiller/d in gamba grass to 1.27 cm/tiller/d in koronivia grass (P<0.05). During the dry season, LElR did not differ between cultivars (P>0.05), but for most grasses LElR in the wet season exceeded (P<0.05) that in the dry season.

Rate of leaf senescence did not differ (P>0.05) among the grasses or between seasons (Table 3).

Stem elongation rate (SER) during the rainy season varied from 0.55 cm/d in Marandu and gamba grass to 0.06 cm/d in Massai (P<0.05) (Table 3). While there were no differences among the grasses during the dry season (P>0.05), SERs during the dry season were much lower than during the wet season.

**Table 2.** Total forage production, leaf:stem ratio, tiller population density and number of dead tillers of 9 tropical forage grasses during the second rainy and dry seasons (2011).

| Cultivar | Forage production (kg DM/ha)[1] | | | Leaf:stem ratio[1] | | Tiller population density (tillers/m$^2$)[1] | | Number of dead tillers (No./m$^2$)[1] | |
|---|---|---|---|---|---|---|---|---|---|
| | Annual[2] | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Koronivia grass | 18,669ABC | 14,160CDa | 4,509Ab | 3.0ABa | 7.1ABa | 521.4Aa | 104.4BCDb | 113.1ABa | 75.7ABa |
| Marandu | 20,102AB | 16,351BCDa | 3,752Ab | 2.6Bb | 9.1ABa | 169.2ABa | 98.3Db | 55.8BCa | 55.8Ba |
| Xaraés | 23,330A | 18,150ABa | 4,662Ab | 3.5ABa | 8.7ABa | 134.7Ba | 111.2BCDa | 48.0Ca | 94.5ABa |
| Piatã | 8,235C | 14,637CDa | 3,599Ab | .2ABa | 9.1ABa | 174.5ABa | 99.6CDb | 45.8Ca | 90.7ABa |
| Mulato | 25,311A | 20,850Aa | 5,180Ab | 5.6ABa | 8.2ABa | 168.9ABa | 169.1ABCa | 46.8Ca | 76.5ABa |
| Signal grass | 16,042BC | 13,375Da | 2,668Ab | 4.7ABa | 5.9Ba | 168.7ABa | 105.9BCDa | 48.8Ca | 80.5ABa |
| Ruzi grass | 14,901BC | 13,098Da | 1,803Ab | 4.2ABa | 7.7ABa | 126.8Ba | 81.7Da | 38.4Ca | 59.5Ba |
| Massai | 11,653BC | 8,939Ea | 2,714Ab | 8.3Aa | 13.1Aa | 356.7Aa | 346.7Aa | 125.4Aa | 150.1Aa |
| Gamba grass | 20,006AB | 17,025BCa | 2,981Ab | 1.7Ba | 6.0Ba | 174.7ABa | 281.7Aa | 48.15Cb | 140.9Aa |

[1]Within parameters, medians followed by the same letter, upper case in columns and lower case in rows, do not differ by Student's t-test (P>0.05).
[2]Means followed by the same letter do not differ by Student's t-test (P>0.05).

**Table 3.** Morphogenic characteristics of 9 tropical forage grasses in rainy and dry seasons of the second year (2011).

| Cultivar | Leaf emergence rate (cm/tiller/d) | | Phyllochron (d/leaf) | | Leaf elongation rate (cm/tiller/d) | | Rate of leaf senescence (cm/tiller/d) | | Stem elongation rate (cm/d) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Koronivia grass | 0.13Aa[1] | 0.05Aa | 8.0Aa | 20.3Ba | 1.27Ba | 0.29Aa | 0.09Aa | 0.23Aa | 0.12ABa | 0.06Aa |
| Marandu | 0.11Aa | 0.03Bb | 9.3Ab | 30.4ABa | 3.74ABa | 0.41Ab | 0.57Aa | 0.50Aa | 0.55Aa | 0.02Ab |
| Xaraés | 0.09Aa | 0.03Bb | 25.1Ab | 61.0Aa | 4.72ABa | 0.56Ab | 0.68Aa | 0.60Aa | 0.44Aa | 0.04Ab |
| Piatã | 0.09Aa | 0.03ABb | 11.2Ab | 33.0ABa | 2.72ABa | 0.59Aa | 0.61Aa | 0.61Aa | 0.27ABa | 0.06Aa |
| Mulato | 0.10Aa | 0.04ABa | 10.3Aa | 30.3ABa | 2.93ABa | 0.35Ab | 0.82Aa | 0.60Aa | 0.29ABa | 0.05Ab |
| Signal grass | 0.11Aa | 0.04ABb | 9.3Ab | 27.1ABa | 2.41ABa | 0.37Aa | 0.47Aa | 0.57Aa | 0.33ABa | 0.07Aa |
| Ruzi grass | 0.11Aa | 0.05ABa | 9.3Aa | 22.5ABa | 3.23ABa | 0.25Ab | 0.55Aa | 0.57Aa | 0.29ABa | 0.03Ab |
| Massai | 0.07Aa | 0.02Bb | 14.0Ab | 48.0Aa | 2.64ABa | 0.29Ab | 0.61Aa | 0.43Aa | 0.06Ba | 0.02Aa |
| Gamba grass | 0.13Aa | 0.04ABb | 8.0Ab | 34.1ABa | 6.02Aa | 0.54Ab | 1.43Aa | 0.62Aa | 0.55Aa | 0.07Ab |

[1]Within parameters, medians followed by the same letter, upper case in columns and lower case in rows, do not differ by Student's t-test (P>0.05).

Life-spans of leaves did not differ (P>0.05) among the grasses in either the rainy or the dry season, but leaves generally lived longer during the dry season (P<0.05) (Table 4).

The final length of the leaf blade (FLLB) during the rainy season varied from 26.8 cm in gamba grass and 24.8 cm in Xaraés to 8.4 cm in koronivia grass (P<0.05) (Table 4). During the dry season, the range in FLLB was 12.0 cm in gamba grass to 6.8 cm in koronivia grass (P<0.05). FLLB in the dry season was lower than that in the rainy season for all cultivars, but differences were not always significant.

The number of live leaves per tiller (NFLT) during the rainy season ranged from 6.38 leaves/tiller for koronivia grass to 3.5 leaves/tiller for Piatã (P<0.05) (Table 4). During the dry season, the range was from 4.51 leaves/tiller for koronivia grass to 2.13 leaves/tiller for Massai and gamba grass (P<0.05). Fewer new leaves appeared in the dry season than in the rainy season for most cultivars (P<0.05).

The density of living tillers did not differ among cultivars during the rainy season (P>0.05), despite a range from 20.05 tillers/plant in ruzi grass to 7.5 tillers/plant in Xaraés (Table 4). During the dry season, the range was from 12.63 tillers/plant in Massai and 10.03 tillers/plant in gamba grass to 2.13 tillers/plant in koronivia grass and Mulato and 2.07 tillers/plant in signal grass (P<0.05).

**Table 4.** Structural characteristics of 9 tropical forage grasses in rainy and dry seasons of the second year (2011).

| Cultivar | Life span of leaves (d)[1] | | Final length of leaf blade (cm)[2] | | Number of live leaves per tiller[2] | | Density of living tillers (tillers/plant)[1] | |
|---|---|---|---|---|---|---|---|---|
| | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Koronivia grass | 17.4Ab | 30.7Aa | 8.4Fa | 6.8Ca | 6.38Aa | 4.51Aa | 8.75Aa | 2.13BCDb |
| Marandu | 18.3Ab | 29.7Aa | 17.7CDa | 11.7ABb | 4.50ABa | 2.66Cb | 15.75Aa | 2.63CDb |
| Xaraés | 12.9Ab | 27.9Aa | 24.6ABa | 14.0Ab | 4.50ABa | 2.57Cb | 7.50Aa | 3.76ABCDa |
| Piatã | 14.8Ab | 27.6Aa | 14.7DEa | 11.2ABCa | 3.50Ba | 2.81BCa | 10.25Aa | 3.44ABCDa |
| Mulato | 15.8Aa | 26.8Aa | 17.4CDEa | 9.9ABCb | 4.38ABa | 3.00ABCb | 12.25Aa | 2.14CDb |
| Signal grass | 13.4Ab | 24.7Aa | 12.8EFa | 8.8BCa | 4.63ABa | 2.94ABCb | 9.50Aa | 2.07Db |
| Ruzi grass | 14.8Aa | 21.6Aa | 16.6DEa | 8.2BCb | 3.63Ba | 2.72Ca | 20.05Aa | 3.13ABCDb |
| Massai | 16.2Ab | 25.4Aa | 21.9BCa | 10.9ABCb | 3.75Aa | 2.13Cb | 17.00Aa | 12.63Aa |
| Gamba grass | 11.1Ab | 24.0Aa | 26.8Aa | 12.0ABb | 4.00ABa | 2.13Cb | 13.25Aa | 10.03ABCa |

[1]Within parameters, medians followed by the same letter, upper case in columns and lower case in rows, do not differ by Student's t-test (P>0.05).

[2]Within parameters, means followed by the same letter, upper case in columns and lower case in rows, do not differ by Student's t-test (P>0.05).

## Discussion

This study has provided valuable information on the comparative production of 9 different grasses in northeast Brazil, which will complement data from other regions. The data collected on morphology and structural characteristics help to explain why some grasses are more productive than others and provide some indications of the likely value of the different cultivars for beef production in the region and how they might be managed. The absence of significant differences between cultivars for some parameters suggests that there was large variation between samples and a greater number of samples per plot or larger samples per plot could have improved the ability to determine differences.

In terms of DM production, Mulato was outstanding throughout the study, with highest production in both the establishment year and the second year. Xaraés and Massai also had good yields in the establishment year, while koronivia grass, gamba grass and Marandu produced good yields in the second year, which was related to greater rainfall in the second year (Figure 1), and shows the greater sensitivity of these species to water stress. In a comparison of 5 cultivars from the *Brachiaria* genus in Mato Grosso, Bauer et al. (2011) also found highest production in Mulato followed by Xaraés (4,200 vs. 3,500 kg/ha). In our research, the high production by Mulato in the establishment year would have been affected by the absence of dead tillers in this cultivar. It has stems with large diameter and hence greater weight than other grasses like Massai, which has thinner and lighter stems.

Dry matter yield is not the only criterion to be considered, as leaf:stem ratio has a marked effect on the quality of the forage produced and the amount of material preferred by grazing animals. The cultivar with outstanding leaf:stem ratio was Massai in both years, as was shown previously by Brâncio et al. (2003) in comparisons of 3 cultivars of *Panicum maximum* in Campo Grande, Mato Grosso do Sul. Despite the fact that it produced only 54% as much dry matter as Mulato in the establishment year, its much higher leaf:stem ratio (13.5 vs. 1.3) resulted in leaf production of 9,436 kg/ha compared with 10,629 kg/ha for Mulato, a difference of only 11%. The high leaf production by Massai was probably a function of the high tiller population density (TPD) of this cultivar (104 tillers/$m^2$) compared with 29–48 tillers/$m^2$ for the remaining grasses. Despite having the highest TPD in rainy and dry seasons, the lowest leaf elongation rate, low stem elongation rate and taking a long time to exhibit consecutive leaves (14–48 days), Massai had high numbers of dead tillers in rainy and dry seasons, which certainly contributed to the lower yield obtained. Nevertheless, this species has great ability to recover after droughts, being one of the first to recover after the first rains, along with gamba grass. Ruzi grass, Piatã and signal grass recovered slowly after a period of prolonged drought, which was associated with high tiller mortality.

The superior dry matter production of Mulato continued into the second year, when Massai produced only 46% as much total forage as Mulato. Leaf:stem ratio did not favor Massai to the same extent as in the establishment year (8.3 vs. 5.6 for Mulato in the rainy season; and 13.1 vs. 8.2 for Mulato in the dry season). Interestingly, species like koronivia grass and gamba grass, which produced low yields in the establishment year, produced much higher total yields in the second year (18,000–20,000 kg DM/ha). Koronivia grass had a high leaf emergence rate and number of live leaves per tiller and low stem elongation rate, and took the shortest time to exhibit 2 consecutive leaves, which compensates for the lowest final length of leaf blade.

Gamba grass and *B. brizantha* cvv. Marandu and Xaraés had higher leaf and stem elongation rates, and higher final length of leaf blade (Table 4), which resulted in higher yields, since the stem is the structural component with higher weight than leaves, and is larger, contributing to increased total forage production.

While all cultivars showed marked seasonality of production as a result of climatic factors, ruzi grass showed the highest level of seasonality and produced only 14% as much forage in the dry season as in the wet. Most grasses produced 20–25% as much in the dry as in the wet, while koronivia grass and Massai showed least effect, producing 30–32% as much in the dry season. Generally, the higher the production during the rainy season, the greater the seasonality of production. This marked seasonality in forage production causes a number of problems, including both availability of fodder for animals and forage quality at the more critical times of year (Pedreira 1973).

The results obtained in this study for Xaraés and Piatã differed from those reported by Euclides et al. (2008), who found a lower leaf:stem ratio (LSR) for Piatã in the rainy season and Xaraés in the dry season; according to these authors, this result indicates that grazing management should be different for these cultivars. In our study, LSR was markedly higher in the dry season than in the wet season for both cultivars, so other criteria would determine if these cultivars should be managed differently.

Leaf:stem ratio is arguably the most important structural characteristic of pasture grasses. According to Pinto et al. (1994), a critical threshold for LSR has been considered to be 1.0, with values lower than this causing a fall in the quantity and quality of the forage produced. While some cultivars in our study had values below or near 1.0 in the establishment year, values for all cultivars exceeded 1.0 in both seasons in the second year. There was no difference in LSR between the rainy and dry seasons, as the higher water deficit, caused by minimal variations in temperature, led to lower stem elongation and leaf length.

Ruzi grass presented the greatest number of dead tillers, which is related to the lower adaptation of this species to the soil and climatic conditions in the study area. Xaraés and ruzi grass had the lowest tiller population density (TPD), but species with high TPD did not present a corresponding increment in biomass, possibly due to their morphological characteristics, which can be evidenced by the smaller number of live leaves per tiller, smaller final length of the leaf blade and slower leaf emergence rate presented. The lower DM yields in the dry period than in the rainy season reflect the lower TPD during the dry through water limitations. Formation, development, growth and senescence of tillers are influenced by climatic conditions, such as temperature, water and nutrient availability (Mazzanti et al. 1994; Fagundes et al. 2006).

In general, higher mortality of tillers occurred in the dry season, which, according to Fagundes et al. (2006), is a result of the plants' specific mechanisms for limiting the breathable area and coping with the worsening water deficiency. These mechanisms include the inhibition of tillering and branching, the anticipation of established tiller death, reduction of the leaf area accelerating the senescence of older leaves, and the further growth of the root system (Morales et al. 1997). Nabinger and Pontes (2001) suggested that, to maintain the development of tillers in growth-limiting conditions, it seems logical that plants would first compromise tillering, rather than reducing the size and life-span of leaves. Understanding the density behavior of living and dead tillers can be an important strategy for the management of pasture, because the density of tillers determines the durability of the pasture (Lemaire and Chapman 1996).

## Conclusions

While DM yields of the forage grasses studied differed in both wet and dry seasons, in general all cultivars followed a similar pattern of behavior with lower growth, higher leaf:stem ratio, higher phyllochron, lower leaf elongation rate and longer leaf lifespan in the dry season. Mulato, Xaraés and gamba grass showed highest DM production, making them an attractive option for livestock feeding, but the high leaf:stem ratio for Massai offsets to some extent the lower DM yields of this cultivar.

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