Universidade Federal de Minas Gerais

Desempenho agronômico, valor nutricional e modelagem de respostas produtivas e fisiológicas de cultivares de milheto no semiárido

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Desempenho agronômico, valor nutricional e modelagem de respostas produtivas e fisiológicas de cultivares de milheto no semiárido

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“He that can have patience can have what he will”

Benjamin Franklin, 1736

“Deixe a pressa lá fora!”

Sábio baiano

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SUMÁRIO

LISTA DE TABELAS

CAPITULO 1

CAPITULO 2

CAPITULO 3

CAPITULO 4

CAPITULO 5

LISTA DE FIGURAS

CAPITULO 1

CAPITULO 2

CAPITULO 4

CAPITULO 5

RESUMO

Diante da conjuntura de uma segunda revolução verde, associada com o advento das mudanças climáticas, torna-se imperativo identificar plantas eficientes em relação ao uso da água. Neste contexto, o milheto (*Pennisetum glaucum* (L.) R.) pode ser uma cultura chave para sistemas agrícolas dependentes de chuva. Desse modo, objetivou-se avaliar o desempenho agronômico e parâmetros nutricionais de cultivares de milheto; calibrar e validar um modelo de simulação de desempenho agronômico, visando a sua aplicabilidade em estratégias de manejo; e avaliar a influência da maturidade fisiológica nas características agronômicas, qualidade e parâmetros nutricionais da silagem de milheto. Foram realizados quatro experimentos, distribuídos em três estações experimentais. No Experimento 1, cinco cultivares de milheto foram avaliadas para produção de silagem. A produtividade de biomassa variou de 9,9 a 14,1 t/MS/ha e a produtividade de matéria seca digestível variou de 5,0 a 7,2 t/MS/ha. No Experimento 2, em condições semelhantes ao experimento anterior, observou-se produtividade de matéria seca variando de 7,6 a 11,5 t/MS/ha, enquanto a produtividade de matéria seca digestível variou de 3,7 a 5,6 t/MS/ha. Na análise de agrupamento observou-se a formação de três grupos distintos, com destaque para o grupo composto pelas cultivares CMS-03 e CMS-01. No Experimento 3 também foram avaliados cinco cultivares de milheto, no entanto além das características agronômicas foram observados parâmetros relacionados a qualidade da silagem, consumo e digestibilidade aparente. A produtividade de matéria seca digestível foi de 6,6 t/MS/ha. O cultivar IPA BULK1-BF apresentou o maior percentual de panícula e digestibilidade *in vitro* da matéria seca, enquanto a cultivar BRS 1501 apresentou as maiores concentrações de ácido butírico e valores de pH. O consumo e a digestibilidade aparente não foram influenciados pelas cultivares. Na avaliação do modelo de predição, foram utilizados os dados experimentais oriundos dos três ensaios citados anteriormente. Baseando-se em dados climáticos dos últimos 15 anos, simularam-se diferentes datas de plantio e avaliou-se o impacto dessa estratégia de manejo no desempenho de quatro cultivares de milheto. Os resultados mostraram que o modelo foi hábil para simular de forma acurada a fenologia e desempenho da cultura, frente aos dados mensurados. Além disso, observou-se que o período ótimo de plantio variou entre as localidades e é dependente de padrões climáticos, mas apresentou a mesma tendência entre as cultivares. No Experimento 4, utilizou-se apenas uma cultivar de milheto cortada em diferentes estágios de maturidade. Os resultados mostraram que a produtividade de matéria seca e matéria seca digestível, a concentração de matéria seca, carboidratos e lignina aumentaram com o avanço da maturidade. No entanto, a concentração de proteína bruta, consumo e digestibilidade aparente decresceram. Conclui-se que as cultivares de milheto apresentaram viabilidade para produção de forragem em condições semiáridas. Para o IPA BULK1-BF observou-se maior potencial para produção de silagem com corte após 50 dias de plantio. O modelo CSM-CERES-Pearl Millet pode ser usado como uma ferramenta estratégica na definição de planos de manejo para a cultura do milheto em condições semiáridas brasileiras.

Palavras-chave: agricultura de sequeiro, eficiência de uso da água, forragem, modelos, ruminantes, silagem

ABSTRACT

Faced with the second Green Revolution scenario, associated with the advent of climate change, becomes imperative to identify water-use efficient plants. In this context, pearl millet (*Pennisetum glaucum* (L) R) can play an important role in rainfed agricultural systems. Thus, the objective was to evaluate the agronomic performance and nutritional parameters of pearl millet cultivars for silage production; calibrate and validate a dynamic crop simulation model, aimed at its application in management strategies; and evaluate the influence of physiological maturity in agronomic traits, quality and nutritional parameters of pearl millet silage. For this, were conducted four trials, distributed in three experimental stations. In Experiment 1, five pearl millet cultivars were evaluated for silage production. The biomass yield ranged from 9.9 to 14.1 t/DM/ha, and digestible dry matter yield ranged from 5.0 to 7.2 t/DM/ha. In Experiment 2, under similar conditions of the previous experiment, was observed a dry matter yield ranging from 7.6 to 11.5 t/DM/ha, while the digestible dry matter yield ranged from 3.7 to 5,6 t/DM/ha. In cluster analysis was observed the formation of three distinct groups, with the group formed by CMS-03 and CMS-01 cultivars out-performed the others. In Experiment 3 were also evaluated five cultivars of millet, however beyond agronomic parameters were observed quality silage, intake, and digestibility. Digestible dry matter yield had an average value of 6.6 t/DM/ha. The cultivar IPA BULK1-BF had the highest percentage of panicle and *in vitro* digestibility of dry matter, while the BRS 1501 showed the highest concentrations of butyric acid and pH values. Intake and apparent digestibility were not influenced by cultivars. In assessing the prediction model, the experimental data from the three trials mentioned above were used. Based on long-term historical weather data, were simulated different sowing dates and evaluated the impact of this management strategy in the performance of four pearl millet cultivars. The results showed that the model was able to simulate the phenology and crop performance accurately, compared to measured data. Furthermore, it was observed that the optimum sowing window varied among locations depending on rainfall patterns, although showing the same trend for cultivars within a site. For the Experiment 4 was used only one pearl millet cultivar harvested at different maturity stages. The results showed that the dry matter and digestible dry matter yield, the concentration of dry matter, carbohydrates and lignin increased with maturity increasing. However, the concentration of crude protein, intake and apparent digestibility decreased. Therefore, it concludes that the pearl millet cultivars had feasibility for forage production under semi-arid conditions. For the cultivar IPA BULK1-BF was observed potential to yield forage within a wide harvest window, which ranges between

50 and 80 days after sowing. The CSM-CERES-Pearl Millet model could be a useful tool for the definition of management strategies for the pearl millet crop at Brazilian semi-arid.

Keywords: crop models, forage, rainfed agriculture, ruminants, silage, water-use efficiency

INTRODUÇÃO

As regiões semiáridas brasileiras são caracterizadas por problemas relacionados à insuficiente disponibilidade de água e, principalmente, por uma distribuição pluviométrica irregular, que impõem severas restrições à produção agropecuária.

De maneira geral, culturas forrageiras tradicionais, como o milho, sofrem instabilidade de cultivo, ocasionada, principalmente, por essa condicionante climática, assim como pela insuficiência de variedades adaptadas, que possam reduzir os riscos de frustrações de safras.

Esses aspectos reforçam a necessidade do uso estratégico de alternativas forrageiras, objetivando melhorar os índices de produtividade e, consequentemente, a renda familiar dos produtores desse setor. Estudos orientados neste sentido podem demonstrar que o uso planejado e diversificado de opções forrageiras, nativas ou introduzidas, que sejam eficientes em relação ao uso da água podem aumentar a chance de sucesso dos sistemas de produção pecuária em regiões semiáridas.

O mesmo efeito negativo dos fatores climáticos sobre a produtividade pode ser observado na pecuária do semiárido nordestino, a qual se baseia na criação de caprinos e ovinos. Esta região é detentora do maior rebanho ovino do país, com 8.186.436 cabeças, o que corresponde a 59% do efetivo nacional (ANUALPEC, 2015). O baixo desempenho zootécnico observado na região semiárida brasileira deve-se, principalmente, a forte dependência que os sistemas de produção têm da vegetação nativa da caatinga, fonte alimentar básica, quando não única, dos rebanhos. A acentuada redução anual na oferta de forragem durante as estações secas é o principal fator determinante do nível de produtividade.

Para suplantar essas adversidades regionais faz-se necessário a utilização de ferramentas que possam viabilizar o agronegócio da pecuária moderna. Dentre as técnicas agropecuárias, o uso da silagem tem sido apontado como opção na manutenção da produção animal, principalmente durante o período seco, quando ocorre déficit de alimento volumoso.

O uso de cultivares modernas de milheto com potencial para atingir produções por área satisfatórias, boa qualidade e que sejam adaptadas às condições locais tem sido apontado como responsável pelos ganhos em produtividade, gerando um produto economicamente viável. A interação entre genótipo e ambiente é importante, pois é desta relação que depende o desempenho e a produção final.

A escassez de informações regionais, pertinentes ao comportamento agronômico, produtivo e valor nutritivo dos diversos materiais genéticos existentes no mercado, constitui um obstáculo para a escolha de genótipos de milheto que se destinem à produção de silagem no semiárido. Portanto, a caracterização agronômica dos materiais genéticos disponíveis no mercado é de fundamental importância para se obter alta produção de silagem com elevado valor nutritivo.

Segundo Almeida Filho et al. (1999), a identificação de plantas mais adaptadas às condições em que serão cultivadas contribuíram para maiores rendimentos da cultura do milheto, ressaltando que, além da genética, a produção é influenciada, entre outros fatores, pela qualidade das sementes, época de plantio, população de plantas, preparo, correção e adubação do solo, controle de plantas daninhas, pragas e doenças, irrigação, entre outros.

Na região semiárida, essa relação entre a cultivar e o espaço edafo-climático torna-se ainda mais importante, dado a peculiaridade dessa região, que possui baixos índices pluviométricos, onde a precipitação é concentrada. A utilização de materiais genéticos de ciclo curto e eficientes na utilização de água é uma alternativa para evitar, ou minimizar, os ricos de insucesso devido a falta de chuvas.

A otimização de sistemas de produção pecuária, viáveis para as condições semiáridas depende, principalmente, da produção de silagem de baixo custo e de alto valor nutritivo, para que o giro de capital investido seja feito no menor tempo possível (Brondani et al., 2000). Assim, de modo geral, pesquisas de comparação entre genótipos adaptados são fundamentais para o avanço dos programas de melhoramento genético, e importantes na recomendação a técnicos e produtores sobre a variedade destinada à produção de silagem que melhor agregue características positivas em relação à produção, valor nutritivo e viabilidade. Desse modo, são necessários estudos com variedades de milheto, adaptadas a região semiárida brasileira, que podem constituir opção volumosa suplementar de alta qualidade na forma de silagem.

O presente trabalho teve como principais objetivos: (*i*) avaliar as características agronômicas, composição químico-bromatológica, qualidade e parâmetros nutricionais das silagens de milheto na região semiárida brasileira; (*ii*) Avaliar um modelo de simulação de fenologia e desempenho agronômico, visando a sua aplicabilidade na análise de estratégias de manejo frente à eficiência produtiva e risco climático para o cultivo dessa espécie; (*iii*) Assim como, estudar a influência da maturidade fisiológica da planta no desempenho, características agronômicas e valor nutricional da silagem de milheto.

A tese foi dividida em cinco capítulos: (*i*) *Performance and genetic divergence among pearl millet cultivars in a Brazilian semi-arid region; (ii) Divergence in agronomic traits and* *performance of pearl millet cultivars in Brazilian semi-arid region; (iii) Agronomic traits, ensilability and nutritive value of five pearl millet cultivars grown in a Brazilian semi-arid region; (iv) Simulated optimum sowing date for forage pearl millet cultivars in multilocation trials in Brazilian semi-arid region; (v) Performance, agronomic traits, ensilability and nutritive value of pearl millet cultivar harvested at different growth stage*. A redação dos capítulos foi realizada de acordo com as normas das revistas *Experimental Agriculture, Crop & Pasture, Journal of Agricultural Science, Crop Science* e *Animal*, respectivamente.

REVISÃO DE LITERATURA

1. Caracterização da agropecuária no semiárido brasileiro

O semiárido brasileiro está limitado pelas latitudes 3º e 18º sul e longitudes 35º e 46º oeste de Greenwich, abrangendo parte dos estados do Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia e Norte Setentrional de Minas Gerais, totalizando uma área de 969.589 km^2. O clima que predomina na região é do tipo BSh, com precipitação anual total média compreendida entre 380 e 760 mm (Araujo Filho et al., 1995).

Segundo Sá et al. (2004), o Nordeste brasileiro é dividido em três zonas: Litorânea, Sertão e Agreste. Estas duas últimas formam, essencialmente, a região semiárida, abrangendo 70% da área nordestina e 13% do Brasil. A área de domínio da Caatinga, único bioma exclusivamente brasileiro, compreende cerca de 800.000 km^2, ou seja, 55,60% da região Nordeste.

A região nordestina do Brasil possui um rebanho caprino que se aproxima a 9,5 milhões de cabeças e a um rebanho ovino com cerca de 8,01 milhões de animais (IBGE, 2014). Assim, Leite e Vasconcelos (2000) citam a produção de pequenos ruminantes como uma das mais importantes atividades econômica e social do semiárido nordestino.

A pecuária tem constituído a atividade básica das populações rurais, onde a exploração da caprinovinocultura e seus produtos como carne, leite e derivados, contribuem para a melhoria da dieta alimentar e para o aumento da renda dos produtores locais (Guimarães Filho et al., 2000).

Uma das grandes variantes para a produção animal na região do semiárido brasileiro é a sazonalidade de produção de forrageiras ao longo do ano, levando a períodos de grande produção durante a estação chuvosa que pode ir de dezembro a março, seguida da estação seca com escassez de chuvas e consequentemente de pasto.

Segundo Souto et al. (2005), na época das chuvas a disponibilidade de forragens, na caatinga, é quantitativa e qualitativamente satisfatória; todavia, nas épocas críticas do ano, além da escassez de forragem, o valor nutritivo das mesmas se apresenta em níveis baixos, o que acarreta queda na produtividade.

Por ser explorada principalmente de modo extensivo, a ovinocaprinocultura no semiárido mostra-se altamente dependente da vegetação natural da caatinga, este fato aliado à utilização de genótipos não especializados, confere ao sistema baixos índices de desempenho, destacando a alta mortalidade de animais jovens (aproximadamente de 20%) e a elevada idade (15 meses) para atingir o peso de abate de 25 kg (Guimarães Filho et al., 2000).

Um dos principais impedimentos à viabilização de sistemas pecuários no Nordeste é a pequena disponibilidade de volumosos de qualidade e o manejo inadequado dos recursos forrageiros existentes. A combinação desses recursos forrageiros, associados a práticas de ensilagem, fenação e utilização de resíduos da agroindústria, representa uma sólida base para edificar sistemas de produção no semiárido.

Armazenar forragens de boa qualidade para utilização no período seco significa ir de encontro a um dos principais problemas da exploração pecuária regional, que é a extrema estacionalidade da produção forrageira. (Maciel et al., 2004).

Como ponto de partida para a estruturação dos sistemas produtivos sertanejos, deve-se almejar o planejamento para produção e conservação de forragens, bem como, a utilização de alimentos alternativos adaptados às condições locais e de resíduos agroindustriais que possam ser destinados à alimentação animal, evitando-se ou amenizando os efeitos negativos da falta de alimentos volumosos na época da seca.

2. Caracterização da espécie

O milheto [*Pennisetum glaucum* (L.) R. Br.] pertence à família *Poaceae*, subfamília *Panicoideae*, gênero *Pennisetum* (Bruken, 1977). Há várias sinonímias botânicas usadas para esta espécie, sendo que nos últimos 200-300 anos, o milheto tem recebido nomes de espécies tais como *Pennisetum glaucum* L. e *Pennisetum typhoides* (Burm.) Stapf e Hubb. Em 1976, foi renomeado *Pennisetum americanum* (L.) Leeke (Terrel, 1976). No entanto, Andrews e Rajewskim (1995) concluíram que *Pennisetum glaucum* L. parece ser o mais apropriado nome para o milheto, dado suas características genéticas.

Segundo (Durães et al., 2003) o milheto é uma gramínea anual, robusta, de crescimento ereto, com altura que varia entre 1,5 e 3,0 m. Os colmos são lisos abaixo da panícula e normalmente possuem entre 1 e 2 cm de diâmetro, sendo que algumas vezes, apresentando ramificações secundárias e terciárias a partir de gemas laterais dos nós. A planta perfilha frequentemente, produzindo uma abundante folhagem. O sistema radicular é muito volumoso, porém aproximadamente 80% das raízes encontram-se nos primeiros 10 cm de profundidade.

As folhas são longas, lisas ou de superfícies pilosas e com lígulas pilosas. As lâminas foliares são lanceoladas e algumas vezes de comprimento entre 90 e 100 cm ou mais e 5 a 8 cm de largura. A nervura pode ser proeminente ou não, para cima ou tombada. Os estômatos são encontrados em ambos os lados da superfície foliar, em números iguais, variando de 50 a 80 por milímetro quadrado. Folhas e colmos podem variar em cor de verde-amarelado a púrpura.

A inflorescência é uma panícula terminal, rígida e compacta, cilíndrica, cônica ou de forma espiralada, de 5 a 50 cm de comprimento por 2 a 10 cm de diâmetro, embora algumas variedades incomuns possam crescer até 150 cm.

As espiguetas (em número de duas por fascículo) são obovadas, curto-pediceladas e de 3,5 a 4,5 mm de comprimento. O florescimento é iniciado aos 50 dias de idade, e o ciclo da planta situa-se entre 70 e 90 dias (do plantio à maturidade fisiológica).

Há algumas variações em tamanho de grão e o tempo para maturidade fisiológica entre grãos em diferentes localizações na panícula. Tipicamente ambos são maiores na base da panícula que no centro ou no ápice e frequentemente maiores no centro que no ápice. Há também considerável variação em tamanho de grão entre variedades, de tão pequeno quanto 3-4 g por 1000 grãos para mais alto, como 10-12 g. Grãos maduros variam em forma, sendo geralmente arredondados no ápice e estreitos na região do hilo (Fussel e Dwarte, 1980).

Uma importante característica agronômica do milheto é sua eficiência no uso da água, e de acordo com Tabosa et al. (1998), a planta utiliza 280 kg água/kg de matéria seca (MS). Chapman e Carter (1976) observaram que o milheto utilizou 302 kg água/kg MS, em comparação com o milho, trigo e sorgo que utilizaram 370, 590 e 321 kg água/kg MS, respectivamente. Comparando com milho e trigo, o milheto conseguiu produzir a mesma quantidade de MS com 25% e 51% menos água, respectivamente.

2.1. Genótipos de milheto para produção de silagem no semiárido

Dada as suas características edafoclimáticas, a região semiárida carece de estudos referentes a forrageiras adaptadas às suas condições. Dentre as forrageiras, devido a seu potencial de utilização nesta região, o estudo de variedades de milheto torna-se uma necessidade premente. Vale ressaltar que a Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) e o Instituto Agronômico de Pernambuco (IPA) desenvolvem um importante trabalho de avaliação de genótipos de milheto para o semiárido brasileiro, objetivando a produção de grãos e forragem.

Os genótipos de milheto, antes de serem indicados aos produtores, são avaliados em redes de ensaio de competição (ensaio nacional), de genótipos, sendo classificados de acordo com a sua aptidão/finalidade.

Atualmente, os cultivares existentes no mercado são em número reduzido e, na maioria das vezes, provenientes de outros países e de polinização aberta. No entanto, estudos nacionais têm lançados produtos bastante promissores como, por exemplo, o cultivar desenvolvido pelo IPA e pela Universidade Federal de Pernambuco lançado em 1977, o IPA BULK1-BF. Este cultivar de milheto forrageiro foi obtido através de um processo de seleção dentre 400 progênies. Compreende material precoce, rústico e adaptado às condições do semiárido. Apresenta porte de até 250 cm com produção de matéria seca por corte da ordem de 6-13 t/ha e produção de grãos variando de 710 a 1.510 kg/ha. Quando colhido entre os estádios de emborrachamento a grão leitoso, a concentração de proteína bruta pode chegar entre 18 a 20% (Tabosa et al., 1999).

O cultivar BN-2 foi lançada em 1991 e os rendimentos médios registrados atestaram o alto potencial para a produtividade desta variedade, justificando assim sua recomendação para exploração comercial nos diferentes sistemas de produção em execução nos distintos ecossistemas brasileiros. As principais características desta variedade sintética oriunda de diversas introduções da África são: hábito ereto, porte de 1,4 a 2,2m, panícula grande (20 a 35 cm), boa produção de sementes, grande perfilhamento, apresenta boa tolerancia à acidez de solo e a produção média é de 10 a 12 t/ha de massa seca (Pereira Filho et al., 2005).

A Embrapa Milho e Sorgo, em 1999, lançou a variedade BRS 1501, adaptada para produção de massa em sistemas de plantio direto. Adapta-se muito bem às condições que oferecem riscos de déficit hídrico e apresenta bom potencial de produção de grãos. É uma variedade de polinização aberta, originada por seleção massal de uma população americana. Possui ciclo médio, boa capacidade de perfilhamento e tem mostrado boa recuperação na rebrota. Além da adaptação às condições climáticas do semiárido, características como ser uma variedade de polinização aberta; apresentar 50% do florescimento entre 50 e 55 dias; altura da planta entre 1,70 m e 1,90 m; grãos semi-duros e de coloração cinza, além do potencial genético para a produtividade de 8 toneladas /hectare de massa seca e produtividade média de grãos de 2,5 toneladas/hectare fazem desta variedade uma das opções para utilização nesta região (Rodrigues et al., 2010).

O programa de melhoramento executado pela Sementes Adriana e Bonamigo Melhoramentos disponibilizou para o mercado a variedade ADR 300, que apresenta ciclo precoce e boa resistência a doenças, principalmente à ferrugem. Algumas características desta variedade como: polinização aberta; 50% de florescimento em 45 a 50 dias; ciclo até a colheita de 92 dias; altura da planta entre 1,89 m a 2,30 m; tamanho de panicula entre 0,20 m a 0,30 cm; tolerância ao acamamento e quebramento; produtividade média de massa seca de 9 toneladas/ha e produtividade média de grãos de 2,3 toneladas/ha, torna esta variedade interessante para a cultura do milheto no semiárido (Pereira Filho et al., 2005).

3. Potencial forrageiro e valor nutricional

Dado o advento das mudanças climáticas, assim como da diminuição das reservas hídricas globais, a partir da ultima década diversos programas de melhoramento genético, em todo o mundo, incorporaram e priorizaram o milheto em suas pesquisas e obtiveram êxito em selecionar espécies com características interessantes como: moderada a alta produção de biomassa, teores de proteína bruta moderados e a capacidade de sobreviver a uma vasta gama de condições ambientais, incluindo solos de baixa fertilidade e deficiência hídrica (Bidinger et al., 2009).

Mclaughlin et al. (2004) afirmaram que o milheto apresenta alto potencial forrageiro, dada as suas observações com esta espécie durante três anos no estado americano do Mississipi, onde essa forrageira apresentou rendimento de matéria seca de 15,7 t/ha, quando submetida à fertirrigação correspondente a 400 kg de nitrogênio/ha.

Em outros países, principalmente àqueles que apresentam características de aridez e semiaridez, a cultura do milheto também apresentou potencialidade para produção de forragem, como descreveu Ayub et al. (2007) que estudaram a influencia de diferentes doses de nitrogênio na produtividade de milheto no Paquistão e observaram produtividades de MS que variaram de 8,1 a 14,8 t/ha.

No México, Morales et al. (2011) avaliaram a produtividade de milheto no primeiro corte e na rebrota, em quatro estádios de maturação, e observaram produtividades de matéria seca 5,2 t/ha para os estádios de florescimento e grão leitoso e 5,0 t/ha para o farináceo. Esses autores observaram ainda que o milheto cortado ao florescimento produziu 30% do observado ao primeiro corte, mas com redução drástica de produção para os tratamentos com estádios mais avançados. Produtividades semelhantes foram observadas por Bashir et al. (2014), no Sudão, onde esses autores observaram produtividade média de 5,1 t/MS/ha para 225 acessos de milheto oriundos do programa de melhoramento genético do Instituto Internacional de Pesquisa de Culturas para o Trópico Semiárido (ICRISAT).

No Brasil, estudos foram realizados nos mais diversos biomas, com objetivos variados, a fim de avaliar a potencialidade desta forrageira. Guimarães Júnior et al. (2009) avaliaram a produtividade de três genótipos de milheto no Sudeste brasileiro, em cinco idades de corte, e observaram produtividades que variaram de 6,0 a 7,5 t/MS/ha, com as plantas cortadas aos 82 dias. Ressalta-se que nesse estudo a rebrota correspondeu a apenas 12% da produtividade observada ao primeiro corte, o que possivelmente esteve relacionada à deficiência hídrica ao final do experimento.

A versatilidade do milheto quanto à adaptação climática foi observada por Silva et al. (2003), que ao estudarem milheto produzido no bioma cerrado reportaram produtividade de MS que variou de 3,8 a 5,4 t/ha, em diferentes épocas de plantio.

A produtividade do milheto cultivado na região semiárida brasileira é semelhante à observada nas outras regiões do país, como foi observado por Aguiar et al. (2006) que relataram produtividade de 5,6 t/MS/ha, para a variedade IPA BULK1-BF cultivada no Rio Grande do Norte. Resultado semelhante foi observado por Silva et al. (2000) quando avaliaram também o IPA BULK1-BF no semiárido, em solo com características de baixa fertilidade, e relataram produtividade média de 5,0 t/MS/ha.

No entanto, em regiões semiáridas a produtividade está intrinsicamente relacionada com a eficiência de utilização de água e nesse aspecto o milheto apresenta-se superior a culturas tradicionalmente utilizadas para produção de volumoso para animais, como o milho e o sorgo. Rostamza et al. (2011) observaram que o milheto submetido a diferentes doses de nitrogênio apresentou eficiência no uso da agua que variou de 290,6 a 352,2 kg água/kg MS.

A eficiência do uso da água também está ligada a produção de outro componente importantíssimo para o desenvolvimento das plantas forrageiras que é a raiz, e nesse sentido Rostamza et al. (2013) observaram que o milheto é mais eficiente que o sorgo uma vez que produziu 3,9 g de MS de raiz/kg água, enquanto o sorgo produziu 3,0 g de MS de raiz /kg água. Com o mesmo propósito Zegada-Lizarazu e Iijima (2005) avaliaram seis espécies de milheto forrageiro (finger millet (*Eleusine coracana*), Job's tears (*coix lacryma-jobi)*, barnyard millet (*Echinochloa utilis*), common millet (*Panicum miliaceum*), milheto (*Pennisetum americanum*) e foxtail millet (*Setaria italica*)) e observaram eficiência na utilização da agua variando de 1,9 a 4,2 g de MS de raiz /kg água, sendo a maior produtividade do *Pennisetum americanum*.

Variações na aceitabilidade, produtividade, composição química, e valor nutritivo das diversas variedades de milheto foram relatados na literatura. Estas variações dependem de fatores climáticos, como temperatura, umidade, precipitação e intensidade luminosa, assim como da variedade e também de práticas de manejo (Munawwar et al., 2014).

A Tabela Brasileira de Composição de Alimentos para Bovinos (Valadares Filho et al., 2006) fornece uma visão geral sobre as características nutricionais da silagem de milheto e mostra que a mesma possui, em média, 26,2% de MS, 8,0% de proteína bruta (PB), 73,0% de fibra insolúvel em detergente neutro (FDN), 38,2% de fibra insolúvel em detergente ácido (FDA), 4,3% de lignina e 60,2% de nutrientes digestíveis totais (NDT).

No entanto, os estudos ao redor do mundo apresentam uma ampla variação em relação à bromatologia da planta do milheto. As principais razões para essa ampla variação está relacionada com a variedade, tempo de colheita e conservação.

Nesse sentido, Ward et al. (2001) realizaram um ensaio onde foi avaliado o híbrido "Pennleaf" *in natura* ou conservado na forma de silagem, sendo que este ensaio apresentou diferenças significativas na pré e pós-ensilagem, principalmente em relação aos teores de carboidratos solúveis (9,8% antes da ensilagem e 1,9% pós-ensilagem) e frações fibrosas, onde na pré-ensilagem a FDN e FDA apresentaram 63,6 e 38,0%, respectivamente, enquanto após a ensilagem os valores foram de 58,7 e 34,9%, para FDN e FDA respectivamente.

Já Hassanat et al. (2006) estudando o valor nutritivo da forragem fresca oriunda de genótipo Brown Midrib (BMR) obtiveram os seguintes valores: 29,6% de MS; 8,3% de PB; 64,0% de FDN; 32,70% de FDA; 17,8% de carboidratos solúveis (CHO) e 9,0% de amido. Após a ensilagem esses autores observaram alterações nos valores para: 24,1% de MS; 8,3% de PB; 66,0% de FDN; 34,6% de FDA; 3,8% de CHO e 11,0% de amido.

No Brasil também foi observada ampla variação na composição bromatológica da silagem de milheto. Costa et al. (2011) avaliaram silagens de cinco genótipos de milheto (ADR 500, ADR 7010, LAB 0730, LAB 0731 e LAB 0732) cortados aos 60 dias, no estádio leitoso farináceo, e obtiveram valores de 28,6 até 30,1 para as porcentagens de MS. Esses mesmos autores observaram que estas silagens apresentaram uma razoável variação quanto ao teor de proteína bruta, variando de 10 a 13% da MS, enquanto a FDN variou de 51,7 a 61,3% e o NDT variou de 54,0 a 64,1%.

No entanto Amaral et al. (2008) analisaram silagens de três genótipos de milheto feitas com plantas colhidas aos 90 dias após plantio, e encontraram os seguintes valores: 27,7% de MS; 7,1% de PB e 41,5% FDA.

O teor de extrato etéreo das silagens de milheto não apresenta ampla variação, estando sempre na faixa entre 1,4 e 2,0 % da MS, em decorrência da variedade e do manejo utilizado (Hassanat et al., 2006)

A variedade pode influenciar no teor de energia encontrado na silagem de milheto, uma vez que as variedades conhecidas como "High WSC" (ricos em carboidratos solúveis em água) diferem significativamente das variedades comuns, onde as variedades HWSC apresentam energia líquida entre 5,7 e 6,8 MJ/kg de MS, enquanto as comuns apenas 4,2 MJ/kg de MS (Amer et al., 2012).

A digestibilidade da matéria seca das silagens de milheto pode variar bastante em decorrência da variedade, estádio fenológico e fatores edafoclimáticos, podendo variar de 70% nas melhores condições até 40% em circunstâncias desfavoráveis (Jung et al., 2012). A correlação entre a redução da digestibilidade da MS com o aumento da maturidade foi observado por Morales et al. (2011) que apresentaram os valores de 68,3; 66,2,; 64,0 e 58,7% de digestibilidade da MS para as idades de corte de 53, 66, 85 e 102 dias após o plantio, em silagens de milheto da variedade de duplo propósito ICMV 221.

4. Silagem de milheto na alimentação de ruminantes

Milheto tem sido utilizado, em várias regiões áridas e semiáridas do mundo, como um recurso forrageiro importante, na complementação de dietas para ruminantes. O pastejo de áreas estrategicamente reservadas para serem utilizadas no período mais crítico do ano, tem sido a sua principal forma de utilização.

Nesse sentido Fontaneli et al. (2005) avaliaram o desempenho de vacas da raça Holandês em lactação em pasto de milheto e relataram consumo de 10,9 kgMS/dia e produção média de leite de 25,1 kg/dia. Rude et al. (2003) também estudaram bovinos pastejando milheto, e observaram que novilhos com peso médio de 214 kg consumiram 2,6% do peso vivo/dia e apresentaram ganho de peso de 770 g/dia, valores considerados aceitáveis pelos autores, uma vez que o milheto era volumoso exclusivo.

O milheto pode, ainda, ser utilizado na forma de feno ou silagem, como reserva alimentar estratégica para períodos de escassez de alimentos. O feno de milheto na alimentação de caprinos foi estudado por Aguiar et al. (2006), e estes autores observaram que o consumo de MS apresentado pelos animais alimentados com feno de milheto (485,7 kg/dia) foi superior aos consumos apresentados por cabritos alimentados por capim elefante, sorgo sudanense e sorgo forrageiro. No entanto, não foi observada diferença na digestibilidade aparente da MS entre as espécies avaliadas.

De maneira geral a silagem de milheto é utilizada como alternativa às culturas tradicionalmente utilizadas para produção de silagem. Nesse sentido, Amer e Mustafa (2010) avaliaram a silagem de milheto em substituição à silagem de milho, em dietas para vacas em lactação, com relação volumoso:concentrado de 53:47, e não observaram diferenças no consumo de MS (24,1 kgMS/dia para silagem de milheto e 23,6 kgMS/dia para silagem de milho) e nem para produção de leite (38,9 kg/dia para silagem de milheto e 37 kg/dia para silagem de milho) e concluíram que a silagem de milheto demonstrou considerável potencial como volumoso para vacas em lactação, por não interferir no desempenho dos animais.

Na alimentação de ovinos, Khan et al. (2011) observaram similaridade no consumo da silagem de milheto (1,0 kg/dia) em comparação com silagens de milho e sorgo (1,1 e 1,2 kg/dia, respectivamente), para machos da raça Sipli com peso médio de 30 kg. No entanto esses autores reportaram diferença entre o ganho de peso dos animais alimentados com silagem de milheto (120 g/dia) e as silagens de milho e sorgo (145 e 132 g/dia, respectivamente), o que os autores atribuíram a menor digestibilidade da MS, PB e FDN da silagem de milheto, assim como do balanço de nitrogênio mais favorável para as silagens de milho e sorgo.

No Brasil, Pinto et al. (1999) avaliaram silagem de milheto em comparação às silagens de milho, teosinto e capim sudão e observaram que apesar do consumo da silagem de milheto ser menor (23,1 g/UTM/dia) do que as silagens de milho, teosinto e capim sudão (67,6, 54,1 e 57,7, respectivamente), não foram observadas diferenças na digestibilidade aparente da MS, PB, FDN e FDA, e concluíram que a silagem de milheto quando comparada às espécies testadas, principalmente o milho, apresenta bom potencial para a alimentação dos ruminantes.

5. Modelos preditores de respostas produtivas em culturas forrageiras

A resposta das espécies às diferentes condições de cultivo tem sido avaliada por meio de modelos de simulação, que incorporam simplificações dos processos de crescimento das plantas e das suas interações com o ambiente, estes modelos com dados de campo e parametrizações, permitem aumentar o entendimento de processos específicos da cultura. Sua utilização é aceita mundialmente como uma ferramenta de fácil aplicação para propósitos de pesquisa e de práticas agronômicas, pois possibilita entender a resposta das plantas a diferentes condições ambientais e, posteriormente, predizer a produtividade das culturas.

Contudo, o sucesso da aplicação de modelos matemáticos depende substancialmente das calibrações realizadas localmente e, consequentemente, da qualidade dos dados usados em tais procedimentos de calibração (Lisson et al., 2005). Os resultados obtidos a partir da geração dos modelos podem ser utilizados como ferramentas de planejamento agrícola e de tomada de decisão, pois permitem reduzir os custos e aumentar sustentabilidade do sistema por meio da maximização do uso dos recursos naturais e da diminuição dos impactos sobre o meio ambiente (Keating et al., 1999). Quando bem elaborados, podem ser utilizados para a definição das melhores datas de plantios para culturas sob condições irrigadas e de sequeiro (Soler et al., 2007); avaliação de estratégias e aplicação de água e nutrientes (Rinaldi et al., 2007); previsão de safras (Yun, 2003); requerimento de água em escala regional (Heinemann et al., 2002); e para a avaliação dos impactos dos cenários de mudanças climáticas sobre a produção agrícola, uso da terra e ações políticas (Olesen e Bindi, 2002).

Todas essas informações são imprescindíveis aos produtores e ao governo com o objetivo de auxiliar no planejamento das atividades agrícolas e reduzir os riscos nas plantações (Hoogenboom, 2000). No Brasil, diversos estudos já foram realizados sobre o potencial de utilização de modelos preditores de desempenho agrícola para culturas como cana, milho, trigo e soja. No entanto, a parametrização e validação de modelos de simulação para milheto no Brasil são incipientes.

The Decision Support System for Agrotechnology Transfer (DSSAT) é um sistema abrangente que tem como principal objetivo dar suporte à tomada de decisão quanto às diversas opções de manejo (Tsuji et al 1994;. Jones et al., 2003; Hoogenboom et al. 2015). Englobado na plataforma DSSAT Version 4.6.1 (Hoogenboom et al., 2015; Jones et al., 2003), está o seu principal modelo de simulação de culturas, o Cropping System Simulation Model (CSM), que é um modelo dinâmico de simulação de culturas, que reproduz o crescimento, desenvolvimento e rendimento de 27 alimentos e outras culturas, incluindo milheto.

Crescimento da cultura é simulado por meio de uma progressão temporal diária, iniciando no plantio e finalizando na colheita, com base em processos fisiológicos que descrevem a resposta de culturas às condições de solo e clima. O potencial de crescimento é dependente da intercepção de radiação fotossinteticamente ativa, ao passo que a produção de biomassa real em qualquer dia é limitada por uma temperatura abaixo do ideal, o déficit de água no solo e deficiência de nitrogênio. Os dados de entrada necessários para executar os modelos do DSSAT incluem dados meteorológicos diários; dados de caracterização do solo; um conjunto de coeficientes genéticos que caracteriza os cultivares; e informações de manejo da cultura, tais como população de plantas, espaçamento entre linhas, profundidade de semeadura e de fertilizantes e estratégias de irrigação.

Fechter et al. (1991) realizou uma avaliação do modelo CSM-CERES-Pearl Millet para o sudoeste da Nigéria, enquanto Thornton et al. (1997) usaram o modelo para estimar a produção de milheto em Burkina Faso. O CSM-CERES- Pearl Millet também foi avaliado para quatro regiões na Nigéria por Ravelo e Planchuelo (1993); o modelo foi hábil para prever crescimento e desenvolvimento com precisão, uma vez que as estimativas de rendimento tinha uma média de erro relativo de 0,07.

Embora estes estudos sejam considerados valiosos, a avaliação do modelo CSM-CERES- Pearl Millet para diferentes regiões do mundo tem sido mínima em comparação com outros modelos de culturas tradicionais. Isso reflete a necessidade de novos estudos utilizando modelagem, especialmente para milheto, uma vez que esta é uma cultura importante para sistemas agrícolas em regiões áridas e semiáridas, que apresenta diferentes cenários de disponibilidade de água e, consequentemente, de eficiência produtiva da cultura.

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CAPÍTULO 1 - PERFORMANCE AND GENETIC DIVERGENCE AMONG PEARL MILLET CULTIVARS IN A BRAZILIAN SEMI-ARID REGION

ABSTRACT

Five pearl millet cultivars for silage production were tested under rainfed conditions in a field trial at a Brazilian semi-arid region. The experiment was set up in a randomized block design with five treatments and five repetitions. Total biomass yield ranged from 9.9 to 14.1 Mg DM ha^{-1} and digestible dry matter yield ranged from 5.0 to 7.2 Mg DM ha^{-1}. The plant height ranged from 161 to 177 cm and harvest index ranged from 27.3 to 36.4%. Average panicle proportion was of 30.6%, while was observed 13.3 and 55.9% for leaf and stem proportion, respectively. Under the conditions of the current study, the results obtained for production of dry and digestible dry matter, and the ratio of plant fractions, indicates the possible use of these cultivars for silage production in the Brazilian semi-arid region.

INTRODUCTION

Rainfed agriculture cropping systems must adapt to the new context marked by a more extreme water stress and extreme events more powerful. Essentially due to climate change, these phenomena are controlled by high temperatures and drought. Diversifying the traditional dryland cropping system employed in the Brazilian semi-arid requires information on the production potential of alternative crops that could be grown in this region. Because of the highly variable and frequently limited nature of precipitation in this region, forage production presents an attractive alternative to grain crop production.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is one of the most drought-tolerant crops, and can provide significant grain and biomass yields, despite its frequent cultivation under severely water-limited conditions, where others crops fail or suffer large yield reductions. Due this, is expected that its importance will be increased under climate change scenarios, for developing resilient cropping systems to extreme limits of hot and dry climate.

For this reason, comparative studies of genotypes are important to contribute to the breeding programs, as well as to evaluate the genotypes available seeking an appropriate balance between plant components, combined with high biomass productivity and nutritional value, for silage production.

The objective of this study was to evaluate the performance and agronomic traits of five pearl millet cultivars, under rainfed conditions, with focus on silage production at a Brazilian semi-arid region.

MATERIALS AND METHODS

Site description

The experiment was carried out at Experimental Station of the Agronomic Institute of Pernambuco (IPA), in the municipality of São Bento do Una, Pernambuco State, Brazil (Lat. 08º31′S; Long. 36º26′W; elevation of 614 m) during the 2011 rainy season, with sowing date on May 17 and harvest date on August 9. The soil type in this region is a eutrophic leptosol, predominantly of sandy loam textural class. The megathermal climate is typically semi-arid with an annual rainfall of 655 mm and average maximum and minimum temperatures of 32.6 and 11.6ºC, respectively. The rainy season was typical of semi-arid zones with erratic rainfall and poorly distributed (Figure 1). The meteorological station from Agronomic Institute of Pernambuco provided the data relating to precipitation, temperature, evaporation, relative humidity, wind velocity and growing degree days during the study (Table 1).

Pearl millet cultivars evaluated

Five pearl millet cultivars, IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and ADR 300, were used in the experiment. IPA BULK1-BF is a cultivar developed by Agronomic Institute of Pernambuco (IPA). It yields up 6.0 t ha^{-1} dry matter under rainfed conditions. It takes 50-60 days to flowering during winter. It is recommended mainly for forage production in Brazilian semi-arid regions. The Brazilian Agricultural Research Corporation (EMBRAPA) developed and released the cultivars BRS 1501, CMS-03 and CMS-01, which are adapted for areas with risks of drought conditions, besides have dry matter production average of 8.0 t ha^{-1} and good grain production potential (2.5 t ha^{-1}). For these cultivars the flowering occurs 50 days after planting. ADR 300 is a cultivar developed by Adriana Seeds Company and released in 2003. Its yields up to 6.6 t ha^{-1} dry matter during winter and 12.3 t ha^{-1} dry matter during spring and takes 45-50 days to flowering. It has good resistance to lodging and it is recommended for places with erratic rainfall conditions (Pereira Filho et al., 2003). The five cultivars were chosen because of their related duration to maturity, thus they are grown under rainfed conditions. The cultivars are already being grown by farmers, and therefore would easily be promoted under water deficit conditions once their performance is established.

Treatments, experimental design and crop management

Treatments were the five cultivars replicated five times in a randomized complete block design (25 plots). Plots measured 10.5 m^2 (5 × 2.1 m), with plants seeded in four rows (0.70 m centres) to a depth of 3 cm. The soil at the site had the following properties: pH (water): 6.6; P (mg/dm^3): 27; K ($cmol_c/dm^3$): 0.06; Al ($cmol_c/dm^3$): 0.20; H + Al ($cmol_c/dm^3$): 2.22; Ca ($cmol_c/dm^3$): 0.80; Mg ($cmol_c/dm^3$): 0.40; O.M. (g/kg): 10.2; value of saturation (S) = Ca+Mg+Na+K (($cmol_c/dm^3$): 1.3; CEC (Cation-exchange Capacity) = value of S + Al + H = 1.3 + 2.22 = 3.5 (($cmol_c/dm^3$); the value of CEC (%) = (value of S / CEC) x 100 = 36 %. At sowing fertilization, were used 150 kg ha^{-1} ammonium sulfate + 450 kg ha^{-1} triple superphosphate + 100 kg ha^{-1} potassium chloride. Two-side dressing fertilizations were applied, the first on the 30th day, and the second on the 60th day after plant emergence, with the dose equivalent to 150 kg ha^{-1} of ammonium sulfate. Before fertilization, approximately 1 t ha^{-1} lime (magnesium) was applied to fix aluminum levels and raise calcium and magnesium levels. Each treatment comprised *c*. 32 plants/m², achieved by thinning plots 20 days after emergence.

Cultivars were harvested when at least 60% of plants in each plot were at the dough stage of grain maturity. Cuttings were made manually and taken at 5 cm above ground level. Only the two central rows in each plot were harvested, with the remainder being discarded. The harvested crop from each plot was collected into baskets and weighed to estimate fresh yield/ha. After chopping a representative sample from each plot, a 400 g sub-sample was oven-dried at 55°C for 48 h to estimate DM concentration and yield of the five cultivars. Dry samples were ground through a 1 mm screen using a Wiley mill and stored at room temperature.

The agronomic characteristics studied included: plant height; population density; extent of lodging; harvest index; days from sowing to anthesis; DM partitioning of organs (panicle, stem and leaf); DM yield (DMY) (Mg ha^{-1}) and digestible DM yield (DDMY) (Mg ha^{-1}). Height of ten randomly selected plants within each plot was determined by measuring from ground to the top of the panicle using a tape measure. Plants were then separated into panicles, stems, and leaves, with the mass of each fraction determined after oven-drying at 65°C for 72 h. Population density was estimated by dividing 10.000 m^2 by the plant spacing in m^2. Score lodging was estimated the percentage area of plot that was lodged and then estimated the angle of stem lodging, where an angle of 10º from the perpendicular was scored as 10 whereas prostrate stems was scored as 90. Lodging for the plot was then calculated as:

(% plot area lodged × angle of lodging from vertical)/90. The DDMY was estimated by multiplying the *in vitro* dry matter digestibility from each repetition by its respective DMY. The water-use efficiency for DM and DDM yield, expressed in kg ha^{-1} mm^{-1}, was estimated by dividing the yield by the amount of accumulated rainfall during the crop cycle (mm). Growing degree days (GDD) were used to calculate and express daily heat unit accumulation relative to the pearl millet crop using temperature data.

Data analysis

Data were analysed using a mixed model approach with cultivar as a fixed effect, random effects of blocks and random residual error using the MIXED procedure of SAS Version 9.1 statistical program. When significant, cultivar means were compared using Fisher's protected LSD (i.e., the DIFF option of the LSMEANS statement). Significance was declared at P < 0.05. Pearson's correlation was used to determine the relationship between the performance and phenological variables and the correlation coefficients were calculated using the PROC CORR procedure from SAS Version 9.1 statistical program. Principal component analysis was based on correlation matrix and computed using adjusted entry means and a biplot was obtained to illustrate the relationships among the 9 agro-morphological traits. The biplot was generated by plotting the entries according to their scores of the first and second principal components, using the computational resources of MINITAB Version 16.2.4.4.

RESULTS

Cultivar height at harvest ranged from 161 to 177 cm, with CMS-01 being 10% taller (P < 0.05) than ADR 300, although no difference was observed between CMS-01, IPA BULK1-BF and CMS-03. At the same plant density, among all cultivars the BRS 1501 exhibited the lowest (P < 0.05) DM yield, while for DM digestible the cultivars CMS-03, CMS-01 and ADR 300 yielded more (P < 0.05) than BRS 1501 and IPA BULK1-BF. The cultivar ADR 300 showed the highest harvest index, since it was 24% above of the others cultivars average (Table 2).

In regards to DM partitioning, the cultivar BRS 1501 exhibited the lowest (P < 0.05) proportion of panicles among all others cultivars, while CMS-01, CMS-03 and ADR 300 exhibited higher panicle fraction than the cultivar IPA BULK1-BF. Furthermore, BRS 1501, IPA BULK1-BF and ADR 300 showed lower (P < 0.05) proportion of stems than CMS-03 and CMS-01. As for lodging, ADR 300 exhibited more (P < 0.05) resilient stems than BRS 1501, CMS-01, CMS-03 and IPA BULK1-BF (Table 2). Average panicle proportion was of

30.6%, while was observed 13.3 and 55.9% for leaf and stem proportion, respectively (Figure 2).

Correlation study showed positive correlation between plant height and the variables DMY, DDMY and lodging with values of 0.68, 0.71 and 0.40, respectively. This analysis also showed that there was positive correlation between DDMY and panicle proportion (0.25), as well as between plant density and DMY and DDMY. However, the variables DMY and DDMY had negative correlation with lodging (Table 3).

Principal components 1 and 2 explained 44 and 8%, respectively, of the total variation. In the resulting biplot, the five pearl millet cultivars were distributed throughout of three of the four sections. The biplot illustrates strong positive associations among the performance traits, especially between stem yield and DMY as well as among panicle yield and harvest index. The cultivars CMS-03 and CMS-01 share a higher relationship with DMY and stem yield variables while ADR 300 and IPA BULK1-BF showed affinity with panicle yield, harvest index and lodging score. Just the variable leaf yield and the cultivar BRS 1501 not followed the same trend of the others components.

DISCUSSION

Others studies have observed the forage potential of pearl millet in semi-arid regions, mainly owing to its desirable characteristics for ensiling and potential to yield high biomass in these regions.

Plant height of cultivars has been of paramount importance in the acceptance of a pearl millet variety by farmers, once they correlate the plant height with roughage productivity. This study identified average plant height of 167 cm, with variation between cultivars. In general, these results are corroborated by Pucher et al. (2015), who observed significant differences in plant height, with mean variation from 128 to 292 cm for pearl millet varieties (grain, forage and dual purpose) in different African regions. Studies have showed that plant height could be affected by genetic characteristics, as well as by the management techniques used for the evaluated genotypes, soil, and climatic conditions of each region. In this sense, Sanon et al. (2014) reported that the photoperiod can have influence on pearl millet height during the vegetative phase and showed that this process can increase the formation of nodes, internodes, primordial and sprouted leaves, which can even result in high production of dry matter. However, in this study the plant height was not decisive to establish difference in DMY for the cultivar ADR 300, since that it was similar to BRS 1501 for plant height, but they were different to DMY, probably due to differences between lodging resistance (Silungwe et al., 2010).

The mean whole-crop DM yield of 12.7 Mg ha^{-1} in the current study was greater than the range of values reported for three African genotypes (7–8 Mg ha^{-1}) and two Brazilian cultivars (7 Mg ha^{-1}) of pearl millet grown in the Brazilian sub-tropical climate (Costa et al., 2005). It is possible that greater daily heat unit accumulation observed during the growing season in north-east Brazil (1648 growing degree days (GDD) - °C) compared with those in south-west Brazil (Costa et al. 2005) (1204 GDD - °C) may explain the differences in DMY, as the cultivars from both experimental sites were cultivated in a soil with similar characteristics and harvested at almost the same whole plant moisture.

Final DDM forage yield is the ultimate goal, which depends upon the genomic as well as management and environmental factors. Among the cultivars in the current study, CMS-03, CMS-01 and ADR 300 had greater DDMY than BRS 1501 and IPA BULK1-BF likely because they had greater panicle proportion, which is the plant fraction more readily digestible. These results were matched with the findings of Morales et al. (2011) that the association and path coefficient analysis exhibited increase in the DDMY due to panicle proportion and leaf:stem ratio. These findings indicate that productivity is not related only with plant height, but also is influenced by lodging and phenological components.

Researches have reported that there is a great variation in plant partitioning (Munawwar et al., 2014). For instance, Yadav and Bidinger (2008), evaluating the performance of pearl millet varieties, detected an average of 21% for harvest index, which was inferior to average found by this study. Bashir et al. (2014) mentioned a large variation of panicle percentage between pearl millet varieties for grain, dual purpose and forage, with mean values between 13.5 and 39.4%, which were similar our results.

The percentage participation of panicle is directly associated with the production of grains and has influence on the quality of forage (Neves et al., 2015). Thereby, the selection of cultivars with higher proportion of panicle is an important criterion to obtain varieties with better nutritional values. Furthermore, according to Yadav and Bidinger (2008), the high proportion of grains in DM could be a factor for biomass production increases, as could be seen for the cultivar ADR 300. At this investigation was observed 55.9% of stem in total biomass. Bika and Shekhawat (2015), studying 30 pearl millet genotypes in India, observed lower percentages of stem compared to our research, with mean values ranged from 34.0 to 51.4%.

Some authors believed that there is a strong correlation between plant height and stem participation (Ganga et al., 2013), which may explain the trend observed at this study for these two characteristics. However, high percentage of stem can also be considered as an undesirable feature for forage production, since stem participation is inversely proportional to nutritional value and quality of silage (Fulkerson et al., 2008).

For this reason, Neves et al. (2015) argued that the analysis of the proportionality relationship among panicle, stem and leaf is very important because it indicates the potential of these genotypes to provide soluble carbohydrates in adequate amounts for optimal fermentation and, consequently, the production of high-quality silages with high productivity.

With respect to the different correlations, it was fairly evident that IPA BULK1-BF, CMS-03 and CMS-01, which showed the highest plant height, also presented the highest DMY, stem fraction and lodging. Although plant height has been used as an outstanding tool to make forage for silage selection in the last few years, it has been suggested other criterions to undertake it. As could be observed in the present study, this variable should be combined not only with DMY, but also with high-quality digestible fiber (DDMY), which is related with phenological components, because both can influence the silage quality and productivity. According to Neves et al. (2015), the determination of the panicle fraction is fundamental because it is positively correlated with the increase in the content of DM, production of grains and silage quality and, thus, it should be included as a criterion for selecting crop forage varieties for silage production.

The relationships illustrated in the principal component biplot describe a negative association between leaf yield and DMY, and this result is in line with the findings of Neves et al. (2015). In the present study, early-flowering accessions tended to have a higher panicle yield, perhaps due to the escape from terminal drought stress. These trait correlations should facilitate the selection of high-yielding cultivars for silage production in semi-arid zones. In general, the biplot illustrated the good prospects for developing pro-silage pearl millet cultivars with a wide range of agro-morphological characteristics and, therefore, different adaptation potential. These findings can contribute to the alleviation of shortage of roughage for production systems in the semi-arid.

At the current study was observed that the pearl millet cultivars could be a strategic feed for Brazilian livestock systems in a sustainable scenery, mainly because these forages require less water to yield DM and digestible DM/ha than other feed sources (such as maize or sorghum) that could be planted in these regions. Indeed, the pearl millet cultivars were more water-use efficient than sorghum and maize grown in temperate climate for maize (11 kg DM ha^{-1} mm^{-1}) grown in the United States and sorghum (14 kg DM ha^{-1} mm^{-1}) planted in China that exhibited lower water-use efficiency than the pearl millet cultivars (Deng et al., 2006; Nielsen et al., 2006).

Therefore, the current study showed that the pearl millet cultivars have potential to yield forage with less water and on the same area of land in a Brazilian semi-arid area or in regions where irrigation is not possible and precipitation limits maize silage production. In terms of agronomic performance and participation of panicles, this work highlights the cultivars CMS-01, CMS-03 and ADR 300, which may be recommended for silage production in Brazilian semi-arid region.

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Table 1. Meteorological data during the experimental period.

Month/Year	Days[1]	Rainfall (mm)[2]	Temperature (ºC)			RH (%)[3]	Wind (m/s)[4]	GDD (HU)[5]
			Max.	Min.	Mean			
May 2011	12	91.8	27.5	19.6	21.6	89.0	4.5	13.5
June 2011	17	56.2	27.0	17.3	21.1	85.6	4.6	12.2
July 2011	22	136.5	25.5	17.0	20.5	86.5	4.9	11.3
August 2011	02	9.1	27.5	16.7	21.2	79.7	5.0	12.1

[1]Occurrence of rainfall in days; [2]Rainfall in millimeters; [3]Percentage relative humidity; [4]Average wind velocity at a height of 2 m; [5]Growing degree days in heat units.

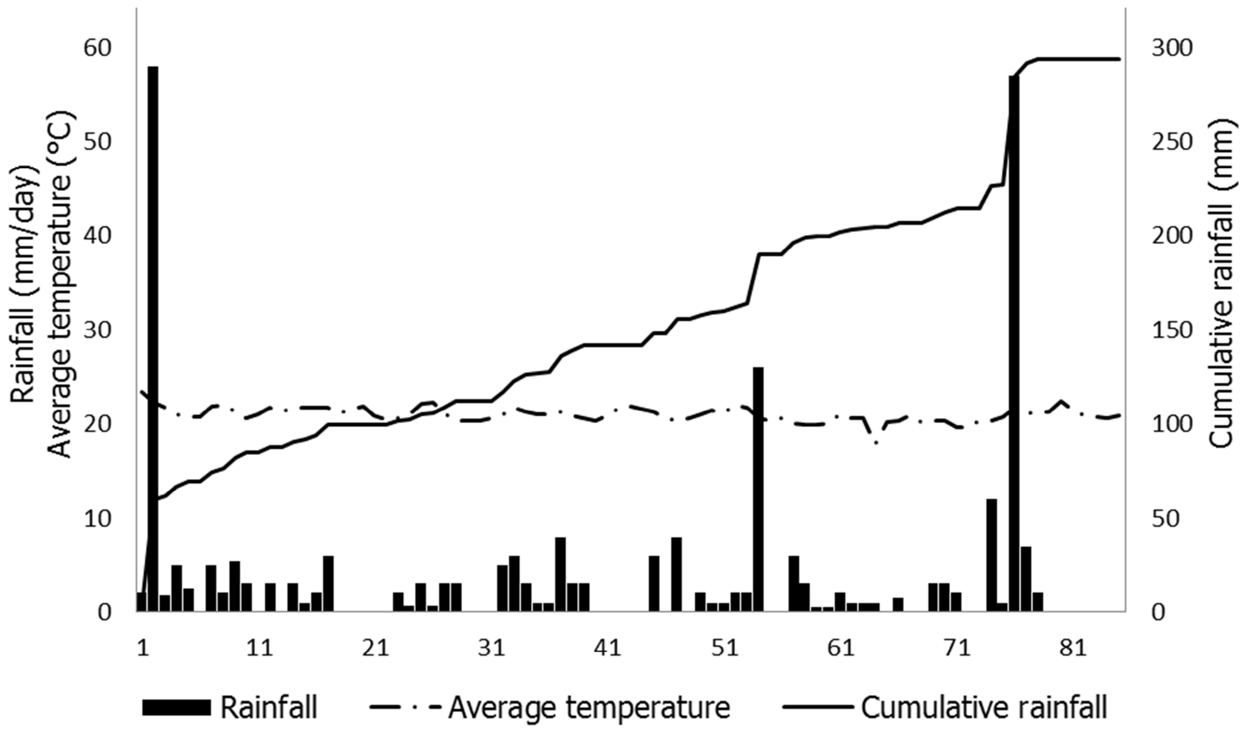

Figure 1. Rainfall distribution (mm) and average temperature (°C) at the experimental station of Agronomic Institute of Pernambuco from May to August 2011.

Table 2. Performance and phenological traits of pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	ADR 300	MEAN	S.E.M.	P
Plant height (cm)	167a	162b	174a	177a	161b	168	3.6	0.006
Plant density (1000 plants/ha)	153	156	157	154	154	154	14.5	0.359
DMY (Mg/ha)	12.6a	9.9b	14.1a	14.0a	13.2a	12.7	0.62	0.002
DDMY (Mg/ha)	5.9b	5.0b	7.2a	7.1a	6.7a	6.4	0.35	<0.001
Lodging score	2.8a	2.3a	2.5a	3.1a	1.7b	2.4	0.43	0.020
Harvest index (%)	31.0b	28.5b	27.3b	30.8b	36.4a	30.8	0.96	0.001
Anthesis	54.0	53.0	53.0	55.0	50.0	53.0	0.90	0.154
Panicles	3.8b	2.8c	4.1a	4.3a	4.8a	4.0	0.26	<0.001
Stems	7.1b	5.6b	7.9a	8.0a	6.8b	7.1	0.54	0.008
Leaves	1.7	1.4	2.0	1.6	1.7	1.7	0.16	0.133

DMY – dry matter yield; DDMY - digestible dry matter yield; DM - dry matter; S.E.M. - standard error of mean; P - probability (if treatments differ at $P < 0.05$); D.F. = 16.

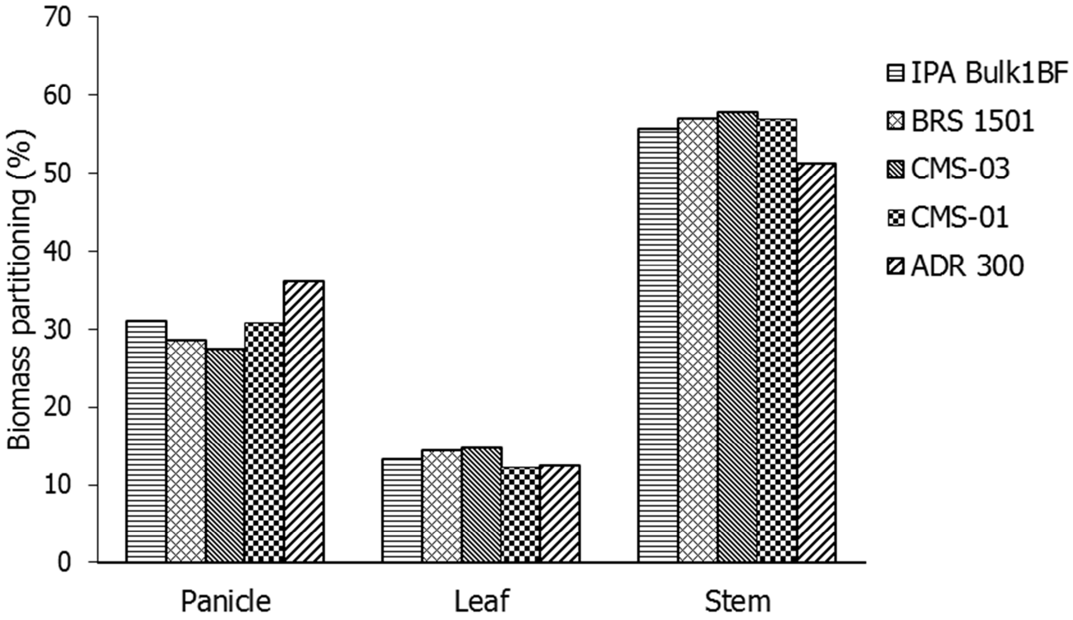

Figure 2. Participation of morphological components (%) in the total biomass of five pearl millet cultivars.

Table 3. Correlation coefficients of agronomic variables of pearl millet cultivars.

Variable[1]	PD	DMY	DDMY	LD	PDM	LDM	SDM
PH	0.04	0.68	0.71	0.40	-0.41	0.27	0.32
PD	-	0.54	0.47	0.16	-0.26	0.25	0.15
DMY	-	-	0.91	-0.23	0.33	-0.31	0.54
DDMY	-	-	-	-0.16	0.25	-0.09	-0.36
LD	-	-	-	-	-0.42	-0.07	0.46
PDM	-	-	-	-	-	-0.21	-0.90
LDM	-	-	-	-	-	-	-0.21

[1]PH – plant height; PD – plant density; DMY – dry matter yield; DDMY – digestible dry matter yield; LD – lodging; PDM – Proportion of panicle; LDM – Proportion of leaf; SDM – Proportion of stem.

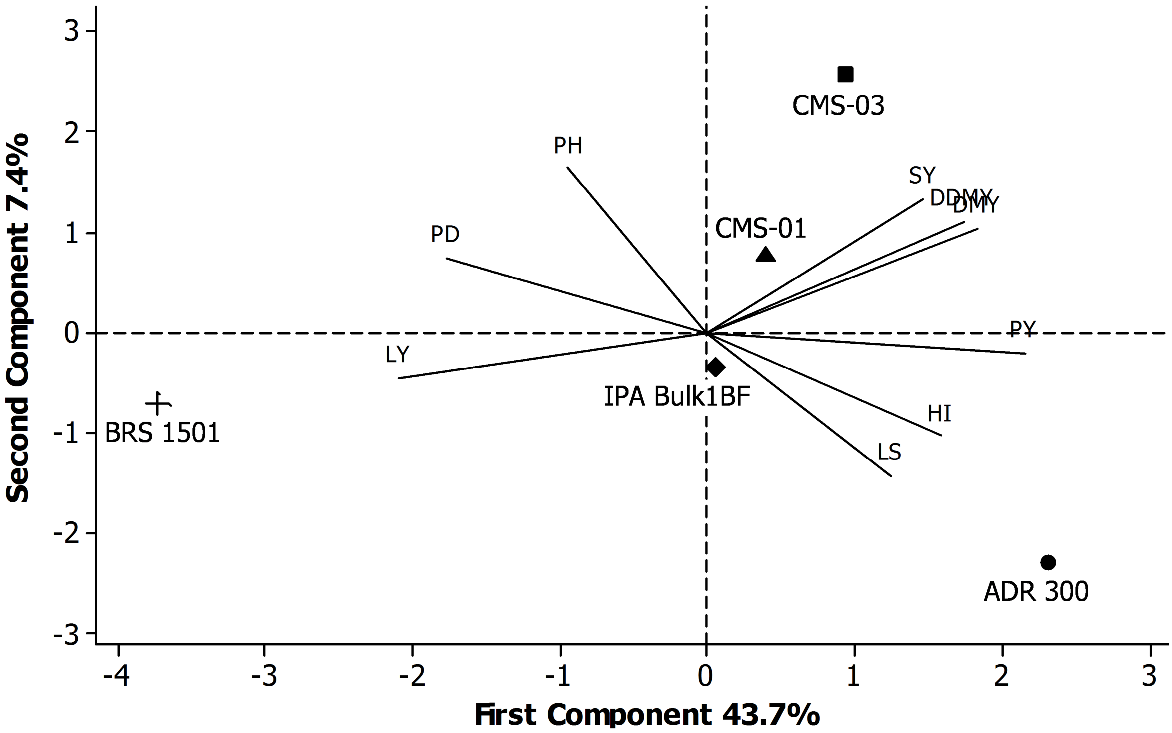

Figure 3. Principal component biplot of the 5 pearl millet cultivars and different agro-morphological traits. Vectors indicate the various traits; symbols mark the pearl millet cultivars. LY, leaf yield; SY, stem yield; PY, panicle yield; DMY, dry matter yield; DDMY, digestible dry matter yield; HI, harvest index; PD, plant density; PH, plant height; LS, lodging score.

CAPÍTULO 2 - DIVERGENCE IN AGRONOMIC TRAITS AND PERFORMANCE OF PEARL MILLET CULTIVARS IN BRAZILIAN SEMI-ARID REGION

ABSTRACT

Pearl millet is an important forage crop for livestock in semi-arid regions, but the use of Brazilian genotypes for silage production in northeastern Brazil has not been adequately described. The objective was to assess the divergence in agronomic traits of five Brazilian pearl millet cultivars, for silage production. The treatments were 5 pearl millet cultivars IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and ADR 300, which were arranged in a randomized complete block design and were replicated 5 times. Agronomic divergence was assessed using canonical variate analysis and agglomerative hierarchical clustering. The cultivar ADR 300 presented the lowest average plant height. There was a range from 7.6 to 11.5 Mg ha^{-1} for dry matter yield. The cultivars CMS-03 and BRS 1501 showed the highest and lowest digestible dry matter yield, respectively. Three distinct agronomic groups were identified: Group I (IPA BULK1-BF and ADR 300), Group II (CMS-03 and CMS-01) and Group III (BRS 1501). Group II had the greatest agronomic value for performance variables while Group III had the least.

INTRODUCTION

Given the advent of climate change, more attention has been paid to the design of more productive and stable systems through improved cropping system management. This strategy comprises various aspects, such as the use of appropriate crop varieties, improved cropping patterns, relay-cropping, and cultural techniques. The identification of suitable crops and cultivars with optimum morpho-physiology, phenology and performance to suit local environmental conditions, especially the pattern of water availability, is one of the important research areas within forage cropping systems for drylands (van Duivenbooden et al. 2000). Short-duration varieties that mitigate the effects of drought periods, as well as cultivars, preferably also with higher harvest indices, are considered an essential component of management strategies in the drought-prone areas. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is one of the most drought-tolerant crops, and can provide significant grain and biomass yields, where others crops fail or suffer substantial reductions in yield.

For this reason, the agronomic characterization of numerous genetic materials available is essential for obtaining pearl millet genotypes with high biomass yield and nutritional value. For silage production, this characterization is based on the percentage of participation and chemical composition of the primary anatomical structures of the plant, defining an average profile of each genotype. Therefore, the objective of this study was to evaluate the agronomic divergence of five cultivars of pearl millet, with the ultimate aim of identifying promising varieties for silage production in a Brazilian semi-arid region.

MATERIALS AND METHODS

Site description

This research was conducted in an experimental field in the municipality of Bom Conselho, Pernambuco State, Brazil, during the 2011 raining season, with sowing date on June 4 and harvest date on August 25. The site has a latitude of 09º10′S, longitude 36º40′W, and is 654 m above mean sea level. The soil of the experimental site is classified as Xanthic ferralsol sand clay, fine texture and pH of 4.5 (Fischer et al. 2008). The megathermal climate is typically semi-arid with an annual rainfall of 431 mm and average maximum and minimum temperatures of 31 and 19°C, respectively. Precipitation and rainfall occurrence data from 2011 were obtained from automated weather station of the Agronomic Institute of Pernambuco (IPA) (Figure 1). The others climate records, including air temperatures, wind flow velocity, evaporation and relative humidity, were obtained from NASA-POWER database (Stackhouse Jr. et al. 2015) (Table 1).

Pearl millet cultivars evaluated

Five pearl millet cultivars, IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and ADR 300, were used in the experiment. IPA BULK1-BF is a cultivar developed by Agronomic Institute of Pernambuco (IPA). It yields up 6.0 t ha^{-1} dry matter under rainfed conditions. It takes 50-60 days to flowering during winter. It is recommended mainly for forage production in Brazilian semi-arid regions (Rodrigues and Pereira Filho 2010). The Brazilian Agricultural Research Corporation (EMBRAPA) developed and released the cultivars BRS 1501, CMS-03 and CMS-01, which are adapted for areas with risks of drought conditions. They have dry matter production average of 8.0 t ha^{-1} and good grain production potential (2.5 t ha^{-1}). For these cultivars, the flowering occurs 50 days after planting (Pereira Filho et al. 2003). ADR 300 is a cultivar developed by Adriana Seeds Company and released in 2003. Its yields up to 6.6 t ha^{-1} dry matter during winter and 12.3 t ha^{-1} dry matter during spring and takes 45-50 days to flowering. It has good resistance to lodging, and it is recommended for places with erratic rainfall conditions (Pereira Filho et al. 2003). The five cultivars were chosen because of their related duration to maturity. Thus, they are grown under rainfed conditions. The cultivars are already being grown by farmers, and, therefore, would easily be promoted under water deficit conditions once their performance is established.

Treatments, experimental design and crop management

Treatments were the five cultivars replicated five times in a randomized complete block design (25 plots). Plots measured 10.5 m^2 (5 × 2.1 m), with plants seeded in four rows (0.70 m centers) to a depth of 3 cm. The soil at the site had the following properties: pH (water): 4.5; P (mg/dm^3): 25; K ($cmol_c/dm^3$): 0.07; Al ($cmol_c/dm^3$): 0.23; H + Al ($cmol_c/dm^3$): 2.11; Ca ($cmol_c/dm^3$): 0.82; Mg ($cmol_c/dm^3$): 0.40; O.M. (g/kg): 9.2; CEC (Cation-exchange Capacity): 10 (cmol/kg). At sowing fertilization, were used 150 kg ha^{-1} ammonium sulfate + 450 kg ha^{-1} triple superphosphate + 100 kg ha^{-1} potassium chloride. Two-side dressing fertilizations were applied, the first on the 30^{th} day, and the second on the 60^{th} day after plant emergence, with the dose equivalent to 150 kg ha^{-1} of ammonium sulfate. Before fertilization, approximately 1 t ha^{-1} lime (magnesium) was applied to fix aluminum levels and raise calcium and magnesium levels. Each treatment comprised *c*. 32 plants/m², achieved by thinning plots 20 days after emergence.

Cultivars were harvested when at least 60% of plants in each plot reached the BBCH (Biologische Bundesanstalt, Bundessortenamt, Chemische Industrie) scale of 86, which means that plants were at the dough stage of grain maturity (BBCH 2001). Cuttings were made manually and taken at 5 cm above ground level. Only the two central rows in each plot were harvested, with the remainder being discarded. The harvested crop from each plot was collected into baskets and weighed to estimate fresh yield/ha. After chopping a representative sample from each plot, a 400 g sub-sample was oven-dried at 55°C for 48 h to determine dry matter concentration and yield of the five cultivars. *In vitro* DM digestibility was determined according to Tilley and Terry (1963).

The agronomic characteristics studied included: plant height; population density; extent of lodging; harvest index; DM partitioning of organs (panicle, stem and leaf); plant fractions yield; DM yield (DMY) (Mg ha^{-1}) and digestible DM yield (DDMY) (Mg ha^{-1}). The height of ten randomly selected plants within each plot was determined by measuring from the ground to the top of the panicle using a tape measure. Plants were then separated into panicles, stems, and leaves, with the mass of each fraction, determined after oven-drying at 65°C for 72 h. The population density was calculated by dividing 10.000 m^2 by the plant spacing in m^2. Score lodging was rated the percentage area of plot that was lodged and then estimated the angle of stem lodging, where an angle of 10º from the perpendicular was scored as 10 whereas prostrate stems were scored as 90. Lodging for the plot was then calculated as (% plot area lodged × angle of lodging from vertical)/90 as described by Bell and Fischer (1994). The DDMY was estimated by multiplying the *in vitro* dry matter digestibility from each repetition by its respective DMY.

The water-use efficiency for DM and DDM yield, expressed in kg ha^{-1} mm^{-1}, was estimated by dividing the yield by the amount of accumulated rainfall during the crop cycle (mm) as described by Devasenapathy et al. (2008).

Multivariate analyses

For to reduce the dimensionality of the data was used a canonical variate analysis. This approaching allowed evaluation of the simultaneous effect of the original characteristics, such plant height, population density, DMY, DDMY, lodging score, harvest index and plant fractions. The magnitude of the standardised canonical coefficients in the canonic variables quantified the relative importance of the agronomic characteristics evaluated. For to select the most relevant variables, initially all variables were tested but were considered just those that the canonical coefficients had greater magnitude, in absolute value, in the first canonical variables. Thus, for the hierarchical clustering procedure were selected five discriminatory variables: DMY, panicle yield, stem yield, plant height and lodging score. The complete linkage method, based on the maximum distance of similarity between cultivars, and standardised, average Euclidean distance, was used to form the dendrogram.

Statistical analyses

Data about agronomic traits and performance were analysed using a mixed model procedure of SAS Version 9.4 statistical program (SAS 2013). The Scott-Knott test, carried out at a significance level of 0.05, was used to compare the means across cultivars, when significant. Pearson's correlation was used to determine the relationship between the performance and phenological variables and the correlation coefficients were calculated using the MINITAB Version 16.2.4.4. (MINITAB 2013). Then, were applied the multivariate variance analysis with the canonical variate analysis (CANDISC of SAS (2013)) and agglomerative hierarchical clustering by the complete linkage method. For this, was used the computational resources of MINITAB Version 16.2.4.4 (MINITAB, 2013), adopting standardized mean Euclidean distance as a primary measure of dissimilarity. Tukey's test, at the 0.05 probability level, was used to evaluate the mean variables of the groups used in cluster analysis.

RESULTS

The cultivar ADR 300 showed the lower plant height, which ranged from 144 to 184 cm. At the same plant density, among all cultivars the BRS 1501 exhibited the lowest ($P < 0.05$) DM yield. For DM digestible the cultivar CMS-03 produced more ($P < 0.05$) than the others cultivars. The lodging score ranged from 3.1 to 7.4, wherein the cultivars CMS-03 and ADR 300 showed a most resilient and less resilient stem, respectively. The cultivar ADR 300 showed the highest harvest index since it was 34.5% above of the others cultivars average (Table 2).

In regards to plant components yield, the cultivar BRS 1501 exhibited the lowest ($P < 0.05$) proportion of panicles among all others cultivars. Furthermore, BRS 1501, IPA BULK1-BF and ADR 300 showed lower ($P < 0.05$) proportion of stems than CMS-03 and CMS-01. The DM partitioning showed an average panicle proportion of 30.6% while was observed 13.3 and 55.9% for leaf and stem ratio, respectively. This study found that the cultivar BRS 1501 exhibited higher panicle fraction ($P < 0.05$) than all others cultivars, but the lowest panicle percentage jointly with CMS-01 (Figure 2).

Correlation study showed a positive coefficient between DMY and the variables panicle yield, stem yield and plant height with values of 0.51, 0.81 and 0.21, respectively. This analysis also showed that there was a positive correlation between DDMY and panicle yield (0.44), as well as between lodging score and panicle yield. However, the variables DMY and DDMY had an adverse correlation with leaf percentage (Figure 3).

The first three canonical variables (i.e., CV1 = 0.21; CV2 = 0.04 and CV3 = 0.01) explained 0.99 of total variance. For this reason, they were used for identification of characters with the greater ability to discriminate among the cultivars based on agronomic characteristics. Variables DMY, panicle yield, stem yield, plant height, and lodging score were considered important for discrimination among cultivars since these had higher canonical coefficients in the first canonical variable. Variable DMY had the greatest canonical coefficient (0.78) in the canonical variable of highest eigenvalue (0.21 of total variance), presenting itself as the main discriminating factor among cultivars. Panicle yield and stem yield, showed canonical coefficients of 0.67 and 0.65, respectively, in the first canonical variable. Despite having a greater canonical coefficient (0.64 and 0.50, respectively) in the second canonical variable, plant height, and lodging score contributed significantly to discrimination among cultivars.

Three distinct groups were formed at a level of 51% similarity. Group III was entirely dissimilar from the other groups with the genotype BRS 1501 as its single component. Group II, composed by CMS-03 and CMS-01, showed 77% similarity while the Group I (IPA BULK1-BF and ADR 300) displayed similarity of 86% (Figure 4). The Group II was particularly notable about the others groups, since it had greater DMY, stem yield, and, plant height. Group I showed highest panicle yield while Group III showed the lowest value of lodging score (Table 3).

DISCUSSION

Several types of research have showed that pearl millet has potential as forage in semi-arid regions, mainly owing to its desirable characteristics for ensiling and likely to yield high biomass in these areas (Silva et al. 2003; Yadav and Bidinger 2008; ICRISAT 2009).

Plant height has been a significant feature of adoption of a pearl millet variety by farmers, once they correlate the plant height with forage productivity. This study identified average plant height of 168 cm, with considerable variation among cultivars. In general, these results are corroborated by Izge et al. (2007), Bashir et al. (2014) and Pucher et al. (2015). These authors observed significant differences in plant height, with mean variation from 128 to 292 cm for pearl millet varieties (grain, forage, and dual purpose) in different African regions. Studies have showed that plant height could be affected by genetic characteristics, as well as by climatic conditions, such solar radiation. In this sense, Sanon et al. (2014) reported that the photoperiod can have an influence on pearl millet height during the vegetative phase. These authors showed that this process could increase the formation of nodes, internodes, primordial and sprouted leaves, which can even result in high production of dry matter. This study observed a relationship between plant height and DMY since there was a trend that cultivars with more tall plants had a higher DMY.

Plant height was decisive to establish difference for DMY between the cultivars CMS-03 and ADR 300. This finding is consistent with results of Guimarães Júnior et al. (2009) and Hassan et al. (2014). However the same trend was not observed for others cultivars, probably due to differences between for another agronomic factor, such lodging resistance (Akromah et al. 2008; Silungwe et al. 2010).

Final DM forage yield is the ultimate goal, which depends upon the genomic as well as management and environmental factors. Despite this variable, generally, to be associated with plant height others agronomic traits could influence its values, such lodging, and phenological components. Among the cultivars in the current study, CMS-03 had the highest DMY likely because it had a lowest lodging score associated with one of the highest stem yields. In contrast, the cultivar BRS 1501 showed the lowest DMY, probably due to its lowest panicle and stem yield and most top leaves percentage. These results were matched with the findings of Morales et al. (2011) that the association and path coefficient analysis exhibited an increase in the DMY due to panicle proportion and leaf:stem ratio.

The DDMY is directly associated with the DM production and its digestibility. Typically, the higher values of digestibility are observed in genotypes with large panicle percentage (Miron et al. 2005). Therefore, high panicle content of dry matter is a desirable feature to improve DDMY. This variable is important to establish the productive silage potential of the cultivars, once it integrates the nutritional value with yield. The highest DDMY observed for the CMS-03 could be attributed to the higher DMY since this cultivar was similar to the cultivars IPA BULK1-BF and ADR 300 for panicle percentage. The DDMY average of 4.7 Mg ha^{-1} obtained in this study was higher than recorded yields of rainfed forage millet with multiple cuttings (Pasternak et al. 2012) and similar to forage yields obtained under high fertilization regimes (Reddy et al. 2003).

Several types of research have reported that there is a considerable variation in plant partitioning (Aguiar et al. 2006; Izge et al. 2007; Munawwar et al. 2014). For instance, Yadav and Bidinger (2008), evaluating the performance of pearl millet varieties, detected an average of 21% for harvest index, which was inferior to average found by this study. Bashir et al. (2014) mentioned a significant variation of panicle percentage between pearl millet varieties for grain, dual purpose, and forage, with mean values between 13.5 and 39.4%, which were similar our results.

The percentage participation of panicle is directly associated with the production of grains and has an influence on the quality of forage (Ward et al. 2001). Thereby, the selection of cultivars with a higher proportion of panicle is an important criterion to obtain varieties with better nutritional values. Furthermore, according to Yadav and Singh (2012), the high proportion of grains in DM could be a factor for biomass production increases, as could be seen for the cultivar ADR 300. At this investigation was observed 59.6% of stem in total biomass. Bika and Shekhawat (2015), studying 30 pearl millet genotypes in India, observed lower percentages of stem compared to our research, with mean values ranged from 34.0 to 51.4%.

Some authors believed that there is a high correlation between plant height and stem participation (Ganga et al. 2013; Murillo et al. 2015), which may explain the trend observed in this study for these two characteristics. However, a high percentage of stem can also be considered as an undesirable feature for forage production, since stem participation is inversely proportional to nutritional value and quality of silage (Fulkerson et al. 2008).

For this reason, Santos et al. (2010) argued that the analysis of the proportionality relationship among panicle, stem, and leaf is critical because it indicates the potential of these genotypes to provide soluble carbohydrates in adequate amounts for optimal fermentation and, consequently, the production of high-quality silages with high productivity.

With respect to the different correlations, it was fairly evident that BRS 1501, which showed the lowest DMY, also presented most top leaves percentage and most inferior stem and panicle yield. According to Flaresso et al. (2000), the determination of phenological components is a strategic way to select genotypes for silage production. The identification of contribution factor of the plant fraction (mainly panicle and stem) is fundamental since it is positively correlated with the increase in the content of DM, production of grains and silage quality.

In addition to the productive aspect, in view of the current scenario of climate change is crucial to identify forage crops that could be strategically sustainable. Pearl millet can play this role because this crop requires less water to yield DM and digestible DM/ha than other feed sources, such as maize or sorghum. The pearl millet cultivars used in this experiment were more water-use efficient than sorghum and maize grown in semi-arid regions of Brazil (43.4 kg DM/ha/mm water for the pearl millet cultivars vs. 29.6 kg DM/ha/mm water for sorghum (Silva et al. 2011); and 21 ± 2.4 kg DM/ha/mm water for the Brazilian maize cultivars (Santos et al. 2010)). The same response has been reported in temperate climate for maize (11 kg DM/ha/mm) grown in the United States and sorghum (14 kg DM/ha/mm) planted in China that exhibited lower water-use efficiency than the Brazilian pearl millet cultivars (Deng et al. 2006; Nielsen et al. 2006).

In the clustering analysis, the Group II, which included CMS-01 and CMS-03 cultivars, stood out dramatically from the remaining cultivars since it showed greater values for the variables plant height, DMY and stem yield. Despite the lack of prior agronomic information about these two cultivars for silage production in semi-arid regions, the results observed in this study indicate their potential for to grow in water-limited conditions, since they were productively superior to other cultivars traditionally used, such as BRS 1501. In contrast to Group II, the elevated leaves yield and the lower panicle yield of the BRS 1501 cultivar resulted in a lower DMY.

The cultivars studied exhibit variation on the agronomic characteristics evaluated and were grouped into distinct subgroups. The CMS-01 and CMS-03 stood out among the cultivars evaluated, providing evidence that they have significant potential to yield forage in a Brazilian semi-arid area or in regions where irrigation is not possible and precipitation limits silage production. The BRS 1501 cultivar was inferior to the other cultivars due to its lowest panicle yield and DMY and consequently its DDMY. Under this experimental conditions, Brazilian pearl millet cultivars showed agronomic traits similar to or better than traditionally used crop forage, highlighting the cultivar CMS-03, which may be recommended for silage production in Brazilian semi-arid region.

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Table 1. Meteorological data during the experimental period

Month/Year	Days of rain	Rainfall (mm)	Temperature (ºC)			RH (%)	Wind (m/s)	GDD (HU)
			Max.	Min.	Mean			
June 2011	18	84.9	32.9	22.4	26.2	73.4	4.2	17.6
July 2011	16	59.9	33.3	22.5	26.6	73.9	3.8	17.9
August 2011	13	83.5	30.9	22.5	25.5	79.4	4.1	16.7

RH, relative humidity; GDD, growing degree days

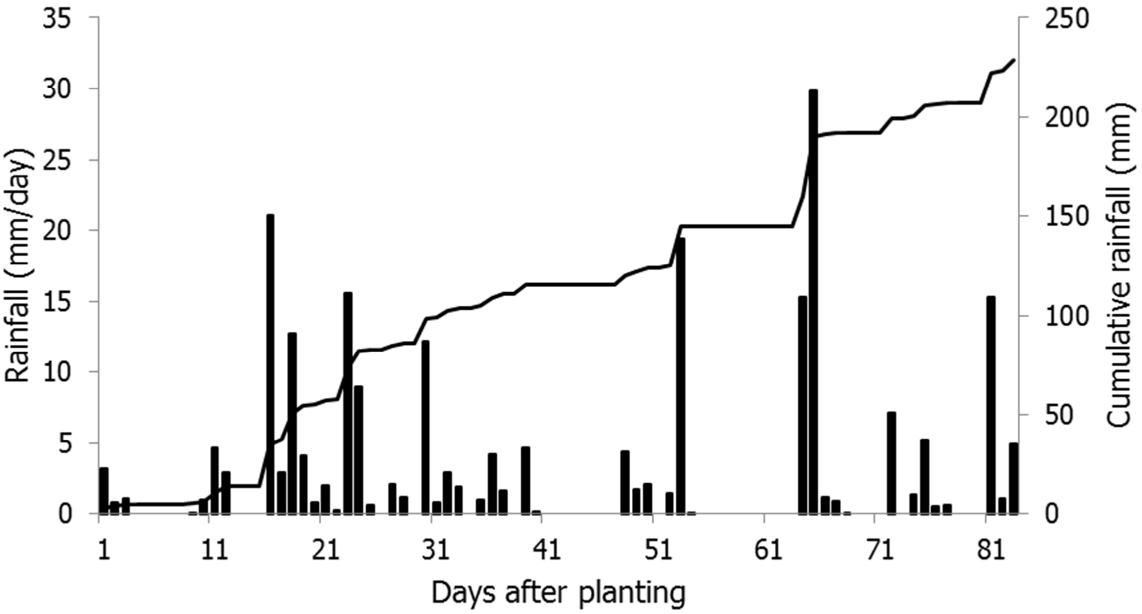

Figure 1. Rainfall distribution (mm) during 2011 rainy season at the experimental field in Bom Conselho, Pernambuco, Brazil

Table 2. Performance and phenological traits of pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	ADR 300	Mean	SEM	*P*
Plant height (cm)	168	172	184	172	144	168	8.2	0.019
Plant density (1000 plants/ha)	231	269	243	188	162	217	30.9	0.103
DMY (Mg/ha)	9.6	7.6	11.5	10.6	10.0	9.9	0.40	<0.001
DDMY (Mg/ha)	4.4	3.7	5.6	5.0	4.8	4.7	0.19	<0.001
Lodging score	5.0	3.8	3.1	5.2	7.4	4.9	1.00	0.049
Harvest index (%)	27.2	21.6	24.6	21.9	32.0	25.4	2.34	0.034
Panicles (Mg/ha)	2.6	1.6	2.8	2.3	3.2	2.5	0.23	<0.001
Stems (Mg/ha)	5.6	4.0	7.3	6.7	5.4	5.8	0.43	0.008
Leaves (Mg/ha)	1.4	1.9	1.3	1.5	1.4	1.5	0.25	0.448

DMY, dry matter yield; DDMY, digestible dry matter yield; DM - dry matter; SEM, standard error of mean; *P*, probability

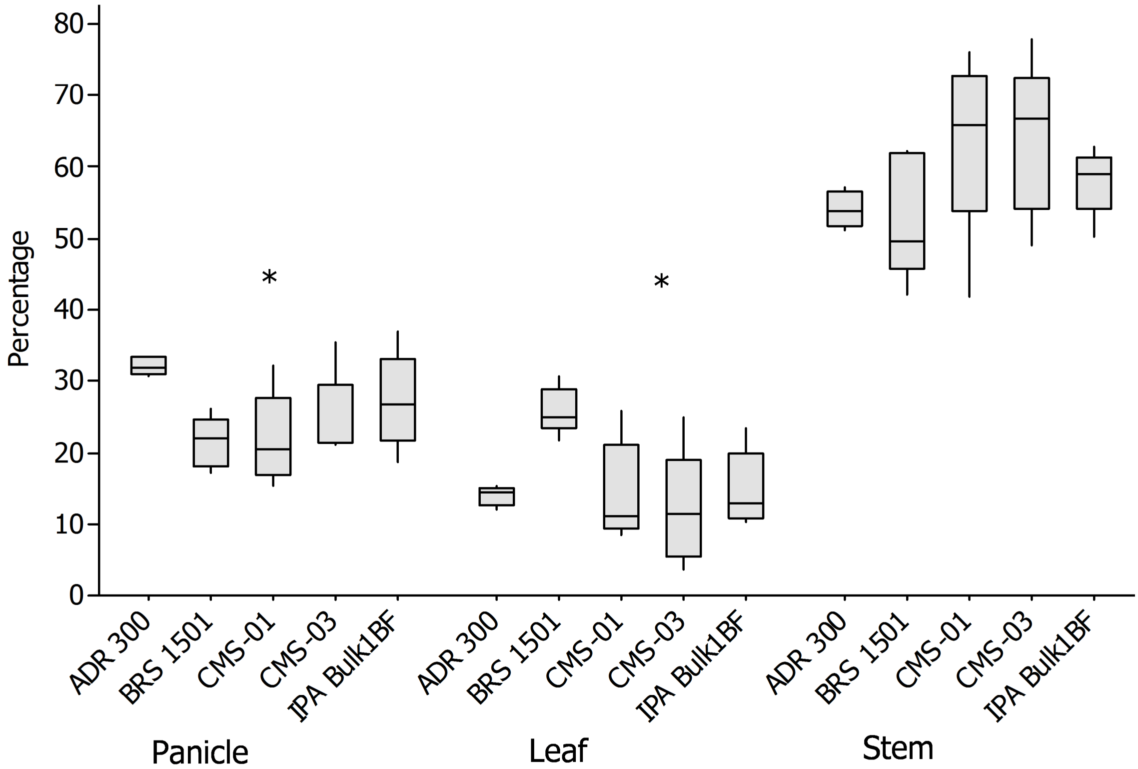

Figure 2. Participation of morphological components (%) in the total biomass of five pearl millet cultivars. Solid lines are means and boxes are the interquartile ranges. Asterisks denote significant differences in plant fractions percentage between cultivars (*P* < 0.05).

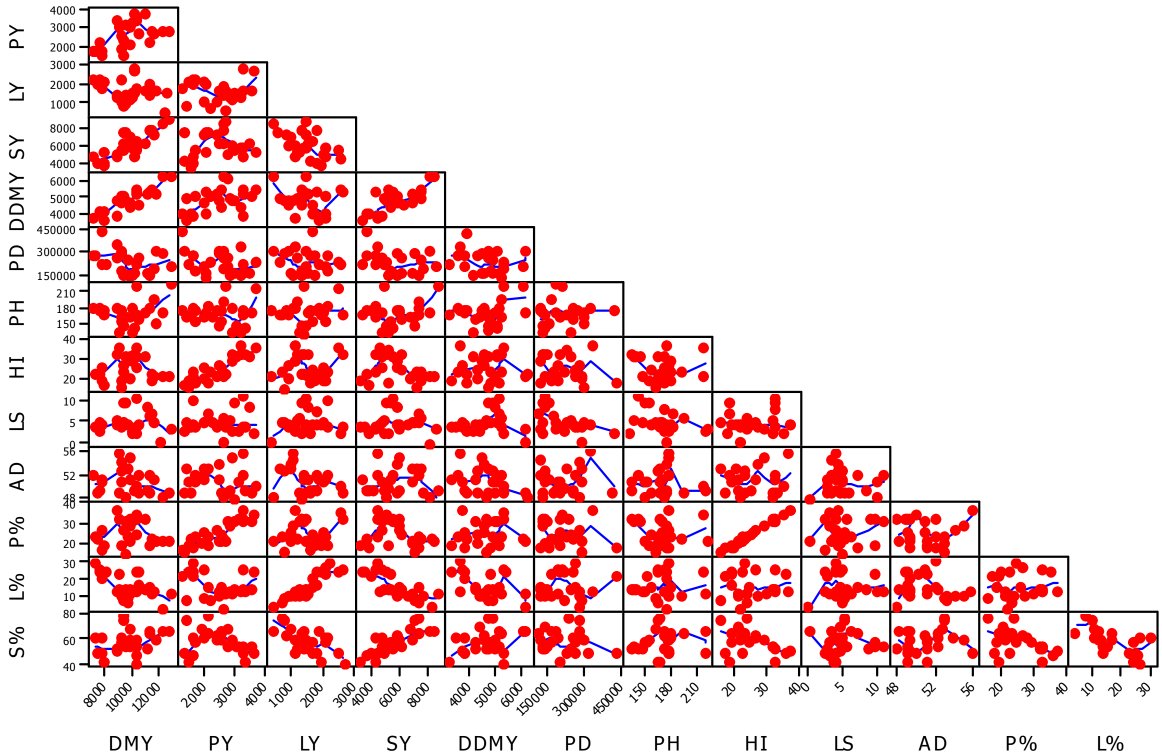

Figure. 3. Scatter plots showing frequency distributions and the relationships among the performance and agronomic traits from the 05 pearl millet cultivars. LY, leaf yield; SY, stem yield; PY, panicle yield; DMY, dry matter yield; DDMY, digestible dry matter yield; HI, harvest index; PD, plant density; PH, plant height; LS, lodging score; AD, anthesis after planting; P%, percentage of panicle fraction; L%, percentage of leaf fraction; S%, percentage of stem fraction.

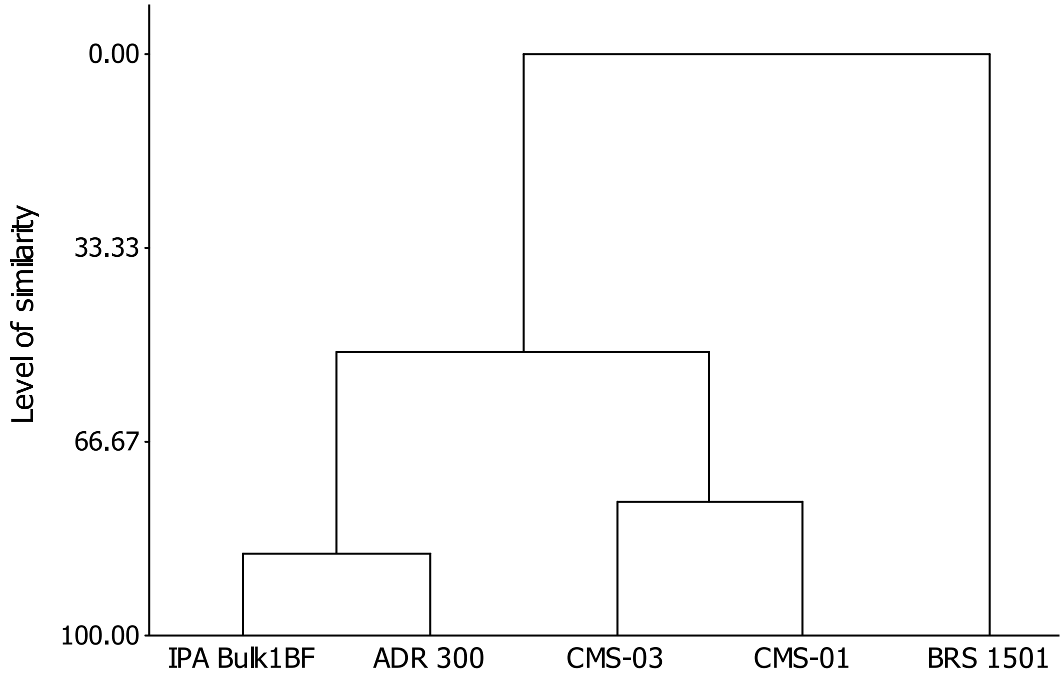

Figure 4. Similarity dendrogram for the agronomic traits of 5 pearl millet cultivars

Table 3. Groups of cultivars of pearl millet obtained by the complete linkage method and the average of the variables in each group

	Groups			SEM	*P*
	I	II	III		
	IPA BULK1-BF	CMS-03	BRS 1501		
	ADR 300	CMS-01			
Plant height (cm)	155	178	172	16.0	0.042
DMY (Mg/ha)	9.8	11.0	7.6	1.56	<0.001
Panicle yield (Mg/ha)	2.9	2.6	1.6	0.62	0.002
Stems yield (Mg/ha)	5.5	7.0	4.0	1.40	<0.001
Lodging score	6.1	4.1	3.8	0.33	0.042

DMY, dry matter yield; DDMY, digestible dry matter yield; SEM, standard error of mean; *P*, probability

CAPÍTULO 3 - AGRONOMIC TRAITS, ENSILABILITY AND NUTRITIVE VALUE OF FIVE PEARL MILLET CULTIVARS GROWN IN A BRAZILIAN SEMI-ARID REGION

ABSTRACT

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] could play an important role as a feed source for ruminants in arid and semi-arid zones of the world owing to its high yield and drought tolerance. The current research assessed the agronomic characteristics, ensilability, intake and digestibility of five Brazilian pearl millet cultivars (IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and BN-2) in a typical Brazilian North-eastern semi-arid climate. Forage was harvested at the dough stage of grain maturity (growth stage 86 according to the BBCH scale) and ensiled under laboratory and farm conditions. Apparent digestibility of the silages was determined using 25 Santa Inês male lambs. The cultivars CMS-01, CMS-03 and BN-2 out-performed the others in terms of dry matter (DM) and digestible DM yield/ha. At DM partitioning among plant tissues, the cultivar IPA BULK1-BF had a greater DM associated with panicles and one of the greatest concentrations of organic matter (OM), lactic acid and *in vitro* dry matter digestibility (IVDMD) among the five cultivars. The cultivar BRS 1501 had greater butyric acid concentration as well as one of the highest pH values. Silage produced from BN-2 not only contained greater acetic acid concentration but also showed one of greatest total volatile fatty acid (VFA) concentrations. There were no differences in feed intake and digestibility of nutrients and fibre fractions across all cultivars. Silage made from BN-2 resulted in greater urinary excretion of nitrogen (N) than those produced from BRS 1501. Under the conditions of the current study, the results obtained for production of dry and digestible dry matter, and the ratio of plant fractions, indicates the possible use of these cultivars for silage production in the Brazilian semi-arid region.

INTRODUCTION

Climate change has been the principal source of fluctuations in global food production in arid and semi-arid regions where extremes of heat and cold, together with drought and floods, have negatively impacted agriculture (Oseni & Masarirambi 2011). Furthermore, social and political-economic factors have contributed to increased vulnerability, economic loss, hunger and dislocation (Sivakumar et al. 2005). Within this context, it is imperative to identify water-use efficient plants that can adapt to climate change and increase the use of rain-fed crops to achieve sustainable agricultural development in areas that are more prone to extreme weather (Lobell et al. 2008).

Pearl millet (*Pennisetum glaucum* (L.) R.) could be a key feed source in agricultural adaptation in dry regions as it is a tropical plant possessing the C4 photosynthetic pathway and tolerance to drought, heat and low soil pH (Maiti & Wesche-Ebeling 1997). Because of its adaptability to harsh conditions, millet can be grown in areas that are unfavourable to other crops such as maize (Singh & Singh 1995). Although several studies have evaluated the potential of pearl millet as silage for ruminants in dry regions (Messman et al. 1992; Hill et al. 1999), data on its nutritive value are limited.

The Brazilian Agricultural Research Corporation (EMBRAPA) has developed and released new varieties of pearl millet for field testing over the last 10 years, including the varieties BRS 1501, CMS-03 and CMS-01, while the Agronomic Institute of Pernambuco (IPA) and Bonamigo Seeds have released the varieties IPA BULK1-BF and BN-2, respectively. In Brazil, small-scale trials were conducted to evaluate field performance of those five new cultivars, mainly in wet regions (Aguiar et al. 2006; Pires et al. 2007; Guimarães Júnior et al. 2009), and it was found that they could serve as a feed source for livestock during the dry season since they exhibited greater dry matter (DM) yield than members of the African and Indian germplasm banks, which are well-adapted to semi-arid conditions (de Rouw 2004; Yadav & Bidinger 2008; Bashir et al. 2014). Before recommending these new Brazilian cultivars for commercial use, other experiments should be carried out to investigate their agronomic and ensiling characteristics (i.e. DM partitioning among plant organs, *in vitro* dry matter digestibility (IVDMD), pH, fermentation end products and chemical composition), as well as intake and *in vivo* digestibility, so that farmers and policy-makers have sufficient information about these new forages to address the food demands of livestock in semi-arid environments.

As a part of an overall strategy to deal with this issue, the current study evaluated agronomic characteristics of five new Brazilian cultivars of pearl millet (IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and BN-2) and assessed their potential application in silage production. Finally, the impact of these new forages on intake and digestibility in lambs was quantified.

MATERIALS AND METHODS

Experiments location and general information

The experiment was conducted from July to October 2011 at the Semi-Arid Experimental Station of the Brazilian Agricultural Research Corporation (EMBRAPA) in the municipality of Nossa Senhora da Glória, Sergipe State, Brazil (10º13′S, 37º25′W, 291 m asl). The soil type in this region is a eutrophic red-yellow podzol (dos Santos et al. 2013), with an average depth of 1.5 m. The climate is typically semi-arid with annual rainfall of 710 mm and average maximum and minimum temperatures of 32 and 20 °C, respectively. Precipitation in the region is low, erratic, and the balance between rainfall and evaporation rate can be negative in some months based on meteorological data from a weather station located about 400 m from the experimental site (Table 1). Seed of the five new pearl millet cultivars (IPA BULK1-BF, BRS 1501, CMS-03, CMS-01 and BN-2) was supplied by the pearl millet breeding programmes of EMBRAPA, IPA and Bonamigo Seeds.

Agronomic characteristics

Treatments were the five cultivars replicated five times in a randomized complete block design (25 plots). Plots measured 10.5 m^2 (5 × 2.1 m), with plants seeded in four rows (0.70 m centres) to a depth of 3 cm. The soil at the site had the following properties: pH (water): 5.8; phosphorus (P): 2.8 mg/dm^3; potassium (K): 0.32 $cmol_c/dm^3$; aluminium (Al): 0.05; hydrogen (H) + Al ($cmol_c/dm^3$): 1.89; calcium (Ca) ($cmol_c/dm^3$): 1.4; magnesium (Mg) ($cmol_c/dm^3$): 0.74 and organic matter (OM; g/kg): 10.54. All plots were randomly allocated and fertilized prior to planting according to soil test recommendations with 150 kg N/ha, 300 kg P/ha and 250 kg K/ha. Two-side dressing fertilizations were applied, the first on the 25th day and the second on the 40th day after plant emergence, at a rate of 60 kg N/ha in each side dressing. Each treatment comprised *c*. 32 plants/m², achieved by thinning plots 20 days after emergence.

Cultivars were harvested when a proportion of at least 0.60 of plants in each plot reached the dough stage of grain maturity (growth stage 86 according to the BBCH scale; BBCH 2001). Plants were harvested manually, cut at 5 cm above ground level. Only the two central rows in each plot were kept, collected into baskets and weighed to estimate wet yield/ha, with the remainder being discarded. After chopping a representative sample from each plot, a 400 g sub-sample was oven-dried at 55 °C for 48 h to estimate DM concentration and yield of the five cultivars. Dry samples were ground through a 1 mm screen using a Wiley Mill (Tecnal Ltd., São Paulo, São Paulo, Brazil) and stored at room temperature.

The agronomic characteristics studied included: plant height; population density; extent of lodging; DM partitioning of plant organs (panicle, stem and leaf); DM yield (DMY) (t/ha) and digestible DM yield (DDMY) (t/ha). The height of ten randomly selected plants within each plot was determined by measuring from ground level to the top of the panicle using a tape measure. Plants were then separated into panicles, stems and leaves, with the mass of each fraction determined after oven-drying at 65 °C for 72 h. Score lodging was estimated the percentage area of plot that was lodged and then estimated the angle of stem lodging, where an angle of 10º from the perpendicular was scored as 10 whereas prostrate stems was scored as 90. Lodging for the plot was then calculated as: (% plot area lodged × angle of lodging from vertical)/90 as described by Bell & Fischer (1994). The DDMY was estimated by multiplying the *in vitro* dry matter digestibility (IVDMD; determined as described below) from each repetition by its respective DMY.

The water-use efficiency for DM and DDM yield, expressed in kg/ha/mm, was estimated by dividing the yield by the amount of accumulated rainfall during the crop cycle (229 mm) as described by Devasenapathy et al. (2008).

Growing degree days (GDD) were used to calculate and express daily heat unit accumulation relative to the pearl millet crop using temperature data as described by Norman et al. (1995).

Ensiling procedure

At harvest, a silage harvester (Nogueira®, São João da Boa Vista, São Paulo, Brazil) was used to chop plants within each treatment to an average of 1.5 cm long and transferred into 25 × 250-litre plastic barrels.

Representative herbage samples from each plot were packed manually into polyvinyl chloride (PVC) mini-silos (five mini-silos × five replications for a total of 25 mini-silos; 10.5 cm diameter × 35.5 cm high, capacity of 2.5 kg and average density of 813.7 kg/m³) using a wooden pestle (Sebastian et al. 1996). The mini-silos were sealed with plastic lids, weighed and stored at room temperature.

Mini-silos were opened following 90 days of ensiling, with forage samples (15 g) from both mini-silos and plastic barrels being homogenized for 1 min in 500 ml of distilled water to measure the pH using a pH meter (TEC-5®, Tecnal Ltd., São Paulo, São Paulo, Brazil). Aqueous extracts (10 ml) were acidified with 50 µl of 9.77 mol/l of sulphuric acid (H_2SO_4) (Kung & Ranjit 2001) and frozen before analysis. Thawed extract samples were centrifuged for 15 min at 10 000 × ***g*** at 4 °C and analysed for acetic, propionic, lactic and butyric acids using a Varian high performance liquid chromatography (HPLC) system (Merck Hitachi, Elite Lachrom HTA, Tokyo, Japan) as described by Adams et al. (1984). Organic acids were separated using an Aminex HPX-87H column (300 × 7.8 mm; Bio-Rad, Hercules, CA, USA) with a mobile phase of 0.013 M H_2SO_4 at a flow rate of 0.5 ml/min. Organic acids were quantified using an ultraviolet detector (Merck Hitachi L-2400) set at 210 nm.

Ammonia was determined using a phenol-hypochlorite reaction, as described by Weatherburn (1967). Finally, silage sub-samples (500 g) were oven-dried at 60 °C for 72 h, ground through a 1 mm screen using a Wiley Mill (Tecnal Ltd., São Paulo, São Paulo, Brazil) and stored at room temperature until further analysis.

Intake and digestibility measurements

All lambs were cared for in accordance with the guidelines of the Brazilian Council on Animal Care (CONCEA 2008). Apparent nutrient digestibility of silages was measured using 25 Santa Inês male lambs (initial body weight (BW): 19 kg ± 1.6 kg) over a 21-day period. Lambs were blocked by weight and assigned randomly to one of five treatments. The first 17 days were used to adapt lambs to the diets in individual metabolic cages equipped with a poly-ethylene sieve tray to separate faeces from urine. Lambs were fed pearl millet silage only (without concentrate) twice daily at 07.30 h and 16.30 h in a manner that assured 0.15 orts at the morning feeding. Water and a trace mineralized salt mixture were available to lambs *ad libitum*.

Apparent digestibility was determined over 5 days, with lambs being fed pearl millet silage *ad libitum* as described by da Silva & Leão (1979). During these 5 days, total faeces, feed and orts of each lamb were measured and sampled daily. Samples of the 5 days were mixed, sub-sampled (400 g fresh faeces, 400 g fresh feeds and 400 g fresh orts per lamb) and stored at –20 °C until analysed. The total urine output of each animal was collected daily into plastic containers containing 100 ml of hydrochloric acid with 2N concentration to prevent fermentation, degradation and N losses. During the 5-day collection phase, subsamples (10% from the total urine volume) were collected in the morning and stored at –20°C until further analysis.

Chemical analysis

Ground samples were analysed for DM and OM as described by AOAC (2005) (methods 942.05 and 934.01). A Leco combustion N analyser (FP-428N Determinator, Leco Corporation, St Joseph MI, USA) was used to measure N concentration. Crude protein (CP) was calculated as N × 6.25. Both neutral detergent fibre (NDF), which was determined by using heat stable α-amylase, and sodium sulphite (ash free), and acid detergent fibre (ADF) were quantified using an Ankom Fibre Analyser (Ankom Technology Corporation, Macedon, NY, USA) as described by Van Soest et al. (1991). Concentration of hemicellulose was determined by subtracting ADF from NDF. Ether extract (EE) was determined as described by AOAC (2005) (method 920.39) using an Ankom Fat Extractor (Ankom Technology Corporation, Macedon, NY, USA).

Gross energy was determined using an adiabatic calorimeter (model 1241; Parr, Moline, IL). Non-fibrous (NFC) carbohydrates were calculated as described by Sniffen et al. (1992): $NFC_{g/kg\ DM} = 100 - (CP + EE + ash + NDF)$. The concentrations of total digestible nutrients (TDN) were calculated as: $TDN_{g/kg\ DM}$ = digestible CP + (2.25 × digestible EE) + digestible NDF + digestible NFC (Weiss & Wyatt 2000).

In vitro DMD analysis of fresh forage and silage was conducted in 100 ml serum bottles and examined in a single run for each forage/silage with triplicate bottles being used per sample. Plant material (0.5 g) was incubated with 10 ml of rumen fluid mixed with 40 ml of McDougall's buffer (McDougall 1948) for 48 h at 39 °C. Samples were subsequently incubated with 0.1N hydrochloric acid (HCL) and 2 g/l pepsin for a further 48 h (Tilley & Terry 1963). Equal volumes of rumen fluid were collected immediately after feeding from three rumen-fistulated bulls fed a mixture of the five pearl millet cultivars. After stirring the three samples, the combined ruminal fluid was used in the IVDMD assay as described above.

Statistical methods

Experiments were analysed using a mixed model approach with cultivar as a fixed effect, random effects of blocks (agronomic and silage quality trials) and lambs (digestibility study), and random residual error using the MIXED procedure of SAS Version 9.1 statistical program (SAS 2002). When significant, cultivar means were compared using Fisher's protected LSD (i.e., the DIFF option of the LSMEANS statement). Significance was declared at $P < 0.05$.

RESULTS

Agronomic characteristics

Cultivar height at harvest ranged from 146 to 200 cm, with CMS-01 being 43% taller ($P < 0.05$) than BRS 1501, although no difference was observed between CMS-01 and BN-2. At the same plant density, BN-2, CMS-01 and CMS-03 yielded more ($P < 0.05$) DM and digestible DM than BRS 1501, which was similar to IPA BULK1-BF.

The cultivar IPA BULK1-BF exhibited the highest ($P < 0.05$) proportion of panicles, although there was similarity in DM partitioning of panicles for CMS-03 and BN-2. As for lodging, CMS-03 exhibited more ($P < 0.05$) resilient stems than BRS 1501 and IPA BULK1-BF, but no difference was observed among CMS-03, CMS-01 and BN-2 (Table 2).

Silage quality

After ensiling, DM concentration of the cultivars ranged from 340 to 371 g/kg and did not differ among treatments. Organic matter concentration ranged from 927 to 939 g/kg and was greater ($P < 0.05$) in CMS-01 than BRS 1501 silage. Silages produced from IPA BULK1-BF, CMS-01 and CMS-03 had greater ($P < 0.05$) IVDMD than BRS 1501 silages.

A larger variation in fermentation products was detected among treatments, with CMS-03 and IPA BULK1-BF silages having the lowest ($P < 0.05$) pH, although they did not differ significantly from CMS-01. Acetic acid concentration was greater ($P < 0.05$) in silages produced from BN-2 compared with the other cultivars. However, concentrations of total volatile fatty acids (VFA) in ensiled BN-2 were greater ($P < 0.05$) than those from CMS-03, although there were no differences among BRS 1501, CMS-01 and IPA BULK1-BF. Concentrations of lactic acid in silages produced from IPA BULK1-BF and CMS-03 were greater ($P < 0.05$) than in BN-2. Finally, concentrations of butyric acid in silages obtained from BRS 1501 were greater ($P < 0.05$) than those observed for BN-2 (Table 3).

Digestion study

Intake and digestibility were not affected by cultivar (Table 4); however, BRS 1501 resulted in a lower ($P < 0.05$) urinary N excretion than BN-2 (Table 5).

DISCUSSION

Several studies have indicated that pearl millet is an excellent feed for livestock in arid regions owing to its desirable characteristics for ensiling and potential to yield high biomass in these regions (ICRISAT 2009; Kholova et al. 2010).

The mean (± standard deviation, S.D.) whole-crop DM yield of 14 (± 3.9) t/ha in the current study was greater than the range of values reported for three African genotypes (7–8 t/ha) and two Brazilian cultivars (7 t/ha) of pearl millet grown in the Brazilian sub-tropical climate (Costa et al. 2005). It is possible that greater daily heat unit accumulation observed during the growing season in north-east Brazil (1648 growing degree days (GDD) - °C) compared with those in south-west Brazil (Costa et al. 2005) (1204 GDD - °C) may explain the differences in

DMY, as the cultivars from both experimental sites were cultivated in a soil with similar characteristics and harvested at almost the same whole plant moisture. Among the cultivars in the current study, CMS-03, CMS-01 and BN-2 had greater DMY than BRS 1501 and IPA BULK1-BF likely because they had greater plant height and were more resistant to lodging (Akromah et al. 2008; Silungwe et al. 2010).

The Brazilian pearl millets evaluated exhibited lower IVDMD than that described for conventional and brown midrib (BMR) pearl millet grown in Canada (Hassanat et al. 2006; Amer et al. 2012), possibly because of a greater concentration of ADF exhibited in the Brazilian cultivars.

In general, the fermentation profile observed in Brazilian pearl millet silages was within the limits recommended by McDonald et al. (1991) and Tomich et al. (2003). These findings also suggest that enterobacteria and clostridia had little activity in the ensiled material, as these microorganisms have limited growth rate in silage exhibiting > 280 g/kg DM and pH < 4 (McDonald et al. 1991). Although butyric acid was detected in silage evaluated in the current work, its concentration was low (0.6 ± 0.13), suggesting that clostridial activity was minimal (Ward et al. 2001). Lower concentration of lactic acid and higher concentration of acetic acid in BN-2 silage as compared with the other treatments may have resulted from heterolactic and/or enterobacterial fermentation (McDonald et al. 1991), although those concentrations were not sufficient to cause DM and energy losses or to reduce gross energy intake in animals fed BN-2.

Intake of DM, OM and CP were similar to results obtained by Amodu et al. (2008). They observed intake (± S.E.M.) of 365 (± 12.4), 319 (± 20.1) and 18 (± 5.3) g/day for DM, OM and CP, respectively, for pearl millet fed Yankasa lambs reared in Nigeria.

The similarity in concentrations of fibre fractions in silage generated from the current work as compared with other trials carried out around the world resulted in almost the same consumption of NDF and ADF as described by Khan et al. (2011), who reported intake of 586 g (± 17.1) NDF/day in animals weighing 30 kg ± 4.45. The average NDF intake as a percentage of body weight (2.8 %) was higher than that shown by dos Santos et al. (2011), who reported a percentage of 1.5 % for Santa Ines lambs reared in the Brazilian semi-arid zone and fed maize silage.

The digestion study revealed that the mean apparent digestibility of DM (0.49 ± 0.089) and NDF (0.43 ± 0.096) of the Brazilian north-eastern pearl millets were quite similar to those reported for pearl millet cultivated in temperate climates (for instance, Ward et al. 2001 obtained values of 0.51 and 0.50 for DM and NDF digestibilities, respectively).

On average, the CP concentration of Brazilian pearl millets (mean ± S.E.M.; 108 ± 0.8 g/kg DM) was similar to other cultivars grown at various locations. For example, Hassanat et al. (2006) reported conventional pearl millet with a CP concentration of 98 (± 0.9) g/kg DM and 107 (± 0.9) g/kg DM for BMR pearl millet. The ratio of N intake to N absorbed in the current study was similar to that observed in Sipli lambs (0.51) fed pearl millet cultivars grown in semi-arid zones in Pakistan as evidenced by Khan et al. (2011). It should be mentioned that the positive N balance and lack of body reserve mobilization observed in all the lambs fed on the Brazilian pearl millet cultivars suggests an adequate digestibility of dietary protein.

Under the conditions of the current study, the Brazilian pearl millet cultivars could play a strategic role in further intensifying Brazilian grazing livestock systems in a sustainable way, mainly because these forages require less water to yield DM and digestible DM/ha than other feed sources (such as maize or sorghum) that could be planted in these regions. Indeed, the Brazilian pearl millet cultivars were more water-use efficient than sorghum and maize grown in semi-arid regions of Brazil (56 ± 2.8 kg DM/ha/mm water for the Brazilian pearl millet cultivars vs. 45 ± 1.9 kg DM/ha/mm water for sorghum; da Silva et al. 2011; and 21 ± 2.4 kg DM/ha/mm water for the Brazilian maize cultivars; dos Santos et al. 2010). The same response has been reported in temperate climate for maize (11 ± 2.5 kg DM/ha/mm) grown in the United States and sorghum (14 ± 1.4 kg DM/ha/mm) planted in China that exhibited lower water-use efficiency than the Brazilian pearl millet cultivars (Nielsen et al. 2006; Deng et al. 2006).

Therefore, the current study showed that the Brazilian pearl millet cultivars have potential to yield forage with less water and on the same area of land in a Brazilian semi-arid area or in regions where irrigation is not possible and precipitation limits maize silage production. The cultivars CMS-03, CMS-01 and BN-2 exhibited higher DM yield/ha as compared with BRS 1501 and IPA BULK1-BF. It should be pointed out that differences in silage chemical composition among cultivars did not influence voluntary feed intake and apparent digestibility of nutrients in lambs. Finally, under the conditions of the current study, the results obtained for production of dry and digestible dry matter, and the ratio of plant fractions indicates the possible use of these cultivars on silage production in semi-arid regions of Brazil.

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Table 1. Meteorological data during the experimental period

Month/Year	Days*	Rain (mm)	Temperature (°C)			Evaporation (mm)	RH (fraction)†	Wind (km/day) ‡
			Max.	Min.	Mean			
Jun 2011	24	48	27	19	22	103	0.69	99
Jul 2011	22	112	26	18	21	81	0.68	100
Aug 2011	21	69	27	18	22	119	0.66	99
Sep 2011	14	46	28	18	22	115	0.67	108
Oct 2011	5	49	31	20	24	132	0.70	115

*Rainfall occurrence in days.
†RH = Relative Humidity (fraction)
‡Wind average speed at 2 m height.
Source: Agro meteorological station in the Experimental Area of Gloria, Embrapa Semi-Arid – Nossa Senhora da Glória – Sergipe State, Brazil.

Table 2. Performance and phenological traits of pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	BN-2	MEAN	S.E.M.	*P*
Plant height (cm)	171	146	183	200	199	179	5.0	<0.01
Plant density (1000 plants/ha)	343	307	345	299	349	329	15.2	0.064
Dry matter yield (t/ha)	10.3	8.4	16.3	16.2	16.2	13.5	1.85	<0.001
Digestible dry matter yield (t/ha)	5.2	3.3	8.2	8.1	8.1	6.6	0.86	<0.001
Lodging score	1.5	1.5	0.6	1.1	1.0	1.1	0.12	<0.001
DM partitioning of plant organs (proportion)								
Panicles	0.54	0.43	0.53	0.45	0.46	0.48	0.026	0.046
Stems	0.35	0.42	0.35	0.42	0.40	0.38	0.023	0.205
Leaves	0.11	0.15	0.12	0.13	0.14	0.13	0.010	0.262

DM = dry matter; S.E.M. = standard error of mean; *P* = probability (if treatments differ at *P* <0.05); D.F. = 16.

Table 3. Chemical composition (g/kg DM) and fermentation product concentrations (g/kg DM) of silages produced from pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	BN-2	MEAN	S.E.M.	*P*
DM (g/kg)	340	341	350	350	371	350	9.8	0.100
pH	3.8	3.9	3.8	3.8	3.9	3.9	0.02	0.003
GE (MJ/kg DM)	16.5	16.4	16.3	16.4	16.1	16.3	0.38	0.906
Chemical composition and fermentation product concentrations (g/kg DM)								
Crude protein	102	106	112	112	109	108	0.4	0.331
NDF	523	567	528	554	577	550	1.8	0.135
ADF	329	348	337	341	353	342	1.3	0.117
Hemicellulose	224	219	191	213	194	208	0.7	0.307
Non-fibrous carbohydrate	311	268	305	287	266	288	1.7	0.174
Organic matter	930	927	938	939	937	934	0.3	0.015
Ether Extract	33	34	42	34	42	37	0.3	0.074
IVDMD (proportion of DM)	0.51	0.43	0.48	0.50	0.48	0.48	0.012	0.009
Acetic acid	14.5	14.4	11.3	12.2	16.3	13.7	0.47	<0.001
Propionic acid	3.2	2.8	2.3	3.9	3.6	3.1	0.55	0.112
Butyric acid	0.51	0.71	0.56	0.57	0.44	0.56	0.025	<0.001
Total VFA	18.2	17.9	14.1	16.6	20.3	17.4	1.01	0.002
NH_3-N/TN	44	48	44	47	52	47	2.7	0.251
Lactic acid	69	63	65	58	55	62	2.4	0.001

DM = dry matter; NDF = neutral detergent fibre; ADF = acid detergent fibre; IVDMD = *in vitro* dry matter digestibility; VFA = acetic acid + propionic acid + butyric acid; TN = total nitrogen; GE = gross energy; MJ = Megajoule; S.E.M. = standard error of mean; *P* = probability (if treatments differ at *P* <0.05); D.F. = 16.

Table 4. Dry matter intake (g/kg) and total apparent digestibility (fraction) of dietary components in lambs fed silage produced from five pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	BN-2	MEAN	S.E.M.	*P*
Intake (g/day)								
Dry matter	421	426	463	459	413	436	76.2	0.983
Organic matter	394	378	438	430	373	403	68.9	0.940
Crude protein	53	46	58	47	44	50	8.1	0.760
NDF	247	218	260	292	242	252	44.5	0.830
ADF	113	103	114	144	113	118	21.2	0.711
Non-fibrous carbohydrates	87	105	111	86	76	92	15.5	0.465
Ether Extract	8	8	11	7	9	9	1.5	0.594
TDN	316	305	342	328	293	317	35.4	0.877
GE, MJ/day	7	8	8	8	7	8	1.3	0.990
Total apparent digestibility (fraction)								
Dry matter	0.51	0.48	0.48	0.50	0.49	0.49	0.043	0.990
Organic matter	0.55	0.50	0.53	0.55	0.52	0.53	0.042	0.863
Crude protein	0.51	0.53	0.54	0.54	0.51	0.53	0.042	0.975
NDF	0.47	0.39	0.42	0.45	0.41	0.43	0.044	0.683
ADF	0.40	0.35	0.31	0.42	0.36	0.37	0.055	0.597
Non-fibrous carbohydrates	0.76	0.82	0.83	0.75	0.79	0.79	0.045	0.589
Ether Extract	0.40	0.41	0.38	0.39	0.43	0.40	0.066	0.989

NDF = neutral detergent fibre; ADF = acid detergent fibre; TDN = total digestible nutrients; GE = gross energy; MJ = Megajoule; S.E.M. = standard error of mean; *P* = probability (if treatments differ at *P* <0.05); D.F. = 16.

Table 5. Nitrogen balance in lambs fed silage of five pearl millet cultivars

Variable	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01	BN-2	MEAN	S.E.M.	*P*
N intake (g/day)	8.5	7.4	9.2	7.5	7.1	8.0	1.29	0.749
N faecal (g/day)	3.9	3.2	4.1	3.4	3.4	3.6	0.64	0.867
N urinary (g/day)	0.5	0.3	0.5	0.7	0.8	0.5	0.08	0.002
N absorbed (g/day)	4.1	3.9	4.6	3.4	2.9	3.8	0.81	0.652
N absorbed / N intake	0.45	0.52	0.50	0.44	0.45	0.47	0.057	0.550

N = nitrogen; S.E.M. = standard error of mean; *P* = probability (if treatments differ at $P < 0.05$); D.F. = 16.

CAPÍTULO 4 - SIMULATED OPTIMUM SOWING DATE FOR FORAGE PEARL MILLET CULTIVARS IN MULTILOCATION TRIALS IN BRAZILIAN SEMI-ARID REGION

ABSTRACT

Forage production is primarily limited by weather conditions under dryland production systems in Brazilian semi-arid regions, therefore sowing at the appropriate time is critical. The objectives of this study were to evaluate the CSM-CERES-Pearl Millet model from the DSSAT software suite for its ability to simulate growth, development and biomass yield of pearl millet [*Pennisetum glaucum* (L.) R. Br.] at three Brazilian semi-arid locations, and to use the model to study the impact of different sowing dates on pearl millet performance for forage. Four pearl millet cultivars were grown during the 2011 rainy season in field experiments conducted at three Brazilian semi-arid locations, under rainfed conditions. The genetic coefficients of the four pearl millet cultivars were calibrated for the model, and the model performance was evaluated with experimental data. The model was run for 14 sowing dates using long-term historical weather data from three locations, to determine the optimum sowing window. Results showed that performance of the model was satisfactory as indicated by accurate simulation of crop phenology and biomass yield against measured data. The optimum sowing window varied among locations depending on rainfall patterns, although showing same trend for cultivars within site. The best sowing windows were from 15 April to 15 May for the Bom Conselho location; 12 April to 02 May for Nossa Senhora da Gloria; and 17 April to 25 May for Sao Bento do Una. The model can be used as a tool to evaluate the effect of sowing date on forage pearl millet performance in Brazilian semi-arid conditions.

INTRODUCTION

In Brazil, the semi-arid region comprises 95 million hectares of which only 3% are suitable for irrigation, leaving an immense dryland area to be exploited if sustainable production practices can be identified and implemented (Martins et al., 2003). Under these conditions, forage production represents one possible alternative.

Within this context, pearl millet is a candidate feed source for agricultural adaptation in dry regions as it is a tropical plant possessing the C4 photosynthetic pathway and it has tolerance to drought, heat and low soil pH (Maiti and Wesche-Ebeling, 1997). Because of its adaptability to harsh conditions, millet can be grown in areas that are unfavorable to other crops such as maize (Singh and Singh, 1995). Although several studies have evaluated the potential of pearl millet as forage for ruminants in dry regions (Hill et al., 1999; Messman et al., 1992), data on its management are limited, especially relative to ideal sowing dates. For semi-arid regions, the planting date decision is important not only because of its effect on yield, but also the need to minimize the risk of establishment failures and to decrease cost and labor required for replanting.

In this context, crop simulation models can be useful tools for the evaluation of alternative management options for a particular location, including planting dates (Ruiz-Nogueira et al., 2001; Saseendran et al., 2005; Tsuji et al., 1998). Furthermore, models that have been developed and validated with local experimental data can be valuable tools for extrapolating these experimental results to other years and other locations (Matthews et al., 2002). Crop simulation models integrate the interdisciplinary knowledge gained through experimentation and technological innovations in the fields of biological, physical, and chemical science relating to agricultural production systems (Andarzian et al., 2015; Soler et al., 2007). Therefore, these models can increase understanding and management of the agricultural system in a holistic way. Crop simulation models have been used to investigate the performance of different pearl millet cultivars at a range of sowing dates in relation to different soil-climate scenarios (Pale et al., 2003; Shivsharan et al., 2003; Soler et al., 2008). The Decision Support System for Agrotechnology Transfer (DSSAT) is a comprehensive decision support system for assessing management options (Hoogenboom et al., 2014; Jones et al., 2003; Tsuji et al., 1998) that includes the Cropping System Simulation Model (CSM)-CERES-Pearl Millet (Hoogenboom et al., 2014; Jones et al., 2003), which is a process-oriented, dynamic crop simulation model that simulates crop growth, development and yield.

The overall goal of this study was to evaluate the performance of the CSM-CERES-Pearl Millet model for simulating growth, development, and yield of four pearl millet cultivars and to determine optimum sowing dates for pearl millet forage yield under rainfed conditions in three Brazilian semi-arid locations.

MATERIALS AND METHODS

Experimental Sites

The experiments were carried out in 2011, under rainfed conditions, at three locations in the Brazilian semi-arid region: Bom Conselho, Pernambuco State; Nossa Senhora da Gloria, Sergipe State; and Sao Bento do Una, Pernambuco State. The experiment in Bom Conselho

(09º10′ S, 36º40′ W, elevation of 654) was conducted at a private property, located in a region in which the soil type is Xanthic ferralsol sand clay (Santos et al., 2013) with a fine texture and pH of 4.5. The climate is typically semi-arid with an annual rainfall of 431 mm and average maximum and minimum temperatures of 31 and 19 °C, respectively. The experiment in Nossa Senhora da Gloria (10º13′ S, 37º25′ W, elevation of 291 m) was conducted at the Semi-Arid Experimental Station of the Brazilian Agricultural Research Corporation (EMBRAPA). The soil type in this region is a Eutrophic podzol clay loam (Santos et al., 2013), with an average depth of 1.5 m and pH of 6.1. The climate is typically semi-arid with an annual rainfall of 710 mm and average maximum and minimum temperatures of 32 and 20 °C, respectively. The experiment in Sao Bento do Una (08º31 ′S, 36º26′ W, elevation of 614 m) was conducted at an experimental station of the Agronomic Institute of Pernambuco (IPA), where the soil was a sandy loam Eutrophic leptosol with medium texture and pH of 6.6. The megathermal climate at this site is typically semi-arid with an annual rainfall of 655 mm and average maximum and minimum temperatures of 32.6 and 11.6 ºC, respectively.

Pearl millet cultivars evaluated

Four pearl millet cultivars, IPA BULK1-BF, BRS 1501, CMS-03 and CMS-01, were used in the experiment. IPA BULK1-BF was developed by Agronomic Institute of Pernambuco (IPA). It yields up to 6.0 Mg ha^{-1} dry matter under rainfed conditions. It takes 50-60 days to reach flowering during winter. It is recommended mainly for forage production in Brazilian semi-arid regions (Rodrigues and Pereira Filho, 2010). The Brazilian Agricultural Research Corporation (EMBRAPA) developed and released the cultivars BRS 1501, CMS-03 and CMS-01 that are adapted to areas with risks of drought conditions. They have dry matter production averaging of 8.0 Mg ha^{-1} and good grain production potential (2.5 Mg ha^{-1}). For these cultivars, flowering occurs 50 days after planting (Pereira Filho et al., 2003). The four cultivars were chosen because of their similar duration to maturity and because they are grown under rainfed conditions. The cultivars are already being grown by farmers, and, therefore, could easily be promoted for use under water deficit conditions once their performance is established.

Treatments, experimental design and crop management

The experiments were conducted under rainfed conditions during the rainy season from May to August 2011. Treatments were the four cultivars replicated five times in a randomized complete block design. Plots measured 10.5 m^2 (5 × 2.1 m), with seed sown to a depth of 3 cm in four rows (on 0.70 m centers). The sowing dates were 4 June 2011, 1 June 2011 and 17 May 2011 for Bom Conselho, Nossa Senhora da Gloria, and Sao Bento do Una, respectively. At sowing the following fertilization was applied: 30 kg ha^{-1} nitrogen (as ammonium sulfate), 450 kg ha^{-1} triple superphosphate and 100 kg ha^{-1} potassium chloride. Two side-dress fertilizations were applied, the first on the 30th day, and the second on the 60th day after plant emergence, with the dose equivalent to 30 kg ha^{-1} of nitrogen (as ammonium sulfate).

Cultivars were harvested when at least 60% of plants in each plot reached the Zadoks scale of 85, which means that plants were at the dough stage of grain maturity (Zadoks et al., 1974). Harvests were made manually and taken at 5 cm above ground level. Only the two central rows in each plot were harvested, with the remainder being discarded. The harvested crop from each plot was collected and weighed to estimate fresh biomass yield ha^{-1}. After chopping a representative sample from each plot, a 400-g sub-sample was oven-dried at 55°C for 48 h to determine dry matter concentration and biomass yield of the four cultivars.

Climate, soil and crop data

The minimum input data set required for DSSAT version 4.6 to simulate crop growth was discussed in detail by Jones et al. (2003). Input data required for the models are crop management information, cultivar-specific parameters (genetic coefficients), soil properties and daily weather variables of the study areas.

Weather data from 2011, for three locations, were obtained from automated weather stations, including daily average, maximum and minimum temperatures, precipitation, daily rainfall, evaporation and relative humidity (Table 1). For trials that were performed on agricultural research stations, on-station data were available. For the experiment that was performed on-farm (Bom Conselho) weather data were obtained from the recording station nearest to the farm (at a distance of 4 km). For analysis of the different simulated sowing dates 15 years of weather records were used for each site, including rainfall data that were obtained from automated weather stations. The other historical weather data including air temperatures, wind flow velocity, evaporation and relative humidity were obtained from NASA-POWER database (Stackhouse Jr. et al., 2015). The method of Priestley and Taylor (1972) was used to estimate the evapotranspiration during the simulations.

The crop data collected in 2011 include phenology dates (sowing and anthesis dates), dry matter biomass yield and aboveground biomass (separated into leaves, stems, and panicles). Total biomass yield was measured at the dough stage since these cultivars were grown for forage production.

Soil P, K, Al, Ca, Mg, organic matter, pH, and initial soil moisture concentration data to a depth of 0.3 m were collected in 2011 before sowing. For simulations for each field, only soil series and surface soil texture were available from Santos et al. (2013). Pedon data from the Harmonized World Soil Database (HWSD) (Fischer et al., 2008) were used to provide estimates of bulk density, organic carbon, and percent sand, silt, and clay in each layer. The methods of Saxton et al. (1986) were used to estimate volumetric soil water content at lower and upper limits and saturated hydraulic conductivity for each soil layer. We assumed a maximum soil profile depth of 1.0 m for all soils and set layer depths to 5, 15, 30, 60 and 100 cm. Soil albedo (SALB), runoff potential (SLRO), and drainage rate (SLDR) were estimated according to the procedures outlined in DSSAT documentation (Hoogenboom et al., 2015). The soil fertility factor (SLPF) was assumed to be 1.0 in all simulations. The soil surface evaporation limit (SLU1) was set to 6.0 mm day^{-1} for all site-years. Initial soil water content was assumed to be at field capacity in all simulations and full recharge at time of sowing. For N fertilization management simulations, was used ammonium sulfate as fertilizer, where N was applied at planting (30 kg ha^{-1}), and as a sidedressing application before flowering (20 kg ha^{-1}).

Model calibration and evaluation

The CSM-CERES-Pearl Millet model of the DSSAT Version 4.6.1 (Hoogenboom et al., 2015; Jones et al., 2003) was used to evaluate the performance of pearl millet under the different sowing dates. The CSM-CERES-Pearl Millet model in V4.6.1 was modified and improved for temperature, water deficit, and tillering response based on extensive data from India and Africa (K.J. Boote, personal communication, 2015). Site-specific calibration of cultivar traits and evaluation of model performance are pre-conditions for using models for other locations than where they were developed (Jones et al., 2001; Van Ittersum et al., 2003). The primary objective of model calibration was to adapt the model parameters to local environmental conditions (e.g., soil types and weather conditions) and crop cultivars so as to gain a good overall agreement between simulated and observed values. The CSM-CERES-Pearl Millet model includes nine cultivar-specific coefficients that require modification for new cultivars not previously used with the crop model. Six specific cultivar coefficients were adjusted for pearl millet during the evaluation process: P1 - Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 10 ºC) during which the plant is not responsive to changes in photoperiod; P5 - Thermal time (degree days above a base temperature of 10 ºC) from beginning of grain filling

(3-4 days after flowering) to physiological maturity; G1 - Scaler for relative leaf size on main stem; GT – Tillering coefficient; G4 - Scaler for partitioning of assimilates to the panicle (head) and PHINT - Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances (Table 2). These genetic coefficients were determined in sequence, starting with the phenological development coefficients and followed by the crop growth coefficients, because of the dependence of the latter coefficients on the performance of the vegetative and reproductive development simulations (Hoogenboom et al., 1992).

Different statistical indices were employed, including Coefficient of Determination (r^2), absolute and normalized Root Mean Square Error (RMSE) (Loague and Green, 1991), and Index of Agreement (*d*-Stat) (Willmott et al., 1985). Normalized RMSE gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent when the normalized RMSE is less than 10%, good if the normalized RMSE is greater than 10% and less than 20%, fair if normalized RMSE is greater than 20 and less than 30%, and poor if the normalized RMSE is greater than 30% (Jamieson et al., 1991). According to the *d*-Stat, the closer the index value is to one, the better the agreement between the two variables that are being compared (Willmott et al., 1985). The combination of coefficients that resulted in the highest *d*-Stat and the smallest RMSE between observed and simulated values were selected as the final cultivar coefficients.

Optimum sowing dates

An analysis of the effect of different sowing dates on biomass yield of pearl millet was conducted using 15 years of weather records for each site. In this study, 14 different sowing dates were simulated using the seasonal analysis tool of DSSAT Version 4.6.1, under rainfed conditions.

The sowing dates started on 1 January and were repeated every 15 days until 15 July. These dates were selected because this period is the regional rainy season, which coincides with the growth window for forage crops such maize and sorghum. However, due to the limitation of available water, there is significant variation for regional planting window. Assumptions for determining the sowing window were that the opening sowing window was the first date on which 85% of the maximum yield could be obtained, and the closing sowing window was the last date for which 85% of the maximum yield could be obtained.

RESULTS

Weather conditions

The three locations have characteristics typical of semi-arid tropical regions, i.e., a hot and dry climate that is highly limited in its hydrologic resources, particularly due to low precipitation and high evaporation rates. These sites have two well-defined seasons, namely, the rainy season, lasting between three and four months during the summer and fall, and the dry season, lasting for the remainder of the year.

The analysis of the series of 15 years (1997-2011) of weather records for Bom Conselho, showed that the average monthly maximum temperatures were always greater than 26 ºC, and the average monthly minimum temperatures were always higher than 19.5 ºC (Figure 1a). The rainfall during the 2011 crop growing season (223 mm) was above the 15-year average (163 mm) and there were more rainy days (44) than the long-term average (24 days).

For Nossa Senhora da Gloria, the 15-year average of weather records showed that the highest maximum average temperatures and maximum solar radiation occurred in November (32 and 23 ºC, respectively) while the highest minimum average temperature occurred in December (22.5 ºC) (Figure 1b). With respect to precipitation, the highest monthly values were observed between January and June, with a maximum for May (111 mm). The 2011 growing season in Nossa Senhora da Gloria was characterized by a higher amount of rainfall (257 mm) and rainy days (61) than the 15-year long-term average growing season (102 mm and 27 days).

Similarly to Nossa Senhora da Gloria, the Sao Bento do Una weather records showed that the highest maximum average temperatures and maximum solar radiation occurred in November (31 and 24 ºC, respectively) while the highest minimum average temperature occurred in December (21 ºC) (Figure 1c). The rainy season, on average, started in January and ended in July, with a maximum precipitation of 121 mm in May. The 2011 growing season for Sao Bento do Una showed a similar amount of rainfall as the average for 15 years, with a total rainfall of 304 mm from 66 rainy days compared with the 15-year average total precipitation of 298 mm from 43 rainy days.

Evaluation of the CSM-CERES-Pearl Millet model

The values for cultivar coefficient P1 showed some variation, ranging from 75.0 to 118.9 degree days. The genetic coefficient P5 also had a significant and large variation, varying from 102.6 degree days for cultivar BRS 1501 to 377.0 for cultivar CMS-03. The value of G1 for IPA BULK1-BF and CMS-03 was 1.0, while the G1 values for BRS 1501 and CMS-01 were 0.5 and 1.2, respectively. The value of GT was 1.0 for all four cultivars. The cultivar reproductive partitioning coefficient G4 was 0.83 for the cultivar IPA BULK1-BF, 1.02 for BRS 1501, 0.65 for CMS-03 and 0.77 for CMS-01. The phyllochron interval coefficient (PHINT) value for all four cultivars was 43.0 degree days.

The model was able to predict the number of days from planting to anthesis and biomass yield for the four pearl millet cultivars grown in all three locations during the 2011 growing season (Table 3).

For Bom Conselho, the simulation exactly reproduced the observed days from planting to anthesis for the cultivars IPA BULK1-BF, BRS 1501 and CMS-03. For the cultivar CMS-01 observed and simulated intervals were similar, 54 and 55 days, respectively. The average observed forage dry matter yield for the four cultivars was 9850 kg ha^{-1} and the corresponding average simulated forage yield was 9540 kg ha^{-1}.

For Nossa Senhora da Gloria the observed number of days from planting to anthesis ranged from 54 to 56 days, while the simulated number of days to anthesis ranged from 51 to 56 days. At this site, the average observed and simulated yield values were 12270 and 11990 kg ha^{-1}, respectively.

For Sao Bento do Una the observed number of days from planting to anthesis ranged from 53 to 55 days, while the simulated number of days to anthesis ranged from 56 to 58 days. The average observed yield for the four cultivars for this location was 12650 kg ha^{-1} while average simulated yield was 13050 kg ha^{-1}.

The values of normalized RMSE and *d* for anthesis ranged from 4.4 to 4.9% and from 0.19 to 0.69, respectively. It is important to note that a given set of genetic coefficients for a cultivar were optimized across all three sites. For all three locations, the normalized RMSE for yield ranged from 2.6 to 5% and the value for *d* ranged from 0.94 to 0.98, the model was well capable of predicting yields across the three sites.

Sowing date analysis

The sowing date analysis using 15 years of weather data (1997–2011) for Nossa Senhora da Gloria showed that the best sowing date for millet depends, in part, on the cultivar that will be used. However for Bom Conselho and Sao Bento do Una, all pearl millet cultivars had similar trends for the best sowing date.

On the rising slope of yield versus sowing date, the average slope was 37, 54 and 29 kg ha^{-1} d^{-1} during the period prior to the peak yield. The slope of decline after peak yield with delayed sowing was 45, 51 and 58 kg ha^{-1} d^{-1}, for Bom Conselho, Nossa Senhora da Gloria and Sao Bento do Una, respectively (Figure 2).

The total simulated transpiration for the entire season had the lowest values for the latest sowing dates and reached a maximum between 1 February and 1 April for all three locations (Figure 3). Usually, under water-limited conditions yield is highly correlated with transpiration. The coefficient of determination between simulated biomass yield and simulated total transpiration for Bom Conselho, Nossa Senhora da Gloria and Sao Bento do Una was 0.97, 0.93 and 0.97, respectively (Figure 4).

Determining sowing window

The length of the optimum sowing window for Bom Conselho was 45 days and was shorter than the other locations. It began on 1 March and ended 15 April. For Nossa Senhora da Gloria, the cultivars influenced the period of the optimum sowing window, but the duration was 60 days for all cultivars. For the cultivars IPA BULK1-BF, CMS-03, and CMS-01, the optimum sowing window commenced on 15 February and ended on 15 April while for BRS 1501 it started on 1 March and ended 1 May. Sao Bento do Una showed the longest optimum sowing window, with a period of 75 days. The sowing window started on 15 January and finished on 1 April for all cultivars.

DISCUSSION

The three semi-arid locations of the present study were characterized by similarity in weather variables, except for rainfall, but the soil properties varied. For the 2011 year, as well as long term, the rainfall in Sao Bento do Una was higher and the period of the rainy season was more pronounced than in Bom Conselho and Nossa Senhora da Gloria.

At the three locations phenology varied among cultivars, since for all four cultivars the period from planting to anthesis ranged from 50 to 56 days. The evaluated Brazilian pearl millet cultivars exhibited a shorter time from planting to anthesis than for three pearl millet varieties grown in Niger (Soler et al., 2008). Among the locations in the current study, Bom Conselho had lower simulated and measured period from planting to anthesis, likely because higher temperatures accelerated crop development and shortened the crop growth cycle. All of the indices imply that there was a good agreement between simulated and measured duration from sowing to anthesis. Based on these results, it can be concluded that the model was very robust in predicting the critical phenological growth stages.

The mean biomass yield of 11.6 Mg ha^{-1} observed for four cultivars at three locations was greater than the range of values reported for three African genotypes (7.5 Mg ha^{-1}) and two Brazilian cultivars (7 Mg ha^{-1}) of pearl millet grown in a Brazilian sub-tropical climate (Costa et al., 2005). This may be due to greater daily heat unit accumulation observed during the growing season in northeast Brazil in the current study (1648 growing degree days (GDD) - °C) compared with those in southwest Brazil (Costa et al., 2005) (1204 GDD - °C), better than usual rainfall in 2011, and possibly better soil fertility than the other environments. The ability of the CERES-Pearl Millet model to predict biomass in the tropical, sub–tropical and temperate environment was verified by previous studies (Dalvi et al., 2010; Hussaini and Halilu, 2013; Shivsharan et al., 2003; Soler et al., 2008). For Sao Bento do Una, higher precipitation resulted in an increase in observed biomass yield, which was 28 and 3% higher when compared to Bom Conselho and Nossa Senhora da Gloria, respectively. The simulated biomass yield had the same trend as the observed since Sao Bento do Una was 36 and 8% higher than Bom Conselho and Nossa Senhora da Gloria, respectively. These significant differences in biomass yield among locations can be attributed to several interrelated factors, including differences in soil texture and acidity levels.

Several studies on sowing date analysis have shown that models can be useful for this type of evaluation, compared with resource-intensive experiments (Andarzian et al., 2015; Dharmarathna et al., 2014; Jibrin et al., 2012). This study showed that for Bom Conselho, long-term simulated yield of all cultivars ranged from 680 to 7040 kg ha^{-1} depending on the sowing date. Maximum yield was simulated for a sowing date of 15 March for the cultivars IPA BULK1-BF, CMS-03, and CMS-01 and 1 April for the BRS 1501. The minimum yield was observed for the 15 July simulated sowing date for all cultivars. With a delay in sowing date from 1 January to 15 March, the average yield was increased in approximately 4.3% per week. Whereas, a delay in sowing date from 15 March to 15 July resulted in a yield reduction of about 5.1% per week. The total simulated transpiration for the entire growing season reached a maximum between 15 March and 1 April for all four cultivars. The highest total transpiration was obtained for the cultivars IPA BULK1-BF and CMS-03 for the 15 March sowing date (106 mm).

For Nossa Senhora da Gloria, the average yield obtained under long-term historical daily weather conditions for this location ranged from 2190 to 10320 kg ha^{-1}. Similar to the response at Bom Conselho, the highest yield was obtained on 1 April for the cultivar BRS 1501 and 15 March for the IPA BULK1-BF, CMS-03, and CMS-01 cultivars, while lowest yields were predicted for the 15 July sowing date. Delaying sowing date from 1 January to 15 March resulted in an increase of 4.9% per week, but delaying the sowing date from 15 March to 15 July decreased the yield in 4.1% per week. Total simulated transpiration for the entire growing season showed reduced values for the late sowing dates and also showed the highest value for the 15 March sowing date for all four cultivars.

In Sao Bento do Una the long-term simulated yield ranged from 3590 to 13850 kg ha^{-1} depending upon the sowing date and cultivar. The simulated yield for this site was higher than the other locations. The highest yield was attained through sowing on 15 February for the cultivars IPA BULK1-BF, CMS-03, and CMS-01 and 15 March for the cultivar BRS 1501. As observed for the other locations, the lowest yields were found on the last simulated sowing date of 15 July, for all four cultivars. For the cultivars IPA BULK1-BF, CMS-03 and CMS-01, when sowing date was delayed from 1 January to 15 February the biomass yield increased 39 kg ha^{-1} d^{-1}, but delaying from 15 February to 15 July decreased yield by 58 kg ha^{-1} d^{-1}. For the cultivar BRS 1501 the yield increase was only 19 kg ha^{-1} d^{-1} when sowing date was delayed from 1 January to 15 March. A delay in sowing date from 15 March to 15 July resulted in biomass yield decrease of 3.2% per week

Similar to other locations, the total simulated crop transpiration was lowest for the final sowing dates. For the cultivars IPA BULK1-BF, CMS-03, and CMS-01 highest total transpiration was obtained for the 15 February sowing date. However, for the cultivar BRS 1501 highest total transpiration was observed for the 1 February sowing date (160 mm).

These results show that biomass production is influenced by cumulative intercepted solar radiance and rainfall, since in all locations solar radiation decreased and rainfall increased from January to May. This coincides with the findings of Costa et al. (2005) and Soler et al. (2008), who found that pearl millet biomass yield varies mainly due to photoperiod and water availability.

Plant transpiration is directly related to yield for most cereals. A reduction in yield may occur when rainfall is insufficient to support the transpiration demand. In the present study, there were high values of the coefficient of determination between total simulated transpiration for the growing season and millet biomass yield grown at all locations and simulated sowing dates. This indicates that water supply is one of the most important factors that limited crop production for this region, when the system is managed with relatively high inputs. These results agree with previous studies (Klaij and Vachaud, 1992; Grema and Hess, 1994; Beggi et al., 2015) that found crop water supply can be considered as the most limiting factor for millet production, when the mineral N demand is supplied. This statement is corroborated by a recent review, where Vadez et al. (2014) argued that high transpiration is indeed related to higher yield.

Therefore, the current study showed that the CSM–CERES-Pearl Millet model was able to simulate accurately growth, development and yield for four forage pearl millet cultivars grown in three Brazilian semi-arid locations under rainfed conditions. The sowing date analysis using 15 years of climate records for Bom Conselho, Nossa Senhora da Gloria and Sao Bento do Una indicated that the best sowing dates occur before the normal forage sowing season, and the sowing window is longer than recommended by the Brazilian government for these regions. This is likely due to the absence of definitive climatic zoning, which could reduce the dependence of farmers on their individual perception of climatic factors.

In general, the results of the simulations confirmed previous field observations of pearl millet responses in this region and showed that crop simulation models can play an important role in identifying best management options for specific environmental conditions. As such, simulation models can provide farmers and policy-makers with information about forage production strategies to aid in addressing the food demands of livestock in semi-arid environments.

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Table 1. Meteorological data during the experimental period for the selected locations

Location¶	Rainfall†	Rain§	Temperature‡			Evaporation§	RH††
			Max.	Min.	Mean		
Bom Conselho	44	223	32	22	26	180	75
Nossa Senhora da Gloria	61	282	27	18	22	217	77
Sao Bento do Una	66	304	27	18	21	243	85

†Rainfall occurrence in days.
§Rain and evaporation in mm.
‡Temperature in ºC.
††RH, Average Relative Humidity (%).
¶Experimental period: Bom Conselho – from 4 June to 25 August 2011; Nossa Senhora da Gloria - from 1 June to 30 August 2011; Sao Bento do Una - from 17 May to 09 August 2011.

Table 2. Genetic coefficients of pearl millet cultivars calibrated in DSSAT

Cultivar coefficient description	IPA BULK1-BF	BRS 1501	CMS-03	CMS-01
P1 - Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 10 ºC) during which the plant is not responsive to changes in photoperiod.	118.9	102.9	75.0	117.4
P5 - Thermal time (degree days above a base temperature of 10 ºC) from beginning of grain filling (3-4 days after flowering) to physiological maturity.	180.0	102.6	377.0	261.4
G1 - Scaler for relative leaf size on main stem.	1.00	0.50	1.00	1.20
G4 - Scaler for partitioning of assimilates to the panicle (head).	0.83	1.02	0.65	0.77
PHINT - Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.	43.0	43.0	43.0	43.0
GT – Tillering coefficient, equivalent to G1, but on tillers.	1.00	1.00	1.00	1.00

Table 3. Biomass yield and anthesis date for pearl millet under rainfed conditions at three locations in Brazil, as measured and simulated.

Cultivars	Biomass Yield			Anthesis		
	Measured		Simulated	Measured		Simulated
	—— kg ha^{-1} ——			—— DAP ——		
			Bom Conselho			
IPA BULK1-BF	9650		10000	53		53
BRS 1501	7650		7620	50		50
CMS-03	11500		10400	50		50
CMS-01	10580		10160	54		55
			Nossa Senhora da Gloria			
IPA BULK1-BF	12050		11920	55		54
BRS 1501	9750		9540	54		52
CMS-03	14090		13700	54		51
CMS-01	13180		12800	56		52
			Sao Bento do Una			
IPA BULK1-BF	12610		13360	54		58
BRS 1501	9870		10830	53		56
CMS-03	14110		14100	53		56
CMS-01	14010		13920	55		57
	RRMSE†	*d*-Stat§	r^2‡	RRMSE†	*d*-Stat§	r^2‡
IPA BULK1-BF	4.2	0.96	0.93	4.4	0.19	0.37
BRS 1501	4.4	0.98	0.96	4.9	0.67	0.50
CMS-03	5.0	0.94	0.99	4.6	0.64	0.17
CMS-01	2.6	0.98	0.99	4.8	0.63	0.10

†RRMSE, Normalized root mean square error (%).
§*d*-Stat, Wilmot's Index of Agreement.
‡r^2, Coefficient of determination.

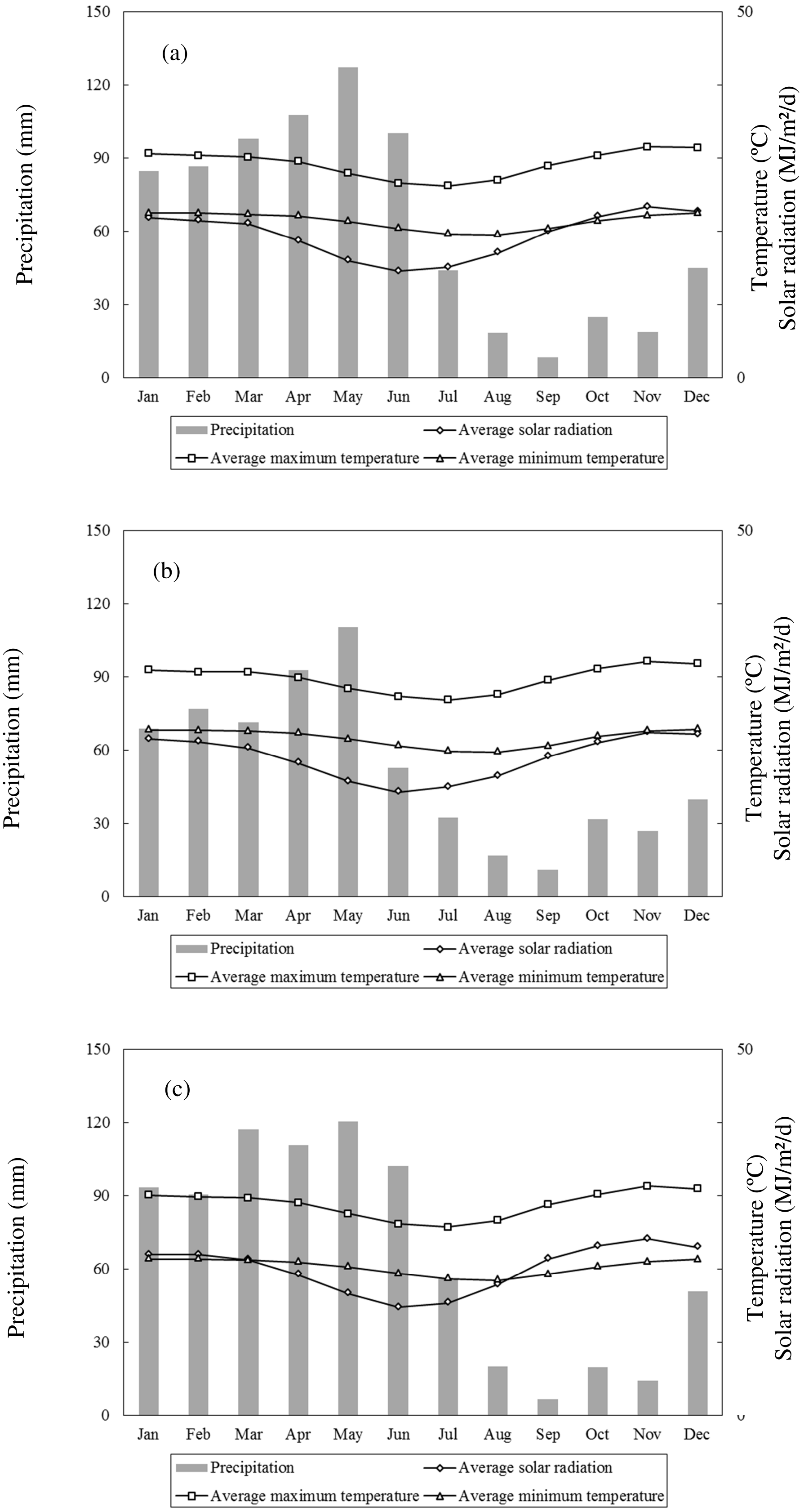

Figure 1. Average monthly precipitation, average maximum and minimum temperature, and average solar radiation for Bom Conselho (a), Nossa Senhora da Gloria (b) and Sao Bento do Una (c) for 1997-2011.

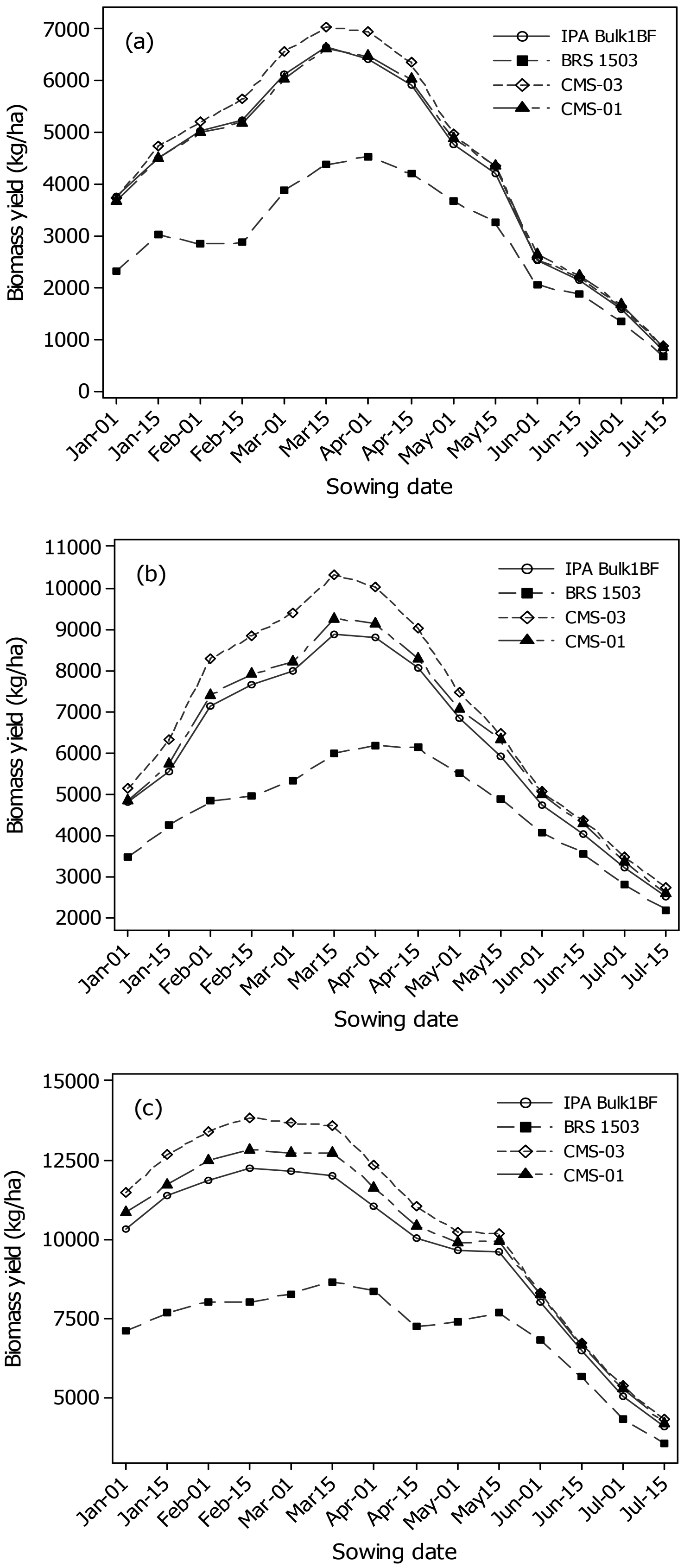

Figure 2. Simulated pearl millet biomass yield for different cultivars at different sowing dates for Bom Conselho (a), Nossa Senhora da Gloria (b) and Sao Bento do Una (c).

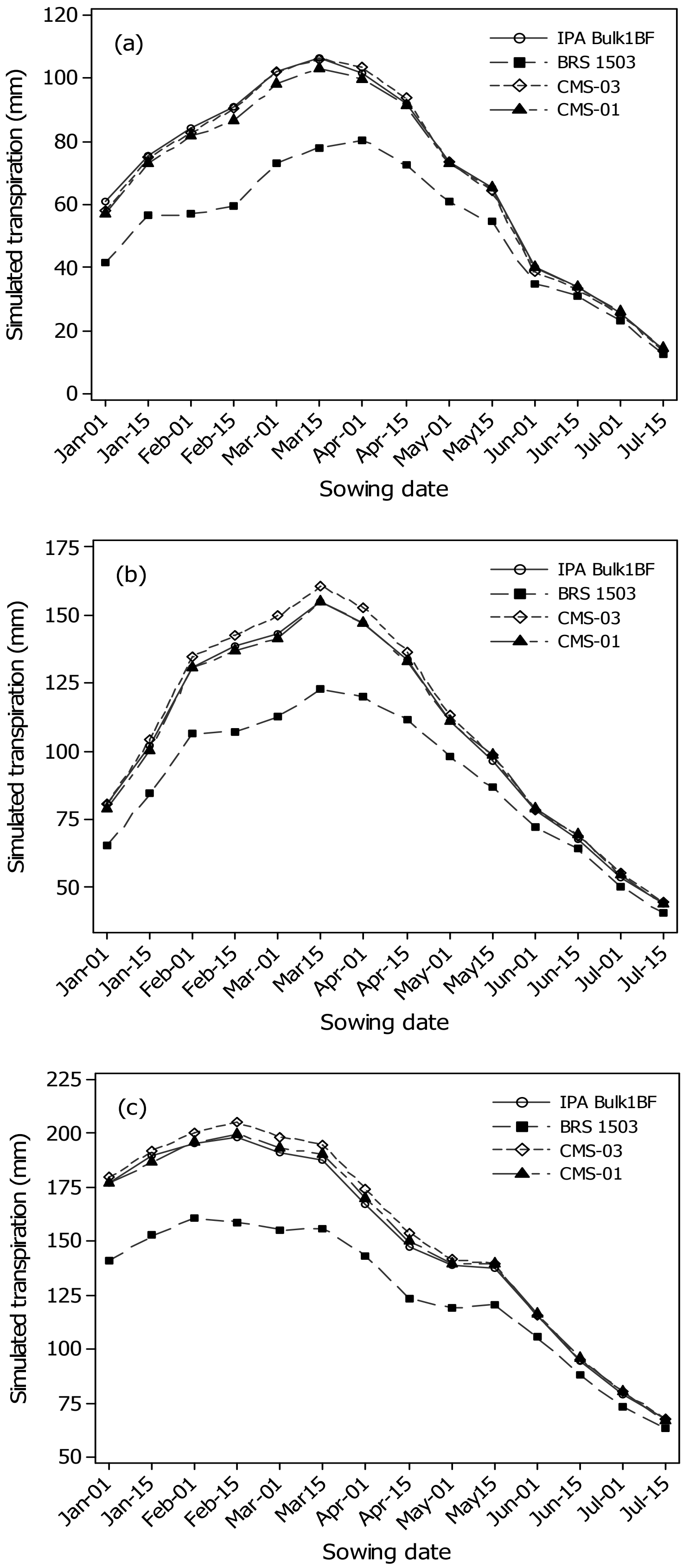

Figure 3. Total crop transpiration from planting to harvest for different cultivars in different sowing dates for Bom Conselho (a), Nossa Senhora da Gloria (b) and Sao Bento do Una (c).

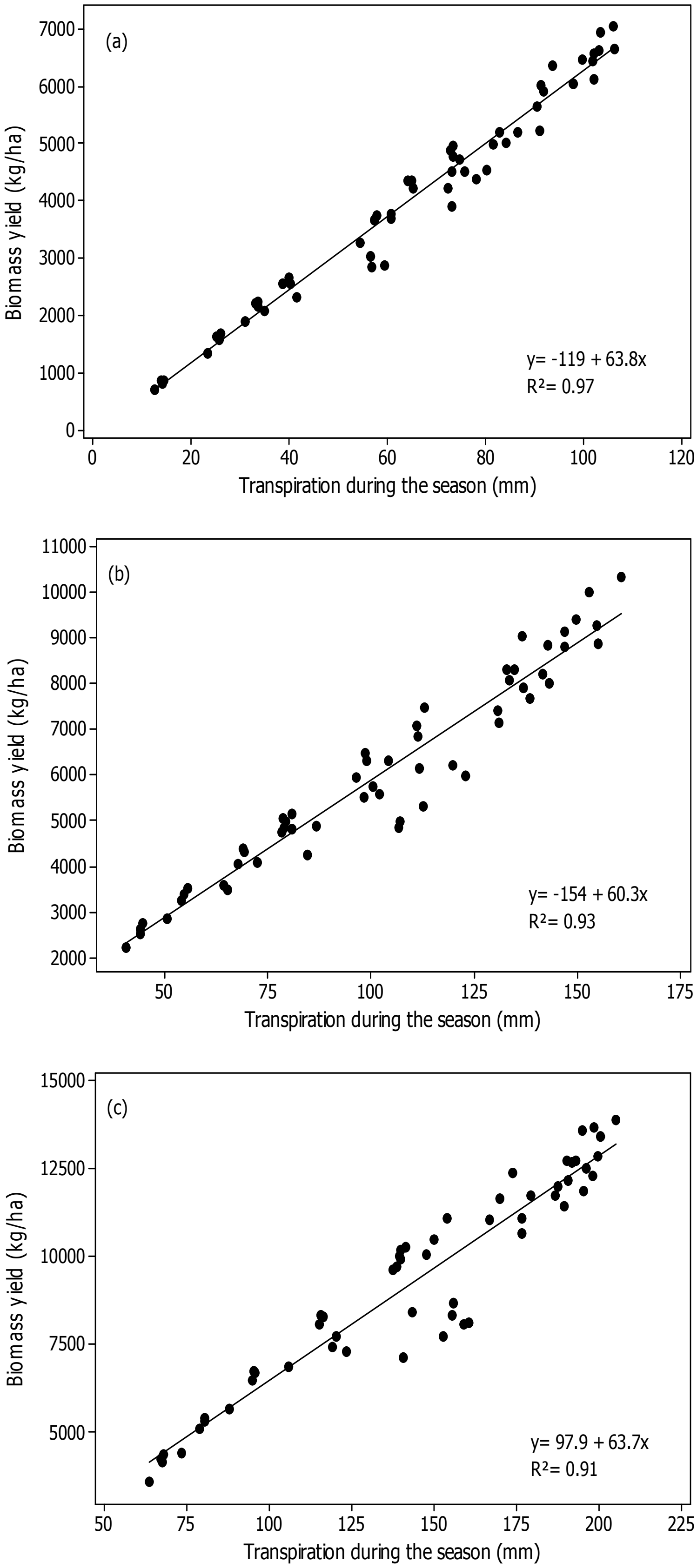

Figure 4. Relation between simulated total transpiration and pearl millet biomass yield for Bom Conselho (a), Nossa Senhora da Gloria (b) and Sao Bento do Una (c). Individual points represent the four cultivars and planting dates.

CAPÍTULO 5 - PERFORMANCE, AGRONOMIC TRAITS, ENSILABILITY AND NUTRITIVE VALUE OF PEARL MILLET CULTIVAR HARVESTED AT DIFFERENT GROWTH STAGE

ABSTRACT

Pearl millet (*Pennisetum glaucum* (L.) R.) is an important crop for rainfed production systems and can play a significant role as a feed source for ruminants owing to its high yield and drought tolerance. It is well-established that the maturity stage can influence the chemical composition and alter conservation quality as well as the nutritional value of crops traditionally used for silage production, although quantitative evidence that this occurs with pearl millet under rainfed conditions is lacking. The current research assessed the agronomic characteristics, ensilability, intake and digestibility of Brazilian pearl millet cultivar (IPA BULK1-BF) harvested at four different growth stages, in a typical Brazilian Northeastern semi-arid climate. Forage was harvested at the 35, 50, 65 and 80 days after sowing (DAS) and ensiled under laboratory and farm conditions. Apparent digestibility of the silages was determined using 24 Santa Inês male lambs. The results exhibited that dry matter (DM), digestible DM yield/ha, and panicle and stem proportion increased with the advancement of maturity. The silage evaluation showed that the DM, total and non-fibrous carbohydrate and lignin concentration increased, while crude protein (CP), ADF and *in vitro* dry matter digestibility decrease with increasing maturity. The fermentation characteristics were improved with increasing maturity. At digestion study was observed DM and N intake and DM and fiber fractions digestibility decreasing, while lignin intake increased. The results obtained for production of dry and digestible dry matter, the ratio of plant fractions, and fermentation parameters indicates the possibility of harvesting the pearl millet forage after 50 days after sowing for silage production in the Brazilian semi-arid region.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an annual tropical grass that can be utilized for grain or forage production. It is highly drought tolerant and resistant to many diseases affecting others crops traditionally used for silage production (Mason et al., 2015). The interest in annual forages such as millet in Brazil is increasing with the recurrence of drought and under this context, it is imperative to identify water-use efficient plants that can adapt to climate change and increase the use of rain-fed crops to achieve sustainable agricultural development in areas that are more prone to extreme weather. The use of forage millet in Brazil has been mainly concentrated in central-west and southern regions. However, forage millet cultivars adapted to Brazilian northeastern condition have been developed including the IPA BULK1-BF cultivar (Agronomic Institute of Pernambuco (IPA), 1999).

Several studies were conducted to evaluate field performance of IPA BULK1-BF cultivar (Bezerra et al., 2011; Costa and Priesnitz 2014; Santos et al., 2015) and it was found that they could serve as a feed source for livestock during the dry season. However, the influence of phenological stage at harvest and the IPA BULK1-BF performance is lacking. The stage of maturity at harvest is a major factor in determining the nutritive value of silage. Maturity effects on silage fermentation and animal performance were observed for corn and sorghum (Bernard and Tao 2015; Peyrat et al., 2015), but the relative scarcity of data on pearl millet for silage production under different management strategies suggests a need for additional studies.

As a part of an overall strategy to deal with this issue, the current study evaluated agronomic characteristics of the IPA BULK1-BF pearl millet cultivar harvested at four different growth stages and assessed its potential application in silage production. Finally, the impact of these forages on intake and digestibility in lambs was quantified.

MATERIAL AND METHODS

Experiments location and general information

The experiment was conducted from June to October 2012 at the Semi-Arid Experimental Station of the Brazilian Agricultural Research Corporation (Embrapa) in the municipality of Nossa Senhora da Glória, Sergipe State, Brazil (10º13′S, 37º25′W, 291 m asl). The soil type in this region is a eutrophic red-yellow podzol (Santos et al., 2013), with an average depth of 1.5 m. The climate is typically semi-arid with annual rainfall of 710 mm and average maximum and minimum temperatures of 32 and 20 °C, respectively. Precipitation in the region is low, erratic, and the balance between rainfall and evaporation rate can be negative in some months based on meteorological data from a weather station located about 400 m from the experimental site (Table 1). Seed of the pearl millet cultivar (IPA BULK1-BF) was supplied by the pearl millet breeding programmes of IPA.

Agronomic characteristics

Treatments were the four harvesting interval (35, 50, 65 and 80 days after sowing) replicated five times in a randomized complete block design (20 plots). Plots measured 10.5 m2 (5 × 2.1 m), with seed sown to a depth of 3 cm in four rows (on 0.70 m centers). The sowing date was 13 June 2012. The soil at the site had the following properties: pH (water): 5.8; phosphorus (P): 2.8 mg/dm^3; potassium (K): 0.32 $cmol_c/dm^3$; aluminium (Al): 0.05; hydrogen (H) + Al ($cmol_c/dm^3$): 1.89; calcium (Ca) ($cmol_c/dm^3$): 1.4; magnesium (Mg) ($cmol_c/dm^3$): 0.74 and organic matter (OM; g/kg): 10.54. All plots were randomly allocated and fertilized prior to planting according to soil test recommendations with 150 kg N/ha, 300 kg P/ha and 250 kg K/ha. Each treatment comprised c. 32 plants/m^2, achieved by thinning plots 15 days after emergence.

Plants were harvested according each treatment, 35, 50, 65 and 80 days after planting. Harvests were made manually and taken at 5 cm above ground level. Only the two central rows in each plot were harvested, with the remainder being discarded. The harvested crop from each plot was collected and weighed to estimate fresh biomass yield/ha. After chopping a representative sample from each plot, a 400-g sub-sample was oven-dried at 55°C for 48 h to determine dry matter concentration and biomass yield of the four treatments.

The agronomic characteristics studied included: plant height; population density; extent of lodging; DM partitioning of plant organs (panicle, stem and leaf); DM yield (DMY) (t/ha) and digestible DM yield (DDMY) (t/ha). The height of ten randomly selected plants within each plot was determined by measuring from ground level to the top of the panicle using a tape measure. Plants were then separated into panicles, stems and leaves, with the mass of each fraction determined after oven-drying at 65 °C for 72 h. Score lodging was estimated the percentage area of plot that was lodged and then estimated the angle of stem lodging, where an angle of 10º from the perpendicular was scored as 10 whereas prostrate stems was scored as 90. Lodging for the plot was then calculated as: (% plot area lodged × angle of lodging from vertical)/90 as described by Bell and Fischer (1994). The DDMY was estimated by multiplying the *in vitro* dry matter digestibility from each repetition by its respective DMY.

Ensiling procedure

At harvest, a silage harvester was used to chop plants within each treatment to an average of 1.5 cm long and transferred into 20 × 250-litre plastic barrels.

Representative herbage samples from each plot were packed manually into polyvinyl chloride (PVC) mini-silos (four mini-silos × five replications for a total of 20 mini-silos; 10.5 cm diameter × 35.5 cm high, capacity of 2.5 kg and average density of 813.7 kg/m³) using a wooden pestle (Sebastian et al., 1996). The mini-silos were sealed with plastic lids, weighed and stored at room temperature.

Mini-silos were opened following 90 days of ensiling, with forage samples (15 g) from both mini-silos and plastic barrels being homogenized for 1 min in 500 ml of distilled water to measure the pH using a pH meter. Aqueous extracts (10 ml) were acidified with 50 µl of 9.77 mol/l of sulphuric acid (H_2SO_4) (Kung and Ranjit, 2001) and frozen before analysis. Thawed extract samples were centrifuged for 15 min at 10 000 × *g* at 4 °C and analysed for acetic, propionic, lactic and butyric acids using a Varian high performance liquid chromatography (HPLC) system as described by Adams et al. (1984). Organic acids were separated using an Aminex HPX-87H column (300 × 7.8 mm) with a mobile phase of 0.013 M H_2SO_4 at a flow rate of 0.5 ml/min. Organic acids were quantified using an ultraviolet detector set at 210 nm.

Ammonia was determined using a phenol-hypochlorite reaction, as described by Weatherburn (1967). Finally, silage sub-samples (500 g) were oven-dried at 60 °C for 72 h, ground through a 1 mm screen using a Wiley mill and stored at room temperature until further analysis.

Intake and digestibility measurements

All lambs were cared for in accordance with the guidelines of the National Council for the Control of Animal Experimentation (CONCEA) (2008). Apparent nutrient digestibility of silages was measured using 24 Santa Inês male lambs (initial body weight (BW): 24 kg ± 1.6 kg) over a 21-day period. Lambs were blocked by weight and assigned randomly to one of four treatments. The first 17 days were used to adapt lambs to the diets in individual metabolic cages equipped with a poly-ethylene sieve tray to separate faeces from urine. Lambs were fed pearl millet silage only (without concentrate) twice daily at 07.30 h and 16.30 h in a manner that assured 0.15 orts at the morning feeding. Water and a trace mineralized salt mixture were available to lambs *ad libitum*.

Apparent digestibility was determined over 5 days, with lambs being fed pearl millet silage *ad libitum* as described by Silva and Leão (1979). During these 5 days, total faeces, feed and orts of each lamb were measured and sampled daily. Samples of the 5 days were mixed, sub-sampled (400 g fresh faeces, 400 g fresh feeds and 400 g fresh orts per lamb) and stored at – 20 °C until analysed. The total urine output of each animal was collected daily into plastic containers containing 100 ml of hydrochloric acid with 2N concentration to prevent fermentation, degradation and N losses. During the 5-day collection phase, subsamples (10%

from the total urine volume) were collected in the morning and stored at –20°C until further analysis.

Chemical analysis

Ground samples were analysed for DM and OM as described by Association of Official Analytical Chemists (AOAC) (2005) (methods 942.05 and 934.01). A Leco combustion N analyser was used to measure N concentration. Crude protein (CP) was calculated as N × 6.25. Both neutral detergent fibre (NDF), which was determined by using heat stable α-amylase, and sodium sulphite (ash free), and acid detergent fibre (ADF) were quantified as described by AOAC (2005) (methods 2002.04 and 973.18) using an Ankom Fibre Analyser. Concentration of hemicellulose was determined by subtracting ADF from NDF. Ether extract (EE) was determined as described by AOAC (2005) (method 920.39) using an Ankom Fat Extractor.

Total (TC) and non-fibrous (NFC) carbohydrates were calculated as described by Sniffen et al. (1992): $TC_{g/kg\ DM} = 100 - (CP + EE + ash)$ and $NFC_{g/kg\ DM} = 100 - (CP + EE + ash + NDF)$.

In vitro DMD analysis of fresh forage and silage was conducted in 100 ml serum bottles and examined in a single run for each forage/silage with triplicate bottles being used per sample. Plant material (0.5 g) was incubated with 10 ml of rumen fluid mixed with 40 ml of McDougall's buffer (McDougall, 1948) for 48 h at 39 °C. Samples were subsequently incubated with 0.1N hydrochloric acid (HCL) and 2 g/l pepsin for a further 48 h (Tilley and Terry, 1963). Equal volumes of rumen fluids were collected immediately after feeding from three rumen-fistulated bulls fed a mixture of the four treatments silages. After stirring the three samples, the combined ruminal fluid was used in the IVDMD assay as described above.

Statistical methods

Experiments were analysed by a mixed model approach with maturity stage as a fixed effect, random effects of blocks (agronomic and silage quality trials) and lambs (digestibility study), and random residual error using the MIXED procedure of SAS Version 9.1 statistical program (SAS 2002). The model used was: $Y_{ij} = \mu + T_i + B_j + E_{ij}$, where Y_{ij} is the observation, μ the overall mean, T_i the treatment, B_j the block/animal and E_{ij} the residual error. When significant, maturity stage means were compared using Fisher's protected LSD (i.e., the DIFF option of the LSMEANS statement). Polynomial contrasts were used to determine linear and quadratic effects of maturity stage. Significance was declared at $P < 0.05$.

RESULTS

Agronomic traits

Plant height, stem, leaves, and panicles proportion increased linearly ($P < 0.05$) with increasing plant maturity. At the same plant density for all treatments, dry matter yield and digestible DM yield increased linearly ($P < 0.05$) (Table 2).

Silage quality

The maturity increase resulted in a linear increase ($P < 0.05$) in DM, OM, TC, NFC, and lignin concentrations, while the CP and ADF concentrations decreased linearly. There was a significant positive quadratic relationship ($P < 0.05$) between hemicellulose and NDF concentration and the age of harvest. However, the relationship was negative for IVDMD ($P < 0.05$) (Table 3). A larger variation in fermentation products was detected among treatments, with linear effect for silage pH and concentration of acetic and butyric acids ($P < 0.05$). A quadratic effect was observed for lactic acid concentration ($P = 0.03$) with the silage of plants cut at 65 days after planting exhibiting the higher value. A quadratic effect ($P < 0.05$) was also observed for propionic acid and ammonia-N concentrations with lower values in silages made with plants harvested at 65 and 80 days after sowing (Table 4).

Digestion study

The dry matter, OM, CP, NDF, ADF intake decreased linearly ($P < 0.05$), while NFC and lignin intake increased quadratically ($P < 0.05$) in animals fed with silage made with plants with higher maturity stage. Digestibility of all variables decreased linearly ($P < 0.05$), except NFC digestibility that did not suffer maturity effect.

DISCUSSION

Agronomic traits

Significant differences were observed among treatments with different harvesting interval regarding plant height, DM and DDM yield, panicles, and stem proportions. All these parameters were significantly enhanced with the delay in harvesting as all the parameters were highest at 80 days after planting, which might be due to more time for the plants to complete its phenological development. With a delay in harvest date from 35 DAS to 80 DAS, the plant height was increased in approximately 2.4 cm per day, an increase similar the average (2.8 cm per day) reported for three Pakistani cultivars of pearl millet grown in the Pakistani hot desert climate (Bukhari et al., 2011).

Increasing DM and digestible DM yields with increasing plant maturity is consistent with other research on silage crops (Marsalis et al., 2010, Atis et al., 2012, Aoki et al., 2013). Monks et al. (2005) reported DM yield ranged from 2.3 to 11.5 t/ha for pearl millet harvested with 44 or 144 DAS and grown in the Brazilian sub-tropical. The increase in the DM yield with increasing maturity was mainly due to increase stem proportion but above all the rise of panicle proportion, which is consistent with a reduction in leaf ratio.

Silage quality

The stage of maturity at harvest is a major factor in determining the nutritive value of silage (Johnson et al., 1999). Previous research (Johnson et al., 2002) has demonstrated that DM concentration of silage increases with advancing maturity. At this study, increasing maturity resulted in a DM concentration increase of 2.4% per week. In general, the nutritive value of forages declines dramatically with increasing maturity, due to the increase in NDF and ADF and decrease in CP (Blaser et al., 1986).

Hassanat et al. (2007) reported that IVDMD of pearl millet stover decreased with advancing maturity and was highly correlated with ADF and lignin contents. However, was observed that IVDMD decreasing was related just to increasing lignin concentrations, once plant maturity not affect the NDF concentration and ADF concentration decreased linearly. Similar results were found by Morales et al. (2014) who reported ADF and IVDMD decreasing associated with increasing lignin concentrations, for pearl millet in four phenological stages. Probably, because increasing proportion of grain as the pearl millet plant matures obscures the relationship between plant maturity and digestibility of whole plant silage. Khan et al. (2007) studied maturity effects in maize, sorghum, and pearl millet silage quality. Concentrations of NDF and ADF in the whole plant decreased as maturity proceeded from pre-heading to milk stage maturity. Despite declining NDF and ADF content, *in situ* digestibility of whole plant DM decreased progressively from early (63.0%) to late (54.1%) maturity. These data highlight the conflict between grain development and stover quality associated with maturity management of pearl millet silage. Identification of pearl millet hybrids that maintain stover quality while increasing grain proportion at advanced stages of maturity is a logical strategy for improved pearl millet silage quality.

The highest level of pH (5.9) and ammonia-N (4.8) was observed in silage made using pearl millet harvested at 35 DAS. These results are in agreement with others that observed high pH silage favors secondary fermentation, leading to an increase in ammonia-N (McDonald et al., 1991). The larger amount of ammonia-N in silage made with plants harvested at 35 DAS is a reflection of its higher moisture and crude protein content at the time of harvest. According to Ferraretto et al. (2015) ammonia-N and soluble CP were good indicators of *in vitro* starch digestibility of whole plant corn silage. A reduction in butyric acid concentration with advancing plant maturity was expected owing to an increase in the DM content of mature forage, as was observed for silage made with plants harvested at 80 DAS. The silages produced from plants harvested after 65 DAS had the highest lactic acid concentration and the lowest pH. Despite the contribution of all acids formed during fermentation, lactate plays a critical role in the reduction of silage pH due to its low dissociation constant (Moisio and Heikonen, 1994). According to Ferreira et al. (2013) the greater lactic acid production can lead to lower dry matter losses in silages, because lactic acid fermentation results in minimum losses while acetic and butyric fermentation are associated to secondary fermentations and dry matter losses in the form of gases.

Digestion study

Increased maturity resulted in decreased DM intake as found in other studies with cereal crop silages (Helander et al., 2015, Khan et al., 2015) probably due to decreased digestibility. Lower intake of silages made with plants in higher stages of maturity could be explained by higher stem proportion and more lignified stems with higher NDF content resulting in a higher NDF and lignin concentration in silage. Overall, decreased digestibility of pearl millet silage decreased DM intake agreeing on the assumption that decreased digestibility decreases intake potential (Illius and Jessop, 1996). A reduction in DM digestibility with an increasing plant maturity could be expected due to a reduction in the plant cell wall digestibility. This was observed in this study by the linear decrease in NDF and ADF digestibility and increase in lignin intake with increasing plant maturity. Davis et al. (2014) demonstrated that DM digestibility was correlated with consumption, digestible dry matter intake and body weight gain in a multiple regression models.

The decreasing CP concentration with increasing plant maturity was observed in others studies (Khan et al., 2007, Guimaraes et al., 2014). The decrease in CP concentration with maturity increase could be related to a higher proportion of stem in the plants, and consequently reducing the protein solubility. It is also important to emphasize that the CP concentrations were higher than 60 g/kg DM for all treatments, a level that is considered suitable to sustain optimal activity by microbes for efficient ruminal fermentation (Van Soest, 1994). Decreasing CP concentration had not effect in CP intake, however, was observed decrease in N intake. On average, N intake and N absorbed in the current study was greater than the seen in Sipli lambs (8.7 and 4.5) fed pearl millet silage in Pakistan as evidenced by Khan et al. (2011). It should be mentioned that the positive N balance and lack of body reserve mobilization observed in all treatments suggests an adequate digestibility of dietary protein.

Therefore, the current study showed that the pearl millet cultivar IPA BULK1-BF have potential to yield forage within a wide harvest window, which ranges between 50 and 80 DAS. According to digestion and *in vitro* digestibility study the nutritive value of pearl millet silage decreases as maturity advances. In contrast, the fermentation parameters were improved with increasing maturity. The possibility of harvesting the pearl millet forage in any of these phenological stages allows harvest management to adapt to climatic conditions, allowing reducing the risks of losses by drought and ensuring forage availability.

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Table 1. Meteorological data during the experimental period

Month/Year	RD	Rain (mm)	Temperature (°C)			Evaporation (mm)	RH (%)	Wind (m/s)[1]	SR (MJ)
			Max.	Min.	Mean				
Jun / 2012	9	31.6	28.0	19.6	22.8	3.5	81.1	1.2	16.6
Jul / 2012	13	43.3	26.1	18.7	21.6	3.2	80.7	1.2	15.2
Aug / 2012	12	32.2	26.4	17.9	21.2	3.7	77.4	1.3	14.7
Sep / 2012	0	0.0	27.8	17.5	21.8	4.5	70.2	1.2	15.3

RD = rainfall occurrence in days; RH = Relative Humidity; SR = solar radiation
[1]Wind average speed at 2 m height.

Table 2. Performance and phenological traits of of cultivar IPA BULK1-BF harvested in different days after planting

Variable	Days after planting				SEM	*P*-value	
	35	50	65	80		Linear	Quadratic
Plant height (cm)	112	200	221	222	3.6	<0.001	<0.001
Plant density (1000 plants/ha)	265	278	257	258	9.8	0.431	0.736
Dry matter yield (t/ha)	2.3	8.1	10.6	13.7	0.69	<0.001	0.065
Digestible dry matter yield (t/ha)	1.5	4.7	5.9	7.1	0.78	<0.001	0.029
Lodging score	2.5	1.9	3.4	1.1	1.11	0.639	0.773
DM partitioning of plant organs (t/ha)							
Panicles	0	0.5	1.4	2.4	0.15	<0.001	0.175
Stems	1.0	5.8	7.2	9.4	0.50	<0.001	0.027
Leaves	1.3	1.8	2.0	1.8	0.19	0.039	0.053

DM = dry matter

Table 3. Chemical composition (g/kg DM) of silages produced from cultivar IPA BULK1-BF harvested in different days after planting

Variable	Days after planting				SEM	*P*-value	
	35	50	65	80		Linear	Quadratic
DM (g/kg)	90	147	210	245	5.6	<0.001	0.071
Chemical composition (g/kg DM)							
Organic matter	850	895	920	931	6.2	<0.001	0.005
Crude protein	124	116	94	71	3.4	<0.001	0.029
NDF	567	600	610	588	9.5	0.059	0.005
ADF	397	377	364	343	7.8	<0.001	0.932
Hemicellulose	171	223	246	246	8.5	<0.001	0.004
Total carbohydrate	664	743	807	840	9.6	<0.001	0.005
Non-fibrous carbohydrate	96	144	198	252	8.9	<0.001	0.674
Ether Extract	62	36	19	20	9.4	0.073	0.051
Lignin	24	35	51	56	2.6	<0.001	0.392
IVDMD (%)	54.9	60.3	54.4	52.5	1.22	0.034	0.011

DM = dry matter; IVDMD = *in vitro* dry matter digestibility

Table 4. Fermentation products concentrations (g/kg DM) of silages produced from cultivar IPA BULK1-BF harvested in different days after planting

Variable	Days after planting				SEM	*P*-value	
	35	50	65	80		Linear	Quadratic
pH	5.85	4.61	3.71	3.50	0.150	<0.001	0.005
Lactic acid	0.0	48	87	79	7.8	<0.001	0.003
Acetic acid	10.9	3.9	3.1	2.6	0.32	<0.001	<0.001
Propionic acid	3.7	3.9	3.1	1.3	0.39	<0.001	0.006
Butyric acid	8.1	3.2	0.0	0.0	0.71	<0.001	0.005
NH_3-N (g/kg TN)	48	30	18	18	3.0	<0.001	0.011

TN = total nitrogen

Table 5. Intake (g/kg $BW^{0.75}$) and total apparent digestibility (fraction) of dietary components in lambs fed silage produced from cultivar IPA BULK1-BF harvested in different days after planting

Variable	Days after planting				SEM	*P*-value	
	35	50	65	80		Linear	Quadratic
Intake (g/kg $BW^{0.75}$ per day)							
Dry matter	84.4	64.3	49.1	45.1	5.30	<0.001	0.150
Organic matter	80.7	70.0	70.3	68.7	1.73	0.004	0.019
Crude protein	11.3	7.8	6.9	6.3	0.31	<0.001	0.004
NDF	52.5	52.5	46.3	45.3	1.23	0.001	0.665
ADF	31.2	33.5	28.2	26.1	0.82	<0.001	0.101
Total carbohydrates	64.9	59.2	61.7	60.6	1.75	0.185	0.198
Non-fibrous carbohydrates	12.4	6.7	15.4	15.3	0.91	0.004	0.005
Ether extract	4.5	2.9	1.8	1.9	0.37	<0.001	0.034
Lignin	1.6	3.7	2.5	2.9	0.27	0.026	0.014
Total apparent digestibility (kg/kg)							
Dry matter	0.69	0.60	0.55	0.52	0.040	0.007	0.475
Organic matter	0.81	0.75	0.80	0.69	0.020	0.003	0.305
Crude protein	0.76	0.68	0.74	0.56	0.031	0.002	0.156
NDF	0.78	0.74	0.75	0.62	0.023	0.005	0.082
ADF	0.77	0.72	0.73	0.56	0.026	<0.001	0.019
Total carbohydrates	0.82	0.75	0.80	0.70	0.019	0.005	0.352
Non-fibrous carbohydrates	0.91	0.85	0.95	0.88	0.023	0.937	0.932
Ether extract	0.89	0.86	0.80	0.64	0.050	0.001	0.204

Table 6. Nitrogen balance in lambs fed silage of cultivar IPA BULK1-BF harvested in different days after planting

Variable	Days after planting				SEM	*P*-value	
	35	50	65	80		Linear	Quadratic
Nitrogen intake (g/day)	27.4	20.1	17.5	16.9	2.42	0.08	0.07
Nitrogen faecal (g/day)	6.4	6.5	4.6	7.3	1.41	0.92	0.74
Nitrogen urinary (g/day)	0.6	0.7	0.6	0.6	0.78	0.88	0.79
Nitrogen absorbed (g/day)	20.4	12.9	12.3	9.0	2.13	0.06	0.25

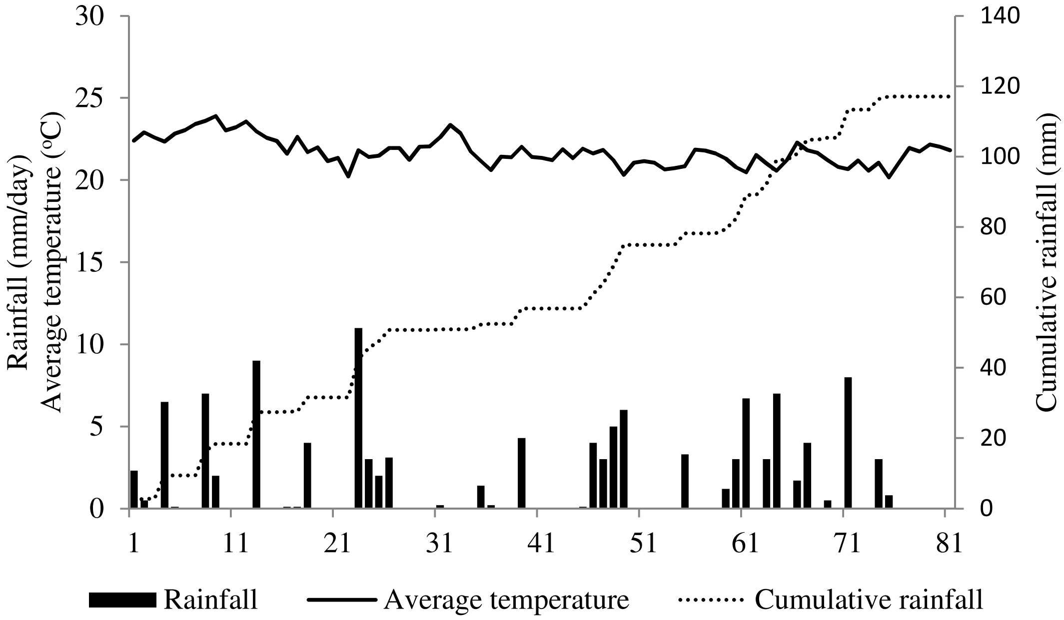

Figure 1**.** Rainfall distribution (mm) and average temperature (°C) at the experimental station of Embrapa Semi-Arid from June to September 2012.

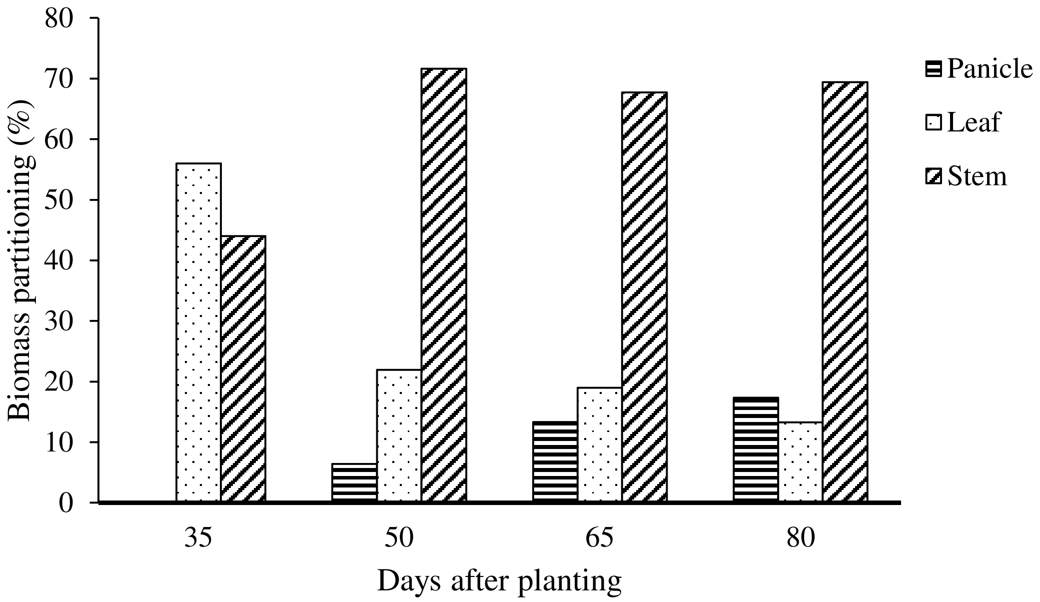

Figure 2. Participation of morphological components (%) in the total biomass of cultivar IPA BULK1-BF harvested in different days after planting.

CONSIDERAÇÕES FINAIS

Os cultivares de milheto produziram forragem de forma satisfatória sob as condições do semiárido brasileiro. Além disso, cinco desses cultivares produziram silagem de boa qualidade. Com o avanço do estágio de desenvolvimento o cultivar IPA BULK1-BF teve sua produtividade aumentada e as características do processo fermentativo da silagem foram melhoradas. No entanto, ocorreu decréscimo da qualidade da forragem.

O potencial de produção apresentado pelos cultivares de milheto em condições semiáridas pode justificar o uso de tecnologias e estratégias de manejo, sobretudo novas abordagens sobre técnicas de conservação e esquemas de plantio e colheita, com o objetivo de maximizar a eficiência dos sistemas de produção. Nesse contexto, o uso de modelos preditores é factível e eficiente como ferramenta de previsão de desempenho para essa cultura em condições de déficit hídrico.