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Challenges and perspectives of tropical grasses silages

Thiago Carvalho da Silva[1], Rosana Ingrid Ribeiro dos Santos[1], Edson Mauro Santos[2], Joao Paulo Pacheco Rodrigues[3], Edson Mauro Santos[4], Aníbal Coutinho do Rego[1]

[1]Federal Rural University of Amazon, Belém-PA, Brazil
[2]Federal Rural University of Amazon, Belém-PA, Brazil
[3]Federal University of South and Southeast of Para, Xinguara-PA, Brazil
[4]Federal University Paraiba, Areia-PB, Brazil

1. Introduction

In tropical regions, ruminant production systems are based in the use of adapted grasses. The use of tropical grasses in the pastures provides the possibility of productivity intensification in those regions. Unlike temperate grasses, tropical grasses present high dry matter (DM) yield due to its C4 photosynthetic pathway, which assimilates CO2 with higher efficiency and produces more biomass than C3 species. In addition, the high tillering capacity of tropical grasses assures its perennity and can provide at least of harvests over the year, depending on the cultivar and environmental conditions (rainfall, fertilization, soil conditions). In general, tropical grasses vary with phenology and growth, which are related with the productive potential.

Tropical grasses are commonly used for grazing in the tropical regions. However, due to the lower DM allowance during the dry season, and the increasingly demand for high quality forage for more efficient livestock production, tropical grasses can be used as conserved forage (silage, hay and haylage). The most productive species are also used as fresh chopped forage in some farms, however in the dry season it may provide lower nutritional value than when properly conserved.

Tropical grasses have high ensiling potential due to its lower liability on climatic conditions when compared with hay and haylage production. When compared to other silage crops (e.g. corn) some tropical grasses such as *Panicum maximum* and *Pennisetum purpureum* cultivars are more adapted to faster growth rate at high temperatures and rainfall. In this way, they can provide greater forage mass to be used in feedlot diets or in supplementation of grazing animals. In Brazil, tropical grass silages are used also as a tool for pasture management, when the grass overcome the target height for grazing, which decreases grazing efficiency. In this situation, the grass can be ensiled to adjust the canopy height and consequently provide proper residues and increase forage accumulation.

Although the described potentialities of ensiling tropical grasses, the combination of nutritive value and time of ensiling may be difficult to manage. Harvesting tropical grasses for combined high productivity and nutritive value may result in low DM content (150 to 200 g/kg), low concentration of water-soluble carbohydrates (WSC; lower than 100 g/kg of DM) and high buffering capacity (Bernardes et al., 2018). The concentration of WSC can be affected by specie, cultivar, phenological stage, environment and fertilization (McDonald et al., 1991). The phenological stage is the most important factor that influences the forage quality, which decreases as the grass grows (Harrison et al., 2003). Thus, the high availability of tropical grasses cultivars and the diversity of management and harvesting strategies leads to a wide perspective in development of strategies to improve efficiency of silage production.

In this text, we will discuss the challenges based on the papers published and discuss the perspectives and new directions to silage production of tropical grasses.

2. Overview of papers on tropical grass silage in the world

The first review about grass silages was published in 1939 by Bender and Bosshardt. These authors mentioned challenges observed during the silage production of temperate grasses, especially in the fermentation processes. A few decades later, similar challenges were observed with tropical grasses in Brazilian conditions.

In Brazil, the production of grass silage started with the cultivation of elephant grass (*Pennisetum purpureum*), which was introduced in 1920, with significant diffusion after 60’s. Later, the expansion of the *Urochloa* and *Panicum* grasses and the development of specific machines for grass harvest, increased the silage production of tropical grasses to store the forage produced, as explained before. A survey performed in dairy farms showed tropical grasses in the third position of crops used for silage production Bernardes & do Rêgo (2014). The impact of this type of silage can be expressed by the numbers of published papers that will be discussed.

To evaluate the changes and the challenges related to tropical grasses silage, we found 115 papers from 1999 to 2019 published in indexed journals (Figure 1). The following search terms were used, both alone and in combination: grass silage, tropical grass silage, silage additive, additives in grass silage, warm-season grass silage. In the Science Direct, Oxford Academic, Cambridge Oxford, ASM journals, Wiley on Library, Scopus, and Google Scholar platforms. From the total of 115 observed papers, 13 papers were excluded: 12 because of lack of information about the silage and one literature review, totaling 102 papers.

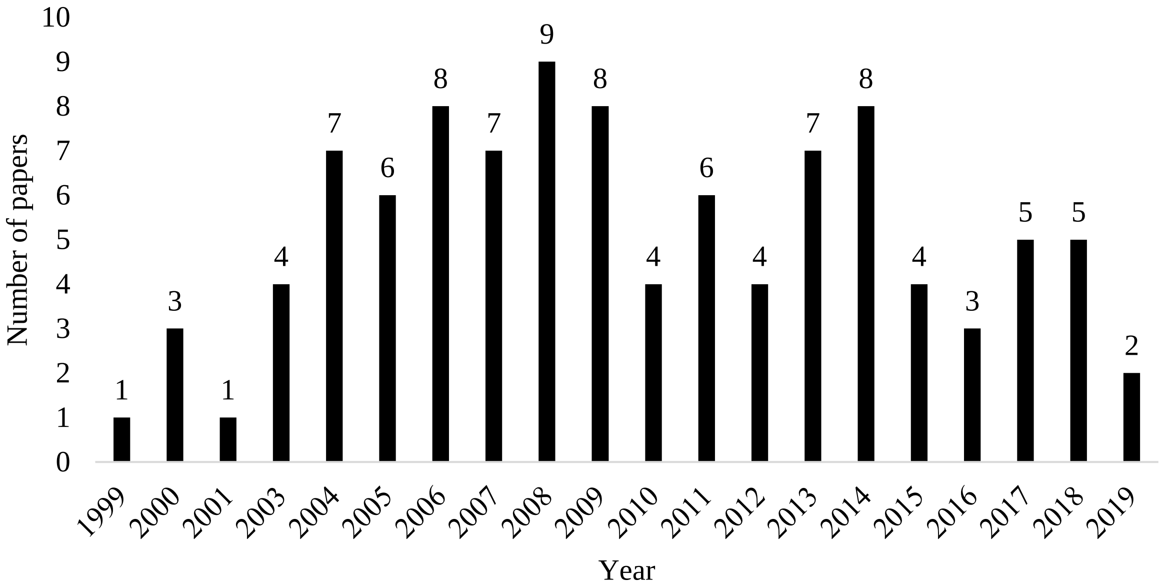


Figure 1: Number of papers with tropical grass silage carried out by year (total number of papers accessed = 102)

The papers with tropical grasses silages comprise different countries from different continents, as South America, North America, Africa, Europe and Asia (Figure 2). Most of the papers were published by Brazilian researchers (73% of the total). It is important to show the common name of some tropical grasses stated by the authors from different countries, which shows some similarities and local variation. The denominations are Napier grass (*Pennisetum purpureum* - JAPAN; Khota et al., 2016), Bana grass (*Pennisetum purpureum* - ZIMBABUE; Manyawu et al., 2003), King grass (*Pennisetum purpureum* – CHINA, INDONESIA; Li et al., 2014; Ridwan et al., 2015), Guinea grass (*Panicum maximum* – JAPAN, TAILAND, BRAZIL; Li and Nishino et al., 2013; Khota et al., 2016; Zanine et al., 2018), Rhodes grass (*Chloris gayana*- JAPAN; Parvin and

Nishino, 2009), Ruzi grass (*Urochloa ruziziensis*- TAILAND; Bureenok et al., 2011), Signal grass (*Urochloa decumbens* – BRAZIL; Santos et al., 2011), Palisade grass (*Urochloa brizantha* – BRAZIL; da Silva et al., 2017), Pasto Saboya (*Megathyrsuss maximus*- ECUADOR; Espinoza Guerra et al., 2016), Kikuyu grass (*Pennnisetum clandestinum* – BRAZIL, Guzzati et al., 2017).

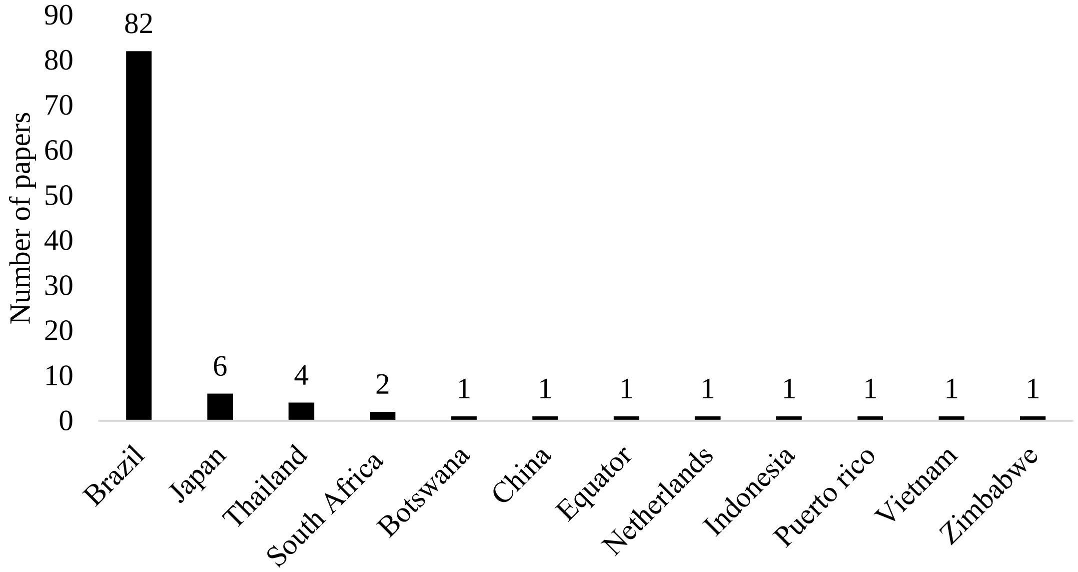
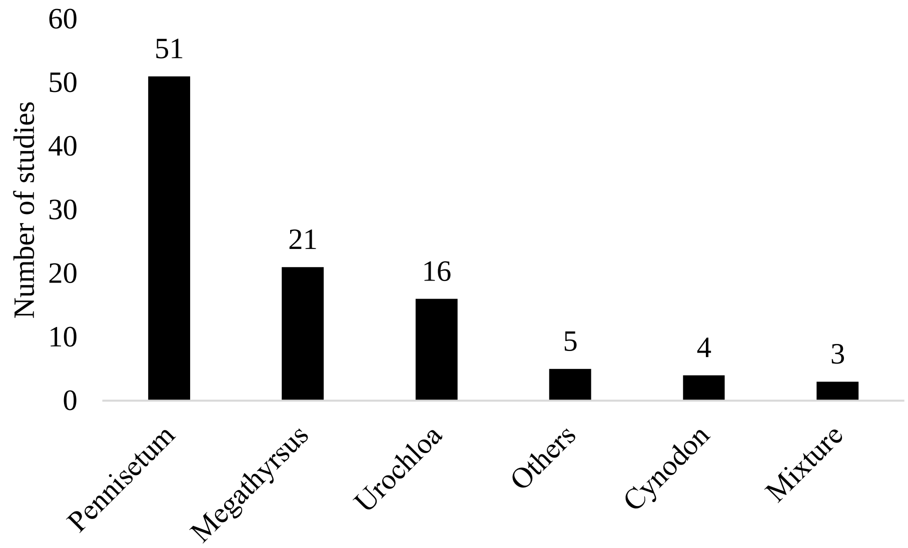


Figure 2: Number of papers with tropical grass silage carried out by country (total number of papers accessed = 102)

When the genera of the tropical grasses were grouped (Figure 3), we observed that 51% of the papers used the *Pennisetum* genus, followed by *Megathyrsus* (21%) and *Urochloa* (16%). The class “others” includes grasses not included in the genera *Pennisetum*, *Megathyrsus*, *Urochloa*, and *Cynodon*, representing 5% of the total papers.

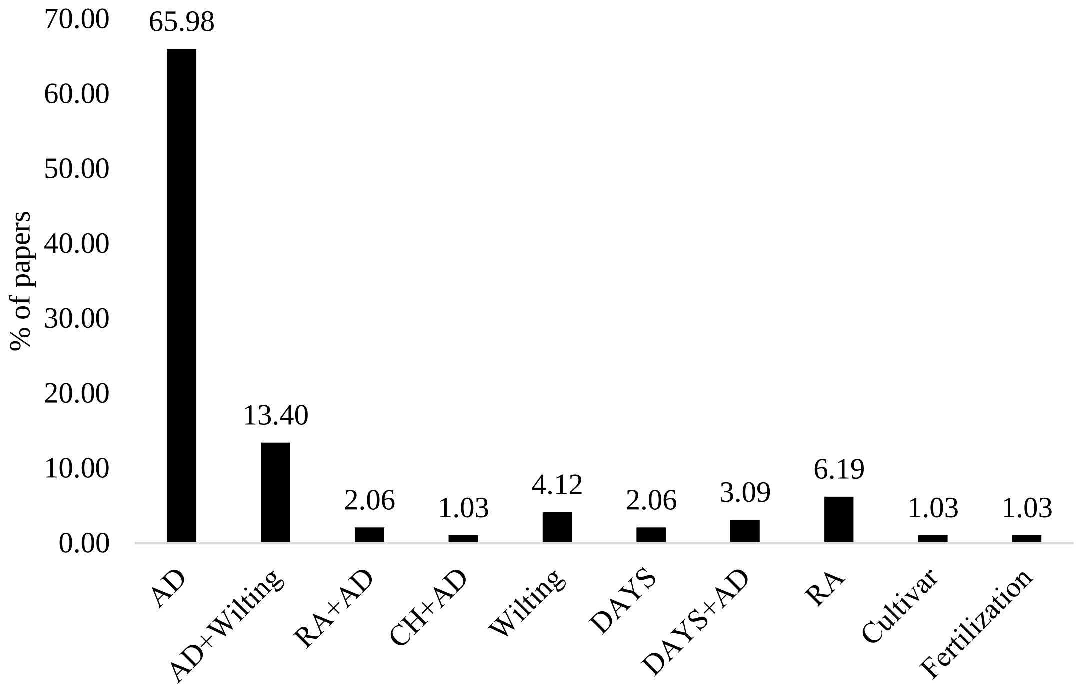


Others grass- (*Digitaria eriantha, Chloris gayana, Cenchrus ciliaris, Lolium multiflorum*). Mixture grass- (70% *Megathyrsus maximum* + 30% Sorghum halapense (Gonzalez e Rodriguez, 2003), *Urochloa ruziziensis* + *Urochloa brizantha* + *Urochloa decubens* (Lukkananukool, et al. 2013), *Pennisetum purpureum* + *Pennisetum americano* (Khota et al, 2018).

Figure 3: Number of papers with tropical grass silage carried out per genus of grass (total number of papers accessed = 102).

The nomination "mixture" includes papers with two different tropical grasses species for ensiling, or two species from the same genus. The *Pennisetum* is the most studied grass because of its high productive potential and its adaptation to different climates. Most of the papers with *Megathyrsus, Urochloa and Cynodon grasses* are recent because these grasses have been used for silage production among the farmers. When the forage canopy overgrows the target height for grazing, these grasses can be used for silage production.

It is known that most of the papers with tropical grass silage have evaluated additives in order to improve fermentation and decrease effluent and DM losses. When the treatments of each study were grouped (Figure 4), we observed that 66% of the papers used additive as main factor. The combination additive+wilting (AD+wilting) was second most evaluated among the summarized papers (12.37%). Other important factors (cutting age, wilting, cultivar, fertilization) were observed in lower percentual.



AD= Additive, RA- Regrowth age, CH- Cutting height, DAYS- Days of storage.

Figure 4: Treatments used in the papers evaluated of tropical grass silage (total number of papers accessed =102).

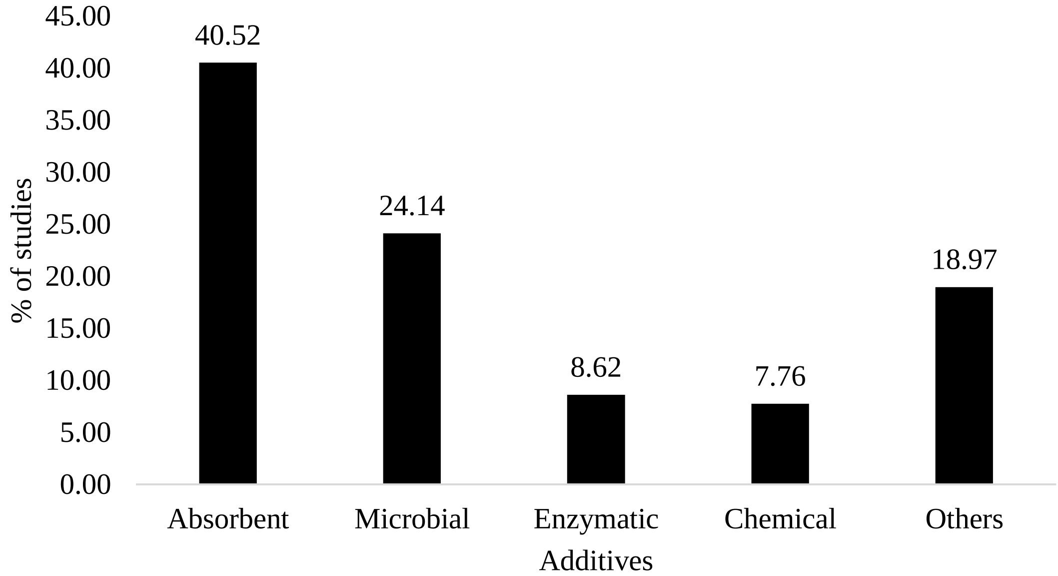
The use of additives was the main factor evaluated according the papers. Based on that, we grouped them by classes, considering the number of observations: chemical, moisture absorbent, microbial, enzymatic, and others (Table 1). Each class of additive was also grouped by the tropical grass genus or specie, and in case of mixtures including tropical grasses. We observed highest number observations for the use of moisture absorbent additives in *Cynodon* and *Pennisetum purpureum* grasses. The level of inclusion of moisture absorbent additives ranged from 0.1 to 40% (fresh basis). *Pennisetum purpureum* is the most studied specie considering all classes of additives, followed by *Megathyrsus* and *Urochloa*. However, considering the genus *Megathyrsus*, the most used additive was microbial inoculant.

Given that the main challenges of production of tropical grasses silages are the low moisture at harvest and high buffering capacity, most of the papers evaluated moisture absorbent additives and microbial inoculants (Figure 5). It demonstrates the greater efforts of the scientific community to improve silage fermentation and decrease DM losses in tropical grasses silages.

Table 1: Number of observations and papers with tropical grass silage by type of additive (total number of papers accessed = 102)

	Number of observations				
Grass	Absorbent	Microbial	Enzymatic	Chemical	Others[1]
Urochloa	19	29	11	7	22
Cynodon	10	1	0	0	2
Mixture[2]	1	0	12	0	2
Others[3]	4	6	6	0	9
Megathyrsus	15	68	42	17	16
Pennisetum	200	53	34	28	78
Total	249	157	105	52	129
	Number of papers				
	Absorbent	Microbial	Enzymatic	Chemical	Others[1]
Urochloa	5	8	3	3	4
Cynodon	4	1	0	0	1
Mixture	1	0	1	0	1
Others	0	1	1	0	2
Megathyrsus	3	10	2	4	4
Pennisetum	34	8	3	2	10
Total	47	28	10	9	22

[1]Others additives- Additives that are nutrient suppliers or without defined class. (Ex: glucose, ground corn, corn kernel, molasses, forage juice, salt, ground sorghum and whey). [2]Mixture grass- (70% *Megathyrsus maximum* + 30% Sorghum halapense (Gonzalez e Rodriguez, 2003), *Urochloa ruziziensis* + *Urochloa brizantha* + *Urochloa decubens* (Lukkananukool, et al. 2013), *Pennisetum purpureum* + *Pennisetum americano* (Khota et al, 2018). [3]Others grass- (*Digitaria eriantha, Chloris gayana, Cenchrus ciliaris, Lolium multiflorum*).



Others: Additives that are nutrient suppliers or without defined class. (Ex: glucose, ground corn, corn kernel, molasses, forage juice, salt, ground sorghum and whey).

Figure 5: Percentage of use of the additives in the papers evaluated (total number of papers accessed = 102).

The microbial additives used included homolactic lactic acid bacteria (LAB), with the main species: Inoculant microbial used in papers: Streptoccocus faescium, Enterococcus faecium, *Lactobacillus plantarum*, *Lactobacillus salivaris*, *Lactococcus lactis*, *Lactobacillus casei*, *Lactobacillus paracasei*, *Pediococcus pentosaceus* and *Pediococcus acidilactici*. In addition, some of them would be combined or not with enzymes, as: celulase, hemicelulase e amilase, acremonium cellulase, maicelase, sucrase, xylanase, trichoderma celulase. The use of homolactic LAB indicates the goal of increase lactic acid production and accelerate the drop in pH, improviing fermentation process and decreasing DM losses. Theoretically, the use of fibrolytic enzymes usually releases sugars from fiber solubilization which can be used as substrates by the inoculants. These effects will be discussed in this text.

Once we know the range of additives, it is important to state some factors that can influence all the evaluations of them, as wilting (h), cutting age (days), cutting height (cm), particle size (cm), days of storage and packing density (kg of fresh matter/ m^3; Table 2). Wilting was evaluated as a treatment in 4% of the papers but was also applied in other papers for all the treatments, which would affect the results of a moisture absorbent additive. The regrowth age showed a large variation among the papers, considering the fact that less than 10% of the have evaluated it as a treatment. The variation in regrowth age could be related to the size of the grass specie, since it varied from 30 to 120 days. Stoloniferous and decumbent grasses showed the regrowth age varied from 30 to 45 and from 30 to 90 days, respectively. The regrowth age for tussock or bunch grasses, as *Megathyrsus* and *Pennisetum* varied from 30 to 120 days. We also observed considerable variations on particle size, days of storage and packing density.

Table 2. Range of factors of ensiling of tropical grasses

Item	n*	Mean	SD	Min	Max
Wilting (h)	163	9.38	10.25	1	48.0
Regrowth age (days)	551	61.66	16.10	30	120.0
Particle size (cm)	425	1.96	0.98	1	6.0
Moisture absorbent additive level (% of FM[1])	92	10.50	11.50	0	60
Days of storage	706	54.43	44.32	1	250.0
Packing density (kg of FM/ m^3)	230	562.96	58.15	450	796.0

[1]Fresh matter * Number of observations for each variable in the 102 papers evaluated

The variation observed in the Table 2 reveals the difficult to perform a comparison among papers because the efficacy of additives varies depending on regrowth age for example. In addition, it is known that the variation on regrowth age affects the chemical composition of the grass, as the concentration of WSC and the nutritive value (Santos et al., 2014). For example, if a microbial inoculant is used in guinea grass harvested with 100 days of regrowth its effect will be lower or absent because the WSC concentration in the fresh forage can be enough to provide an adequate fermentation. On the other hand, the same inoculant would have a different effect if the same grass is harvested with 60 days of regrowth. The variation observed in the concentration of WSC confirm this hypothesis. These facts affect the chemical composition at ensiling, which shows significant variation (Table 3).

Table 3. Range of fermentative characteristics, microbiology and chemical composition of tropical grass at ensiling (total number of papers accessed = 102)

At ensiling					
Item[1]	n	Mean	SD	Min	Max
Yeasts (log cfu/g)	5	6.59	0.91	5.1	7.38
Molds (log cfu/g)	1	4.0	-	4.0	4.0
Enterobacteria (log cfu/g)	18	5.50	0.78	4.26	6.94
Clostridia (log cfu/g)	2	3.10	2.83	1.1	5.11
LAB (log cfu/g)	18	4.71	0.95	1.52	5.72
DM (g/kg)	225	280	110	124	787.9
Ash (g/kg)	71	84.92	26.79	34.9	143
CP (g/kg)	179	89.6	58.13	25.9	743
NDF (g/kg)	169	666.27	112.76	252.3	861.5
ADF (g/kg)	158	396.53	87.03	119	603.3
NIDN (g/kg of TN)	28	346.31	127.41	152	631.23
NIDA (g/kg of TN)	50	346.31	145.74	9.2	593.86
Celulose (g/kg)	55	364.61	58.16	73.5	465.8
Hemicellulose (g/kg)	96	285.37	73.94	122.1	741.4
Lignin (g/kg)	71	60.32	39.59	3.04	186
NFC (g/kg)	27	122.36	96.84	12.8	340.5
WSC (g/kg)	70	50.99	34.54	1.8	156
BC eq.mg HCl/100 g MS	35	59.77	70.70	5	243
IVDMD (%)	38	64.96	9.54	40.45	89.34

* Number of observations for each variable in the 102 papers evaluated; DM- dry matter; CP- crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; NDIN- neutral detergent insoluble N; ADIN- acid detergent insoluble N; NFC- Non fibrous carbohydrates; IVDMD- in vitro DM digestibility;

Average DM was 280 g/kg, with a range from 124 to 787.9 g/kg. In general, we observed significant variations in the chemical composition, which can be related to the factors described in Table 2, but also with other treatments evaluated (as moisture absorbent additives). Considering the 551 observations, we can state that the average regrowth age is around 60 days (Table 2), which shows the balance between DM yield and nutritive value, and DM concentration above 200 g/kg. In general, it is related in the averages observed for chemical composition (Table 3).

Based on the collection of published papers, the challenges of ensiling tropical grasses are related to the harvest time and to the fermentation process, because of the characteristics at ensiling. Many efforts have been made to overcome these limitations, but we still observed a low number of papers and a lack of standardization.

In order to visualize the effects of additives and wilting, we grouped the papers considering the averages of the treatments and the percentual of positive responses (Table 4).

Table 4. Positive responses obtained and number of papers that evaluated fermentative characteristics, microbiology and chemical composition of published papers that used absorbent additives

Absorbent additive				
Item	n° of papers	% positive responses	Mean	
			With additive	Without additive
Yeasts (log cfu/g)	1	0	2.30	1.81
Molds (log cfu/g)	1	0	2.48	2.03
Enterobacteria (log cfu/g)	0	0	-	-
Clostridia (log cfu/g)	0	0	-	-
LAB (log cfu/g)	1	100	9.26	6.95
LA (g/kg)	12	91.6	47.87	33.24
AA (g/kg)	11	27.2	7.25	7.16
PA (g/kg)	9	22.2	1.03	0.64
BA (g/kg)	10	50	0.90	1.47
pH	24	66.6	4.09	4.37
N-NH_3 g/kg of TN	20	75	76.2	103.8
Ethanol (% of DM)	2	0	1.25	0.18
GL (% of DM)	7	71.4	2.13	2.64
EL (kg/ton of MV)	6	83.3	10.06	27.57
DML (g/kg of DM)	0	0	-	-
DMR (% of DM)	5	100	91.94	81.67
DM (g/kg)	36	97.2	290.44	197.98
Ash (g/kg)	6	50.0	81.54	84.23
CP (g/kg)	33	6.0	86.18	61.89
NDF (g/kg)	32	9.3	662.87	727.58
ADF (g/kg)	32	9.3	433.45	455.96
NIDN (g/kg of TN)	8	25.0	342.28	277.51
NIDA (g/kg of TN)	15	33.3	160.91	151.02
Celulose (g/kg)	13	76.9	343.80	378.23
Hemicellulose (g/kg)	19	84.2	233.06	261.26
Lignin (g/kg)	13	15.3	102.51	65.42
NFC (g/kg)	5	100	111.91	83.56
WSC (g/kg)	6	100	77.07	32.03
IVDMD 48h (%)	5	40.0	54.38	56.07

LAB- Lactic acid bacteria; LA- Lactic acid; AA- Acetic acid; PA- Propionic acid; BA- Butiric acid; GL- Gas losses; EL- Efluent losses; DML- Dry matter losses; DMR- Dry matter recovery; DM- dry matter; CP- crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; NDIN- neutral detergent insoluble N; ADIN- acid detergent insoluble N; NFC- Non fibrous carbohydrates; WSC- Water soluble carbohydrates; IVDMD- in vitro DM digestibility;.

We can observe that important parameters as microbial populations (yeasts, molds, and lactic acid bacteria) and nutritive value (in vitro dry matter digestibility (IVDMD)) are evaluated in a low number of papers that evaluated moisture absorbent additives as the main factor.

Silages treated with moisture absorbent additives showed higher concentration of lactic acid (90% of the papers) and lower pH concentration of butyric acid and ammonia nitrogen compared with untreated silages. In addition, the concentration of fiber components (neutral detergent fiber, acid detergent fiber and lignin) reduced with the addition of moisture absorbent additives, because they are usually concentrates or by-products with low fiber content. As the main effect of moisture absorbent additives, effluent losses were reduced in 75% of the four summarized papers. As a consequence of improvements in fermentation, DM recovery was increased in 100% of the papers when these additives were used.

The second most used class of additives used in the tropical grass silages were the microbial inoculants. Among the 102 papers, we grouped only 10 papers that exclusively evaluated microbial inoculants (Table 5). In their other papers the microbial inoculants were combined with moisture absorbent additives, enzymes, harvest time or wilting. As observed before, a few numbers of papers have evaluated the microbial populations. However, the effect of microbial inoculants on the fermentation profile by increasing lactic acid and decreasing pH was consistent in more than 80% of the papers.

The treatment with microbial inoculants reduced the concentrations of ammonia nitrogen and butyric acid in 80 and 85% of the papers, respectively. Considering both DM loss and DM recovery we observed positive results in 100% of five papers, which is an important achievement as a consequence of improvements in the fermentation. Despite the low number of papers with microbial inoculants, the compilation of papers showed positive results. However, these results must be verified under farm conditions with large amounts of silage and greater environmental influence, which is a key challenge.

By performing an overview of the published papers, we observed that the majority of research with tropical grasses silage is performed by Brazil, followed by other tropical countries. In addition, the number of published papers about this topic has decreased over the last five years. The use of additives proved to be a suitable practice to improve silage fermentation and decrease DM losses. However, it has not been tested in farm conditions, neither considering the costs.

Table 5. Positive responses obtained and number of papers that evaluated fermentative characteristics, microbiology and chemical composition of works that used Inoculant microbial additive

Treated with Inoculant microbial additive				
Item	n° of papers	% positive responses	Mean	
			Inoculated	Untreated
Yeasts (log cfu/g)	0	0	-	-
Molds (log cfu/g)	0	0	-	-
Enterobacteria (log cfu/g)	2	100	2.93	3.99
Clostridia (log cfu/g)	0	0	0.44	1.23
LAB (log cfu/g)	2	50.0	7.94	6.72
LA (g/kg)	6	83.3	60.4	47.95
AA (g/kg)	6	83.3	7.39	11.58
PA (g/kg)	4	75.0	1.86	2.29
BA (g/kg)	5	80.0	0.97	1.19
pH	10	100	4.46	4.61
$N\text{-}NH_3$ g/kg of TN	7	85.7	42.77	47.18
Ethanol (% of DM)	1	0	47.18	1.03
GL (% of DM)	4	75.0	2.77	4.44
EL (kg/ton of MV)	3	66.6	41.5	41.1
DML (g of DM)	1	100	60.9	127
DMR (% of DM)	4	100	92.64	90.62
DM (g/kg)	10	90.0	238.68	240.01
Ash (g/kg)	3	0	107.62	109.46
CP (g/kg)	10	70.0	86.63	76.38
NDF (g/kg)	9	55.5	725.76	720.51
ADF (g/kg)	9	66.6	447.74	447.61
NIDN (g/kg of TN)	1	0	176.45	185
NIDA (g/kg of TN)	2	0	150.62	137.77
Celulose (g/kg)	2	50.0	137.77	330.16
Hemicellulose (g/kg)	6	83.3	306.35	309.46
Lignin (g/kg)	3	0	90.25	82.78
NFC (g/kg)	0	0	-	-
WSC (g/kg)	3	100	23.28	17.83
IVDMD 48h (%)	6	33.3	62.8	61.03

LAB- Lactic acid bacteria; LA- Lactic acid; AA- Acetic acid; PA- Propionic acid; BA- Butiric acid; GL- Gas losses; EL- Efluent losses; DML- Dry matter losses; DMR- Dry matter recovery; DM- dry matter; CP- crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; NDIN- neutral detergent insoluble N; ADIN- acid detergent insoluble N; NFC- Non fibrous carbohydrates; WSC- Water soluble carbohydrates; IVDMD- in vitro DM digestibility;

By grouping published papers, we could discuss the main challenges of tropical grasses silages and bring an overview of this topic. Despite the large variation observed and the low number of studies, the use of moisture absorbent additives and microbial inoculants can improve the fermentation of tropical grasses silages in most of the cases. However, considering the influence of many factors, these technologies may not be efficient at a farm level. Based on that, we observe quite good experiences and unsuccessful ones. Based on that, the adequate harvest time remains as a challenge for researchers, consultants and farmers. In addition, the use of tropical grasses silages in the diets for ruminants has not been studied as it should be, which is also an important topic to discuss.

3. Impacts of tropical grasses silages utilization on animal performance

The number of studies evaluating animal performance with animals fed tropical grasses silages is considerably low. Despite the advances in the ensiling technologies, the effects of additives and management practices on animal performance has not been studied extensively. The studies performed evaluating animal performance have testes the effects of microbial inoculants (Restle et al., 2003; Paziani et al.,2006; Cezario et al., 2015), moisture absorbent additives, as citric pulp, coffee hulls. cocoa meal, cassava meal and dehydrated passion-fruit peel (Carvalho Junior et al., 2009; da Cruz et al. 2011), and other additives as urea and cassava bagasse (Carvalho et al., 2006); Silva et al., 2006).

The three studies evaluating microbial inoculants have not observed effects on intake and productive performance of beef cattle. The species and the forage:concentrate ratio used in these studies were *Urochloa plantaginea*, *Megathyrsus maximus*, *Urochloa brizantha* cv Marandu and 65:35, 55:45 e 50:50 for Restle et al. (2003), Paziani et al. (2006) and Cezario et al. (2015), respectively. These results show that the use of additives has high impact on the fermentation process than the intake and performance. It means that they will not always improve weight gain even though they have improved fermentation process. However, if the DM losses are reduced by improving fermentation, the microbial additive has reached its goal, which will reduce the feeding cost. When moisture absorbent additives were evaluated, Carvalho Junior et al. (2009) and Cruz et al. (2011) observed that some additives increased nutrient intake and productive performance, as cassava meal (15%, fresh basis) and dehydrated passion-fruit peel (up to 30%, fresh basis). The addition of cassava bagasse levels during ensiling of Pennisetum purpureum did not affect animal performance in diets containing 40% of concentrate. The impact of using moisture absorbent additives depends on the composition of the concentrate, plant, by-product and others that is used, which can be checked in small scale trials. Some moisture absorbent additives, as coffee hulls and some fruit by products may not improve animal performance because of the high concentration of lignin. All effects of additives, as discussed before, will depend on many effects, specially the forage:concentrate ratio and harvest time.

The harvest time was studied by Daniel et al. (2016) and Cezario et al. (2015). Cezario et al. (2015) observed that harvesting the *U. brizantha* with 35 or 70 days of regrowth did not affect intake of total digestibly nutrients, nutrient digestibility and productive performance. Daniel et al. (2016) stated that feeding lactating cows with bermudagrass ensiled after 4 weeks of regrowth improved energy intake and milk production compared with the cows fed bermudagrass ensiled after 7 weeks of regrowth. Missio et al. (2019) showed that the dietary inclusion of 100 and 400 g/kg of Mulato II grass (*Urochloa* sp.) silage resulted in similar productive performance of young Nellore bulls and dairy crossbreeds. The decision of harvesting tropical grasses for silage production should be based on the proportion of the diet that grass silage will be used and on the fermentation characteristics of the grass specie, and other factors that will be discussed.

4. Perspectives about production and utilization of tropical grasses silages

After an overview about tropical grasses silages we will discuss some perspectives as provocations for researchers and consultants. Despite the lower nutritive value compared with corn, ensiled tropical grasses can be used to reduce feeding costs, to help pasture management, and as a forage source in feedlots or dairy farms. As discussed before, tropical grasses have a great potential to be used in diets for ruminants, but to be fairly compared with other crops, we suggest quantifying the digestibly energy produced by hectare. However, we still need to define what should base the decision of harvesting the grass. For example, when the dietary inclusion of tropical grasses silages is low (eg. feedlots), the harvest can be directed to obtain more DM per hectare because the silage is going to act as effective fiber in diets with high proportion of concentrate. On the other side, lactating cows need the maximum of nutritive value from the grass silage because they are an important energy source in the diet.

This is a wide discussion and we would say that there is not just the only specific time of harvest. In this context, some criteria of harvesting tropical grasses for silage production can be cited: the growth phase, days of regrowth, light interception and sward height. It will depend on many factors, but the purpose that the grass silage will be used. In addition, when considering harvest for silage production, the balance between DM yield and nutritive value would vary depending on the final purpose of the system that the silage will be used.

The researches about pasture management in rotational grazing systems has considered the maximum yield of leaves in order to provide an efficient harvest by the animal and to improve productive performance (Burns and Sollenberg, 2002; Mezzalira et al. 2014). The main recommendation to reach this harvest point is when the sward intercepts 95% of the incident light, which is correlated with sward height. This is considered the threshold point where the plants have more proportion of leaves than stem and dead material, which is related with the nutritive value (da Silva et al., 2015). Based on that, recommendations of grazing target height for maximum yield without compromising nutritive value were generated and they also match with animal behavior and productive performance. This recommendation could be used for harvesting tropical grasses for silage production.

However, the amount of DM harvested by hectare is important for silage production because it affects the costs per stored DM (Busano et al., 2019). Tropical grasses are quite efficient on producing biomass in short periods, especially when submitted to adequate management practices (da Silva et al., 2015). If we consider the harvest by machines for silage production, the concepts of grazing efficiency would not be directly applied.

By using machine harvesters, in order to improve efficiency, the grasses can be harvested at higher heights than those recommended for grazing, in order to increase harvested DM and decrease production costs. The research conducted by Thomas et al. (2018) with *M. maximus* cv. Mombaca drives new directions for harvesting tropical grasses for silage production. They recommended harvesting the grass with 130 cm height and 20 cm from the soil to achieve the maximum fermentability coefficient and to maximize DM yield. In this case, they remove 85% of the sward, while the recommendations for grazing are between 40 to 60% of removal and considering a lower height (90 cm). Thus, we can state that we need to generate new target heights for the purpose of silage production. These new goals should consider the characteristics for ensiling process (buffering capacity, DM content and concentration of WSC) and they should be directed to the maximum harvest of total digestible nutrients or digestible DM per hectare.

Based on that, the adequate harvest time for each cultivar of grass should be determined and the farmers and consultants should base this decision on the percentual of dietary inclusion of tropical grass silage and on the animals that will be fed with this silage.

5. Final remarks

Efficiency of the production and utilization of tropical grasses is essential for livestock production in tropical regions, and silage production is a key strategy for efficient production systems. Ensiling tropical grasses as a suitable tool of pasture management and for animal supplementation is extremely important for the sustainability of livestock systems and to reduce production costs.

Most of the research were conducted in Brazil and they focused more on the fermentation profile. The use of moisture absorbent and or microbial inoculants additives provides significative beneficial effects for tropical grass silage fermentative process. Chemical additives have not been significantly evaluated in tropical grasses. The height target for ensiling tropical grasses can be higher than the ones used for grazing. However, these recommendations for all cultivars of grasses do not exist yet.

As tropical grasses are a heterogeneous group both regarding to species/cultivars variabilities and regarding to phenological stage and management, studies combining and not combining these factors with additives are needed. Studies at farm level, evaluating new cultivars and additives, measuring digestibility and animals' performance are relevant gaps to be fulfilled.

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