UNDERSTANDING THE DYNAMICS OF HERBAGE ACCUMULATION IN TROPICAL GRASS SPECIES: THE BASIS FOR PLANNING EFFICIENT GRAZING MANAGEMENT PRACTICES[1]

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Abstract

The paper outlines initially general principles involving plant responses to defoliation practices and highlight the importance of target sward conditions for planning, monitoring and controlling grazing management of temperate pastures. Then, using this as a reference point, it moves on to presentation and discussion of available results from recent research on tropical and sub-tropical species evolving into a comparative analysis between the two types of grasses (tropical *vs* temperate). Similarities and differences are highlighted and opportunities for manipulation and management identified, demonstrating the importance and the potential benefits of using target sward conditions also for tropical/sub-tropical pastures. The need for analogous information on animal responses is recognised and briefly discussed.

Introduction

Tropical and sub-tropical pasture species are well recognised for their high potential of dry matter production (Humphreys, 1981). Although there are reports of very efficient pastoral systems (25 to 30,000 kg milk/ha.year – Corsi et al., 2001 -

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and 1,000 to 1,600 kg LWG/ha.year – Moraes et al., 2002), animal production and productivity from tropical/sub-tropical pastures have traditionally and consistently been associated with low levels of performance and feeding value of the herbage on offer (Hardy et al., 1997; Sollenberger and Burns, 2001), those being the generally accepted and alleged reasons used to justify the lack of success in benefiting from the high dry matter yield potential of those forage species. The extensive nature of most production systems in the tropics provide very little opportunity for controlling the grazing process and, therefore, sward structure accordingly (Hodgson and Da Silva, 2002), imposing serious restrictions to the establishment of such cause and effect relationship between plant characteristics and animal responses (Da Silva and Pedreira, 1997). This suggests that, in order to benefit from the advantages of the tropics and tropical/sub-tropical species, it is necessary to understand the functional relationship between plant and animal responses to defoliation strategies (Da Silva and Corsi, 2003; Nascimento Jr et al., 2004). The dynamics of herbage accumulation is certainly one of several processes essential to that understanding and a key feature for planning and conceiving efficient and sustainable animal production systems from pastures. The objective of this paper is to present recent evidences and to discuss how the understanding of plant responses to defoliation can contribute to improve the productivity and efficiency of tropical pastoral systems, updating and elaborating further on the tentative recommendations of grazing management targets for tropical and sub-tropical pastures presented by Hodgson and Da Silva (2002).

The herbage accumulation process and grazing management

Principles

In perennial grass species, the continuous sequence of phytomer development results in a complex pattern of herbage production in which the growth of new tissue and the loss of mature tissue to senescence and decomposition occur simultaneously (Valentine and Matthew, 1999). Additionally, growth and senescence are processes that take place in two levels of complexity, one related to the turnover of leaves on individual tillers and other to the turnover of tillers in sward tiller population (Matthew et al., 2000), indicating the importance of knowledge on causative relationship between defoliation practices (e.g. frequency, intensity and time of defoliation) and plant responses (e.g. tiller demography, morphogenesis, tissue flows) for the efficient planning and development of grazing management strategies.

In general, temperate grass species (e.g. perennial ryegrass, tall fescue) alter morphological and physiological responses to defoliation in order to optimise their leaf area index and ensure persistence and production (Lemaire and Chapman, 1996; Matthew et al., 2000) within the limits of their resistance to grazing (Briske, 1996). In a vegetative state, the main component of plant growth is leaf elongation (Lemaire and Agnusdei, 2000), with pseudostem/stem elongation being small. Under those circumstances, herbage production is basically a result of the balance between leaf growth and senescence (Bircham and Hodgson, 1983), and planning of grazing management practices is based on efficient harvest of leaf tissue before it enters in an advanced stage of senescence (Mazzanti et al. 1994ab; Lemaire and Chapman, 1996; Lemaire and Agnusdei, 2000). This would ensure high utilisation of the herbage produced and avoid deterioration of sward structure by excessive accumulation of pseudo-stem/stem and dead material (Hodgson and Da Silva, 2002).

Detailed studies on plant morphogenesis, tiller demography and dynamics of herbage accumulation revealed a substantial flexibility in plant morphology, tillering behaviour (Figure 1) and leaf turnover in temperate grass species (Figure 2) that allows for compensation of very substantial contrasts in grazing management maintaining stability of sward dry matter production across a wide range of pasture conditions (Hodgson and Da Silva, 2002). Analogous information related to the effects of sward structure on forage intake and production of grazing animals (Hodgson et. al., 1994) led to the development of grazing management strategies based on the concept of "sward state" (Figure 3), with management targets defined in terms of sward height (Hodgson, 1990) or herbage mass (Matthews et al., 1999) to meet the needs of the pasture and of the grazing animals with defined performance requirements (Hodgson and Da Silva, 2002). This has proved to be a very interesting and effective option for planning animal production from pastures, and revealed the possibility of doing it in a very objective way according to particular characteristics of a given system (Matthews et al., 1999). In this context, sward state is considered to be the real system "driver" and manipulation of parameters like stocking rate, grazing pressure and rotation length is used as part of strategies to achieve and maintain target sward conditions (Hodgson, 1985) as well as to guide and orientate the strategic use of forage conservation and supplementary feeds (Matthews et al., 1999).

Tropical and sub-tropical forage species

Traditionally, experimentation and use of tropical/sub-tropical grass forage species have been based on fixed intervals between defoliations, fixed values of stocking rate or herbage on offer and herbage production measured directly at the end of regrowth intervals as being a “single” process. Under those circumstances, the composition of the herbage produced is usually characterised by a high proportion of stem and dead material, with a low leaf-to-stem ratio. Chemical analyse of the herbage reveal a consistent low crude protein content and digestibility that would be responsible for the low levels of animal performance commonly associated with those measurements. This becomes even more evident in situations where high inputs of nitrogen fertiliser and irrigation are used resulting in very high herbage accumulation rates with no correspondent adjustment (reduction) in regrowth interval (Da Silva and Corsi, 2003). The combined result is the general believe that tropical/sub-tropical grass species are capable of producing very large quantities of dry matter but with low nutritive and feeding value, limiting animal performance and, therefore, overall system productivity.

The use of fixed, pre-established numbers for stocking rate, levels of herbage on offer and defoliation intervals, for example, is relatively easy to understand since it provides a simple and comfortable way of planning field work in advance and having it running “around the clock” (set grazing dates and animal numbers), facilitating measurement activities and system “monitoring and control”. On the other hand, it results in a large degree of inconsistency in pasture and animal performance to the associated grazing management practices (e.g. pastures might be super-utilised or under-utilised for a given grazing interval used depending on growth conditions), with responses varying from year to year, seasons within year, levels of soil fertility, use of fertilisers and irrigation etc. This indicates the limitations of generalising grazing management recommendations under those circumstances and draw interest to alternative ways and means of planning and monitoring grazing management practices that would be capable of providing greater degree of consistency and ensure satisfactory levels of pasture and animal performance.

Recent experimental work at USP-ESALQ (from 1999 onwards) on grazing management of tropical and sub-tropical grass species revealed the need of appropriate monitoring and control of defoliation practices based on an objective set of sward variables, similarly to temperate grass species. This series of experiments was designed to evaluate functional relationships between plant and animal responses to defoliation strategies characterised by tight control of sward conditions either under continuous or intermittent stocking management (Hodgson, 1985). It covered a significant range of plant structure (size and shape) and flexibility to grazing management (continuous and intermittent stocking), varying from sward forming, prostrate-high tillering (*Cynodon* cultivars Tifton 85, Florakirk and Coastcross) to semi-prostrate (*Brachiaria brizantha* cv. Marandu) and tall-tufted growing species (*Panicum maximum* cultivars Mombaça and Tanzânia), and was conceived with the objective of providing a basis for studying the comparative ecophysiology of temperate and tropical/sub-tropical grass species.

Cultivars of *Cynodon* and *Brachiaria brizantha*, the most flexible plants used, were submitted to continuous stocking regimes where Tifton 85, Florakirk and Coastcross were grazed by sheep to maintain sward surface height (SSH) at 5, 10, 15 and 20 cm (roughly equivalent to 3000, 4000, 5000 and 6000 kg DM/ha) (Fagundes et al., 1999ab; Carvalho et al., 2000ab; Carnevalli et al., 2000; Carnevalli et al., 2001ab; Fagundes et al, 2001; Carvalho et al., 2001ab; Pinto et al., 2001ab; Sbrissia et al., 2001 and 2003) and Marandu was grazed by cattle to maintain SSH at

10, 20, 30 and 40 cm (roughly equivalent to 6000, 8000, 10000 and 12000 kg DM/ha) (Gonçalves, 2002; Lupinacci, 2002; Andrade, 2003; Sarmento, 2003; Molan, 2004; Sbrissia, 2004). In these two sets of experiments monitoring of both plant and animal responses was performed during a 12-month period. The results of measurements of tissue turnover during the summer period (Figures 4 and 5) showed close similarities to perennial ryegrass (Figure 2), although the range of apparent flexibility in net herbage production occurred at greater sward height (*Cynodon* – 10 to 20 cm - and *Brachiaria* – 20 to 40 cm - compared to 3-8 cm for perennial ryegrass). Stem elongation contributed significantly to the herbage accumulation process, comprising around 50-70% and 20-30% of the gross production of *Cynodon* and Marandu swards maintained at 5-20 and 20-40 cm, respectively. Although the number of live leaves per tiller remained steady around 5 for *Cynodon* and 4 for *Brachiaria*, leaf appearance rate decreased and leaf life span increased with increasing SSH (Pinto et al., 2001ab; Sbrissia, 2004). Measurements related to plant and sward responses also revealed a continuous turnover in tiller population (Carvalho et al., 2000ab; Carvalho et al., 2001a, Sbrissia, 2004) and a dynamic pattern of compensation involving tiller size and population density (Sbrissia et al., 2001 and 2003; Sbrissia, 2004) similar to that described for temperate pasture plants (Matthew et al. 1995; see Figure 1). Chemical analyse of herbage samples harvested simulating grazing revealed high contents of crude protein (around 17.5 and 12.5%) and organic matter digestibility (76.3 and 64.7% for *Cynodon* and *Brachiaria*, respectively, regardless of SSH) (Carnevalli et al, 2000; Carnevalli et al., 2001ab; Andrade, 2003), indicating that measured differences in intake (Sarmento, 2003) and live weight gain (Carnevalli et al, 2000; Carnevalli et al., 2001ab; Andrade, 2003) were not due to nutritive value of the herbage but to behavioural factors affecting the intake by the grazing animal

(Sarmento, 2003; Molan, 2004). The live weight gain of growing sheep for *Cynodon* reached a maximum at a sward surface height of 15 cm (Carnevalli et al., 2000; Carnevalli et al., 2001ab; see Figure 6) and of growing cattle for *Brachiaria* responded linearly within the range of SSH studied (Andrade, 2003; see Figure 7). Defoliation intensity of Marandu leaves was relatively constant for all sward heights studied (around 67% of the leaf lamina length) with defoliation frequency (Figure 8) and utilisation efficiency (Figure 9) being a direct function of the stocking rate used to maintain sward targets (Gonçalves, 2002). Leaf lamina was the main component of the top 50% of sward height (Molan, 2004), indicating that around 33% (67% leaf x 50% SSH) of the upper strata of the swards were being effectively explored by the grazing animals (Gonçalves, 2002) and re-enforcing the argument about non-nutritional constraints to intake (Sarmento, 2003). Comparison of the information from Figures 4, 5, 6 and 7 clearly indicates the potential for developing grazing management strategies based on sward height targets for sward-forming prostrate and semi-prostrate tropical plants like *Cynodon* and *Brachiaria*. In this case the optimum sward height to balance pasture and animal requirements under continuous stocking management would be about 15 cm for *Cynodon* and 30 cm for Marandu, equivalent to a herbage mass measured to ground level of about 5000 and 10000 kg DM/ha, respectively.

Since *Panicum maximum* cultivars are tall-tufted growing plants, they do not adapt too well to continuous stocking management. For that reason, analogous experimentation to cultivars of *Cynodon* and *Brachiaria* had to be carried out under intermittent stocking management, the difference being the need to set two references for sward targets instead of just one (a pre and a post-grazing condition) (Hodgson, 1985). Classical work with temperate forage species (e.g. Brougham, 1955, 1956, 1957, 1959; Korte et al., 1982; Parsons et al., 1988) revealed that regrowth intervals longer than the time interval needed to reach 95% of sward light interception (LI) would result in reduction of herbage accumulation rates and deterioration of sward structure by accumulation of pseudo-stem/stem and senescent/dead material, indicating that delaying grazing beyond this point would not be an interesting practice. However, because in theory it would still be possible to accumulate dry matter up until 100% LI, particularly for tall-tufted tropical growing species, this sward condition had also to be considered as a reference point in the evaluation process.

Against that background and assuming that similar behaviour during regrowth would apply to tropical species (encouraged by the previous results from experiments with *Cynodon* and *Brachiaria*), *Panicum maximum* cultivars were then submitted to rotational grazing characterised by combinations between sets of pre and post-grazing targets of sward condition during a 12-month period. Grazings were executed by mob grazing and did not last longer than two days. For Mombaça, pre-grazing conditions corresponded to either 95 or 100% LI and post-grazing conditions to residual heights of either 30 or 50 cm (Uebele, 2002; Bueno, 2003; Carnevalli, 2003). For Tanzânia, the corresponding values where 90, 95 or 100% LI and 25 or 50 cm, respectively (Barbosa, 2004). Evaluations comprised detailed measurements of plant responses and nutritive value of the herbage produced. The results demonstrated a high degree of consistency and applicability of the criterion of interrupting regrowth at 95% LI, as for temperate species, and a positive effect of associating this pre-grazing condition to lower post-grazing residues compatible with the necessity of plants to maintain a minimum residual leaf area in order to initiate a new regrowth process and ensure efficient utilisation of the herbage produced. In general, the highest herbage production was recorded for the 95% LI treatments when associated to post-grazing residues of 25 and 30 cm for Tanzânia (Barbosa, 2004) and Mombaça (Carnevalli, 2003), respectively, with significant reduction in dry matter (Tables 1 and 2) and leaf lamina (Table 3) accumulation when grazings were executed at 100% LI or to a 50 cm post-grazing residue. For Tanzânia, shorter regrowth periods defined by the pre-grazing condition of 90% LI also resulted in lower herbage as well as leaf lamina production (Tables 2 and 3). The lower production for the 90% LI treatments might have been a consequence of limitations to the growth process, since there was not enough leaf area to exploit all incident light. On the other hand, the lower production for the 100% LI treatments was a result of the excessive senescence and death of tissues, consequence of the intense competition for light under those circumstances that also favoured the accumulation of stem, reducing the proportion of leaves and increasing the proportion of stem and dead material in the pre-grazing herbage mass (Table 4). This variation in morphological composition was responsible for reductions in crude protein content and organic matter digestibility of the herbage produced (Table 5), which could have negative implications to animal performance.

The pre-grazing conditions of 95 and 100% LI for Mombaça presented a consistent and high correlation (r = 0.84) with sward surface height (“leaf horizon”) regardless of season of the year and physiological state of plants (vegetative or reproductive – 90 cm for 95% and 110 cm for 100% LI) (Table 6). The same happened for Tanzânia, with 90, 95 and 100% LI corresponding to sward surface heights of 60, 70 and 85 cm, respectively, indicating that sward height could be used as a reliable field guide for monitoring and controlling regrowth and the grazing process. Mello and Pedreira (2004), working with Tanzânia swards under irrigation and high input of nitrogen fertiliser (640 kg N/ha), also reported 95% of sward light interception consistently associated with a 70 cm sward surface height.

In addition to the lower herbage production of lower nutritive value, less frequent grazing, characterised by the 100% LI treatments, resulted in an increase of the post-grazing heights of 25 (around 40 cm at the end of the experiment) and 30 cm (around 50 cm at the end of the experiment) in Tanzânia and Mombaça, respectively, a consequence of excessive accumulation of stem material under those circumstances (Table 7). Detailed evaluations of the herbage accumulation process during regrowth revealed that up until 95% LI accumulation of leaf lamina was the predominant process, but from that point onwards the processes of stem elongation and senescence were considerably increased (Figures 10 and 11). These results are being corroborated by recent experimentation with other *Panicum* cultivars like Tobiatã, Massai and Atlas under cutting regimes, where accumulation of stem and dead material was much increased after swards had reached 95% LI during regrowth (Figure 12).

In general, a continuous pattern of tillering was verified, with leaf appearance rate increasing and leaf life span decreasing for the more frequent and severe grazing treatments. The number of live leaves per tiller remained steady and around four, regardless of the *Panicum* cultivar. There was also a dynamic compensating behaviour between tiller size and population density during the regrowth of both Mombaça and Tanzânia, with proportionally higher reduction in tiller numbers with increasing tiller size at the end of regrowth, particularly for the less frequent and less severe grazing treatments (Carnevalli, 2003; Barbosa, 2004). Tissue flow measurements in tillers of varying ages in Tanzânia swards demonstrated a strong aging effect on leaf elongation rate (Figure 13), suggesting the importance of manipulating the grazing process also with the objective of generating a younger profile of tiller population in order to augment the growth process and increase herbage production. Uebele (2002) found no difference in tiller population density for the range of treatments used in the series of experiments reported for Mombaça, but the results from the tiller demography measurements revealed a higher tiller turnover for the 95% LI condition associated with the post-grazing residue of 30 cm (younger population of tillers), the combination that resulted in highest herbage production (Table 1).

These findings are in keeping with those obtained under very controlled conditions in glasshouse experiments in New Zealand, in which Mombaça and Tanzânia plants were grown in pots and cut to 10, 20 or 40 cm height at approximately monthly intervals for 8 months (Carvalho, 2002). The results showed that tiller population per plant increased progressively as defoliation severity increased and tiller size declined, and the result was that both gross and net herbage production increased progressively with increasing defoliation severity from 40 cm down to 10 cm. This indicated similar degrees of adjustment in tiller dynamics and tissue turnover to those for perennial ryegrass as well as higher leaf elongation rates for young (less than two months of age) in relation to old (over four months of age) tillers (Carvalho et al., 2001). However, a further study with mini-swards in the glasshouse over a period of 18 months showed that regular clipping to 15 cm at approximately monthly intervals resulted in a progressive decline in tiller population density and herbage production compared with defoliation at 30 cm (Carvalho et al., 2002ab), a result consistent with field observations in Brazil (Santos, 2002). Under those circumstances, Mombaça had a consistently smaller population of larger tillers with larger leaves than Tanzânia, with a higher level of production under lenient cutting but greater sensitivity to severe defoliation, emphasising the importance of fitting sward management to the needs of specific plant genotypes (Hodgson and Da Silva, 2002).

The interval between successive grazings for Mombaça varied substantially with treatments and time of the year, with highest values recorded for the 100% LI treatments during autumn and winter (Figure 14), time of the year of low rainfall and low temperatures. Similar pattern was reported for Tanzânia, with grazing interval varying from 24 to 150 days (Barbosa, 2004), indicating the limitations of using fixed periods of regrowth or grazing intervals as reference for “controlling” and defining rotational grazing management practices. Evaluations of the grazing process in Mombaça revealed that more lenient (50 cm residue) and less frequent grazing (100% LI) resulted in high herbage losses (severed material on the soil surface or hanging in the tussock without being harvested), indicating that, in addition to the higher amounts of herbage lost to senescence and death during regrowth (Figure 10), there were associated high losses due to the physical action of the animal during grazing (Table 8).

Evidence from these experiments indicates that *Panicum maximum* is adaptable to a substantial range of management control, and is apparently tolerant of a more severe level of defoliation than would normally be used in the field (Humphreys, 1991), at least over limited periods of time. This could provide, for example, the opportunity for relatively close defoliation to control stem elongation in the summer and culm development in the autumn/winter period (Santos et al., 2001b). In these studies there was a relatively continuous pattern of tillering activity and several tiller cohorts contributed to flowering activity in winter (Carvalho, 2002; Santos, 2002). As a consequence, control of stem development during summer and of flowering tillers over autumn and winter cannot be achieved with a single, strategic hard grazing.

The results from the sequences of experiments reported for *Panicum* cultivars under rotational grazing demonstrated a very consistent pattern of plant responses to grazing management. This encouraged the conduction of similar field work on a forage species of contrasting morphology, *Brachiaria brizantha* cv. Marandu, with the objective of evaluating the consistency of responses across a wide range of plant structures. Preliminary results, from a short period of measurements, already show a striking degree of consistency and resemblance in plant response to that reported for Mombaça and Tanzânia. Experimental treatments are defined by pre-grazing conditions of 95 and 100% LI and 10 and 15 cm post-grazing residues. In general, herbage production is higher for the more severe grazing treatments (10 cm residue) with apparently no influence of grazing frequency (95 or 100% LI). However, the combination between more frequent and more severe grazing (95% LI and 10 cm residue) is resulting in highest dry matter yield (Table 9) with high proportion of leaves and low proportion of stem and dead material in the pre-grazing herbage mass (Table 10). As for Mombaça and Tanzânia, detailed measurements of the herbage accumulation process during regrowth are showing that up until 95% LI accumulation of leaf lamina is the predominant process, but from that point onwards senescence is being considerably increased (Figure 15). Stem elongation was small during the measurement period in relation to the results for *Panicum* probably because plants were already reproductive and growth process was quite slow. Description of the structural characteristics of the herbage mass during each regrowth period show a high degree of consistency for the values of sward height correspondent to the pre-grazing targets of 95 and 100% LI (around 25 and 30 cm, respectively; see Table 11), re-enforcing the argument about the possibility of using sward targets for monitoring and controlling the regrowth and the grazing processes.

Practical implications

The results presented show an encouraging degree of similarity over tropical and temperate pasture species in terms of principles of sward dynamics and equilibrium, indicating that some of the concepts developed and widely adopted for planning grazing management strategies for perennial ryegrass swards can also be used for tropical and sub-tropical pastures, provided that some relevant adjustments are made. Stem elongation is certainly one of the difficulties and is the starting point of most problems related to degeneration of sward structure, reduction of herbage nutritive value and intake by the grazing animals. Control of sward structure and its pattern of variation is, therefore, a key feature for the development of efficient and sustainable grazing management practices.

Apparently, herbage accumulation during regrowth of tropical/sub-tropical grass species is a two-stage process in which leaf production is the predominant feature up until competition for light increases (95% LI), situation where plants start to elongate stem in order to push new leaves into light and old leaves at the base of the sward engage in an intense senescence process for being shaded. For that reason, grazing frequency is a powerful tool for controlling stem elongation, culm development and dead material accumulation, as is severity of grazing for controlling and adjusting utilisation efficiency and herbage production. However, instead of defining grazing interval as a time-related decision only, the use of sward state targets defined from the integration of a series of detailed observations on plant and animal responses can provide the lacking objectivity and allow for the desired consistency in response to defoliation practices, the basic requirement for sound generalisations in terms of grazing management strategies. In this context, the 95% LI criterion and its high correlation with pre-grazing sward height provide the grazier with a powerful tool for adjusting grazing interval accordingly to variations in growth conditions (e.g. time of the year, use of nitrogen fertiliser and irrigation etc.), avoiding super and under-utilisation of pastures and the problems related to them.

The high consistency in plant responses to defoliation across a wide range of plant morphology and structure indicates the applicability and the potential benefits of using target sward conditions as a useful criteria for monitoring, controlling and defining grazing management practices. There are several variables that can be used to monitor and control sward state (e.g. sward height, herbage mass). However, regardless of the variable used, this should only be seen as a “reference” representing the need to control and monitor the grazing process and sward structure by means of adjustments in the type and magnitude of the management tools available like stocking rate, herbage allowance, grazing intervals, grazing days, use of fertilisers, irrigation, forage conservation and supplementary feeds etc. The adoption of grazing management practices based on target sward conditions implies the existence of the consciousness and care with the routine of monitoring pastures in the farm.

In general, within the limits of plant resistance, grazing management practices for most productive grass species in cultivated pastures in Brazil should comprise more frequent and severe defoliations than otherwise implied and traditionally used.

Definition of a proper post-grazing residue, consistent with satisfactory levels of animal performance and herbage utilisation, and adjustments in stocking rate and grazing interval in continuous and intermittent managements, respectively, with the objective of maintaining and/or achieving target sward conditions would certainly favour optimal use and nutritive value of the herbage produced. Under those circumstances, animal performance is much more related to grazing behaviour and herbage intake, responses extremely dependent of sward structure. Recognition of this fact highlight the need for understanding aspects of plant-animal interface and animal responses to defoliation practices, an area that still needs considerable amount of work and effort in terms of research. In this context, the use of supplementary feeds to overcome the potential negative consequences of the very pronounced seasonality of production of tropical/sub-tropical pastures should also be thoroughly studied, since it has direct and indirect impact on sward structure and consequently on plant and animal responses.

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Table 1. Herbage production (kg DM/ha) of Mombaça grass pasture submitted to grazing either at 95 or 100% sward light interception (January 2001 to February 2002).

Residue	Sward light interception (%)		
(cm)	95	100	Mean
30	26900	24900	25900 A
	(2493)	(2493)	(1764)
50	17920	20280	19100 B
	(2493)	(2493)	(1764)
Mean	22410	22590	22500
	(1764)	(1764)	

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Source: Carnevalli (2003)

Table 2. Herbage production (kg DM/ha) of Tanzânia grass pasture submitted to grazing either at 90, 95 or 100% sward light interception (July 2003 to May 2004).

	Sward light interception (%)			
Residue	90	95	100	Mean
25	11740 Ab	15120 Aa	11620 Ab	12830 A
	(770)	(770)	(770)	(444)
50	9440 Bb	11940 Ba	12710 Aa	11360 B
	(770)	(770)	(770)	(444)
Mean	10590 b	13530 a	12170 a	12100
	(544)	(544)	(544)	(314)

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Barbosa (2004)

Tabela 3. Leaf lamina accumulation (kg DM/ha) of Tanzânia grass pasture submitted to grazing either at 90, 95 or 100% sward light interception (July 2003 to May 2004).

	Sward light interception (%)			
Residue	90	95	100	Mean
25	9000 Ab (392)	10600 Aa (392)	8030 Ab (392)	9210 A (226)
50	8360 Aa (352)	8060 Ba (392)	6750 Bb (392)	7720 B (226)
Mean	8680 a (277)	9330 a (277)	7390 b (277)	8470 (160)

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Barbosa (2004)

Table 4. Morphological composition (%) of the pre-grazing herbage mass of Mombaça grass pasture submitted to grazing either at 95 or 100% sward light interception (January 2001 to February 2002).

	Sward light interception (%)		
Residue (cm)	95	100	Mean
	% Leaf		
30	70.9 Aa	60.3Ab	65.6 A
	(3.10)	(3.10)	(2.20)
50	57.7 Ba	57.5 Aa	57.6 B
	(3.10)	(3.10)	(2.20)
Mean	64.3 a	58.9 b	61.6
	(2.20)	(2.20)	
	% Stem		
30	14.7 Ab	26.4 Aa	20.6
	(2.40)	(2.40)	(1.70)
50	18.9 Aa	22.1 Aa	20.5
	(2.40)	(2.40)	(1.70)
Mean	16.8 b	24.2 a	20.5
	(1.70)	(1.70)	
	% Dead material		
30	13.7 Bb	19.0 Aa	16.4
	(2.02)	(2.02)	(1.43)
50	20.7 Aa	18.1 Aa	19.4
	(2.02)	(2.02)	(1.43)
Mean	17.2	18.6	17.9
	(1.43)	(1.43)	

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Carnevalli (2003)

Table 5. Crude protein (CP) content and *in vitro* organic matter digestibility (IVOMD) (%) of the pre-grazing herbage mass of Mombaça grass pasture submitted to grazing either at 95 or 100% sward light interception (January 2001 to February 2002).

	Sward light interception (%)		
Season	95	100	Mean
	CP (%):		
Summer	11.3 Aa	9.7 Ab	10.5 A
Autumn/winter	10.9 Aa	9.0 ABb	9.9 AB
Spring	11.4 Aa	8.2 Bb	9.8 B
Mean	11.2 a	9.0 b	
	IVOMD (%):		
Summer	59.9 Ba	56.6 Ab	58.3 A
Autumn/winter	52.4 Ca	53.0 Ba	52.7 B
Spring	61.9 Aa	55.3 ABb	58.6 A
Mean	581 a	55.0 b	

Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Bueno (2003)

Table 6. Sward surface height (cm) of Mombaça grass in the pre-grazing condition for the 95 and 100% light interception treatments throughout the year.

	Sward light interception (%)		
Season	95	100	Mean
Spring	86.7	109.8	98.3 B
	(3.05)	(3.05)	(2.16)
Summer	86.9	110.4	98.7 B
	(3.05)	(3.05)	(2.16)
Autumn	92.2	116.9	104.6 A
	(3.05)	(3.05)	(2.16)
Winter	88.9	125.0	107.0 A
	(3.05)	(3.31)	(2.16)
Mean	88.7 b	115.5 a	102.2
	(1.53)	(1.56)	

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Carnevalli (2003)

Table 7. Sward surface height (cm) of Mombaça grass in the post-grazing condition for the 95 and 100% light interception treatments throughout the year.

	Sward light interception (%)		
Residue (cm)	95	100	Mean
	Spring		
30	33.4 Ba	33.8 Ba	33.6 B
50	48.4 Aa	50.6 Aa	49.5 A
Mean	40.9 a	42.2 a	41.6 C’
	Summer		
30	35.2 Bb	42.2 Ba	38.7 B
50	50.1 Aa	53.5 Aa	51.8 A
Mean	42.7 b	47.9 a	45.3 B’
	Autumn		
30	33.2 Bb	41.3 Ba	37.2 B
50	51.1 Aa	54.7 Aa	52.9 A
Mean	42.1 b	48.0 a	45.1 B’
	Winter		
30	33.0 Bb	50.7 Ba	41.9 B
50	50.4 Ab	59.0 Aa	54.7 A
Mean	41.7 b	54.9 a	48.3 A’

Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Means for season of the year followed by the same upper case letter with (‘) are not different (P>0.10)
Source: Carnevalli (2003)

Table 8. Herbage losses (kg DM/ha) during grazing of Mombaça grass pasture submitted to grazing either at 95 or 100% sward light interception (January 2001 to February 2002).

	Sward light interception (%)		
Residue (cm)	95	100	Mean
30	3120 Bb	5810 Aa	4470
	(778)	(778)	(550)
50	5000 Aa	5900 Aa	5450
	(778)	(778)	(550)
Mean	4060 b	5860 a	4960
	(550)	(550)	

Numbers between parentheses correspond to standard error of the mean.
Means followed by the same upper case letter in columns are not different (P>0.10).
Means followed by the same lower case letter in lines are not different (P>0.10).
Source: Carnevalli (2003)

Table 9. Herbage production (kg DM/ha) of Marandu grass pasture submitted to grazing either at 95 or 100% sward light interception (February to May 2004).

Residue (cm)	Sward light interception (%)		Mean
	95	100	
10	2480 (100)	1970 (79.4)	2230 (89.9)
15	1500 (60.5)	1870 (75.4)	1690 (68.1)
Mean	1990 (80.2)	1920 (77.4)	

Numbers between parentheses correspond to relative values (%) of dry matter production.
Source: GEPF (2004)

Table 10. Morphological composition (%) of the pre-grazing herbage mass of Marandu grass pasture submitted to grazing either at 95 or 100% sward light interception (February to May 2004).

Residue (cm)	Sward light interceptiom (%)		
	95	100	
	Leaf (%)		Mean
10	80.4	73.5	77,0
15	79.8	74.2	77,0
Mean	80.1	73.9	
	Stem (%)		Mean
10	11.7	20.9	16.3
15	15.0	20.8	17.9
Mean	13.4	20.9	
	Dead material (%)		Mean
10	3.8	5.0	4.4
15	4.1	4.4	4.3
Mean	4.0	4.7	

Source: GEPF (2004)

Table 11. Sward surface height (cm) of Marandu grass in the pre-grazing condition for the 95 and 100% light interception treatments (February to May 2004).

Residue (cm)	Sward light interception (%)		Mean
	95	100	
10	21.9	28.8	25.4
15	22.4	27.3	24.9
Mean	22.2	28.1	

Source: GEPF (2004)

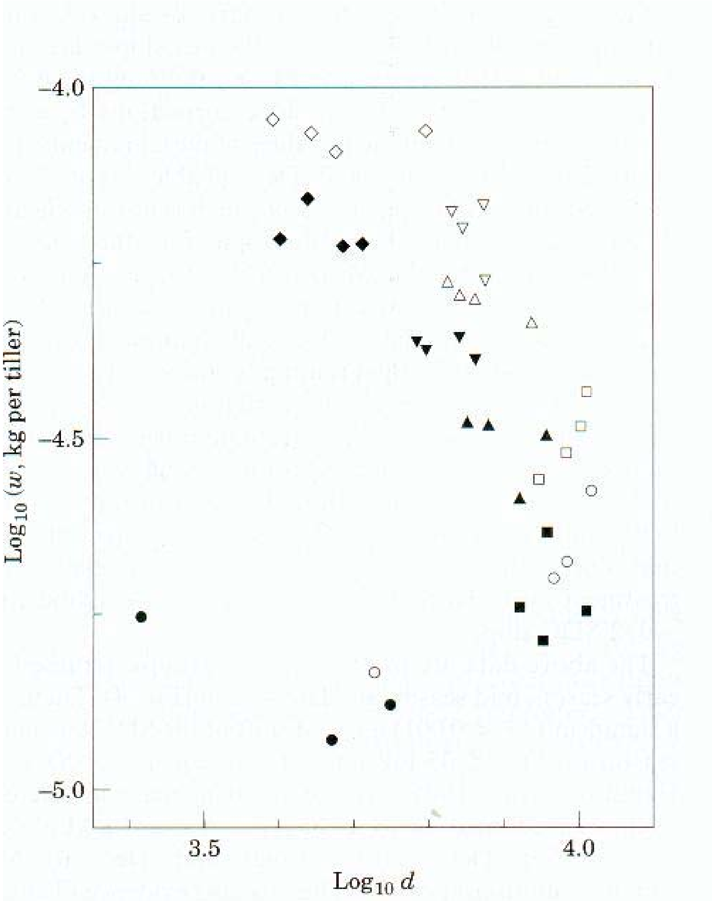

Figure 1. Relationship between tiller size and density in glasshouse swards of perennial ryegrass (from Matthew *et al.,* 1995).

Both tiller size (kg/tiller) and density (tillers/m^2) are expressed as Log_{10}. Symbols represent cutting heights of 2cm (●), 4cm (■), 8cm (▲), 12cm (▼) and 16cm (◆); closed symbols October harvest, open symbols November harvest (Southern hemisphere). Swards were sown in May and clipped twice weekly to the designated height from June onwards. Note that the severely defoliated sward (20mm) takes time to adjust to the general size/density relationship.

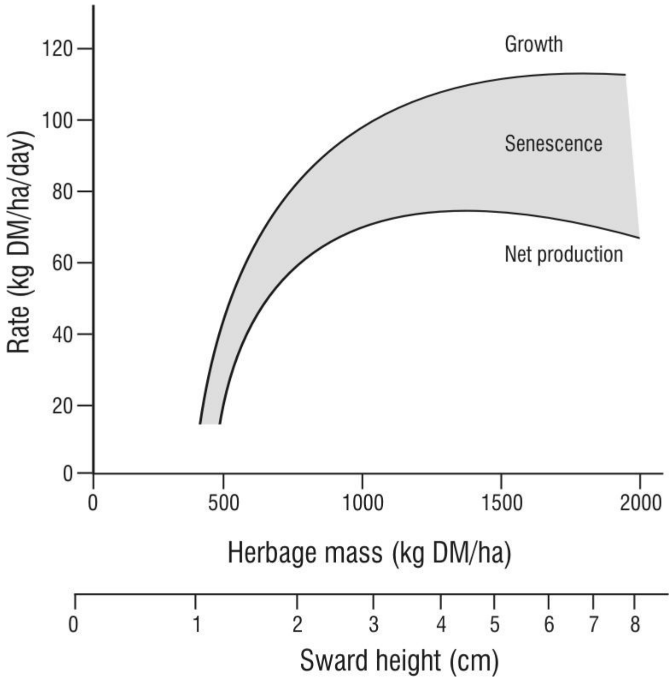

Figure 2. Relationship between sward conditions and herbage production in perennial ryegrass/white clover swards (from Hodgson, 1990).

Net herbage production (kg DM/ha/day) is the balance between the growth of new plant tissue and the loss of mature tissue to senescence and decay, and shows little change between swards of 3cm (1000kg DM/ha) and 8cm (2000 kg DM/ha). These results relate to continuously stocked swards, but predicted results for rotationally stocked swards are similar (Parsons *et al.,* 1988).

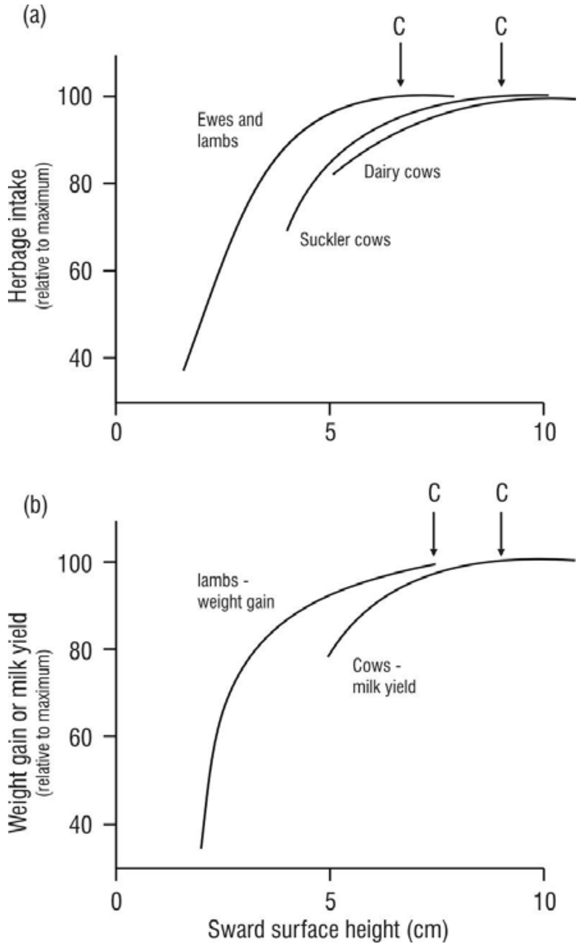

Figure 3. Relationship between sward surface height (cm) and herbage intake or animal performance (both expressed relative to maximum values) in grazing cattle and sheep (from Hodgson and Brookes, 1999).

Point C represents the attainment of maximum performance in each case. Note the consistent difference between sheep and cattle in sensitivity to short swards. These results relate to continuously stocked swards, but results are similar for rotational stocking management when intake and performance are related to post-grazing residues (Hodgson, 1990).

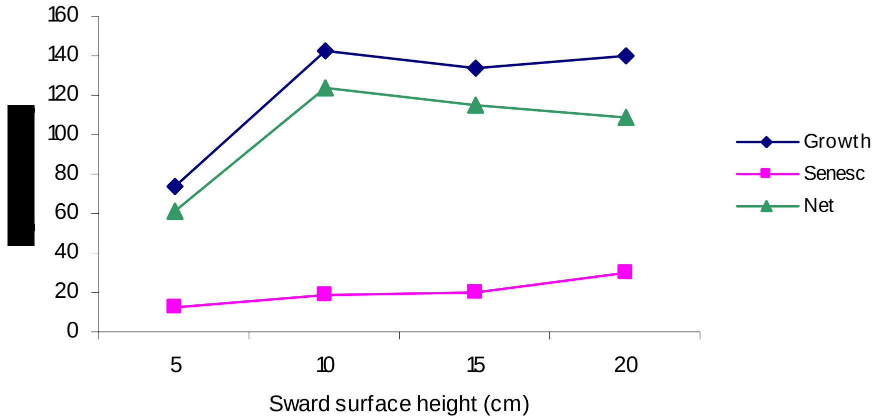

Figure 4. Relationship between sward surface height (cm) and herbage production in cultivars of *Cynodon* under continuous stocking management (from Pinto *et al.*, 2001a,b).

Results are means for three *Cynodon* cultivars in the period Dec-Feb.

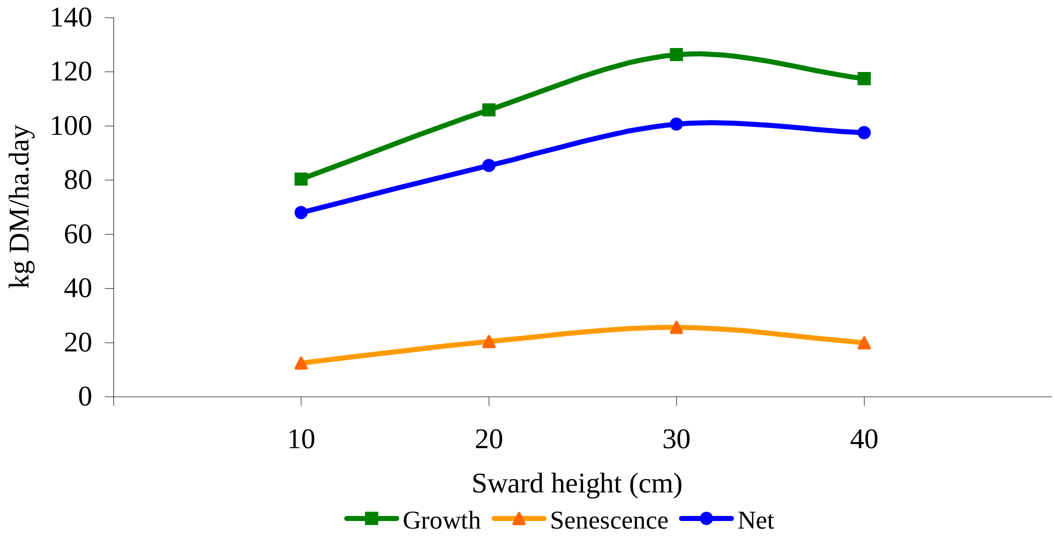

Figura 5. Relationship between sward surface height (cm) and herbage production in *Brachiaria brizantha* cv. Marandu under continuous stocking management during summer (Jan-Mar) (from Sbrissia, 2004).

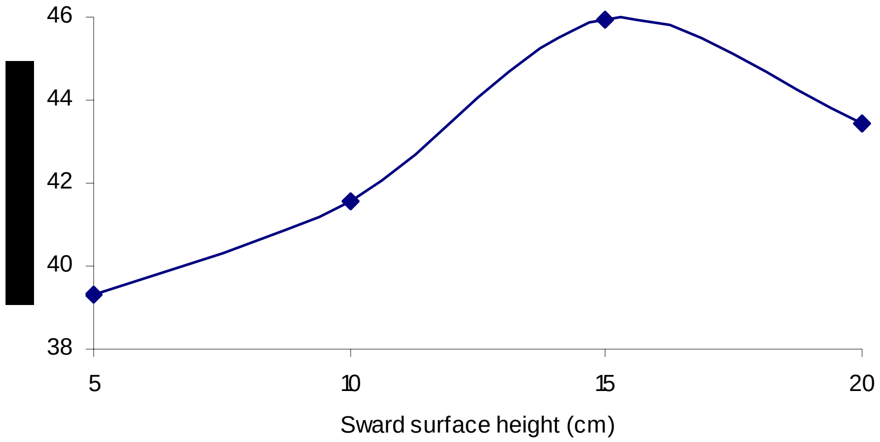

Figure 6. Relationship between sward surface height (cm) in continuously stocked paddocks of *Cynodon* spp. and the live weight gain (g/day) of grazing lambs (from Carnevalli *et al.,* 2000; 2001 a,b).

The results shown are means for three cultivars of *Cynodon*, with animal numbers adjusted to maintain the specified sward heights.

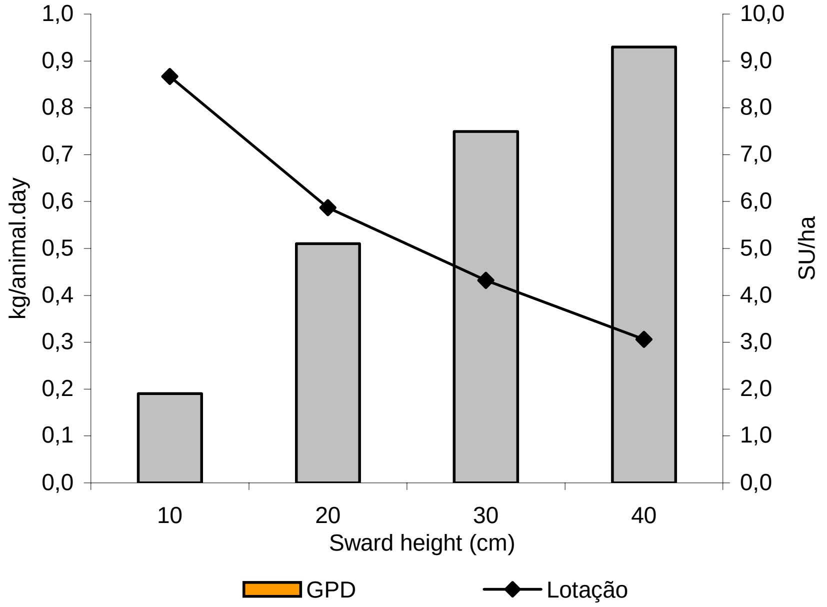

Figure 7. Relationship between sward surface height (cm) in continuously stocked paddocks of *Brachiaria brizantha* cv. Marandu, live weight gain (kg/day) and stocking rate of grazing cattle during summer (Dec-Mar) (from Andrade, 2003).

Stocking rate values were calculated as the number of stock units (equivalent to an adult animal weighing 450 kg) per unit area (ha) necessary to maintain the specified sward heights.

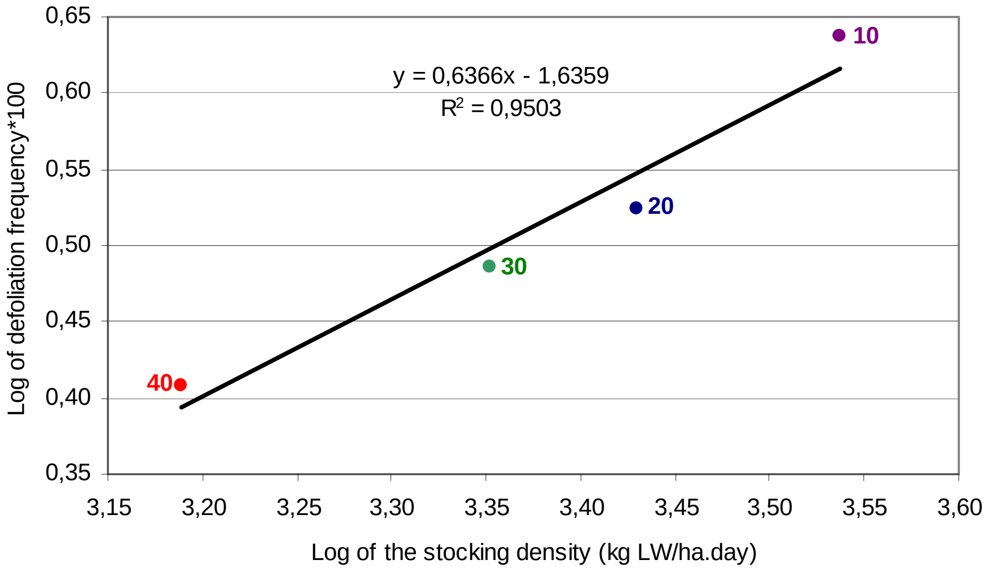

Figure 8. Relationship between stocking density (kg LW/ha.day) and leaf defoliation frequency in continuously stocked paddocks of *Brachiaria brizantha* cv. Marandu grazed by cattle (from Gonçalves, 2002).

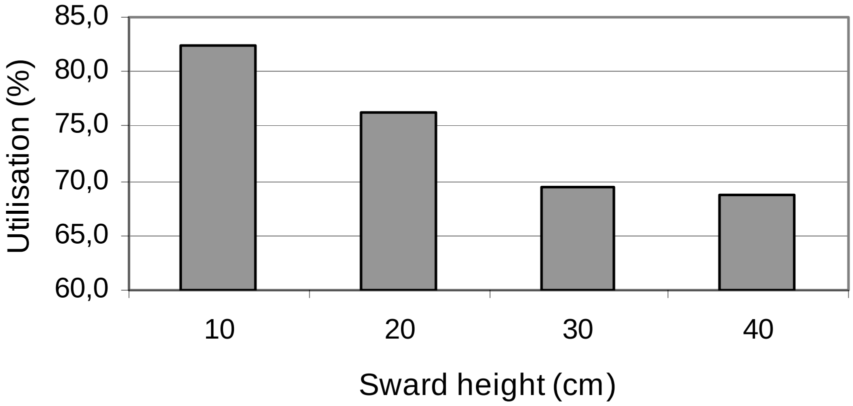

Figure 9. Relationship between utilisation efficiency (%) and sward surface height in continuously stocked paddocks of *Brachiaria brizantha* cv. Marandu (from Gonçalves, 2002).

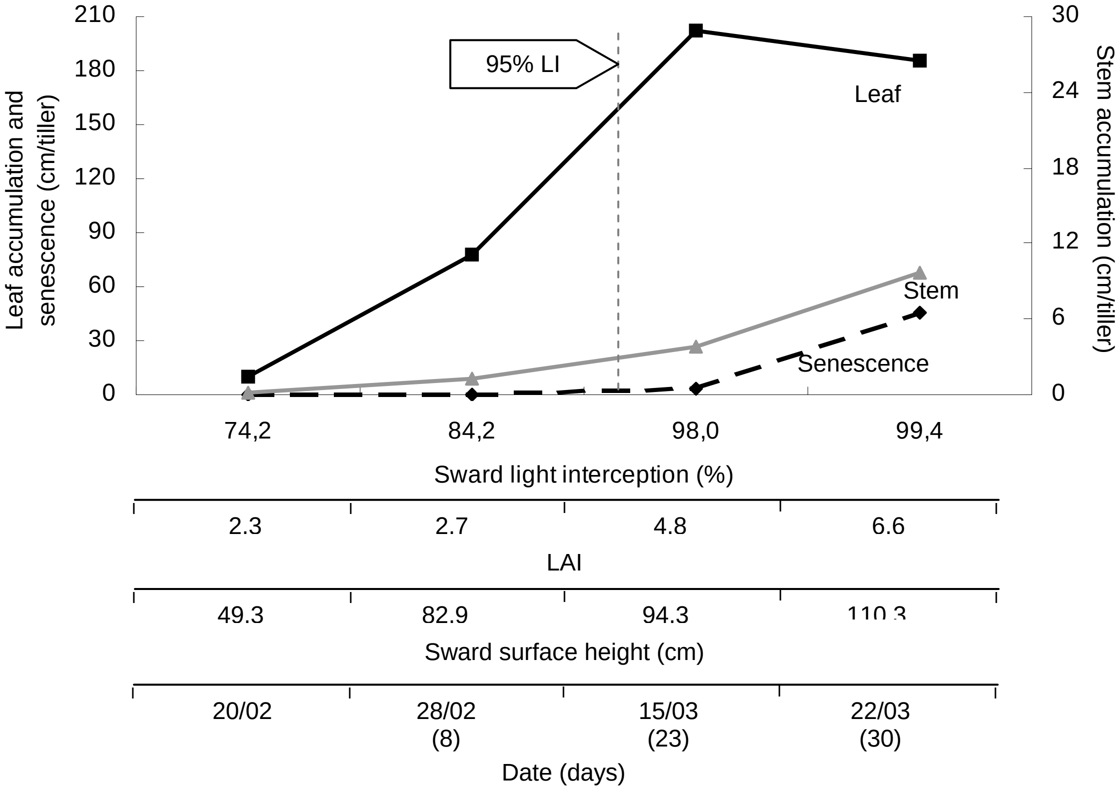

Figure 10. Dynamics of herbage accumulation during regrowth of Mombaça grass grazed at 100% sward light interception and post-grazing residue of 50 cm (from Carnevalli, 2003).

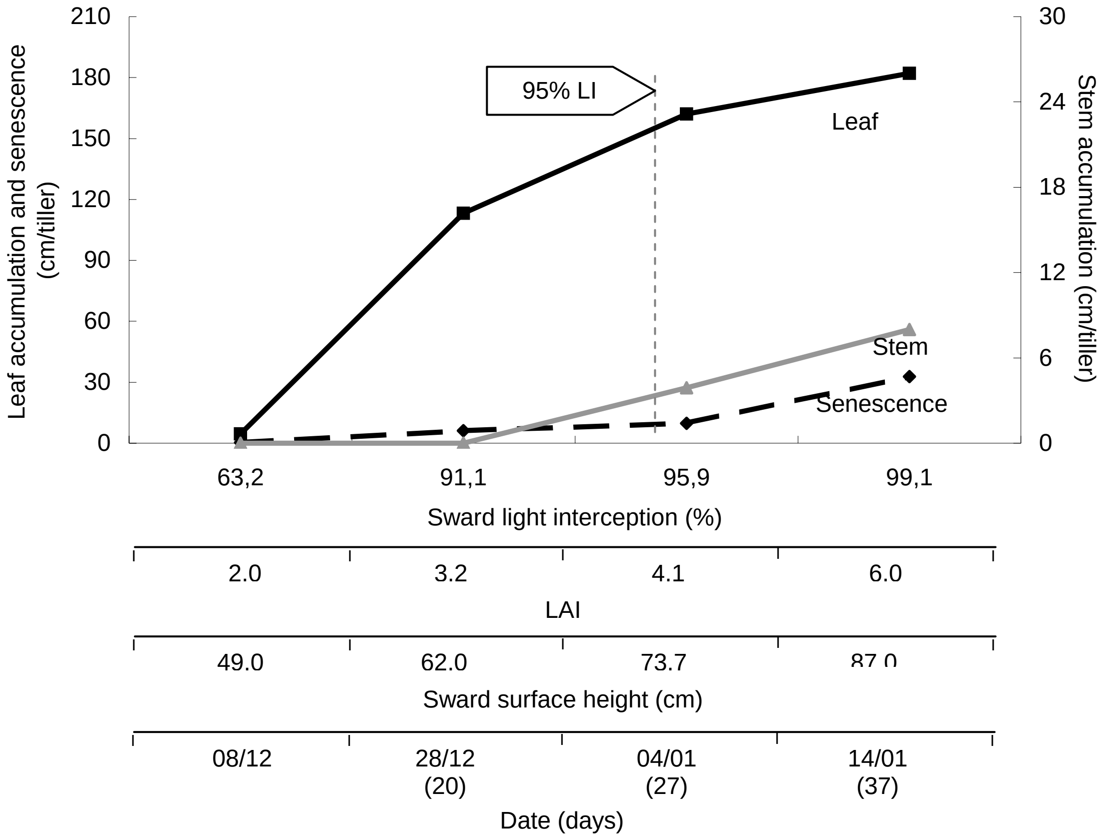

Figure 11. Dynamics of herbage accumulation during regrowth of Tanzânia grass grazed at 100% sward light interception and post-grazing residue of 50 cm (from Barbosa, 2004).

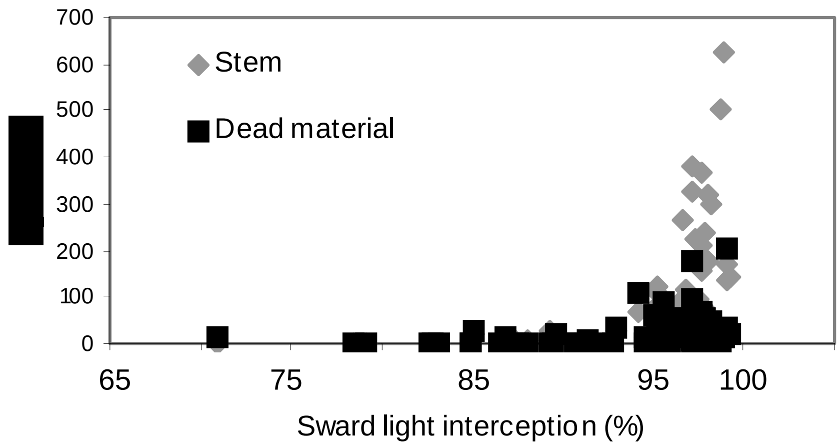

Figure 12. Accumulation of stem and dead material during regrowth of *Panicum maximum* cultivars (Tobiatã, Tanzânia, Mombaça, Massai e Atlas) submitted to cutting regimes (Moreno, 2004).

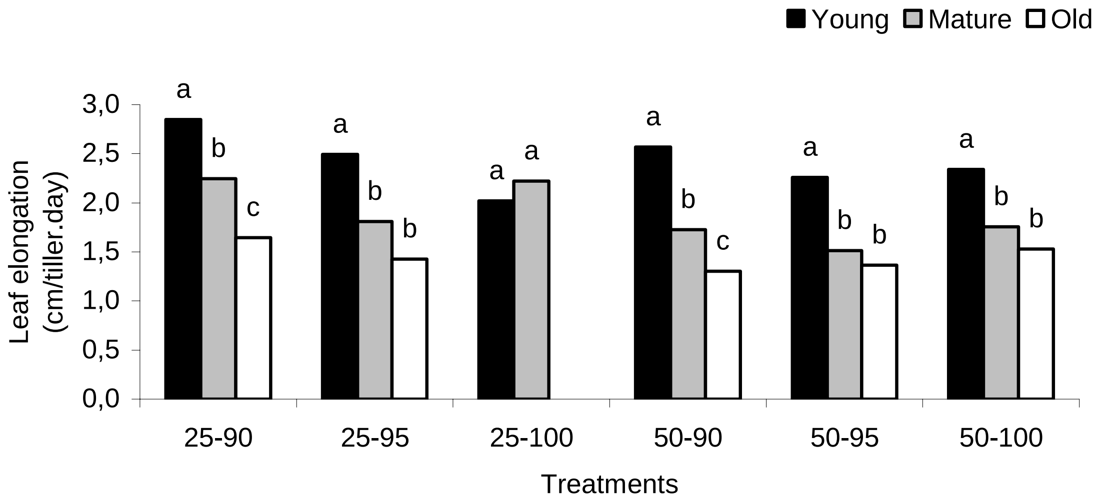

Figure 13. Leaf elongation rate (cm/tiller.day) in tillers of Tanzânia of varying ages (from Barbosa, 2004).

Means followed by the same letter within treatment classes are not different (P>0.10).

Young = tillers less than 2 months old; Mature = tillers between 2 and 4 months of age; Old = tillers more than 4 months old.

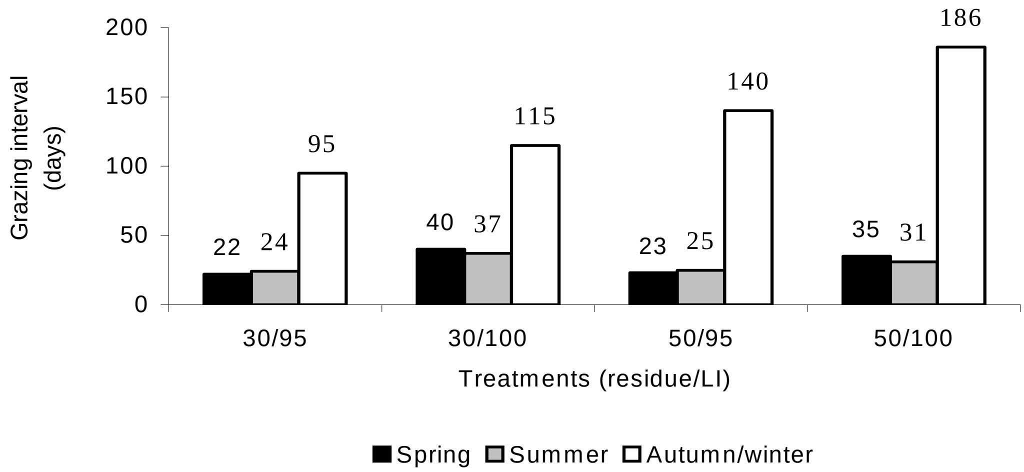

Figure 14. Mean grazing interval for Mombaça grass grazed at either 95 or 100% sward light interception and post-grazing residues of 30 and 50 cm (from Carnevalli, 2003).

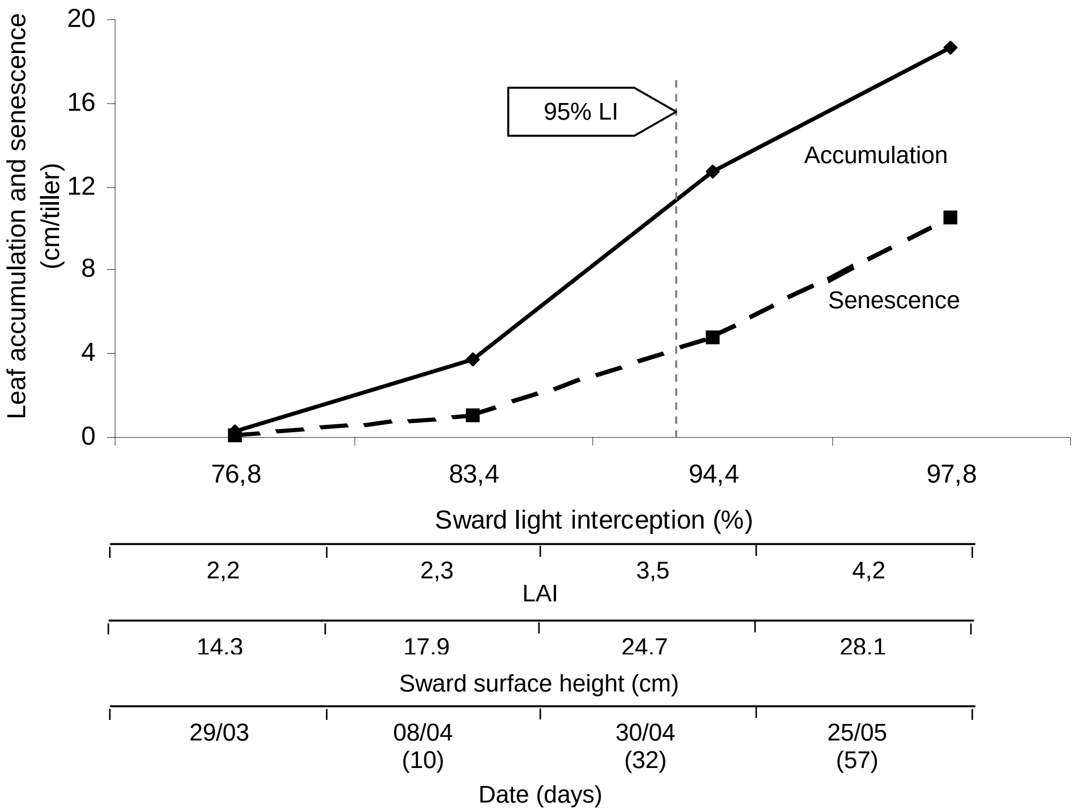

Figure 15. Dynamics of herbage accumulation during regrowth of Marandu grass grazed at 100% sward light interception and post-grazing residue of 15 cm (GEPF, 2004).