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MITIGATING THE NUTRITIONAL LIMITATIONS TO ANIMAL PRODUCTION FROM TROPICAL PASTURES: A REVIEW

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ABSTRACT: Pasture represents the cheapest, most abundant and available feed resource for ruminant animals in the tropics. However, because of high variability in chemical composition and sward morphology due to seasonality, species/ pasture types, environment and management factors which resulted in low intake and inefficient utilization, tropical pastures are usually insufficient, as a sole feed to sustain high levels of production. On the other hand, the inability of farmers to exploit the growth advantage and high dry matter produced by tropical pasture species by adopting and using the available technologies have contributed significantly to the low productivity from tropical pastures. It is an accepted fact that optimizing herbage dry matter intake at pasture is the single most important factor limiting production from tropical pastures. Cognizant of this limitation researchers have endeavored to find solutions to optimize herbage intake and improve utilization efficiency while exploiting the proven advantages of tropical pastures. To this effect, several strategies have been successfully identified inclusive of; preferred grazing, optimizing carrying capacity and stocking rate, mixed specie grazing, semi and or zero grazing, improving sward state to enhance grazing efficiency, concentrate supplementation, grass/legume pasture association, forage conservation and synchronizing animal type/breed with the available feed resources. Importantly, the success of any tropical pasture-based production systems is heavily dependent on optimum management and integration of several of these strategies as part of their production practice. The inability of producers to make informed and timely decision regarding the nutritive value and sward characteristics prior to grazing has been cited as additional constraints. This review aims to examine the distinct characteristics of tropical pasture species and their effects on animal production, in addition to highlighting and discussing management strategies to offset likely feeding limitations and improve the utilization and grazing efficiency of tropical pastures.

Keywords: nutritive value, tropical pastures, animal production, utilization efficiency

Introduction

Ruminant production systems have, historically, contributed significantly to the consumption of animal protein as well as to the economies of tropical developing countries. The current instability in grain markets and the attendant spiraling cost of concentrated feeds suggest a dire need for greater reliance on available feed recourses, particularly in non-grain producing countries. Freshly grazed or conserved forages represent approximately 75% of the diet consumed by most domestic ruminants (Chesson, 2000). In the tropical regions, grazed pastures are the most abundant and economical feed resource available to the ruminant farmer (Soder et al., 2009). This underscores the importance of tropical grazed pastures towards improving the competitiveness and production of animal protein for human consumption, hence the significance of optimally exploiting this resource. Miller et al. (2003) reported that feed including imported concentrate represents approximately 40% of the variable cost to produce milk on Jamaican farms. It is only logical to think that improving the contribution of tropical pastures to milk production will significantly enhance the competitiveness of the tropical pasture-based production systems. To this effect, Miller et al. (2003) further suggested that pasture can be produced at 1/30th (dry matter equivalent) the cost of concentrate feed. Dillon et al. (2006) showed a strong relationship (R^2 = 0.78) between the proportion of grazed pasture in the diet of dairy cows and the cost of milk production from data obtained from both temperate and tropical countries. It is interesting to note that Australia and New Zealand –two countries which employ predominantly year-round grazing systems– enjoyed the lowest cost of production, rendering them more competitive than the European Union and North America, countries in which animals are confined for substantial periods of the year and offered conserved fodder in conjunction with high levels of concentrate feeds. The relationship shows that for every 10% increase in grazed grass in the dairy-cow diet, cost per litre of milk declines by 2.5 cents. It becomes clear that optimizing intake and efficiency of utilization must be the principal objective of tropical pasture-based production systems to sustainably address the ensuing challenge of efficiently and economically feeding ruminant animals.

Pasture quality has long been regarded as a function of intake (Poppi et al., 2000) and the level of production obtained. Many authors including, Allen (1996) studied and reviewed (Decruyenaere et al., 2009) the factors affecting these processes. Probably the most important feature of tropical pasture species is the tremendous growth potential and hence potential carrying capacity (Jennings, 2002).

A major characteristic of tropical pastures is a marked seasonal fluctuation in energy, nutritive value and quantity, thus restricting nutrient intake for large parts of the year (Hughes et al., 2012). This presents farmers with a major challenge to provide pasture of adequate quality and quantity on a year round basis. This has frequently resulted in seasonal fluctuations in production; as weight gained during the wet season is lost during the drier months of the year (Paterson et al., 1992). In addition to seasonal variations, maturity is arguably the single factor with the largest influence on pasture quality. Advancement in pasture maturity is associated with increased proportion of structural carbohydrates and reduced crude protein concentration (Enoh et al., 2005) which negatively affects digestibility and intake (Allen, 1996). Therefore, efficient utilization of tropical pastures requires the adoption of a more holistic production model capable of exploiting the growth potential and yield advantage of tropical pasture species and maximizing herbage intake while sustaining a greater quantity of higher-quality herbage throughout the year. On the other hand, the physical state of the pasture offered for grazing must be considered. It has been suggested that the state of the sward presented for grazing may have a greater influence on intake than nutritive value *per se.* (da Silveira et al., 2013; de Carvalho et al., 2013; da Silva et al., 2013). This provides a possible justification for the low levels of milk production (< 15L/day/cow) of milk production on Jamaican dairy farms despite relatively high nutrient value (IVOMD, ME and CP above 600 g/kg, 8.5 MJ/kg DM and >140 g/kg, respectively) of grazable pasture herbage (Hughes et al., 2012). The challenge, therefore, now is how to optimize sward state to facilitate this. The situation is further compounded by the absence of instantaneous diagnostic tools to determine nutritive profile and sward state. The existing methods are dependent on invasive methods and laboratory assays that are very costly to undertake and time consuming. This suggests a critical need for accurate, easy-to-use and affordable techniques which provide results instantaneous to assist farmers in their day-to-day management. The objective of this review is to examine the distinct characteristics of tropical pasture species and their effects on animal production; in addition to highlighting and discussing management strategies to offset likely feeding limitations and improve the utilization efficiency of tropical pastures.

Characterizing Tropical Pastures

Photosynthetic efficiency

There are many biological characteristics which distinguish tropical and temperate pastures species. However, the C_4 (four-carbon organic acid) photosynthetic pathway of tropical grasses stands out as perhaps one of the most distinctive features (Figure 2). This bio-chemical characteristic provides for more efficient use of sunlight, water and nutrients, but leads to a high content of structural carbohydrates which can negatively impacts intake and digestibility (Jung and Allen, 1995). The higher rate of photosynthesis and the increased radiation intensity in the tropics enables tropical pasture species to enjoy significantly higher growth rate and productivity compared to temperate grasses (Enoh et al., 2005).

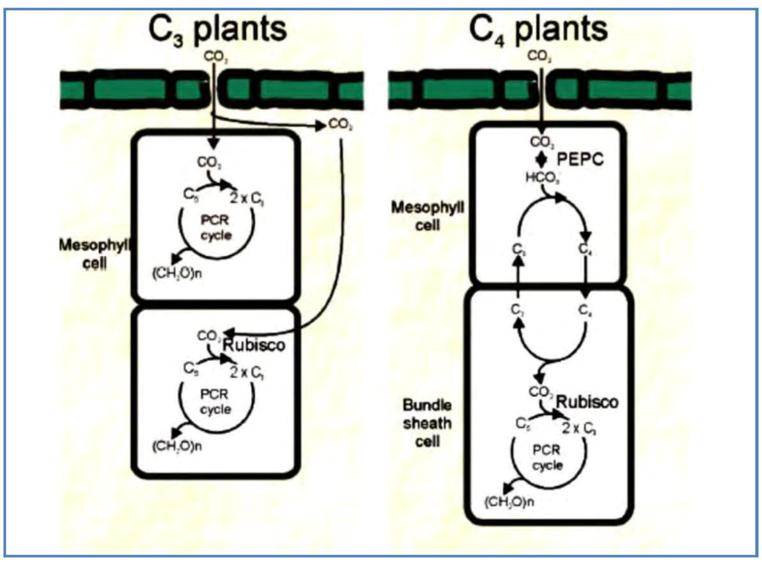

Figure 3. Schematic diagram of C3 and C4 photosynthetic pathways (Lara and Andreo, 2011).

Characteristics of Tropical Swards

Tropical pastures have been recognized by their high potential for dry matter (DM) production but labeled as producing herbage of low nutritive and feeding value (Allen, 1996). This has generated the widespread mis-perception that tropical pastures are not capable of supporting medium to high levels of animal performance and productivity (da Silva et al., 2009). Temperate pasture species can be approximately 13% more digestible than tropical grasses (Minson and M^c^Leod, 1970). The high level of indigestible fibre can contribute to lower daily intake of feed and consequently lowers animal production (Stobbs, 1974).

Sward height, bulk density, spatial distribution, proportion pasture species and leaf-stem (Sollenberger and Burns, 2001), total or green tissue herbage yield (Boval et al., 2007) are some sward characteristics influencing grazing behavior. Bite mass is regarded as the variable most sensitive to these pasture characteristics (Boval et al., 2007). There is a close relationship between forage distribution and availability (Allison, 1985), leaf proportion (Stobbs, 1975[a]), green leaf mass (Boval et al., 2007), sward density, canopy height (Boval et al., 2007) and dry matter intake under rotational grazing. Tropical swards exhibit distinct vertical heterogeneity in both chemical composition and physical sward state (Sollenberger and Burns, 2001). Overall, the density of tropical swards is lower than that of temperate swards thus affecting the potential bite size for prehension (Sollenberger and Burns, 2001). Green leaf proportion and yield of the upper sward canopy are usually are greater importance with tropical grasses. However in temperate pastures, bite weight has a closer associated with sward height (Sollenberger and Burns, 2001). This highlights the importance of developing methods to determine the optimum sward condition necessary to achieve maximum herbage intake in tropical pastures. The vertical and horizontal heterogeneity of tropical swards provides ample justification for the lower level of intake observed from tropical pastures. Consequently, biting rate and frequency are reduced because of additional time spent selecting leaf over stem and dead material (Sollenberger and Burns, 2001) and moving from one preferred location to another. The animal partly compensate for decreased biting rate by increasing grazing time (Decruyenaere *et al.,* 2009) resulting in more energy being spent during the grazing process.

Factors Affecting the Nutritive Value of Tropical Pastures

Plant Factors

Genus

Grass genus has been found to have significant effects on nutritive value of tropical pasture species (Filho et al., 2000; Arthington & Brown, 2005). In Brazil, Filho et al., (2000) studied the chemical composition and *in-vitro* organic matter digestibility kinetics of *Cynodon* spp. *(dactylon and plectostachyus)*, *Brachiaria humidicola* and *Pennisetum purpureum* harvested at 10cm above ground after 100 days re-growth. Crude protein concentration was lower, and organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) higher in the *Cynodon* genera than in *Brachiaria* and *Pennisetum* genera. The *Pennisetum* genus recorded the highest apparent organic matter digestibility while that of the other genera was comparable.

Differences between genera were also highlighted by Arthington and Brown (2005). From their study, they found that CP concentration and IVOMD were higher, while NDF, ADF and ADL concentrations were lower for *Paspalum* versus *Hemarthria* genus.

Species

It is important to note that grasses, even of the same species, grown in the same environment and exposed to the same management show marked differences in nutrient profile. Mislevy and Martin (1998) compared the crude protein (CP) content of *Cynodon nlemfuensis* (African Star grass) and *Cynodon dactylon* (Bermuda grass) over three consecutive years, at similar stages of growth, and found crude protein content to be lower in *nlemfuensis* species. Similarly, Arthington and Brown (2005) found CP was lower for African Star grass compared to Bermuda grass at four weeks re-growth over two years. However, Bermuda grass (53.9%) had a superior *in-vitro* organic matter digestibility (IVOMD) to Star grass (48.2%).

Grass versus legume

The proportions of structural carbohydrates are significantly lower in tropical leguminous forages than grasses at comparable stages of maturity. Relative to grasses, legumes contain a higher proportion of crude protein and are more digestible (Mtui et al., 2009). For example, Ravhuhali et al. (2010) showed that buffel grass *(Pennisetum ciliare)* hay was 15.5% less digestible than the average of hay from four cow pea *(Vigna unguiculata)* varieties. The report of Mtui et al. (2009) is consistent with the generally accepted knowledge of the superiority of legumes compared to pasture grasses with reference to nutritive value. Although legume forages are of higher nutritive value than grasses, their potential contribution to animal production in the tropics is underexploited (Tobia et al., 2008) primarily because of the difficulty in managing grass/legume pasture associations and their susceptibility to stand loss and slow recovery under poor management and or unfavorable weather conditions.

Management Factors

Harvesting (cutting or grazing) Height

Vertical heterogeneity in the proportion and distribution of leaf and stem fractions affects chemical composition and digestibility of herbage from different canopy layers (Newman *et al.,* 2003). The lower half of the grass sward is generally considered to contain more fiber and lignin that would be less digestible than the upper portion. Hughes et al. (2012) showed that whole grass samples contained on average 10%, higher NDF, ADF and lignin and 36%, 27% and 26% lower crude protein, metabolizable energy, respectively, and are 26% less digestibility, than samples harvested by hand plucking to simulate grazing.

Similarly, Newman et al. (2003) showed that the leaf percentage, leaf and stem crude protein (129 – 123 g/kg and 50 – 40 g/kg leaf and stem CP, respectively, and *in-vitro* organic matter digestibility were greater in the upper 25% strata of a Limpograss (*Hemarthria* altissima) sward canopy compared to the next lower 50% of the canopy. Leaf CP concentration was as much as three times greater than stem CP.

Stage of Maturity/Harvesting Frequency

The major changes occurring in pasture species are those that accompany maturation, illustrated schematically in Figure 2. As pasture matures, the fiber fraction increases resulting in higher levels of lignification, lower protein content (Enoh et al., 2005) and non-structural carbohydrates. Brown and Mislevy (1988) suggested that on average, crude protein content of tropical forages decreases below 9% after six weeks re-growth. Because of the relationship between grass maturity, quality and chemical composition, management regimes with more frequent harvests that remove forage at less mature growth stages, often result in improved forage quality than regimes with less frequent harvesting (Sheaffer et al., 1998). However, increased harvesting frequency can be associated with lower biomass yield, compromised root system that impacts plant recovery from defoliation and pasture persistence under grazing. Published data generally show that there is a progressive decline in digestibility and crude protein and a corresponding increase in NDF, ADF (Arthington and Brown, 2005) and lignin (Laredo and Minson, 1973) as grasses transition from an immature to a more mature vegetative state.

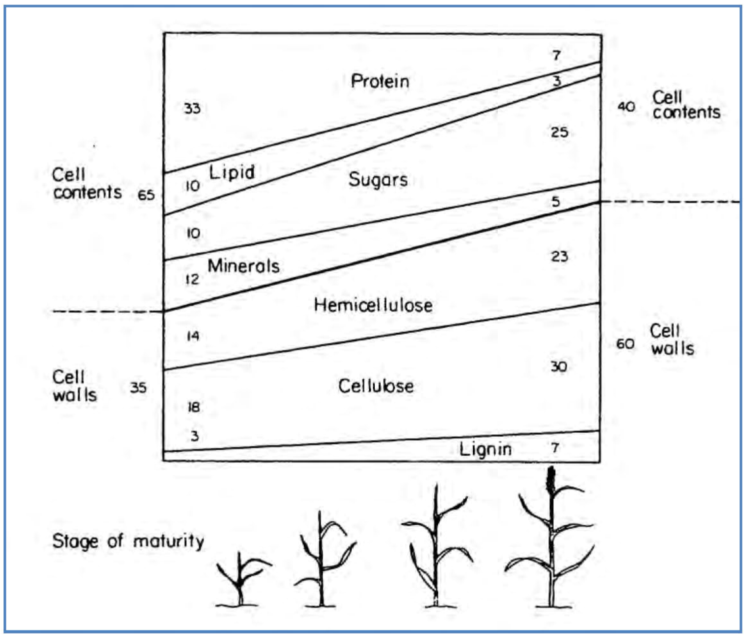

Figure 2. Schematic representation of the changes in the chemical composition of grasses which accompany advancing maturity (Osbourn, 1980).

Leaf-to-Stem Ratio

Leaf/stem ratio is primarily associated with maturity of the grass and harvest height and contributes significantly towards determining diet selection, forage intake and digestibility (Ramírez et al., 2008) because leaves contain a greater proportion of digestible nutrients and metabolizable energy than stems. The concentrations of cell wall fractions (NDF, ADF and lignin) of tropical grasses are usually lower and crude protein usually higher in leaf than in stem (Hare et al., 2009) which influences intake and production response. Ruminant animals are primarily "leaf seaker" - prefering plants with higher proportion of green leaf. Laredo and Minson (1973) separated leaf and stem of similar digestibility from five grasses and found that intake of leaf was 46% higher than stem when fed to sheep. Under grazing conditions, the uppermost leaves are consumed first by cattle, followed by leaf-bearing stems while leafless stems are only grazed when herbage availability is severely limited (Stobbs, 1975). As a result, the nutritive value of the herbage consumed is higher than that of the total herbage on offer to the animal (Sollenberger and Burns, 2001) when ample herbage is supplied.

Nitrogen Fertilizer Application

The seminal work on response to fertilizer N by tropical pastures was done by Vicente-Chandler *et al*., (1959), who examined the effect of N fertilization and cutting frequency on yield and chemical composition. Since then, numerous reports have also shown that crude protein content generally increases with increasing nitrogen (N) fertilization. Applying fertilizer to pasture not only improves quality but also increases the biomass yield of the pasture (Johnson et al., 2001). However, there seems to be a threshold level where incremental gains in both quality and biomass yield cease. In terms of biomass yield, Vicente Chandler et al. (1964) showed that increases in fertilizer N application resulted in a linear biomass yield response up to application of 450 kg N/ha. Beyond 450kg N/ha, the response in herbage mass become asymptotic. Adeli et al. (2005) reported similar response to increased fertilizer N by biomass yield and CP concentration. Crude protein concentration of Bermuda grass *(Cynodon dactylon)* (96 - 184 g/kg) and Johnson grass (*Sorghum halepense)* (103 – 156 g/kg) increased with incremental levels of fertilizer N up to an application rate of 450 kg N/ha., where a peak was realized. A reduction in both crude protein and biomass yield was observed at higher rates. Johnson et al. (2001) and Adeli et al. (2005) indicated a positive response in *in-vitro* organic matter digestibility and *in-vitro* true digestibility, respectively, with increasing N fertilizer application. Generally, there are variations in the response of the structural constituents of pasture forages to increased N fertilization.

Stocking Rate and Degree of Defoliation

Stocking rate is normally expressed as number of animals per hectare for a given time period. Grazing management that includes increasing stocking rate usually result in an improvement in pasture quality. Many researchers including Mayne et al. (1987) showed that higher grazing pressure and grazing severity can significantly increase the organic matter digestibility of pasture swards for the following grazing cycle. This is mainly due to a decline of post-grazing residual mass and hence a greater proportion of green herbage and less senescent and fibrous material associated with greater removal of pasture herbage and subsequent emergence of higher proportion of young tillers at the onset of each grazing cycle at higher stocking rates compared to lower stocking rates (Fales et al., 1995). However, as the quantity of pasture allowance increases, the amount of refused pasture increases and this will lead to a decrease in herbage quality in subsequent grazing rotations (M^{c}Evoy et al., 2008). For this reason, mowing rotationally grazed tropical pastures at least once annually was recommended by Hughes et al. (2011).

Environmental Factors

The effect of seasonality on pasture production results in limited herbage availability and or poor quality at some periods of the year, when ingested herbage falls short in satisfying the nutritional requirements of the ruminant animal (Grimaud et al., 2005). Generally, the dry season is the most challenging period in providing pastures of adequate quantity and quality. During this period tropical pastures tend to have low protein concentration (Mtui et al., 2009), digestibility and metabolizable energy (Hughes et al., 2012), and high structural carbohydrate contents (Hughes et al., 2011), in addition to a shortfall in supply. This is due to the prevailing climatic conditions where they grow, particularly the high degree of solar radiation, resulting in rapid lignifications and a reduction in intake and digestibility. The seasonal fluctuations in feed supply and pasture quality experienced in the tropics results in a seasonal pattern of live weight gain associated with the wet season and live weight loss during the dry season (Poppi and M^{c}Lennan, 1995), principally due to a shortfall in pasture supply and sharp decline in nutrient characteristics of pastures in the dry season.

Quality and Nutritional Value of Tropical Pastures

Forage quality is an encompassing attribute that includes nutritive value/chemical composition, intake and animal performance. The nutritional contribution of forages to the diet can be assessed in several ways. The most utilized methods are the proximate analysis of Van Soest (1967), modified to utilize the NDF and ADF determinations (Cheeke, 1999). Laboratory analysis of ruminant feeds generally involves determining the dry matter, organic matter, structural carbohydrate (NDF, ADF and ADL), soluble carbohydrates and crude protein contents of the feedstuff (France et al., 2000). Van Soest (1967) presented a comprehensive system of feed analysis and a classification of forages fractions based on their nutritional characteristics (Table 1). To date, this system has been used extensively to provide a crude approximation of forage quality.

Table 1. Classification of forage fractions according to nutritive characteristics (Van Soest, 1967).

Class	Fraction	Nutrient Availability	
		Ruminant	Non-ruminant herbivore
Category A (Cellular contents)	Sugars, Soluble carbohydrates,	Complete	Complete
	Starch, Pectin	Complete	High
	Non-protein nitrogen	High	High
	Protein, Lipids	High	High
	Other solubles	High	High
Category B (Cell wall)	Hemicellulose	Partial	Low
	Cellulose	Partial	Low
	Heat-damaged protein	Indigestible	Indigestible
	Lignin	Indigestible	Indigestible

It has been widely accepted that the quantity of forage ingested by the grazing animal and their production response are the most important factors determining its quality (Aregheore, 2007). A review of the factors affecting intake by grazing ruminants is provided in Fisher (2002). Chief among these factors is digestibility. Hence, digestibility is an important factor in determining nutritive value for forages because as digestibility increases, feed intake also increases in response to higher rumen turnover rate (Laredo and Minson, 1975). In addition, the higher the digestibility, the more nutrients (Forejtova et al., 2005) and energy (Lukas et al., 2005) are liberated for use by the animal which will have a positive effect on performance. A summary of available data on chemical composition and digestibility of some tropical pasture species is presented in Table 2. Le Du et al. (1979) suggested that herbage availability significantly influences intake, and digestibility only becomes more important when herbage on offer is considered non-limiting. Leaver (1981) from the UK suggests that such *ad-lib* conditions exist on temperate pasture at a minimum sward height of 9 cm at which point herbage allowance would likely exceed maximum voluntary intake by a factor of 3. Stobbs (1977) in Australia suggested that on tropical pasture *(Panicum maximum)* such*'ad-lib'* conditions would exist when herbage allowance is approximately four times maximum voluntary intake.

Production Response from Tropical Pastures

The spiraling increases in the cost of supplementary concentrate feeds has brought farmers in non-grain producing countries to the reality that over-reliance on concentrate feed and the low response of milk production to concentrate feeding is neither sustainable, economically nor nutritionally justified. This situation will undoubtedly challenge farmers to confront the conventional wisdom that tropical pastures are insufficient to maintain medium to high milk yields (Tamminga and Hof, 2000). However, the results of numerous studies from as early as the 1970's have disproved this theory, giving much hope to tropical ruminant production systems. Argel (2006) estimated that adaptation of improved pasture species in South and Central America has resulted in a 26% and 6% increase in productivity of milk and beef production, respectively. The early work by McDowell et al. (1975) and Martinez et al. (1980) to a large extent have set the standard for milk production from tropical pastures. On intensive managed Pangola grass pasture in Puerto Rico, McDowell et al. (1975) reported unsupplemented daily yields of approximately 11 liters from Holstein cows stocked at 2.5 cows per hectare. Reporting out of Cuba, Martinez et al. (1980) obtained whole-lactation milk yield in excess of 4,120 liters from Holstein cows stocked at 3.6 cows per hectare grazing Coast Cross 1 (*Cynodon* sp.) pasture without recourse to supplementary feed. For animals fed supplementary feeds, the average response was 0.14 L milk/kg concentrate fed indicating that when pasture herbage of good quality is in ample supply the response to supplementation is poor and uneconomical (Martinez et al., 1980). At similar stocking rate, dairy cows grazing well fertilized (350kg N/ha./yr.) *Cynodon dactylon* or *Panicum maximum* pastures, Rivero et al. (1988) reported unsupplemented daily milk yield of 12 – 14 kg over two lactations. Even at higher stocking rates tropical pastures have proved to be more that capable of producing above expected yields. With a stocking rate of five cows per hectare, Jennings (1980) recorded unsupplemented milk yields of 11,050 liters per hectare from irrigated Pangola grass *(Digitaria eriantha)* pastures fertilized with 316kg N/ha./year in six split applications. These results were consistent with Stobbs and Thompson (1975) who suggested that daily milk yields in the order of 7.2 liters is attainable from unsupplemented tropical pastures grazed by Jersey-type cows.

Table 2. Yield, chemical composition and digestibility of some tropical pasture species.

Species	Cultivar	Yield (t. DM/ha.)	Fertilizer (kgN/ha.)	Maturity (days)	Chemical Composition (g/kg)					IVOMD (g/kg)	Source
					DM	CP	NDF	ADF	ADL		
Cynodon				28		110	809	410	63	482	Arthington and Brown, 2005
nlemfuensis		1.6	78	28		148	739	336		546	Johnson et al., 2001
		1.7	447	21		140	652			584	Miller, *et. al.* 2005
				14	240	170	680	360	62	568	Hughes et al., 2012
Brachiaria	Basilisk	11.32	176			86	637	347			Hare *et. al.,* 2009
decumbens	""	7.3	125	42		65	784	449	82	521	Norton *et. al.,*1991
				33	22	120	690	350	42	571	Hughes et al., 2012
Digitaria				42	268	70	700		73		Juarez Lagunes *et.al.,1999*
eriantha				45	226	79	724	418	43	632	Tikam, *et al.,*2010
		4.1		42	212	61	650	329			Isuwan, *et al.,*2007
Panicum Maximum	Gaton		80 – 160	105		75 – 117	621	319		692	Pieterse *et. al.,*1997
	Vencidor		80-320	160		36 - 52	609	270		813	"" "" ""
	T58	1.9	0	42	482	55	306**			548*	Sodeinde *et. al.,*2006
	T59	4.8	400	42	655	101	261**			714*	"" "" ""

It must be pointed out that recent studies aiming to establish the production potential of grass-only production systems are very limited which can partly be attributed to the wide-scale acceptance of the necessity for inclusion of concentrate in the diet of ruminants fed tropical pastures, presumably, in an effort to align these production systems with those commonly found in the more developed temperate regions.

Improving dry matter intake and utilization efficiency of tropical pastures

Low dry matter intake and inefficient utilization are the main factors limiting the productive potential of tropical pastures. A review of the literature has further revealed that the inability of producers in the tropics to optimally exploit the benefits of pastures and overcome these limitations is not a result of lack of available information but is more due to their inability and reluctance to adopt and utilize the vast amount of available technologies. Dillon (2006) articulated the fundamental principles surrounding optimizing pasture dry matter intake by the grazing dairy cow –which provides the basis for improving utilization efficiency and enhancing competitiveness of outputs from tropical grazing systems. Maximizing intake and improving utilization efficiency of tropical pastures can be practically achieved by the following strategies.

Grazing Management

Preferred Grazing/"Leader-follower" System

The leader-follower grazing method involves two or more groups of animals with different nutritional requirements grazing a pasture sequentially (Archibald et al., 1975). The first group of animals, usually with the highest nutritional requirement - such as dairy cows in early lactation, is given first access. The other group(s); with lower nutritional requirements than the first, is allowed to graze after moving the first group to a new pasture. This method can be labour intensive and complex but can significantly improve forage utilization and output without compromising sward health and quality (Mayne et al., 1988). Preferential treatment of high-producing British Friesian dairy cows comprising the "leader" group produced up to 9% more milk per day compared to similar high-producing cows in the control group (Mayne et al., 1988). In contrast, Archibald et al. (1975) reported similar milk yield for "leader" and "follower" cows to that of the control groups and hence concluded that the potential benefit of the "leader-follower" system is unlikely to exceed conventional grazing systems. It seems therefore, the sward state and grazing time at first grazing can significantly impact intake by the "leader" group and that the potential benefits of this system will be more apparent if more than one "follower" groups are introduced.

Optimum stocking rate/carrying capacity

A generalized model of the relationship between stocking rate and animal production was described by Mott (1973) [Figure 3]. The model suggest that at low stocking rates individual animal performance is relatively insensitive to increased stocking rate, resulting in large increments in output per hectare. Beyond a critical stocking rate, individual animal performance declines rapidly until a point is reached where output per hectare is also jeopardized. Therefore, the optimal range in stocking rate occurs where attempts are made to match herbage availability with herbage dry matter requirements.

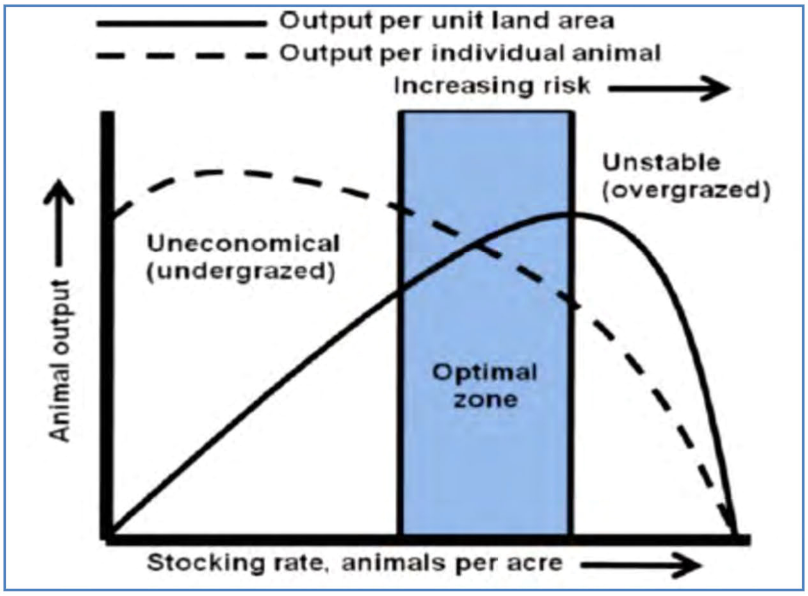

Figure 3. Relationship between output of animal production and stocking rate (Mott., 1973).

Jennings (1992) attributed the low productivity of Jamaican pastures to the inability of farmers to fully exploit the growth potential of tropical pastures by adopting an approach to optimize carrying capacity. Hughes et al., (2011) showed that the typical Jamaican dairy farm employed a stocking density of 0.8 – 3.4 AU/ha. On the background of earlier work done in Puerto Rico, Jennings (1992) outlined a practical approach towards increasing carrying capacities with the application of fertilizer N (Table 3). Dry matter production was predicated on the basis of a response of 30kg DM per kg N fertilizer applied up to 450 kg N/ha. This response, however, was later shown to be very conservative as with the subsequent introduction of Cynodon spp. even higher yield responses have been realized (Miller et al., 2005).

Table 3. Carrying capacities and expected milk yield at different N fertilization levels (Jennings, 1992)

N fertilizer (kg/ha.)	Herbage yield (kg DM/ha./an	No. cows/ha.	Milk production/ha.	
			No supplementation	Supplementation (40% DMI)
0	10,000	2.0	4,925	7,100
56	11,800	2.3	5,850	8,450
112	13,450	2.7	6,780	9,780
170	15,140	3.0	7,400	10,100
225	16,800	3.5	8,620	12,450
336	20,200	3.9	9,850	14,200
450	23,550	4.7	11,700	16,900

Mixed Species Grazing

Mixed species grazing has been shown to enhance forage utilization, which translates into higher output per unit area and reduced cost of production compared to grazing with a single species. Logan and Jennings (1995) compared eight Jamaica Red Poll bulls vs. six Jamaica Red Poll bulls plus 15 weaned lambs rotationally grazing *Brachiaria decumbens* pastures (0.2 ha) at 5 AU/ha. in two experiments. The results indicated an average 37% and 33% higher live-weight gain/ha and pasture utilization, respectively, when pastures were co-grazed by cattle and sheep. These findings were consistent with reports by Nolan and Connolly (1989) and Mendiola-Gonzalez et al. (2007). However, Nolan and Connolly (1989) showed that under single species grazing, 10 – 13% more area was required to produce the same grazing season output as under mixed grazing. Abaye et al. (1993) found that mixed grazing resulted in earlier attainment of target lamb weaning weight and improved lamb performance. However, animal production per hectare was not significantly affected. This was mainly because of decreased forage availability as the grazing season progressed and forage demand by cattle increased. Bennett et al. (1970) reported similarly higher than expected performance of sheep when grazed together with cattle while that of cattle reduced slightly then recovered in spring through compensatory gain. Mixed-species grazing confers competitive advantage to sheep but not necessarily at the expense of cattle. Differences between sheep and cattle in their mechanical ability to be selective offer opportunities for complementary pasture use (Logan and Jennings, 1995). Differences in grazing habits could indicate that cattle are more sensitive to changes in quantity of available graze material and that sheep are more tolerant to grazing the lower sward strata including weeds.

Semi- and/ or Zero-Grazing

Zero-grazing provides a way of improving the efficiency of utilization by eliminating the losses of herbage due to fouling by excreta, trampling and poaching under grazing thereby reducing residual dry-matter accumulation and encouraging greater consumption of the forage on offer. Hood (1962) reported that zero-grazed beef cattle gave 10.1% higher output of live weight gain per hectare over rotationally grazed cattle offered the same forage. The corresponding increase in production of dressed carcass weight per hectare was 13.3%. The quantity of forage rejected by the zero-grazed animals was consistently low, averaging 1.7% of the forage offered. Improved forage utilization is achieved from the zero-grazed system mainly because the animals eat almost the entire plant depending on presentation. This is in contrast to rotational grazing where the animal will give priority to selecting green leaves and will only resort to grazing the more fibrous fraction when herbage availability becomes limited. Consequently, the nutritive value of the diet of the grazing animal is higher than that of the zero-grazed (Sollenberger and Burns, 2001). Zero grazing also offers the opportunity to integrate forage with other feed resources, in a homogenous mix, as with total mixed rations, to improve the quality of the diet offered as well as promoting overall increased feed intake. The most obvious disadvantage with this system is an increased cost associated with housing the animals, as done in intensive management systems, and harvesting and transportation of the forage to make it available to the animal.

Improving sward state

Under rotational grazing, the primary limiting factor to maximizing grazed herbage intake is not chemical composition *per se* but more to do with sward state i.e. the way the herbage presents itself to the animal so as to facilitate prehension and ingestion. In addressing the state of swards presented for grazing much focus has been towards measurements of leaf area index (LAI) and light interception (LI) as a determinant of "efficient grazable herbage presented" (de Carvalho et al., 2013; da Silva et al., 2013). Generally, these studies have concluded that (like temperate pastures) LI 95% correlates well with optimum LAI which provides the condition for grazing-thus ensuring high grazing efficiency (Difante et al., 2009) The very stoloniferous species such as Cynodon nlemfunsis which seems LI 90% might be more indicative of optimal Leaf:Stem ratio (de Carvalho et al., 2013) is an exception. In addition, Fonseca et al., (2012) suggested that animal withdrawal from pasture must be done when sward height reaches 40 – 60% of the pre-grazed height to facilitate high levels of intake and performance. The underlining question now is how do we achieve this optimum sward state for presentation to the animal to facilitate efficient grazing? Da Silva et al. (2013) suggested that sward structure of rotationally grazed tropical pasture can be modified by alteration in height and LAI pre-grazing and by LI post-grazing.

Under rotational stocking, de Silveira et al. (2013) observed optimum sward condition; i.e. pre-grazing LI 95% and post-grazing height of 20 cm from Mulato pasture (*Bracharia* spp.) which resulted in efficient grazing as a result of high leaf proportion. Defoliation severity producing a residual sward height of 20 cm was also reported by de Carvalho et al. (2013) to produce optimum sward condition (LI 90%, highest tiller population density and leaf blade: stem ratio) for grazing *Cynodon nlemfuensis* pastures.

Concentrate Supplementation

Concentrate supplementation is most cost-effective when used to supplement seasonal herbage deficits (M^{c}Evoy et al., 2008a), offset forage nutrient deficiencies (Moore et al., 1999) or to increase carrying capacity without negatively affecting individual animal production (Becky et al., 2008). Supplementing animals with concentrate has been shown to increase total and herbage dry matter intake (M^{c}Evoy et al., 2008a). However, the effect of concentrate on herbage intake of the grazing cow has been shown to depend on the level of daily herbage allowance (Meijs and Hoekstra, 1984). Peyraud and Delaby (2001) showed that substitution rate increases with increasing pasture availability, from 0 for high grazing pressure to 0.6 – 0.8 when grazing pressure is reduced. An inverse relationship between substitution rate and milk production efficiency was highlighted by Horan et al., (2006) [Figure 4]. There is evidence in the literature to suggest that when adequate pasture is available concentrate supplementation produces a low response in terms of milk yield of dairy cows (Meijs and Hoekstra, 1984). A review by Leaver et al., (1968) showed average response of 0.33, 0.40 and 0.27 kg milk per kg concentrate DM, respectively. In contrast, from a review of responses to supplementary feeding in whole-lactation experiments on tropical pastures by Jennings and Holmes (1985), an average response of 0.82 kg milk per kg concentrate feed was reported. Similar supplementation efficiencies (0.85 kg milk per kg concentrate DM) were reported by Delaby and Peyraud (1997). The varied response in milk yield to grazing supplementation is likely related to the differing realized level of herbage utilization between experiments as well as the difference in optimal level of herbage utilization between temperate and tropical pastures. Leaver (1981) and Stobbs (1977) reported contrasting optima for temperate and tropical in respect of the herbage allowances at which intake is maximized in dairy cattle. For temperate pastures, the indicative optimum is where herbage allowance is equivalent to 2.5 to 3 times dry matter intake while on tropical pastures the ratio is closer to 4:1.

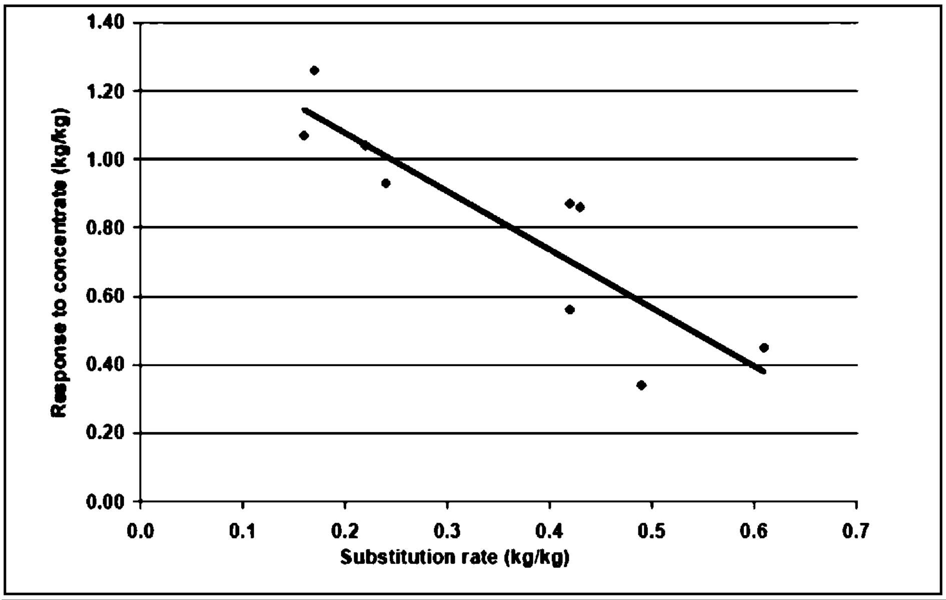

Figure 4. Relationship between substitution rate and milk yield response to concentrate supplementation (Horan et al., 2001).

Grass/Legume Association

Associating grasses with legumes offers a viable economic option for improving pasture quality and productivity and hence animal production in tropical regions, particularly with soils of low natural fertility (Lascano et al., 1989). Hill et al. (2004, 256) pointed out that financial pressures are promoting increased use of legume-based pastures to increase protein intake and improve the efficiency of energy utilization in Australia. The rationale for this alternative is that tropical legumes have a higher nutritive value than grasses and, through symbiotic nitrogen fixation can enhance the DM production and quality of the sward and improve soil fertility. Grass/legume association not only improves the nutritive value of the pasture but also enhance physical and morphological sward state offered for grazing resulting in improved grazing efficiency and intake. However, the higher growth potential of C_4 grasses causes difficulties in the maintenance of a grass-legume balance (Humphreys, 1991). Maintaining grass/legume pastures has been difficult mainly because animals exhibit selection preference for the legume in addition to suppression of the legume by the fast-growing grass particularly when pastures are heavily grazed (Lascano, 2000). Additionally, the disparate optimum defoliation intervals of tropical grasses (four weeks) and tropical forage legumes (eight weeks) pose practical difficulties in balancing herbage presentation mass against nutritive value.

It is important to point out that the work described by Lascano (2000) was conducted on the acid soils of South America, where extensive management of pastures and hence grass/legume associations is more appropriate. However, in the general Caribbean and other tropical areas where returns from specialized grazing systems are marginal thus forcing extensive grazing management; grass/legume associations might be more economical than resorting to inorganic N fertilization. Haynes (1980) suggested that the use of legumes in grass pastures may result in increased N content, digestibility and balanced mineral content of the pasture herbage. Paterson et al. (1979) reported a live weight advantage of 40 kg/head to *Panicum/Glycine* mixture compared to a monoculture *Panicum* pasture when grazed by Brangus bulls during the dry season in Bolivia. Legume content of the pasture decreases linearly with increasing stocking rate (Cowan et al., 1975). Thomas (1992) suggested that legume contents of 20 – 45% of the herbage DM could provide the nitrogen requirements for a productive and sustainable pasture. Under such conditions the pasture is more palatable than a grass-only pasture and utilization can be up to 40% higher (Thomas 1992). It is important to note that in the tropics, the extent of N-fixation by forage legumes tends to maximize at approximately 115 – 200 kg N/ha/yr. (Cadisch et al., 1989). This level of biologically fixed N is sufficient to sustain a range of herbage DM yields of 3 – 22 tonn DM/ha/ yr (Thomas, 1992) but will limit carrying capacity of grass/legume pastures to below 3.5 AU/ha (Table 3). Where land values make it imperative to maximize carrying capacity the economics of grass/legume pastures have to be carefully evaluated. In addition, the choice of legume and grass species must be carefully considered to maximize the benefits of both while maintaining the mix stand for the longest possible time in optimum state.

Forage Conservation

Forage conservation offers one of the most critical and practical solutions to address the severe dry-season herbage deficit common to tropical areas. Hughes et al. (2011) showed that in excess of 12,000 tons DM/ha. are produced on some Jamaican farms at certain times of the year while, during the dry season, herbage availability presents a critical constraint. This offers the possibility of harvesting herbage during periods of surplus and preserving it as either silage or hay (including haylage) to be used to supplement pasture herbage deficit during the dry season (Clark and Kanneganti, 1998). The nutritive value of conserved fodder is usually lower than when freshly cut. Wilkinson (1984) suggested that the feeding value of ensiled forage falls by about 2.5 units per week.

However, it is common understanding that herbage quality is of secondary consideration when herbage availability is low. Harvesting and conserving excess pasture/forage herbage also offers the benefits of:

- Maintaining adequate grazing pressure thereby improving utilization efficiency
- Maintaining the sward with a high proportion of leaf by discouraging/removing high accumulation of residual dry matter (Hughes et al., 2011)
- Minimizing the effect of “fouled” herbage on consumption on subsequent grazing

Mechanical or manual harvesting of forage can be beneficial to sustainable sward management. Forage banks, comprising high DM producing forages such as sugarcane *(Saccharum officinarum)* and *pennisetum spp* to be fed as “green chop” and the use of high protein tree forages to supplement low pasture availability and or nutrient deficit (Edwards et al., 2012) are also viable option that should also be put into practice to address pasture shortage during the dry season. Deferred grazing or “stockpiling” forage is another alternative. This method, however, is only practical where land space is not limiting and usually offers forage of a lower quality. Deferred grazing or “Stockpiling” refers to allowing forage to accumulate for grazing at a later time (Clark and Kanneganti, 1998).

Synchronizing Animal Type/Breed with Available Feed Resources

NRC (2001) showed that a Holstein and Jersey cow of 680 kg and 454 kg body weight, respectively, both producing 25 kg milk will consume 20.3 kg and 18.0 kg, respectively, DM daily. This suggests that a greater proportion of the feed consumed by the Holstein cow will be portioned towards meeting maintenance requirement compared to the smaller sized Jersey cow, hence smaller-sized dairy breeds are more efficient in converting feed consumed to milk (Table 4). Jennings (1992) showed that the Jamaica Hope dairy cow milk yield per 100 kg OMD was approximately 8 units superior to that of the Holstein cow. Additionally, Devendra (1975) pointed out that the dairy goat is by far a more efficient in converting feed to milk than cows. At maintenance level, NRC (2001) suggested large and small breed dairy cows required in the order of 10.1 and 7.6 Mcal. daily net energy, respectively. Jennings (1992) provided evidence showing that the Jamaica Hope cow [450 kg BW] will produce in excess of 1.2 kg more milk per kg live weight compared to the Holstein cow [650 kg BW] (Table 5) when maintained on unsupplemented tropical pastures. More importantly, from this study, it was interesting to observe that 50% of the Holstein cows developed reproductive problems after the first lactation which prevented them from progressing further in the study further highlighting the superiority of the smaller breed dairy cow on unsupplemented tropical pastures.

Therefore, since the energy and nutrient density of tropical pastures/ pastures (4.8 – 10 MJ/kg DM [Hughes et al., 2012]) are relatively lower than those of temperate pastures and legumes and the nutritional requirements of the large breed dairy cow is greater, tropical pastures are better able to meet the energy and nutritional requirements of animals of smaller body size. This is further validated with the data presented on yield/unit live weight of the dairy goat (Prakesh and Khanna, 1972; Devendra and Burns, 1970).

Table 4. Milk yield per 100kg digestible organic matter (DOM) of goats, cows and buffalo

Specie/Breed	Location	Milk yield (kg)		Reference
		Daily	Per 100kg DOM	
Goats				
British Alpine	Trinidad	5.0	125.6	Devendra 1975
Anglo-Nubian	Trinidad	2.6	71.7	Devendra 1975
French Alpine	Guadeloupe	1.4	145.0	Devendra 1975
Jamunapari				Devendra 1975
Cross	Malysia	0.9	67.1	
Cows				
Zebu/Holstein	Trinidad	7.7	86.0	Devendra 1975
Local Indian	Malysia	3.6	101.5	Devendra 1975
Holstein	Jamaica	6.8	77.3	Jennings 1992*
Jamaica Hope	Jamaica	7.5	85.2	Jennings 1992*
Buffalo				
Murrah	India	5.9	73.6	Devendra 1975

*Grass only/unsupplmented diet

Table 5. Comparison of milk yield/kg live weight of goats, cows and buffalo

Species	Average milk yield (kg)	Average live weight (kg)	Yield/kg live weight	Reference
Goats				
3/4 Anglo-Nubian × Local	236.8	55.5	4.2	Devendra & Burns 1970
Beetal	181.0	22.7	8.0	Prakesh & Khanna, 1972
F1 Anglo-Nubian × Local	295.5	41.8	7.1	Devendra & Burns 1970
Cows				
Jamaica Hope	2,207.	408.5	5.4	Jennings 1992*
Holstein	1,885	464.5	4.1	Jennings 1992*
Jersey	1,377.3	409.1	3.4	Devendra & Burns 1970
Buffalo				
Murrah	1,814.1	454.5	4.0	Devendra & Burns 1970

*Grass only/unsupplmented diet

Informed Decision Making Prior to Grazing

Traditional methods used to determine pasture nutritive value and characteristics are time consuming as they require destructive sampling, exhaustive and expensive laboratory assays. As a result the outcome of these assays has very little impact on present and immediate decision making to inform and guide the grazing/feeding process. Hence, the need exist to develop alternative methods and tools capable of providing instantaneous information on pasture condition prior to grazing which will facilitate judicious supplementation. The chlorophyll meter seems to be one such tool with great potential. In fact, Madakadze et al. (1999) tested the accuracy of the SPAD 502 chlorophyll meter to predict yield and N (crude protein) concentration of Switch grass *(Panicum virgatum* L*)*. This close association between tissue chlorophyll and N exist because green tissue contains the majority of plant N. Starks et al. (2006) also reported that indirect chlorophyll measurements (NDVI) are strongly correlated with other plant macro-constituents such as NDF and ADF. However, much more calibration studies are needed to truly asses the utility of chlorophyll meters. Other methods have been tested, for example, the rising plate meter and sward stick for estimating herbage mass but the vertically heterogeneous nature of tropical pasture were the main limitations hindering their accuracy.

Conclusion

Seasonal fluctuations in pasture supply, high structural carbohydrate concentration and sward morphological structure that inhibits maximizing intake at grazing remain the most significant environmental and grass-related limitations to intake and nutrient absorption from tropical pastures. However, these limitations are preceded by the slow adaptation and utilization of proven practical management approaches aimed towards improving utilization efficiency and intake of tropical pastures. Knowledge pertaining to production, utilization and management of tropical pasture is extensive. For example, quality, quantity and availability and animal response from tropical pastures and the factors affecting them have been widely researched. The seminal work by Vicente Chandler et al. (1968) investigating management factors for improving both quality and quantity of tropical pasture have since been vastly extended. Earlier reports suggesting tropical pastures are incapable of supporting mid-high levels of animal output have been dispelled by numerous studies. Moreover, the introduction of improved tropical grass species has contributed significantly to increased animal production from tropical pastures, particularly due to the superior growth rate and dry matter production which facilitated increased stocking rates and carrying capacity.

What is lacking is in-depth understanding of the sward-animal interface as it relates to sward morphological conditions necessary to optimizing intake at grazing and simple and accurate tools for providing real-time information on sward characteristics and nutritive value.

References

Abaye, A. O., V. G. Allen and J. P. Fontenot. 1994. Influence of grazing cattle and sheep together and separately on animal performance and forage quality. Journal of Animal Science, 72: 1013 – 1022.

Adeli, A., J. J. Varco, K. R. Sistani, and D. E. Rowe. 2005. Effects of Swine Lagoon Effluent Relative to Commercial Fertilizer Applications on Warm-Season Forage Nutritive Value. Agronomy Journal, 97:408–417.

Allen, M.S. 1996. Physical constraints on voluntary intake of forages by ruminants. Journal of Animal Science, 74: 3063-3075.

Archibald, K. A. E., R. C. Compling, W., Holmes. 1975. Milk production and herbage intake of dairy cows kept on a leader and follower grazing system. Animal Production, 21: 147 – 156.

Aregheore, E. M. 2007. Voluntary intake, nutrient digestibility and nutritive value of foliage of fluted pumpkin (Talfairia occidentialis) - haylage mixtures by goats. Livestock Research for Rural Development. Volume 19, Article #56. Retrieved July 28, 2010, from http://www.lrrd.org/lrrd19/4/areg19056.htm

Argel, P. J. 2006. Contribution of improved pastures to animal production in dual purpose systems. Archives of . Latin American Animal Production, 14: 65 – 72.

Arthington, J. D and W. F. Brown. 2005. Estimation of feeding value of four tropical forage species at two stages of maturity. Journal of Animal Science, 83: 1726-1731.

Becky, P. A., D. S. Hubbell, T. W. Hess and S. A. Gunter. 2008. Case Study: Stocking rateand supplementation of stocker cattle grazing wheat pasture interseeded into Bermudagrass in Northern Arkansas. The Professional Animal Scientist, 24: 95 – 99.

Bennett, D. F., F. H. W. Morley, K. W. Clark and M. L. Dudzinski. 1970. The effect of grazing cattle and sheep together. Australian Journal of Experimental Agriculture and Animal Husbandry, 47: 694 – 709.

Bovel, M., A. Fanchone, H. Archimede and M. J. Gibb. 2007. Effect of Structure of a Tropical Pasture on Ingestive Behaviors, digestibility of diet and Daily Intake by Grazing Cattle. Grass and Forage Science, 62: 44 – 54

Brown, W. F., and P. Mislevy. 1988. Influence of maturity and season on the yield and quality of tropical grasses. pp 46–54: in Florida Beef Cattle Res. Rep. Univ. of Florida, Gainesville.

Cadisch, G. R. Sylvester-Bradley and J. Nosberger. 1989. ^{15}N – Based Estimation of Nitrogen Fixation by eight Tropical Forage Legumes at two levels of P: K Supply. Field Crops Research, 22: 165 – 180.

Cheeke, R.P. 1999. Applied Animal Nutrition: Feeds and Feeding. 2nd edition. New Jersey, Prentice Hall.

Chesson, A. 2000. Feed Characterization. In: M.K. Theodorou and J. France (eds), Feeding Systems and Fed Evaluation Models. Wallingford, UK: CAB International

Cowan, R. T., I. J. R. Byford and T. H. Stobbs. 1975. Effects of stocking rate and energy supplementation on milk production from tropical grass-legume pasture. Australian Journal of Experimental Agriculture and Animal Husbandry, 15: 740 – 746.

Da Silva, W. L., L. Galzerno, R. Andrade Reis and A. C. Ruggier. 2013. Structural characteristics of forage mass of Tifton 85 pastures managed under three post-grazing residual leaf areas. Brazilian Journal of Animal Science, 42: 238 – 245.

Da Silveira, T.C.M., S.C. da Silva, S.J. de Souza Jr., L.M. Barbero, C.S. Rodriques, V. A. Limao, K. da Silva Peno and D. da Nascimento Jr. 2013. Herbage accumulation and grazing losses on mulato grass subjected to strategies of rotational stocking management. Agricultural Science, 70: 242 – 249.

De Carvalho, C., S.T. Camargo Filho, D. S.C. Paciullo, P.G. Zanella, E. C. Modesto and P.B. Fernades. 2013. Structural characteristics of Puerto Rica stargrass *(Cynodon nlemfuensis)* pastures under different frequencies and severities of defoliation. Tropical Grasslands, 1: 60 – 62.

Decruyenaere V., A. Buldgen and D. Stilmant. 2009. Factors affecting intake by grazing ruminants and related quantification methods: a review. Biotechnology,. Agronomy and Society and Environment ,13: 559 - 573.

Delaby, L. and J. L. Peyroud. 1997. Influence of concentrate supplementation strategy on grazing dairy cow's performance. Proceedings of the XVIII international grassland congress, Winnipeg, session 29, pp. 137 – 138.

Devendra, C., 1975. Biological efficiency of milk production in dairy goats. World Review of Animal Production, Vol. XI, pp. 46-53.

Devendra, C. and Bums, M., 1970. Goat Production in the Tropics, Tech. Commun. No. 19, Commonw. Bur. Anim. Breed. Genet., Commonwealth Agricultural Bureaux, Famham Royal, U.K. C.A.B 1970, 184 p.

Difante, G. S; J. Nascimento, D. Euclides, V. P. B. Da Silva, S. C. Barbosa, R. A. Gonçalves, W. V. 2009. Sward structure and nutritive value of Tanzânia guinea grass subjected to rotational stocking managements. Brazilian Journal of Animal Science, 38: 9-19.

Dillon, P. 2006. Achieving high dry-matter intake from pastures with grazing dairy cows, In: Fresh herbage for dairy cattle. (eds.) A. Elgersma, J. Dijkstra and S. Tamminga. Springer, Netherlands. pp: 1 - 26

Edwards, A., V. Mlambo, C.H.O. Lallo and G.W. Garcia. 2012. Yield, chemical composition and in vitro rumimal fermentation of leaves of Leucaena Leucocephala, Gliricidia Sepium and Trichanthera Gigantea as influenced by harvesting frequency. Journal of Animal Science Advances, 2: 321 – 331.

Enoh, M. B., C. Kijora, L. K. Peters and S. Yonkeu. 2005: Effect of stage of harvest on DM yield, nutrient content, in vitro and in situ parameters and their relationship of native and Brachiaria grasses in the Adamawa Plateau of Cameroon. Livestock Research for Rural Development. Vol. 17, Art. #4. Retrieved July 20, 110, from http://www.lrrd.org/lrrd17/1/enoh17004.htm

Fales, S. L., L. D. Muller, S. A. Ford, M. O'Sullivan, R. J. Hoover, L. A. Holden, L. E. Lanyon, and D. R. Buckmaster. 1995. Stocking rate affects production and profitability in a rotationally grazed pasture system. Journal of Production Agriculture, 8: 88–96.

Filho Nogueira, M. C. J., M. Fondevila, A. Barrios Urdaneta, M. Gonza'lez Ronquillo. 2000. In vitro microbial fermentation of tropical grasses at an advanced maturity stage. Journal of Animal Feed Science and Technology, 83: 145 – 157.

Fisher, D. S. 2002. A Review of a few key factors regulating Voluntary Feed intake in Ruminants. Journal of Crop Science, 42: 1651 – 1655.

Fonseca, L., J. C. Mezzalira, C. Bremm, R. S. A. Filho, H. L. Gonda, P. C. F. Carvalho. 2012. Management targets for maximizing the short-term herbage intake rate of cattle grazing in Sorghum bicolor. Livestock Science, 145: 205-211.

France, J., M. K. Theodorou, R. S. Lowman and D. E.Beever. 2000. Feed Evaluation for Animal Production. In: M.K. Theodorou and J. France (eds), Feeding Systems and Fed Evaluation Models. Wallingford, UK: CAB International.

Grimaud, P., J. Sauzier, R. Bheekhee and P. Thomas. 2005. Nutritive value of tropical pastures in Mauritius. Tropical Animal Health and Production, 38: 159 – 167.

Hare, D. M., P. Tatsapong and S. Phengphat. 2009. Herbage Yield and Quality of *Brachiaria* cultivars, *Paspalum atrotum* and *Panicum maximum* in north-east Thailand. Journal of Tropical grasslands, 43: 65 – 72.

Haynes, R. J. 1980. Competitive Aspects of the Grass-Legume Association. Advances in Agronomy, 33: 227 – 261.

Horan, B., P. Faverdin, L. Delaby, M. Rath and P. Dillon. 2001. The effect of strain of Holstein-Friesian dairy cow and pasture-based system on grass intake and milk production. Animal Science, 82: 435 – 444.

Hill, J. O., R. Clem, M. J. Robertson, B. C. Pengelly and A. M. Whitbread. 2004. Beef Production From Tropical Pasture Legumes on Cropping Soils. Proc. of the 25th Biennial Conference of the Australian Society of Animal Production. pp. 256. Available online: http://www.publish.csiro.au/issue/1038.htm Accessed: 04/11/09

Hood, A. E. M. 1962. Silage for Beef Cattle. Journal of Grass and Forage Science. 17: 264 – 267.

Humphreys, R.L. 1991.Tropical Pasture Utilization (1st ed.). Cambridge. Cambridge University Press.

Hughes MP, Jennings PGA Mlambo V and Lallo CHO. 2012. Effect of season and harvesting method on chemical composition, predicted metabolizable energy and in vitro organic matter digestibility of rotationally grazed pastures. Online Journal of Aniamal and Feed Research, 1: 405 – 417.

Hughes, M. P., P. G. Jennings, V. Mlambo and C. H. O. Lallo. 2011. Exploring seasonal variations in sward characteristics and nutritive value of tropical pastures grazed by beef and dairy cattle on commercial farms in Jamaica. Journal of Animal Science Advances, 1: 47 – 60.

Isuwan, A., J. Saelim and S. Poathong. 2007. Effects of levels of sulfur Fertilizer on *Digitaria eriantha* grass. Silpakorn U Science and Technology Journal, 1: 13 – 19.

Jennings, P. G. 2002. Perspectives on the Jamaican Dairy Industry; The Role of the Jamaica Hope in the National Milk Production Enhancement Strategy. JAGRIST 14: 14-25 In:. Jennings, P. G 2006 (Ed). Livestock Production in Unfavorable Economic Environments. USA: BookSurge Pub.

Jennings, P. G. 1992. Yield and nutritive value of African Star grass *(Cynodon nlemfuensis)* in response to levels of nitrogen and fertilizer and defoliation frequency. In: Jennings,

P. G. 2006, Livestock Production in Unfavorable Economic Environments. BookSurge Pub.
Jennings, P. G. 1980. Production and Performance of Lactating Dairy Cattle on Grass. J. Scientific Research Council, Jamaica 5: 45 – 57. In: Jennings, P. G. 2006 (Ed). Livestock Production in Unfavorable Economic Environments. USA: BookSurge Pub.
Jennings, P. G. and W. Holmes. 1985. Supplementary feeding to dairy cows grazing tropical pastures: A Review. Tropical Agriculture, 62: 266-272.
Juarez Lagunes, I. F., D. G. Fox, R. W. Blake and A. N. Pell. 1999. Evaluation of tropical grasses for milk production by dual-purpose cows in tropical Mexico. Journal of Dairy Science, 82: 2136 – 2145.
Johnson, C. R, B. A., Reiling, P. Mislevy and M. B. Hall. 2001. Effects of nitrogen fertilization and harvest date on yield, digestibility, fiber, and protein fractions of tropical grasses. Journal of Animal Science, 79: 2439–2448.
Jung, G. H. and M. S. Allen. 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. Journal of Animal Science, 73: 2774 – 2790.
Forejtová J., F. J. Lád, M. Tøináctý, L. Richter, P. Gruber, P. Doležal, P. Homolka and L. Pavelek. 2005. Comparison of organic matter digestibility determined by in vivo and in vitro methods. Czech Journal of Animal Science, 2: 47–53.
Lara, M. V. and C. S. Andreo. 2011. C4 Plants Adaptation to High Levels of CO2 and to Drought Environments. In: Abiotic Stress in Plants - Mechanisms and Adaptations, Shanker, A. (Ed.), ISBN: 978-953-307-394-1, InTech, DOI: 10.5772/24936.
Laredo, A. M. and D. J. Minson. 1973. The voluntary intake, digestibility and retention time by sheep of leaf and stem fractions of five grasses. Australian Journal of Agricultural Research, 24: 875 – 888.
Laredo, A. M. and D. J. Minson. 1975. The voluntary intake and digestibility by sheep of leaf and stem of *Lolium perenne.* Journal of British Grassland Society, 30: 73 - 77.
Lascano, C. E. 2000. Selective grazing on grass-legume mixtures in tropical pastures. In: Grassland ecophysiology and grazing ecology. pp 251 - 263 (eds.) Lemaire, G., J. Hodgson, A. de Moraes, C. Nabinger and P.C de F. Carvalho. CAB International, Wallingford, UK.
Lascano, C. E., J. Estrada and P. Avila. 1989. Animal production of pastures based on Centrosema spp. in the Eastern plains of Columbia. In: Proceedings of the XCIth International Grassland Congress, Nice, France. AFPF, Versailles, France. 251 – 265.
Leaver, J. D., R. C. Campling and W. Holmes. 1968. Use of supplementary feeds for grazing dairy cows. Journal of Dairy Science Abstracts, 30: 355 – 361.
Leaver, J. D. 1981. The contribution of grass and conserved forages to the nutrient requirement for milk production. In: Recent Advances in Animal Nutrition. (ed.) W. Haresign; Butterforths (Pub.)
Le Du, Y. L. P., J. Combellas, J. Hodgson and R. D. Baker. 1979. Herbage intake and milk production by grazing dairy cows, 2. The effects of level of winter feeding and daily herbage allowance, 34: 249 – 260.
Logan, J. and P. G. Jennings. 1995. Mixed grazing of cattle and sheep. In: Jennings, P.G.A. 2006, Livestock Production in Unfavorable Economic Environments. BookSurge Pub.
Lukas, M., K. H. Sudekum, G. Rave, K. Friedel and A. Susenbeth. 2005. Relationship between feacal crude protein concentration and diet organic matter digestibility in Cattle. Journal of Animal Science, 83: 1332 – 1344.

Madakaddze, I. C., K. A. Stewart, R. M. Madakadze, P. R. Preston, B. E. Coulman and D.L Smith. 1999. Field evaluation of the chlorophyll meter to predict yield and N concentration of Switchgrass. Journal of Plant Nutrition. 22: 1001 – 1010.

Martinez, P. O., R. Ruiz, and R. Herrera. 1980. Milk Production of Cows Grazing Coast Cross 1 Bermuda Grass: I. Different Concentrate Supplementation Levels. Cuban Journal of Agricultural Science, 14: 225-232.

Mayne, C. S., R. D., Newberry and S. C. F. Woodcook. 1988. The effects of a flexible grazing management strategy and Leader/follower grazing on the milk production of grazing dairy cows and sward characteristics. Grass and Forage Science, 43: 137 – 150.

Mayne, C. S., R. D. Newberry, S. C. F. Woodcock and R. J. Wilkins. 1987. Effect of grazing severity on grass utilization and milk production on rotationally grazed dairy cows. Grass and Forage Science. 43: 137 – 150.

McDowell, R. E., H. Cestero, J. D. Rivera-Anaya, F. Roman-Garcia, J. A. Arroyo-Aguilu, C. M. Berrocal, M. Soldevia, J. C. Lopez-Alberty and S.W. Metz. 1975. Tropical grass pasture with and without supplement for lactating cows in Puerto Rico. Bulletin, Agricultural Experiment Station, University of Puerto Rico, No. 238

McEvoy, M., M. O'Donovan, E. Kennedy, J. P. Murphy, L. Delaby and T. M. Boland. 2008. Effect of pre-grazing herbage mass and pasture allowance on the lactation performance of Holstein-Friesian dairy cows. Journal of Dairy Science, 92: 414 – 422.

McEvoy M., E. Kennedy, J. P. Murphy, T. M. Boland, L. Delaby and M. O'Donovan. 2008a. The Effect of herbage allowance and concentrate supplementation on milk production performance and dry matter intake of spring-calving dairy cows in early lactation. Journal of Dairy Science, 91: 1258 – 1269.

Meijs, J. A. and J. A. Hoekstra. 1984. Concentrate supplementation of grazing dairy cows. 1. Effects of concentrate intake and herbage allowance on herbage intake. Grass and Forage Science, 39: 59 – 66.

Mendiola-Gonzalez, A., P. A. Martinez-Hernandez, E. Cortes-Diaz and C. Sanchez-del Real 2007. Effect of mixed and single grazing on an alfalfa-orchard pasture. Journal of Agriculture Science, 41; 395 – 403.

Miller, R. C., D. L.Ffrench, D. C. M^{c}Donald and P. G. Jennings. 2005. Yield and nutritive value of African Star grass and Tifton 85 Bermuda grass pastures on commercial dairy farms in Jamaica. Available from internet http://www.moa.gov.jm/data

Miller, R. C., D. L.Ffrench, D. C. M^{c}Donald and P. G. Jennings. 2003. Cost of producing grass under commercial conditions in Jamaica. http://www.moa.gov.jm/data

Minson, D. J. and M. N. M^{c}Leod. 1970. The digestibility of temperate and tropical grasses. Proceedings X1th International Grassland Congress: 719 – 722.

Mislevy, P., and F. G. Martin. 1998. Comparison of Tifton 85 and other Cynodon grasses for production and nutritive value under grazing. Soil and Crop Science Society. Florida Proccdings, 57:77–82.

Moore, J. E., M. H. Brant, W. E. Kunkle and D. I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility and animal performance. Journal of Animal Science, 77: 122 – 135.

Mott, G. O., and J. E. Moore. 1970. Forage evaluation techniques in perspective. In Proceedings. National Conference on Forage Quality Evaluation and Utilization; Lincoln, Nebraska Center of Continuing Education, L1-10.

Mtui, D. J., P. F. Lekule, N. M. Shem, T. Ichinohe and T. Fujihara. 2009. Comparative potential nutritive value of grasses, creeping legumes and multipurpose trees

commonly in sub humid region in the Eastern parts of Tanzania. Livestock Research for Rural Development. Volume 21, Article #158. Retrieved July 27, 2010, from http://www.lrrd.org/lrrd21/10/mtui21158.htm
Newman, C. Y., L. E. Sollenberger and C. G. Chambliss. 2003. Canopy characteristics of continuously stocked Limpograss swards grazed to different heights. Agronomy Journal, 95: 1246 – 1252.
Nolan, T. and J. Connolly. 1989. Mixed vs. mono-grazing by steers and sheep. Journal of Animal Production, 48: 519 – 533.
Norton, B. W., J. R. Wilson, H. M. Shelton and K. D. Hill. 1991. The effects of shade on forage quality, In: H. M. Shelton and W. W. Stur (eds.). Forage for Plantation Crops. Canberra, ACIAR Proceedings, 32: 83 – 88.
Osbourn, D. F. 1980. The feeding value of grass and grass products. In: Grass: Its production and utilization. (ed.) Holmes, W. London: Blackwell Scientific Publications.
Paterson, T. R., P. Philip and P. Maynard. 1992. A Guide to Improved Pastures for the Drier Areas of the Eastern Caribbean. Technical Bulletin no. 10. CARDI, UWI campus, St. Augustine, Trinidad.
Paterson, R. T., G. Sauma and C. Somur. 1979. The Growth of Young Bulls on Grass/Legume Pastures in Sub-Tropical Bolivia. Journal of Tropical Animal Production, 4: 154 – 161.
Prakesh, C. and R. S. Khanna. 1972. Effect of order of lactation and lactation length on milk production in a closed herd of Beetal goats. Indian Journal of Animal Production, 2: 10-13.
Peyraud, J. L. and L. Delaby. 2001. Ideal concentrate feeds for grazing dairy cows: responses to supplementation in interaction with grazing management and grass quality. In: Garnsworthy, P. C. and Wiseman, J. (eds.). Recent advances in animal nutrition. Nottingham University Press, Nottingham, 203-220.
Pieterse, P. A., N. F. Rethman and J. Van Bosch. 1997. Production, water use efficiency and Quality of four cultivars of *Panicum maximum* at different levels of nitrogen fertilization. Journal of Tropical Grasslands, 31: 117 – 123.
Poppi, D. P., J. France and S. R. McLennan. 2000. Intake, passage and digestibility. In: M.K. Theodorou and J. France (eds), Feeding Systems and Fed Evaluation Models. Wallingford, UK: CAB International.
Poppi, D. P. and W. D. M^{c}Lennan. 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science, 73: 278 – 290.
Ramírez de la Ribera, J. L., C. Kijora, I. L. Acosta L, M. Cisneros López and W. Tamayo Soza. 2008. Effect of age and growing season on DM yield and leaf to stem ratio of different grass species and varieties growing in Cuba. *Volume 20, Article #148.* Retrieved July 9, 2010, from: http://www.lrrd.org/lrrd20/9/rami20148.htm
Ravhuhali, K. E., J. W. Ng'ambiand, D. Norris. 2010. Chemical composition and enzymatic in vitro digestibility of cowpea cultivars and buffalo grass hay grown in Limpopo province of South Africa. Livestock Research for Rural Development. Volume 22, Article #170. Retrieved December 12, 2010, from http://www.lrrd.org/lrrd22/9/ravh22170.htm
Rivero, J. L., 1988. A comparative study of Coast Cross 67 Bermuda grass *cynodon dactylon* and common Guinea grass *panicum maximum* with and without supplementation on milk yield and composition. Cuban Journal of Agricultural Science, 143-148.

Sheaffer, C. C., P. Seguin and G. J. Cuomo. 1998. Sward characteristics and management effects on cool-season grass forage quality. In: Cherney, J. H. and D. J. R. Cherney (eds). Grass for Dairy Cattle. Wallingford, UK: CAB International. pp 75 – 100.

Sodeinde, F. G., I. O. A. Adeley, V. O. Asaolu, S. R. Amao and O. A. Olaniran. 2006. Yield, mineral content and nutritive value of *Pannicum maximum* Cv. T58 in the derived savanna zone of Nigeria. Research Journal of Biological Sciences, 1-4: 55 – 59.

Soder, K. J., P. Gregorini, G. Scaglia and A. J. Rook. 2009. Dietary selection by domestic grazing ruminants in temperate pastures: Current state of knowledge, methodologies and future direction. Rangeland Ecology Management. 62: 389 – 398.

Sollenberger, L. E. and J. C. Burns. 2001. Canopy characteristics, ingestive behavior and herbage intake in cultivated tropical grasslands. In: J. A. Gomide, W. R. S. Mattos and S. C. Da Silva (eds). Proceedings of the 19th international grassland congress, Sao Pedro, SP, Brazil, 321 – 327.

Starks, P.J., D. Zhao, W.A. Phillips and S.W. Coleman. 2006. Herbage mass, nutritive value and canopy reflectance of Bermuda grass pastures. Grass and Forage Science, 61: 101 – 111.

Stobbs, T. H. 1977. Short-term effects of herbage allowance on milk production, milk composition and grazing time of cows grazing nitrogen-fertilized tropical grass pasture. Australian Journal of Experimental Agriculture and Animal Husbandry, 89: 892 – 898.

Stobbs, T. H. 1974. Rate of biting by Jersey cows as influenced by the yield and maturity of pasture swards. Tropical Grasslands, 8: 81 – 87.

Stobbs, T. H. and P. A. Thompson.1975. Milk production from tropical pastures. World Annual Review 13: 27 – 31.

Stobbs, T. H. 1975. Factors limiting the nutritional value of grazed tropical pastures for beef and milk production. Tropical Grasslands, 9: 141.

Stobbs, T. H. 1975[a]. The effect of plant structure on the intake of tropical pastures. III. Influence of fertilizer nitrogen on the size of bite harvested by Jersey cows grazing *Setaria anceps* cv. Kazungula Swards. Australian Journal of Agriculture Research, 26: 997 – 1007.

Tamminga, S. and G. Hof. 2000. Feeding systems for dairy cows. In: M.K. Theodorou and J. France (eds), Feeding Systems and Fed Evaluation Models. Wallingford, UK: CAB International.

Thomas, R. J. 1992. The role of legume in the nitrogen cycle of productive and sustainable pastures. Grass and Forage Science, 47: 133 – 142.

Tikam, K., C. Mikled, T. Vearasilp, C. Phatsara and K. H. Sudekum. 2010. Digestibility of nutrient and evaluation of energy of Pangola grass in sheep compared with Napier grass. In Proceedings; Conference on International Research on Food Security, Natural Resource Management and Rural Development. September 14 – 16, ETH Zurich. Available from internet: http://www.tropentag.de/2010

Tobía, C., E. Villalobos, A. Rojas, H. Soto and J.K. Moore. 2008. Nutritional value of soybean *(Glycine max L. Merr.)* silage fermented with molasses and inoculated with Lactobacillus brevis 3. Volume 20, Article #106. Retrieved July 28, 2010, from http://www.lrrd.org/lrrd20/7/tobi20106.htm

Vicente-Chandler, J., S. Silva and J. Figarella. 1959. The effects of nitrogen fertilization and frequency of cutting on the yield and composition of three tropical grasses. Agronomy Journal, 51: 202 – 206.

Vicente-Chandler, J., R. Caro-Costas, R. W. Pearson, F. Abruna, J. Figarella and S. Silva. 1964. The intensive management of tropical forages in Puerto Rico. Bulletin, Agricultural Experiment Station, University of Puerto Rico. No. 187.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analyses and its application to forages. Journal of Animal Science, 26:119-128.