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EFFECT OF ENSILING TIME AND BROWSE SPECIES ON SILAGE MINERAL INTERACTIONS IN RELATION TO GOAT'S NUTRIENT REQUIREMENTS

***[1]Ogungbesan A.M., [1]Fasina O.E., [1]Eniolorunda O.O., [1]Olanloye S.A. and [2]Adewusi K.M.**

[1]Department of Animal Production, Olabisi Onabanjo University Ago-Iwoye, Ogun State, Nigeria
[2]Department of Crop Production, Olabisi Onabanjo University Ago-Iwoye, Ogun State, Nigeria

*Corresponding author's email: ogungbesan.ademola@oou.edu.ng

ABSTRACT

Four different browses viz Gmelina arborea Roxb, Gliricidia sepium Jacq, Azadirachta indica A. Juss, and Leucaena leucocephala Lam were used to investigate the effect of browse and sampling time on silage major minerals interactions in relation to nutrient requirements of goats. The four browses were ensiled in air-tight rubber drum for 90 days and samplings were done at day 0, 30, 60, and 90 for mineral analysis. Mineral interactions included calcium and phosphorus, calcium and magnesium, calcium and sulfur, phosphorus and magnesium, sodium and potassium, potassium and magnesium, potassium/calcium + magnesium along with nitrogen and sulfur ratios. All the values/ratios were within range of optimum values for goats. Hence, goats fed with these browses will neither experience any clinical and sub-clinical deficiency symptoms nor the attendant low productivity and reproduction associated with sole feeding, thereby reducing the extra cost of procuring custom or commercial salt supplements.

Key words: browse-species, preservation-time, nutrient's-interaction, animal-requirement

INTRODUCTION

Industrially, the stem of browse trees can be used in the pulp and paper industry (Paulo, 2000). This usefulness as industrial raw material precipitates the conservation of the resultant abundant herbage for use as animal feed in any form or state (Okonkwo *et al.,* 2008; Stevens *et al.,* 2018). Ensiling may be an appropriate method for preservation because browse tree leaves are surplus in wet season during which drying is rather difficult (Angthong *et al*., 2007). According to Angthong *et al.* (2007), silage is widely used in animal feeds for monogastrics and ruminants as a source of nutrients. Grazing of rural livestock from tropical countries do not receive mineral supplementation except for common salt (NaCl) and must depend almost exclusively on forage for their mineral requirements (McDowell, 1985; Akinsoyinu and Onwuka, 1998).

Mineral relationships can be compared to a series of intermeshing gears which are all connected, some directly and some indirectly (Watts, 1990). Any movement of one gear (mineral) will result in the movement of all the other gears (minerals). Ledoux and Shannon (2005) defined mineral interactions as interrelationships among mineral elements as shown by physiological or biochemical responses. Ledoux and Shannon (2005) divided interactions into two major classes, positive and enhancing bioavailability (commonly synergistic) and negative (antagonistic). A high concentration of an antagonist element decreases the biologic effectiveness of its target element. Antagonistic interactions are often expressed as a mutual inhibition of absorption from the intestinal tract but can also occur at the cellular level (Ledoux and Shannon, 2005) and secondary deficiency (Boyd, 1989; Watts, 1990; Ogungbesan *et al.,* 2011). Peradventure situation may arise when sole feeding of these ensiled materials may be expedient for a short period during which elemental antagonism can potentiate subclinical symptoms and affect production (Ayoade *et al.,* 1998).

There is little or no information regarding the possibilities of mineral deficiency symptoms (either clinical or subclinical) manifestation. Hence, there is the need to investigate the effects of different browses and sampling times on the silage minerals from different browses and sampling time interaction in relation to goat's nutrient requirements.

MATERIALS AND METHODS

Site Description

The experiment was carried out at the experimental site of Pasture and Range unit of the Department of Animal Production, College of Agricultural Sciences, Olabisi Onabanjo University, Isa-Ope Campus, Ayetoro. The study area is located within longitudes 2° 45′ E and 3° 5′ E, latitudes 6° 55′ N and 7° 15′ N at an altitude of 90-120 m above sea level (Google, 2023). The climate/vegetation is typically sub-humid forest mosaic savanna type with an annual rainfall of 1945.30 mm. Rainy season is between early April and late October. Rainfall pattern is bi-modal with two peaks in June and September. Maximum temperature varies 29°C

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during the peak of the wet season and 34°C at the onset of the wet season. The mean relative humidity is 72.81% while evaporation is 1806.90 mm (Google, 2023). The soil type is Oxic Paleustalf while soil texture is sandy loam (FAO, 2006). The soil chemical and physical parameters are shown in Table 1. The entire area is made up of undulating surfaces, which are drained mainly by Rivers Rori and Ayinbo (Ogungbesan *et al.,* 2013).

Browse Harvesting

Trees of *Gmelina arborea* Roxb (Ga)*, Gliricidia sepium* Jacq (Gs)*, Azadirachta indica* A. Juss (Ai) and *Leucaena leucocephala* (Li), under which tarpaulin have been carefully spread to avoid soil and associated bacterial contamination, were harvested of the leaves (leaves plus fine stem up to 6 mm in diameter) with harvesting hook (Tarawali *et al.,* 1995; Ogungbesan *et al.,* 2013). The leaves were sorted making them flexible enough to be easily packed into high density polyethylene drums and tightly sealed. These leaves were manually chopped into 2-5 cm length, and allowed to wilt overnight under shady air-dry conditions on a tarpaulin that was laid open in a well-ventilated shed (Goering and Waldo, 1974; t`Mannetje, 2000). The chopping created an air-tight condition that promotes fermentation and preservation due to action of bacteria on forage and forage juices.

Ensiling Drums

Typical ensiling is usually done in large bunkers or tower silos or even in large bales that can be left out in the fields to ferment. Due to the relatively small-scale nature of this project compared to multi-tonne silage production, we chose much smaller ensiling vessels. High density polyethylene drums of 30-L capacity and capable of being tightly sealed and easily handled were used for this experiment. They were placed on a tarpaulin laid open in a well-ventilated shed.

Mixing, Packing and Storage of Silage

The wilted and chopped materials (20 kg each) were packed on the tarpaulin, and was then thoroughly mixed manually together with the ground maize additives at the rate of 90% (forage) and 10% (ground maize) common and equal in all the browses (João and Luiz, 2011). The mixture was then packed into the drums (four drums that is one per browse) until they were full to the top, with as little head space as possible at the rate of 0.64 g cm^{-3} (Hendrix and Miller, 1964). It was compacted by trampling (polyethylene sheet covered feet) to ensure a vacuumed condition (João and Luiz, 2011). The barrels were then sealed with a metal clasp and placed out of direct sunlight until they were put into long-term storage. To ensure that the four barrels were absolutely air tight, each top half of the barrel (including lid) was wrapped with three to four layers of shrink wrap and sampled for at 0, 30, 60 and 90 days after ensiling (João and Luiz, 2011).

Table 1: Soil chemical and physical parameters

	Chemical		
Exch. Na (cmol kg^{-1})	50.00	Soil pH (in water)	5.50
Exch. K (cmol kg^{-1})	22.00	Available P (mg kg^{-1})	6.86
Exch. Ca (cmol kg^{-1})	95.00	Zinc (mg kg^{-1})	6.75
Exch. Mg (cmol kg^{-1})	86.00	Nitrogen (%)	0.07
Exch. H (cmol kg^{-1})	0.13	Organic carbon (%)	0.79
CEC (cmol kg^{-1})	2.70	Organic manure (%)	1.19
Physical	Sand (%)	75.16	
	Clay (%)	15.57	
	Silt (%)	9.25	

Ogungbesan *et al.* (2013); CEC – cation exchange capacity

Treatments, Sampling Times and Blocks (Browse Species)

Treatment 1 is silage sampled at day 0 after ensiling; treatment 2 is silage sampled at day 30 after ensiling; treatment 3 is silage sampled at day 60 after ensiling; while treatment 4 is silage sampled at day 90 after ensiling. The Ga contains 90% *Gmelina arborea* leaves mixed with 10% ground maize; Gs contains 90% *Gliricidia sepium* leaves mixed with 10% ground maize; Ai contains 90% *Azadirachta indica* leaves mixed with 10% ground maize; while Li contains 90% *Leucaena leucocephala* leaves mixed with 10% ground maize.

Sampling Silage

To get a representative sample of the entire barrel of prepared silage for analysis after storage, core samples were extracted using a custom-made sharpened steel tube. The core sampler was fabricated to fit the browse press hydraulic cylinder. Core samples measured ca. 25 cm in length, had a diameter of 5 cm, and weighed ca. 300 g. Once core samples were extracted, they were placed in labeled heavy duty zip lock bags, squeezed to remove excess air emptied in a desiccator.

Laboratory and Chemical (Mineral) Analysis

The desiccated samples were oven-dried at 60°C for 48 h in a forced draught air oven, ground in a mill using a steel screen (10 mm mesh), bulked and then the determine the residual moisture content was determined. Ground samples were digested by wet method in concentrated HNO_3 and per chloric acid at ratio 5:1, while phosphorus was measured calorimetrically according to Harris and Popati (1954), concentrations of calcium, magnesium, potassium, sulfur, and sodium were estimated with atomic absorption spectrophotometer (Model 420, Gallenkamp London) following the procedure described in AOAC (2000). Also, another wet digested sample was further subjected to Kjeldahl's method to determine the nitrogen content.

Statistical Analysis

Means of data generated were analyzed using two-way analysis of variance of randomized complete block design. Differences among the means were tested with least significant differences method at the 5% level of probability using the general linear model (SAS, 2000), defined thus:

$$X_{ijk} = \mu + X_i + b_j + e_{ijk};$$

where e_{ijk} is the individual data generated from the effect of the two fixed factors, μ is the grand population mean, X_{ijk} is the sampling time effect (specie effect), b_j is the browse specie effect (sampling time), e_{ijk} is the error (replicate) term within each treatment and block.

RESULTS AND DISCUSSION

Calcium and Phosphorus Ratio of Silage from Different Browses

In Figure 1, highest value was recorded in Gs (1.47), followed by Li (1.46), then Ga with 1.25 and Ai with 1.06 as the least value.

Calcium and Phosphorus Ratio of the Silage at Different Sampling Times

Figure 2 shows that calcium and phosphorus ratio at day 90 was highest (1.38), and at day 30 and 60 had 1.35, while the least ratio was observed at 0-day (1.19). Calcium exists as calcium phosphate, calcium oxalate, and is easily bound to pectin and lignin (Fahey and Spears, 1994). Calcium is considered as immobile and is expected to deviate from mobile elements such as P, Mg, K, and S in its behavior during plant growth. This is probably the reason for the stable Ca concentration during over-aging (Marković *et al.*, 2009). Phosphorus also exists as inorganic phosphate, ribonucleic acid, phospholipids, phytic acid, and other phosphate esters (Fahey and Spears, 1994). The P from both the browses and sampling times were practically within limit, Ca:P 1:1 or 2:1. Contents of P being higher than Ca will impede Ca absorption or utilization. The Ca:P ratio considered most suitable for farm animals other than poultry was generally within the range 1:1 to 2:1, although there is evidence that suggests that goats (ruminants) can tolerate higher ratios provided that the P requirements are met (McDonald *et al.,* 2010). It is generally recommended that diets of livestock should have Ca:P ratio of about 1:1 to 2:1 (Underwood, 1981). Livestock will tolerate dietary Ca:P ratios of more than 10:1 without any serious effect provided the P intakes are adequate (Khan *et al.,* 2007). Furthermore, it seems that ruminants can sustain high Ca:P ratio until 1:16, without affecting P metabolism as observed by Arab *et al.* (2017).

Calcium and Magnesium Ratio of Silage from Different Browses

The Ca:Mg as shown in Figure 3 depicts Li to have 1.38 as the highest ratio, followed by Gs (1.35) and Ga (1.21), with least ratio in Ai (1.14).

Calcium and Magnesium Ratio of the Silage at Different Sampling Times

Figure 4 represents Ca:Mg ratios from sampling days. The trend showed day 90 (1.29) to be greater than day 30, with day 60 (1.27) greater than day 0 (1.26). The pharmacological interaction of Ca and Mg which exists as ions, present in chlorophyll and at times bound to lignin, have been recognized for nearly a century (Fahey and Spears, 1994; Whitehurst, 2014). Nutritionally, excess dietary Ca decreases Mg absorption and status in animals. Mg deprivation decreases growth rate and lead to soft tissue calcification (Whitehurst, 2014). Also, the detrimental effect of high Ca relates to decreased Mg absorption (Whitehurst, 2014). Excess Ca in feed decreases assimilation of Mg and zinc (Suttle, 2010). The presence of Ca:Mg ratios greater than 50:1 in the rib bone indicate a probability of hypo-magnesaemic tetany in sucking or milk-fed calves and lambs, but are unreliable in the lactating animal because values fluctuate in synchrony with other minerals, including P (Suttle, 2010). High intakes of Ca and P may suppress Mg in albumin and a daily supplement of 150 g calcium carbonate for 4 days post-calving has been found to have a hypo-magnesaemic effect in cows (Suttle, 2010).

Calcium and Sulfur Ratio of Silage from Different Browses

In Figure 5, Ca:S was highest in Gs (2.08), Li was next with 2.04, then Ga (1.52) and Ai (1.45).

Calcium and Sulfur Ratio of Silage at Different Sampling Times

In Figure 6, the highest value (1.81) was at day 90, followed by day 0 (1.79) and lowest (1.75) at both days 30 and 60. The interaction between Ca and S (which sometimes either exists as sulfur amino acids or other organic sulfur-containing compounds like sulfate) is somehow antagonistic (Fahey and Spears, 1994). This is because excess S impedes the utilization and absorption of Ca. This consequently leads to water belly (urolithiasis/urinary calculi/urinary struvite calculi), rickets (weak/soft bones in young animals), osteodystrophies (i.e., osteopenia, osteoporosis, osteomalacia: demineralization of structural bone in mature animals), and hypocalcaemia i.e., milk fever or downers (Whitehurst, 2014). Also, toxicity of S from Ca deficiencies and disorder in terms of nerve impulse transmission in cattle are often called stargazers or brainers, because the animals appear disoriented, wander in circles, and literally gaze upwards with little or no consciousness of their surroundings (Whitehurst, 2014).

Phosphorus and Magnesium Ratio of Silage from Different Browses

Figure 7 shows P:Mg ratio to be highest in Ai (1.07), Ga and Li had 0.96, and the lowest was in Gs (0.92).

Phosphorus and Magnesium Ratio of the Silage at Different Sampling Times

As depicted in Figure 8, the highest value was at day 0 (1.06) while days 30, 60, and 90 recorded 0.94. High intakes of Ca and P may suppress albumin Mg. A daily supplement of 150 g $CaCO_3$ for 4 days post-calving has been found to have a hypo-magnesaemic effect in cows (Suttle, 2010).

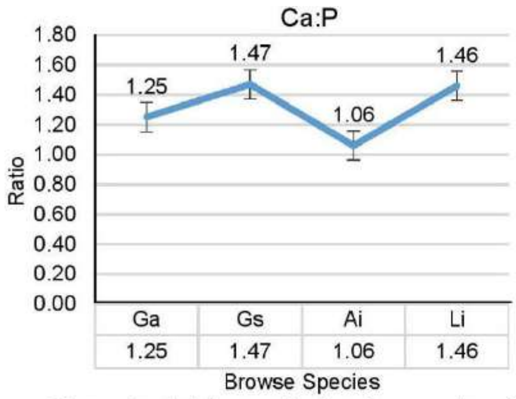

Figure 1: Calcium and phosphorus ratio of silage from different browses

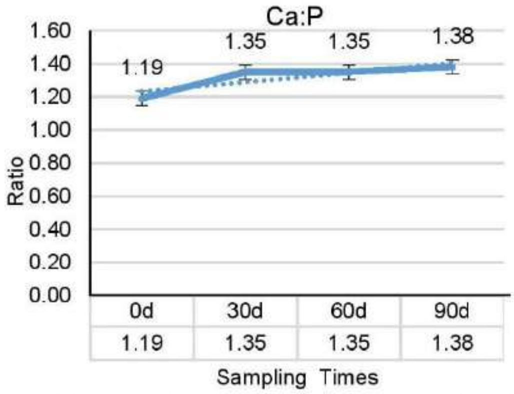

Figure 2: Calcium and phosphorus ratio of silage at different sampling times

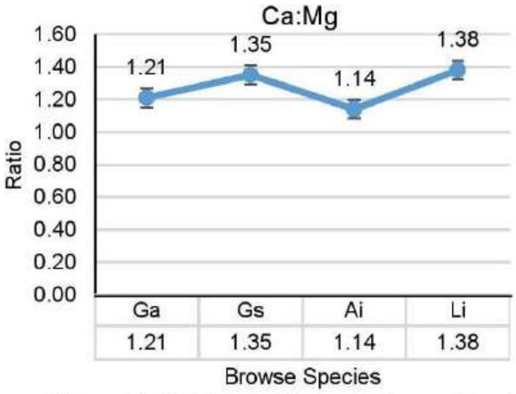

Figure 3: Calcium and magnesium ratio of silage from different browses

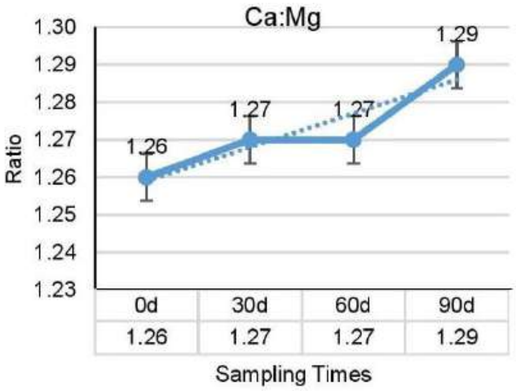

Figure 4: Calcium and magnesium ratio of silage at different sampling times

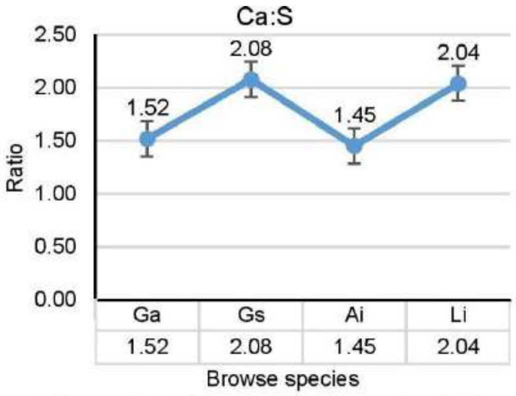

Figure 5: Calcium and sulfur ratio of silage from different browses

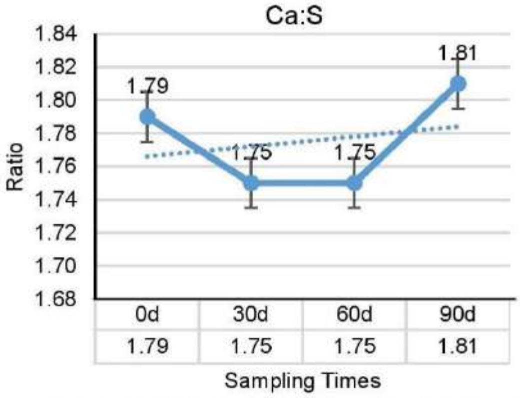

Figure 6: Calcium and sulfur ratio of silage at different sampling times

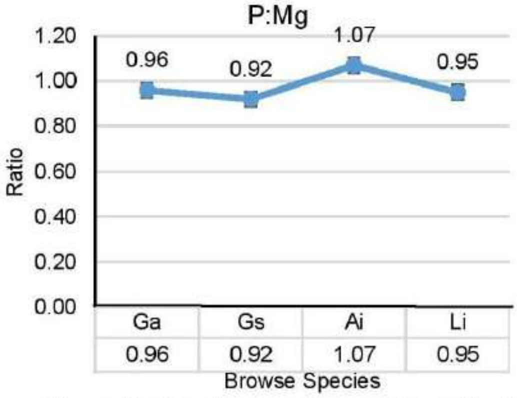

Figure 7: Phosphorus and magnesium ratio of silage from different browses

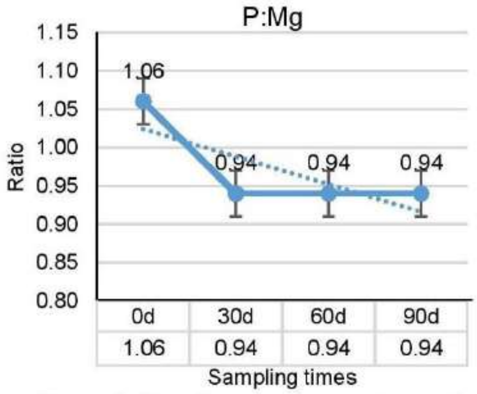

Figure 8: Phosphorus and magnesium ratio of silage at different sampling times

Sodium and Potassium Ratio of Silage from Different Browses

The Na:K ratio in Figure 9 shows Ai was highest (0.35), followed by Ga (0.33) while Gs had the least value of 0.20 behind Li (0.21).

Sodium and Potassium Ratio of the Silage at Different Sampling Times

All the sampling dates had the same Na:K value of 0.25 (Table 1). This outcome may be attributed to the fact that Na and K exist as ions according to Fahey and Spears (1994). Thus, the ratio of N must not be less than 0.10 regardless of the relative abundance of K (Suttle, 2010). Note that K is the principal cation of intracellular fluid, whereas Na is the principal cation of extracellular fluid. Hence, the intracellular separation of theses cations is maintained by the active transport of K and Na across the cell membrane. These elements also play an important role in the electrical activity of nerve and muscle cells. Also, K functions in acid-base balance and in the retention of water. In ruminants, absorbability can be low and K reduces the efficiency of absorption by inhibiting the two active transport systems in the rumen wall that carry magnesium against the electrochemical gradient. However, K does not affect absorption beyond the rumen (MacDonald *et al.,* 2010).

Potassium and Magnesium Ratio of Silage from Different Browses

In Figure 11, the K:Mg was highest in Li (4.65), followed by Gs (4.60), Ga (3.10), and then Ai (2.86).

Potassium and Magnesium Ratio of the Silage at Different Sampling Times

The K:Mg ratio from different sampling dates in Figure 12 shows that the highest value of 3.91 was obtained from both days 30 and 60 of sampling, which was followed by 3.80 in day 0 while day 90 recorded 3.23. For normal Mg solubility, the ratio of K:Mg must be lower than 4:1. A dietary excess of K is normally excreted rapidly from the body, chiefly in the urine. There are reports that high intake of K may interfere with the absorption and metabolism of magnesium in the animal, which may be an important factor in the aetiology of hypomagnesaemic tetany (NRC, 2001; Linn, 2016). Presence of K inhibits the absorption of magnesium from the rumen. Expression of the antagonism varies with feed type, but often results in a doubling of magnesium requirement over the range of potassium levels commonly found in herbages (NRC, 2001). The K/Mg antagonism is exacerbated by Na deprivation and the induction of aldosterone, which raises rumen K concentrations (NRC, 2001). High K intakes can thus increase the risk for hypomagnesaemic tetany through a triple interaction of K, Na and Mg (Suttle, 2010). The underlying mechanism is a decreased mobilization of calcium from bone at a time of increased calcium demand for lactation, an effect exacerbated by hypomagnesaemia, giving scope for a quadruple interaction of K, Na, Mg, and Ca (Suttle, 2010). The dependence of aldosterone secretion on calcium-ion-signaling pathways provides a possible pathway for interactions with parathyroid hormone (Suttle, 2010). According to Khan *et al.* (2007), the dietary Mg availability to stock is markedly affected by other dietary components (especially K). High dietary levels of K and N will inhibit Mg absorption from the rumen.

Potassium/Calcium + Magnesium Ratio of Silage from Different Browses

The K/Ca + Mg or tetanigenic ratio of silage from the different browses was highest in Gs (3.77); the next was from Li (3.74), followed by Ga (2.88), while lowest (2.48) was found in Ai (Figure 13).

Potassium/Calcium + Magnesium Ratio of the Silage at Different Sampling Times

Figure 14 shows the tetanigenic ratio from sampling days where day 90 had highest value of 3.41, both days 30 and 60 recorded 3.40, while day 0 was 3.38. Suttle (2010) used the ratio of K to Ca + Mg in forage as a prognostic threshold; when the ratio was less than 2.20, the risk of grass tetany. The K/Mg antagonism is exacerbated by Na deprivation and the induction of aldosterone, which raises rumen K concentrations (Suttle, 2010). High K intakes can thus increase the risk for hypomagnesaemic tetany through a triple interaction of K, Na, and Mg (Suttle, 2010). Grass tetany (hypomagnesemia) induced by Mg deficiency may be the most important health problem in ruminants caused by mineral imbalances. The Mg absorption by herbivores is negatively affected by K, and forms the basis for the K/(Mg + Ca) index in forages that indicate risk level. Inclusion of Ca in the index is because it counters some of the effects of K on Mg absorption. The risk of grass tetany increases exponentially when the herbage K/(Ca + Mg) index increases above 4.40 when expressed on a mass basis (i.e., g g^{-1} or percentage by weight) (Suttle, 2010). This implies that all the values are still below the injury threshold of 4.40 and as such safe for animal consumption which does not call for any supplementation because the plant chemo-availability and animal bioavailability are functional (Ogungbesan *et al.,* 2014). Other factors that reduce Mg availability to ruminants include high concentrations of N and low concentrations of soluble carbohydrate, e.g., sugars and starches (Suttle, 2010).

Nitrogen and Sulfur Ratio of Silage from Different Browses

The N:S ratio from browses in Figure 15 was highest in Gs (16.17) followed by Ai (15), Li was next (14.75) while Ga had 12.83.

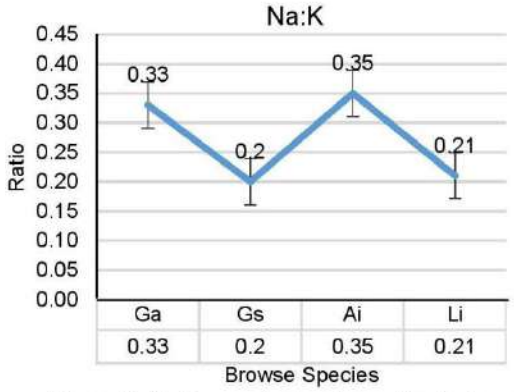

Figure 9: Sodium and potassium ratio of silage from different browses

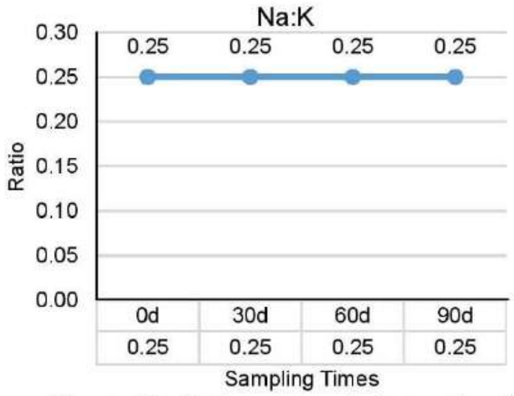

Figure 10: Sodium and potassium ratio of silage at different sampling times

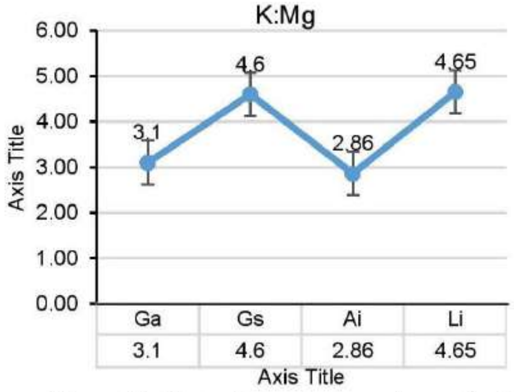

Figure 11: Potassium and magnesium ratio of silage from different browses

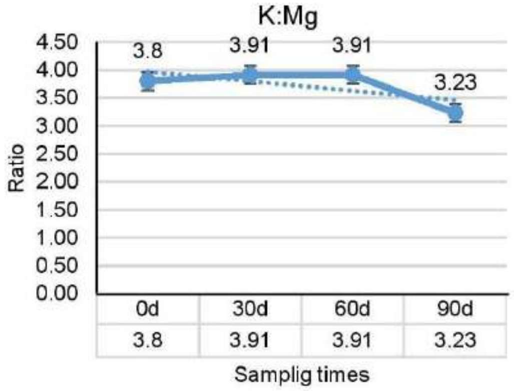

Figure 12: Potassium and magnesium ratio of silage at different sampling times

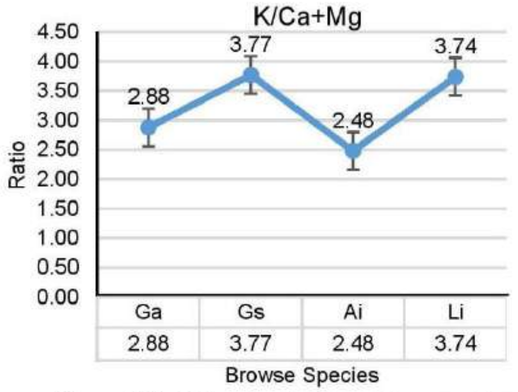

Figure 13: Potassium /calcium + magnesium ratio of silage from different browses

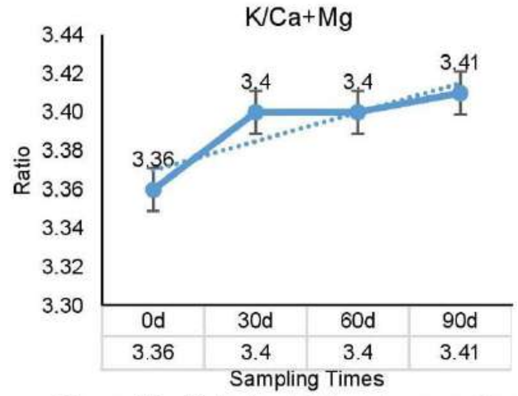

Figure 14: Potassium/calcium + magnesium ratio of silage at different sampling times

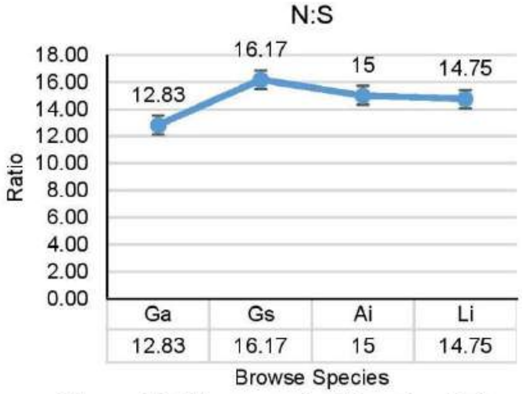

Figure 15: Nitrogen and sulfur ratio of silage from different browses

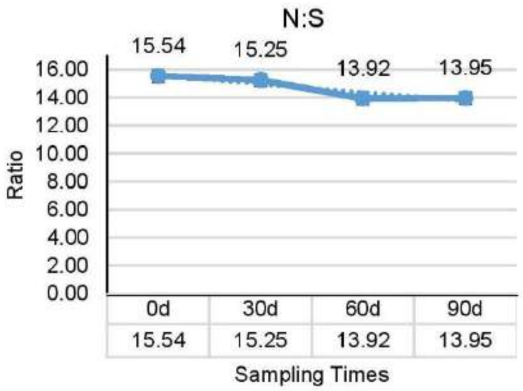

Figure 16: Nitrogen and sulfur ratio of silage at different sampling times

Nitrogen and Sulfur Ratio of the Silage at Different Sampling Times

Figure 16 represents the N (as the element derived from crude protein divided by 6.25) and N:S ratio from days of sampling. The highest value of 15.54 was obtained on day 0, followed by 15.25 on day 30, 13.95 on day 90 and the least value (13.92) on day 60. The UK Agricultural Research Council had recommended that the requirement for rumen-degradable S should be calculated by multiplying the rumen-degradable nitrogen requirement by 0.07, i.e., equivalent to an N:S ratio of 14:1 (NRC, 2001). The ratio of N:S in wool protein is narrower, at 5:1, and the supply of S-containing amino acids may be limiting for sheep with a high rate of wool production (MacDonald *et al.,* 2010). Also, S as a macro element is essential in ruminant feeds, having rumen where foregut fermentation and microbial nutrient synthesizing takes place. The ability of the ruminant microbe to synthesize amino acid with a balance and complete of non-S-containing and S-containing unit is based on the ability of the feeding materials to contain some amount of nutrient such that the proportion of S-containing amino acid will be sufficient in the whole protein unit complex (Linn, 2016). Although total concentration of a mineral in forage is important, the biological availability of the mineral is equally important. Biological availability (absorption and utilization) of minerals varies substantially among animal species and breeds within a species, as well as among forages. Feeding resources and feeding systems for livestock vary from one place to another. The creation of a custom 4-part iodized table salt, 2-part steam bone meal, and 4-part shell as computed by Williamson and Payne (1984) or commercial mineral supplement for a specific farm would require an extensive investment of time and sampling of both soil and plant tissues throughout the growing season (Masters and White, 1996; CES, 2013). The bioavailability of a mineral in the diet may depend upon such factors as its physicochemical form and the protein and vitamin content of the ration (Masters and White, 1996).

CONCLUSION AND RECOMMENDATION

Planting of browse trees which can be ensiled after it has been used for other economic purpose is recommended. Ensiling is essential because the nutrients are all in utilizable and bearable level, since majority of ruminant produced are under extensive or semi-intensive managerial system which depend largely on ranging foraging, grazing and zero-grazing. Hence, proper cognizance must be taken of the incidences of these negative interactions in order for pro- active measures to be taken.

AUTHORS CONTRIBUTION

Ademola Ogungbesan was the team leader, designed and coordinated the experiment. Kayode Adewusi was responsible for the field experimental operation and sourcing of partial funding. Olubunmi Fasina handled the data analysis and some aspects of the manuscript draft, while Oluseyi Eniolorunda gave information concerning feed preservation and resources.

CONFLICT OF INTEREST

Authors have declared that no conflict of interests.

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