Original scientific paper
Journal of Central European Agriculture, 2025, 26(1), p.162-175

DOI: /10.5513/JCEA01/26.1.4133

# Mineral concentration and mineral ratios of two *Megathyrsus* varieties: Effect of swine manure rate and age at harvest of the grasses

Peter Aniwe DELE[1] (✉), Ayooluwa Oluwaremi OMODEWU[1,2], Bolanle Temitope AKINYEMI[1], Olajumoke Lydia AIYESA[1], Chika Chiamaka ANOTAENWERE[1], Foluke Eunice ENWETE[1], John Osaze IDEHEN[3], Oluwasanmi Moses ARIGBEDE[1], Alaba Olufunmilayo JOLAOSHO[1]

[1] Department of Pasture and Range Management, Federal University of Agriculture, Abeokuta, Nigeria
[2] National Biotechnology Development Agency, Federal Capital Territory, Abuja, Nigeria
[3] Department of Environmental Management and Toxicology, Federal University of Agriculture, Abeokuta, Nigeria

✉ Corresponding author: delepa@funaab.edu.ng

Received: October 8, 2023; accepted: January 14, 2025

## ABSTRACT

This experiment investigated the effect of swine manure rate and age at harvest on the mineral concentration and ratios of two *Megathyrsus maximus* varieties. The study was a 4 × 2 × 3 factorial experiment in a split-split-plot design with four replications. The calcium concentration ranged from 2.51 g/kg DM for the *M. maximus* var. Local fertilized at the rate of 100 kg N/ha and harvested at 8 WAP to 5.05 g/kg DM for the unfertilized *M. maximus* var. Ntchisi harvested at 4 weeks after planting (WAP). The *M. maximus* var. Local fertilized at 200 kg N/ha harvested at 4 WAP recorded the highest value of phosphorus. The unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP had the highest Ca:P ratio. The unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP and *M. maximus* var. Ntchisi fertilized with 300 kg N/ha harvested at 12 WAP recorded the lowest tetany ratio. *M. maximus* var. Ntchisi fertilized with 300 kg N/ha and harvested at 8 WAP and 12 WAP having the highest Mn and Fe concentration, respectively. The Fe: Mn ratio ranged between 1.29 and 4.39 for *M. maximus* var. Ntchisi fertilized with 100 kg N/ha harvested 4 WAP and the same variety fertilized with the same rate of manure but harvested at 12 WAP. In conclusion, the Ca concentrations were observed to be higher in younger grasses (4 WAP), especially the *M. maximus* var. Local and N concentrations of the grasses decline with maturity across the manure rate. The grasses also recorded tetany ratio values lower than 2.2 as *M. maximus* var. Ntchisi fertilized with 100 kg N/ha harvested at 8 WAP recorded the lowest value (0.5).

**Keywords:** grasses, productivity, ruminants, tetany, tropics

## INTRODUCTION

Minerals are essential components of the diets of animals for optimal growth, physiological functions, and maximum productivity (Herdt and Hoff, 2011) and are also noted to be highly important for the maintenance, growth, reproduction, and health of livestock (Jones and Tracy, 2013). The growth performance and health of grazing ruminants are associated to the adequacy and availability of minerals from pastures and soil (Islam et al., 2003). In the tropics, minerals are crucial for the health and well-being of ruminant animals because both an abundance and a deficiency could result in poor productivity (Dele et al., 2021). Mineral-related health issues are posing significant challenges to animal production in developing countries (Reid and Jung, 1991), so knowledge of factors responsible for the availability of minerals in the soil-plant-animal chain is needful. Fardous et al. (2010) noted that variations in the mineral content of forage crops are species/variety/cultivar dependent and from soil to soil.

Nutrient concentration accumulation in plants depends on soil characteristics, elemental totals and plant-available quantities, cultivation and fertilization, climate, and plant characteristics (Bengtsson et al., 2003; Warman and Termeer, 2005). Juknevičius and Sabienė (2007) reported that deficiencies and surpluses in mineral content are species-related and even with higher content of individual mineral concentrations, there may still be an imbalance because of the synergistic-antagonistic interactions between the nutrients.

*Megathyrsusmaximus* (Jacq.) commonly called Guinea grass, is a major as well as significant pantropical grass that is used for grazing, cut-and-carry, silage, and hay throughout the tropics. It is a leafy, quickly growing grass that is tasty to cattle and has a high nutritional value (Dele, 2012; Heuzé and Tran, 2020). Guinea grass was originally found in tropical Africa and has spread across the tropics. It typically occurs in shady areas, open grasslands, and wooded areas. In the tropics, *M. maximus* has been known to be widespread in its natural state, commonly referred to as natural pastures, which for most of the year do not retain sufficient nutrient and biomass to satisfy the requirements of the animals (Ademosun, 1973; Mohammed-Saleem, 1994). The insufficient supply of both macro and micronutrients in grasses has been reported widely across the tropics (McDowell, 1996; Lamidi and Ologbose, 2014; Olanite et al., 2018). To improve its quality and to meet the nutritional requirements of ruminant animals, deliberate sowing and purposely managed *M. maximus* has been widely suggested (Olanite, 2002; Onifade et al., 2005; Dele, 2008, 2012).

Four major factors have been noted to have an effect on the concentrations of all minerals in plants; namely: the genotype/species/variety/cultivar of the plant, the soil environment, the temperature, and the maturity stage (Suttle 2010; Dele, 2012; Dele et al., 2021). Tropical Soils are typically known for their inherent low fertility (Sanchez, 1994) and soil amendment like manure have been suggested to improve the fertility of the soil (Villa et al., 2021) but there is little or no information on the different ratio of the mineral concentrations, hence the objective is to evaluate the influence of swine manure rates and age at harvest on the mineral concentrations and mineral-mineral relationship of two *M. maximus* varieties as it relations to ruminant livestock production.

## MATERIALS AND METHODS

### *Experimental sites description*

The experiment was conducted at the Organic Research farm and laboratory analysis was carried out at the laboratory of the Department of Pasture and Range Management, Federal University of Agriculture, Abeokuta, Nigeria. The experimental site in Nigeria lies within the savanna agroecological zone of Southwestern Nigeria (latitude: 7°N, longitude 3.5°E, average annual rainfall: 1037 mm). The rainfall pattern of the study area is bimodal rainfall which is typically at peaks in July and September with a break of two to three weeks in August. Temperatures are fairly uniform with daytime values of 28 to 30 °C during the rainy season and 30 to 34 °C during the dry season with the lowest night temperature of around 24 °C during the harmattan period between December and February. Relative humidity is high during the rainy season with values between 63 and 96% as compared to dry season values of 55 to 84%. The temperature of the soil ranges from 24.5 to 31.0 °C (Dele et al., 2021).

### *Land preparation, manure sampling, analysis, and application*

The land was cleared, followed by ploughing after which the land was allowed to rest for a period of two weeks before harrowing. The experimental land was mapped out after harrowing. After land preparation and before planting, soil samples were randomly collected from the plots at a depth of 0-15 cm using soil auger to represent the topsoil. The samples were bulked per replicate, mixed thoroughly and sub-samples taken for analysis to determine the pre-planting nutrient status of the soil. The swine manure used for this study was sourced from the Teaching and Research Farm, Federal University of Agriculture, Abeokuta. The manure was applied 14 days after collection and sub-samples were taken and analyzed before application with nutrient composition (pH 7.3, N:17.3 g/kg DM, P: 6.8 g/kg DM, K: 7.2 g/kg DM, Ca: 29.3 g/kg DM, Mg: 17.9 g/kg DM, Na: 2.2 g/kg DM, Fe: 713.0 mg/kg DM, Zn: 79.8 mg/kg DM, Cu: 17.8 mg/kg DM and Mn: 208.9 mg/kg DM).

### *Experimental design, planting and harvesting*

The study was a 4 × 2 × 3 factorial experiment in a split-split-plot design with an experimental area measuring 4,224 $m^2$ divided into four (4) replicates. The manure rates were the main plot, the grass varieties were the subplot and the age at harvest was the subplot. The four manure rates (0, 100, 200 and 300 kg N/ha DM basis), two grass varieties (*M. maximus* var. Local and *M. maximus* var. Ntchisi) and three age at harvest (4, 8 and 12 weeks after planting [WAP]) which made up twenty-four (24) treatments. The sub-sub plot area was 5 m × 5 m (25 $m^2$). The grass varieties planted are *M. maximus* var. Local and *M. maximus* var. Ntchisi and vegetative propagules (crown splits) from already established plots were used. The grasses were planted at the spacing of 0.5 m x 0.5 m with each plot labelled properly with treatments indicated. Forage samples were harvested at 4, 8 and 12 WAP, at each harvesting time, a 1 x 1 m quadrat was thrown three times in each sub-sub plot and herbage was harvested and weighed, then subsamples of 500 g weighed and oven–dried at 65 °C to constant weight and stored for mineral analysis.

### *Mineral analysis*

The mineral concentration analysis was carried out in the laboratory of the Department of Pasture and Range Management, Federal University of Agriculture, Abeokuta, Nigeria using wet ashing technique with nitric acid and hydrochloric acid (3:1) making 40 ml and making up to 100 ml after ashing. The samples were analyzed for some macro minerals (Ca, P, K, Na and Mg) and micro minerals (Cu, Zn, Mn and Fe) (Fritz and Schenk, 1979). The nitrogen (N) concentration was determined using the Dumas method. The mineral concentrations were expressed in g/kg DM and mg/kg DM basis for macromineral and micromineral, respectively. To determine the relationships between the minerals, the ratio values were calculated. The tetany (K / (Ca + Mg)) ratio was estimated by milliequivalents per 100 g were used.

### *Statistical analysis*

Data obtained were analyzed using the general linear model of SAS 9.4 (SAS Institute, 2010) design and treatment means were compared using Duncan's multiple range test (DMRT) at $P = 0.05$ probability level.

## RESULTS

The macromineral composition of two tropical grasses as influenced by swine manure rate and age at harvest are presented in Table 1. The Ca concentration ranged from 2.51 g/kg DM for the *M. maximus* var. Local fertilized at the rate of 100 kg N/ha and harvested at 8 WAP to 5.05 g/kg DM for the unfertilized *M. maximus* var. Ntchisi harvested at 4 WAP. The *M. maximus* var. Local fertilized at 200 kg N/ha harvested at 4 WAP recorded the highest value of P, whereas the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP recorded the lowest value of P. The lowest value of Mg was recorded for *M. maximus* var. Local fertilized at 100 kg N/ha harvested at 8 WAP and the highest concentration was recorded for *M. maximus* var. Ntchisi fertilized at 300 kg N/ha and harvested at 12 WAP. The K concentration of *M. maximus* var. Local fertilized at 300 kg N/ha and harvested at 4 WAP was the highest and recorded the lowest value when harvested at 12 WAP. The concentration of Na was found to be highest for *M. maximus* var. Ntchisi fertilized at 300 kg N/ha when harvested at 12 WAP when compared with other treatments. The nitrogen content ranged from 12.38 g/kg DM for *M. maximus* var. Local unfertilized and harvested at 12 WAP to 22.78 g/kg DM for *M. maximus* var. Ntchisi fertilized with 300 kg N/ha harvested at 4 WAP. There was a general decline in the nitrogen content with advancement in the age of the grasses (Table 1).

**Table 1.** Macromineral concentrations (g/kg DM) of two *Megathyrsus maximus* varieties as affected by swine manure rate and age at harvest

| Variety | Manure Rate | Age at harvest | Ca | P | Mg | K | Na | N |
|---|---|---|---|---|---|---|---|---|
| Local | 0 | 4 | 3.43 | 0.99 | 3.76 | 28.10 | 0.76 | 15.26 |
| | | 8 | 3.17 | 1.16 | 5.56 | 40.86 | 0.97 | 13.55 |
| | | 12 | 3.83 | 1.33 | 4.91 | 28.02 | 0.89 | 12.38 |
| | 100 | 4 | 3.77 | 1.48 | 6.84 | 36.71 | 1.04 | 16.99 |
| | | 8 | 2.51 | 1.14 | 3.37 | 21.91 | 0.70 | 15.10 |
| | | 12 | 3.01 | 1.63 | 5.12 | 19.12 | 0.85 | 13.78 |
| | 200 | 4 | 3.52 | 1.92 | 5.36 | 30.21 | 0.97 | 20.14 |
| | | 8 | 3.24 | 1.26 | 4.74 | 28.12 | 0.85 | 18.14 |
| | | 12 | 3.51 | 1.62 | 4.56 | 22.30 | 0.79 | 14.35 |
| | 300 | 4 | 4.07 | 1.63 | 6.84 | 44.51 | 0.99 | 22.45 |
| | | 8 | 2.77 | 1.89 | 5.32 | 31.71 | 0.90 | 18.74 |
| | | 12 | 2.88 | 0.96 | 3.65 | 17.41 | 0.66 | 14.74 |
| Ntchisi | 0 | 4 | 5.05 | 0.88 | 7.85 | 42.10 | 1.01 | 15.62 |
| | | 8 | 4.50 | 0.82 | 7.16 | 30.21 | 0.96 | 14.30 |
| | | 12 | 3.49 | 0.58 | 4.84 | 20.10 | 0.72 | 12.67 |
| | 100 | 4 | 2.68 | 0.94 | 4.18 | 24.72 | 0.70 | 17.39 |
| | | 8 | 3.57 | 1.18 | 6.07 | 25.11 | 0.96 | 15.30 |
| | | 12 | 3.79 | 1.60 | 6.78 | 24.82 | 0.84 | 14.06 |
| | 200 | 4 | 3.89 | 1.66 | 5.95 | 40.10 | 0.91 | 20.53 |
| | | 8 | 4.06 | 1.06 | 7.29 | 29.72 | 0.93 | 18.74 |
| | | 12 | 3.69 | 0.90 | 5.93 | 25.30 | 0.97 | 14.42 |
| | 300 | 4 | 2.84 | 1.09 | 4.93 | 26.32 | 0.75 | 22.78 |
| | | 8 | 3.33 | 1.15 | 6.76 | 28.40 | 0.95 | 19.02 |
| | | 12 | 4.28 | 1.27 | 8.29 | 25.82 | 1.42 | 15.50 |
| SEM | | | 0.05 | 0.03 | 0.11 | 0.60 | 0.01 | 0.24 |
| *P*-value | | | | | | | | |
| Manure rate (M) | | | *** | *** | *** | *** | *** | *** |
| Varieties (V) | | | *** | ** | *** | ** | ** | *** |
| Age at harvest (A) | | | *** | *** | *** | *** | *** | *** |
| R*V | | | *** | ** | *** | *** | * | * |
| R*A | | | *** | *** | ** | *** | ** | *** |
| V*A | | | * | *** | *** | *** | *** | * |
| R*V*A | | | *** | *** | ** | ** | * | *** |
| Requirement+ | | | 1.9-8.2 | 1.2-4.8 | 1-2.5 | 5-10 | 0.6-1.8 | >10.4[#] |

*< 0.05, **<0.01, ***<0.001, SEM: Standard error of means

+ Recommended mineral requirement for all classes of ruminants as summarized by McDowell (1997)

# Minson (1981)

The Ca:P ratio of the grasses varied with the application of manure rate and age at harvest as the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP had the highest Ca:P ratio and the *M. maximus* var. Local fertilized with 300 kg N/ha harvested at 8 WAP recorded the lowest Ca:P ratio. The unfertilized *M. maximus* var. Local harvested at 4 WAP recorded the highest Ca:Mg ratio (0.91) whereas *M. maximus* var. Ntchisi fertilized with 300 kg N/ha harvested at 8 WAP had the lowest Ca:Mg ratio. The K:Mg ratios varied from 3.11 to 7.47 with the unfertilized *M. maximus* var. Local harvested at 4 WAP with the highest value. The unfertilized *M. maximus* var. Local harvested at 8 WAP recorded the highest K:Ca ratio (12.91) and tetany ratio (1.70) and the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP and *M. maximus* var. Ntchisi fertilized with 300 kg N/ha harvested at 12 WAP recorded the least values of K:Ca and tetany ratios, respectively. The N:P ratio of the grasses significantly ($P<0.05$) varied with the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP having the highest N:P value and *M. maximus* var. Local fertilized with 100 kg N/ha harvested at 12 WAP recorded the least value.

The Mn concentration of the grasses was affected significantly ($P < 0.05$) by the swine manure rate and age at harvest, which ranged from 20.02 mg/kg DM to 54.05 mg/kg DM with the *M. maximus* var. Ntchisi fertilized with 300 kg N/ha and harvested at 8 WAP having the highest Mn concentration. The *M. maximus* var. Ntchisi fertilized with 300 kg N/ha of swine manure harvested at 12 WAP recorded the highest Fe concentration (134.15 mg/kg DM) whereas the same variety fertilized with 100 kg N/ha and harvested at 4 WAP recorded the lowest Fe concentration. The concentration of Cu ranged from 2.52 mg/kg DM for *M. maximus* var. local fertilized with 100 kg N/ha manure harvested at 8 WAP to 9.09 mg/kg DM for *M. maximus* var. Ntchisi same rate of manure and age at harvest. Zinc concentration varied significantly ($P<0.05$) with *M. maximus* var. Ntchisi fertilized at 300 kg N/ha harvested at 4 WAP having the highest (39.36 mg/kg DM) concentration (Table 3).

The Fe:Cu ratio of the grasses was significantly ($P<0.05$) affected by the manure rate applied and age at harvest. The unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP had the highest Fe:Cu (31.36) ratio and the same variety fertilized with 100 kg N/ha harvested at 8 WAP recorded the lowest Fe:Cu value. The *M. maximus* var. Ntchisi fertilized with 200 kg N/ha harvested at 8 WAP recorded the highest Fe:Zn (5.14) ratio whereas the lowest Fe:Zn (1.33) ratio was recorded for the same variety fertilized with 300 kg N/ha of swine manure harvested at 4 WAP. The Fe:Mn ratio ranged between 1.29 and 4.39 for *M. maximus* var. Ntchisi fertilized with 100 kg N/ha harvested 4 WAP and the same variety fertilized with the same rate of manure but harvested at 12 WAP. The influence of manure rate and age at harvest on the Zn:Cu ratio of the two grasses was significantly ($P < 0.05$) affected by the *M. maximus* var. Local fertilized with 100 kg N/ha and harvested at 8 WAP recorded the highest value of Zn:Cu (13.66) ratio and *M. maximus* var. Ntchisi fertilized with the same rate of manure and age at harvest recorded the lowest Zn:Cu ratio (Table 4).

**Table 2.** Macromineral ratios of two *Megathyrsus maximus* varieties as affected by swine manure rate and age at harvest

| Variety | Manure Rate | Age at harvest | Ca:P | Ca:Mg | K:Mg | K:Ca | K:(Ca+Mg) | N:P | K:P | K:N |
|---|---|---|---|---|---|---|---|---|---|---|
| Local | 0 | 4 | 3.46 | 0.91 | 7.47 | 8.21 | 1.50 | 15.42 | 28.40 | 1.84 |
| | | 8 | 2.73 | 0.57 | 7.35 | 12.91 | 1.70 | 11.69 | 35.23 | 3.02 |
| | | 12 | 2.88 | 0.78 | 5.71 | 7.33 | 1.20 | 9.32 | 21.07 | 2.26 |
| | 100 | 4 | 2.54 | 0.55 | 5.37 | 9.75 | 1.25 | 11.49 | 24.81 | 2.16 |
| | | 8 | 2.20 | 0.74 | 6.50 | 8.73 | 1.39 | 13.25 | 17.22 | 1.45 |
| | | 12 | 1.84 | 0.59 | 3.74 | 6.36 | 0.86 | 8.45 | 11.73 | 1.39 |
| | 200 | 4 | 1.83 | 0.66 | 5.64 | 8.60 | 1.25 | 10.49 | 15.74 | 1.50 |
| | | 8 | 2.57 | 0.68 | 5.94 | 8.69 | 1.30 | 14.40 | 22.32 | 1.55 |
| | | 12 | 2.17 | 0.77 | 4.89 | 6.35 | 1.04 | 8.86 | 13.77 | 1.55 |
| | 300 | 4 | 2.49 | 0.59 | 6.51 | 10.95 | 1.49 | 13.77 | 27.31 | 1.98 |
| | | 8 | 1.46 | 0.52 | 5.97 | 11.47 | 1.41 | 9.91 | 16.78 | 1.69 |
| | | 12 | 3.00 | 0.79 | 4.77 | 6.75 | 1.00 | 15.35 | 18.14 | 1.18 |
| Ntchisi | 0 | 4 | 5.74 | 0.64 | 5.37 | 8.33 | 1.20 | 17.75 | 47.86 | 2.70 |
| | | 8 | 5.49 | 0.63 | 4.22 | 6.71 | 0.95 | 17.45 | 36.85 | 2.11 |
| | | 12 | 6.02 | 0.72 | 4.15 | 5.76 | 0.90 | 21.86 | 34.69 | 1.59 |
| | 100 | 4 | 2.85 | 0.64 | 5.92 | 9.24 | 1.33 | 18.31 | 26.30 | 1.42 |
| | | 8 | 3.02 | 0.59 | 4.14 | 7.04 | 0.50 | 12.96 | 21.29 | 1.64 |
| | | 12 | 2.37 | 0.56 | 3.66 | 6.56 | 0.85 | 8.79 | 15.52 | 1.77 |
| | 200 | 4 | 2.34 | 0.65 | 6.74 | 10.31 | 1.50 | 12.37 | 24.16 | 1.95 |
| | | 8 | 3.83 | 0.57 | 4.08 | 7.32 | 0.95 | 17.61 | 28.04 | 1.59 |
| | | 12 | 4.11 | 0.62 | 4.27 | 6.87 | 0.96 | 16.07 | 28.22 | 1.76 |
| | 300 | 4 | 2.60 | 0.58 | 5.34 | 9.28 | 1.23 | 20.91 | 24.15 | 1.16 |
| | | 8 | 2.89 | 0.49 | 4.20 | 8.54 | 1.00 | 16.55 | 24.70 | 1.49 |
| | | 12 | 3.37 | 0.52 | 3.11 | 6.03 | 0.74 | 12.21 | 20.33 | 1.67 |
| SEM | | | 0.10 | 0.01 | 0.10 | 0.15 | 0.02 | 0.32 | 0.68 | 0.36 |
| *P*-value | | | | | | | | | | |
| Manure rate (M) | | | *** | *** | *** | *** | *** | *** | *** | *** |
| Varieties (V) | | | *** | *** | *** | *** | *** | *** | * | *** |
| Age at harvest (A) | | | *** | *** | *** | *** | *** | *** | *** | *** |
| R*V | | | *** | *** | *** | *** | *** | *** | *** | * |
| R*A | | | *** | *** | *** | *** | *** | *** | *** | *** |
| V*A | | | *** | *** | *** | *** | *** | ** | *** | *** |
| R*V*A | | | *** | *** | *** | *** | *** | *** | *** | *** |

*< 0.05, **<0.01, ***<0.001, SEM: Standard error of means

**Table 3.** Micromineral concentrations (mg/kg DM) of two *Megathyrsus maximus* varieties as affected by swine manure rate and age at harvest

| Variety | Manure Rate | Age at harvest | Mn | Fe | Cu | Zn |
|---|---|---|---|---|---|---|
| Local | 0 | 4 | 20.35 | 41.05 | 4.04 | 20.52 |
| | | 8 | 31.03 | 111.12 | 6.87 | 31.28 |
| | | 12 | 30.03 | 101.11 | 8.08 | 33.30 |
| | 100 | 4 | 42.04 | 111.12 | 6.06 | 27.25 |
| | | 8 | 20.02 | 62.07 | 2.52 | 28.26 |
| | | 12 | 21.02 | 73.08 | 6.06 | 29.26 |
| | 200 | 4 | 30.03 | 63.07 | 6.06 | 28.26 |
| | | 8 | 32.03 | 101.11 | 8.08 | 25.23 |
| | | 12 | 33.03 | 73.08 | 6.06 | 27.25 |
| | 300 | 4 | 43.04 | 100.45 | 7.07 | 32.63 |
| | | 8 | 32.03 | 101.11 | 5.05 | 33.30 |
| | | 12 | 21.02 | 41.05 | 4.04 | 27.25 |
| Ntchisi | 0 | 4 | 52.05 | 82.09 | 5.05 | 30.61 |
| | | 8 | 42.04 | 70.08 | 8.08 | 29.26 |
| | | 12 | 30.70 | 60.73 | 3.03 | 19.17 |
| | 100 | 4 | 24.02 | 31.03 | 3.03 | 15.24 |
| | | 8 | 41.04 | 70.08 | 9.09 | 24.22 |
| | | 12 | 30.36 | 133.15 | 5.05 | 33.30 |
| | 200 | 4 | 43.04 | 92.10 | 5.05 | 24.22 |
| | | 8 | 42.04 | 132.15 | 7.07 | 25.90 |
| | | 12 | 36.04 | 71.08 | 5.05 | 29.26 |
| | 300 | 4 | 30.03 | 52.06 | 5.05 | 39.36 |
| | | 8 | 54.05 | 100.11 | 5.05 | 32.29 |
| | | 12 | 41.04 | 134.15 | 7.07 | 33.30 |
| SEM | | | 0.79 | 2.42 | 0.19 | 0.45 |
| *P*-value | | | | | | |
| Manure rate (M) | | | *** | *** | *** | NS |
| Varieties (V) | | | *** | *** | * | NS |
| Age at harvest (A) | | | *** | *** | *** | ** |
| R*V | | | *** | *** | *** | NS |
| R*A | | | *** | *** | *** | * |
| V*A | | | *** | *** | NS | *** |
| R*V*A | | | *** | *** | *** | *** |
| Requirement+ | | | 20-40 | 30-50 | 7-11 | 20-40 |

*< 0.05, **<0.01, ***<0.001, SEM: Standard error of means

+ Recommended mineral requirement for all classes of ruminants as summarized by McDowell (1997)

**Table 4.** Micromineral ratios of two *Megathyrsus maximus* varieties as affected by swine manure rate and age at harvest

| Variety | Manure Rate | Age at harvest | Fe:Cu | Fe:Zn | Fe:Mn | Zn:Cu |
|---|---|---|---|---|---|---|
| Local | 0 | 4 | 12.20 | 2.00 | 2.02 | 6.05 |
| | | 8 | 16.19 | 3.60 | 3.59 | 4.56 |
| | | 12 | 13.11 | 3.04 | 3.37 | 4.35 |
| | 100 | 4 | 19.78 | 4.10 | 2.65 | 4.95 |
| | | 8 | 30.42 | 2.20 | 3.13 | 13.66 |
| | | 12 | 13.15 | 2.51 | 3.49 | 5.15 |
| | 200 | 4 | 11.19 | 2.24 | 2.11 | 4.97 |
| | | 8 | 13.11 | 4.03 | 3.16 | 3.22 |
| | | 12 | 13.15 | 2.70 | 2.22 | 4.79 |
| | 300 | 4 | 15.12 | 3.09 | 2.34 | 4.96 |
| | | 8 | 32.69 | 3.04 | 3.16 | 7.56 |
| | | 12 | 12.64 | 1.52 | 1.96 | 8.01 |
| Ntchisi | 0 | 4 | 18.44 | 2.69 | 1.58 | 6.74 |
| | | 8 | 9.10 | 2.40 | 1.67 | 3.83 |
| | | 12 | 31.36 | 3.21 | 1.98 | 9.17 |
| | 100 | 4 | 15.17 | 2.06 | 1.29 | 7.13 |
| | | 8 | 8.01 | 2.90 | 1.71 | 2.79 |
| | | 12 | 29.83 | 4.01 | 4.39 | 7.56 |
| | 200 | 4 | 20.42 | 3.83 | 2.14 | 5.53 |
| | | 8 | 19.83 | 5.14 | 3.15 | 3.80 |
| | | 12 | 15.99 | 2.43 | 1.97 | 6.66 |
| | 300 | 4 | 11.50 | 1.33 | 1.74 | 8.91 |
| | | 8 | 22.21 | 3.11 | 1.85 | 7.33 |
| | | 12 | 20.15 | 4.04 | 3.27 | 5.05 |
| SEM | | | 0.83 | 0.08 | 0.07 | 0.30 |
| *P*-value | | | | | | |
| Manure rate (M) | | | NS | *** | *** | * |
| Varieties (V) | | | NS | *** | *** | NS |
| Age at harvest (A) | | | NS | *** | *** | NS |
| R*V | | | * | *** | *** | * |
| R*A | | | * | *** | *** | NS |
| V*A | | | *** | *** | *** | ** |
| R*V*A | | | ** | *** | *** | *** |

*< 0.05, **<0.01, ***<0.001, NS: Not significant
SEM: Standard error of means

## DISCUSSION

### *Macrominerals*

The interactions of a variety of factors, which include soil nutrients, plant species/variety/cultivar, stage of maturity, management factors such as fertilizer application, weeding management, and climate greatly affect the concentrations of individual minerals (Alli et al., 2019) as well as their synergistic and antagonistic nature in forages. The highest Ca concentration in this study was recorded for unfertilized *M. maximus* var. Ntchisi harvested at 4 WAP followed a similar pattern to previous studies (Dele et al., 2017, 2018) when different animal manures were applied to the same varieties as in this study. This higher Ca concentration associated with the unfertilized could be attributed to the loose state of Ca in the soil when manure is not applied (Chang et al., 1994), therefore making the uptake of Ca higher because of less or no bond affinity (Ketterings et al., 2006). The majority of the Ca concentration reported in this study exceeded 3.0 g/kg which was reported to meet the requirement of beef cattle (National Research Council, 1996). The range (1.8-8.2 g/kg) reported by McDowell (1992, 1997) showed that the Ca concentrations in this study fell within the range recommended for all classes of ruminant animals.

The maximum P concentration as observed was recorded for *M. maximus* var. Local fertilized with 200 kg N/ha harvested at 4 WAP, which was lower than that was reported by Dele et al. (2018) when 200 kg N/ha in poultry manure was applied to *M. maximus*. In this study, almost 50% of the P concentration recorded fell within 1.2-4.8 g/kg recommended for different classes of ruminants (McDowell, 1997). The low status of P of the grasses in this study affirmed the report of McDowell et al. (1984) that forages in Nigeria are generally low in P and in concordant with Olanite et al. (2018) of the low nature of P of forages grown in tropical soils. The concentration of P gives credence to the fact that P is generally immobile in soil solution (Brady and Weil, 2002). Legume intercropping can help ameliorate the low P status of these grasses if they are to be grazed by animals, and the grazing of such grasses without legumes could be aided with direct P supplementation using non-protein supplementation in urea-mineral blocks which might serve as a viable and valuable alternative (Alli et al., 2019).

Magnesium has been reported to be relatively high in abundance in soft tissues (Suttle, 2010) as 60-70% of it is stored up in the skeleton (Underwood and Suttle, 1999). Factors such as plant species/varieties, season, stage of maturity, climatic conditions, and soil fertility have been noted for their impact on the magnesium concentration in forages (Jumba et al., 1995; Dele, 2012). The Mg concentrations were all higher than the range recommended by McDowell (1997) which implied that if animals are fed such grasses, they might not be exposed to tetany disorder. Harris and Shearer (2003) reported that animals that are fed or grazed on forages with Mg concentration less than 2.0 g/kg might experience tetany disorder. The higher mean Mg concentration of *M. maximus* var. Ntchisi than the *M. maximus* var. Local attested to the report of Jumba et al. (1995) that genetic makeup influences Mg concentration as observed in this current study and that there are species/varietal differences in the concentration of Mg among plants (Underwood and Suttle, 1999). The higher Mg concentration in this study attested to the findings of Minson (1990) that tropical forages are higher than their temperate counterparts in terms of Mg. Ruminants feeding on tropical forages have not been reported to experience hypomagnesemic tetany (Minson and Norton, 1982; Minson, 1990) and this can also be deduced from the concentration of Mg in this study.

The decrease in the N concentration for both grasses is in accordance with the reports of Belesky et al. (1995) and Dele (2012) who reported that as plants mature, they tend to get stemmy thereby accumulating more cell walls instead of cell content which also relates with reduction in leaf:stem ratio which is a major determinant of N concentration. The relative higher N concentration for both grass at the highest rate of manure at the earliest time of harvest was expected and concordant with the reports of Dupas et al. (2016) and Delevatti et al. (2019). The higher nitrogen concentration in this study could be a result of the increased nitrogen supply from the high manure rate. Early harvest restricts biomass accumulation, which reduces nitrogen dilution in plant tissues and results in a greater relative concentration. This is consistent with the principle that nutrient content is inversely proportional to biomass increase over time. The concentrations of N are higher than the range (10.4-12.9 g/kg) reported by Minson (1981) to be the minimum prescribed for optimum performance of tropical ruminant animals. The N concentration showed that manure application promotes N uptake in plants, and this as observed is above the critical limit below which forage intake by ruminant and rumen microbial activities would be suppressed.

***Macrominerals relationship***

Calcium and phosphorus ratios are crucial in the diets of young animals, especially for the promotion of bone growth and development (Reiné et al., 2020) than their individual concentration. The Ca:P ratios recorded were within the range (1:1 to 7:1) that was reported to have shown results in a similar trend for animal performance so much that the phosphorus requirement is met (Fluharty, 2008). The highest Ca:P ratio was recorded for the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP, this was similar to the report of Dele et al. (2021) where unfertilized leguminous forages had a higher Ca:P ratio than the fertilized counterparts. This is evident because of the lower P concentration of the unfertilized forage and as the forage advanced in age the phosphorus has been reported to be markedly reduced (Suttle, 2010). The *M. maximus* var. Local fertilized with 300 kg N/ha harvested at 8 WAP recorded the lowest Ca:P ratio which is lower than 2:1 which has been reported to precipitate urinary Ca in sheep (National Research Council, 1984).

The result showed that the Ca:Mg ratios of the grasses ranged from 0.49 to 0.91 in this study and were all less than 1, which was a result of the Mg concentration being higher than the Ca concentration. The lower Ca concentration in this study has been related to manure application (Chang et al., 1994) though not less than that which was required to meet the basic needs of ruminant animals (McDowell, 1992; 1997).

The K:Mg ratio (3.11 to 7.47) of the grasses was greatly affected by manure application, which is reflected by the concentration of Mg increasing with manure applied and as plants mature on average the K:Mg ratio decreases, and this might reduce the risk level of animals to tetany disorder (Qian et al., 2005). Ruminants consume pasture and forage, so the amount of magnesium in the soil affects how much magnesium is available to them. The amount of magnesium in the soil varies depending on the type of soil, and the amount of organic matter, fertilization, and soil pH all have an impact on how readily plants can access that magnesium (Gransee and Führs, 2013).

The tetany ratios recorded in this study were lower than 2.2 which was reported above when tetany disorder will occur (Jefferson et al., 2001). Harris and Shearer (2003) also noted that when K and N concentrations of forages are higher than 30 g/kg and 40 g/kg, respectively, the animals that feed on such forages are likely to be confronted with grass tetany but if such forages have Mg concentration > 2.5 g/kg then the occurrence of grass tetany might not be. Going by the result, the Mg concentrations were generally > 2.5 g/kg with few having K concentration > 30 g/kg and all having N concentration < 40 g/kg. This affirmed that the grasses could not lead to grass tetany if fed to the animals. The application of manure in this study generally reduced the tetany risk potential as the grasses mature. The closest K / (Ca+Mg) ratios (0.5 – 1.70) in this study to 2.2 was found with the unfertilized *M. maximus* var. Local harvested at 8 WAP and the farthest (0.5) was *M. maximus* var. Ntchisi with 100 kg N/ha harvested at 8 WAP. Invariably, the unfertilized *M. maximus* var. Local harvested at 8 WAP was closer to being hazardous to ruminant animals (Sleper et al., 1989; Zelal, 2017).

The N:P ratio (8.45 – 20.91) has been considered a diagnostic tool of value (Koerselman and Meuleman, 1996). The N:P ratio (21.86) of the unfertilized *M. maximus* var. Ntchisi harvested at 12 WAP is a clear indication of a forage highly limiting in Phosphorus and this is in line with the report of Güsewell et al. (2003) that stated that forages with N:P ratio > 20 implied of phosphorus limiting and might respond to P-fertilization. The higher N:P ratio for the unfertilized varieties is in line with the findings of Dele et al. (2021) where unfertilized forage legumes recorded higher N:P ratios than their fertilized counterparts. The K:N ratio (1.16 – 3.02) in this study ranged between 1.16:1 to 3.02:1 which according to FAO (1991) ranked all the forages to be surplus in K:N ratio.

***Microminerals***

Microminerals are available in comparatively small amounts in forages but are crucial components of ruminant livestock's diet (Brink et al., 2006). Manganese, the fifth most common metal on Earth, is necessary for development and fertility in animals (Suttle, 2010) as well as lipid and carbohydrate metabolism (Muraina et al., 2020). Most of the Mn concentrations found in this study were within the range (20-40 mg/kg) recommended for all classes of ruminant animals (McDowell, 1992; 1997) but few (about 33.3%) were above the recommended range and it showed that the Mn concentrations in this study were far from be toxic as 1000 mg/kg was the maximum tolerable level (NRC, 1984; 1989) for both beef and dairy cattle.

Iron is the most abundant element on Earth (Frey and Reed, 2012), a vital component of every living organism, and an essential micronutrient for all animal species. Iron is naturally abundant in forages; deficiencies in grazing animals are uncommon but could result from blood loss brought on by severe parasitic infestation or another type of hemorrhage (Suttle, 2010). Forage Fe concentration is impacted by variations in the species, the stage of growth and fertilization (Dele, 2012; Dele et al., 2021). *Megathyrsus maximus* fertilized with 100 kg N/ha harvested at 4 WAP recorded the least Fe concentration in this study, which fell within the range (30-50 mg/kg) recommended by McDowell (1992; 1997) for all classes of ruminants. More than 87 % of the forages in this study recorded Fe concentration higher than the range recommended, which could mean that the soil Fe concentration ab initio was high before the application of the different manure rates. The Fe concentration of all the forages in this study is above 30 mg/kg which classified them as "excessive" in Fe content (Tainton, 1988).

Copper is known as an essential microelement required by all ruminant species to sustain normal body functions and has many variations among the ruminant species, especially the small ruminants and is linked with both deficiency and toxicity disease concerns (Van Saun, 2012). The concentration of copper varies in forages as factors such as species, strain and maturity of the plant, with certain soil conditions and fertilizers play vital roles (McFarlane et al., 1990). However, Cu deficiencies have been generally traced to grazing animals (Spears et al., 2022). From this study, it was observed that a slightly similar or above 25% recorded Cu concentration was reported by MacPherson (2000) as the mean Cu (7.8 mg/kg) concentration for tropical grasses. Going by the 8 mg/kg recommended level for beef cattle (National Research Council, 1984), it showed the grasses are deficient in Cu concentration despite the different manure rates applied and this could be a result of Cu deficiency that is associated with tropical soils as reported by Abat et al. (2012). This might imply that Cu-related fertilizer might be needed to boost the Cu concentration of grasses as in this study. The higher Cu concentration (10 mg/kg) for dairy cattle (National Research Council, 1989) suggests that neither of the grasses nor all rates of manure applied could supply the Cu concentration need of dairy cattle.

As a component of metalloproteins and metalloenzymes, zinc is extensively distributed throughout the body of ruminant animals and plays a crucial role in a number of biological and metabolic processes. (Vallee and Falchuk, 1993), with its germane roles, it was observed that the range recorded in this study is high enough to meet the nutritional requirements of all classes of ruminants (McDowell, 1992; 1997) and fell within the range (20-40 mg/kg) recommended except for the unfertilized *M. maximus* var. Ntchisi harvested at

12 WAP and *M. maximus* var. Ntchisi fertilized at 100 kg N/ha harvested at 4 WAP with Zn concentration of 19.17 mg/kg and 15.24 mg/kg, respectively.

### *Microminerals relationship*

Iron and manganese are biochemically antagonistic as the abundance of one might lead to the non-availability of the other and are in competition with each other in terms of their absorption and enzyme-binding properties (Mengel and Kirby, 1978; Adriano, 2001). Healthy plants have been reported to have concentrations of Fe and Mn in ratios ranging between 1.5:1 to 2.5:1 (Adriano, 2001). About 58 % of the forages in this study were found to be classified as healthy plants and 42 % as having Fe concentration whose activities surpassed that of Mn and none was found to be less than 1.5 for which the Mn activities would have been considered higher than that of Fe.

The antagonistic risk between Fe and Cu have been classified into three namely low risk (<50:1), marginal risk (50-100:1) and high risk (>100:1) (Underwood and Suttle, 1999). By this classification, all the forages in this study were found to be low risk and this might mean that Fe had a lower impact on the concentration of Cu in terms of bioavailability of Cu.

The relationship between Fe and Zn has also been considered to be antagonistic in nature (Stewart, 2017), as Zn absorption has been reported to be suppressed whenever the Fe:Zn exceeds 2:1, which was evident in this study as about 88 % of the forages recorded Fe:Zn ration > 2:1. Invariably if animals are fed or grazed these forages, Zn supplementation will be needful to improve their body weight gain and feed efficiency (Stewart, 2017).

The relationship of zinc and copper is closely tied in terms of absorption and is to be maintained in a ratio of 3:1 (Stewart, 2017) and should not exceed 4:1 but all the forages in this study exceeded 3:1 except for *M. maximus* fertilized with 100 kg N/ha of manure harvested at 8 WAP which was in the ratio of 2.79:1.

## CONCLUSION

The calcium concentrations of the grasses are high enough to meet the nutrient requirement of different classes of ruminants and the tetany ratio values of both varieties in this study were lower than 2.2. The younger the grasses (4 WAP), the more they tend to be prone to tetany disorder compared to the older grasses (8 WAP and 12 WAP). The unfertilized grasses tend to be more prone to tetany disorder than the fertilized grasses and *M. maximus* var. Local was observed to be prone to tetany risk compared to *M. maximus* var. Ntchisi especially that which fertilized with 100 kg N/ha harvested at 8 WAP which recorded the least value (0.5). The grasses have sufficient microminerals to meet the nutritional requirements of different classes of ruminants except for copper concentration. The results show sufficient macro an microminerals to meet most classes of ruminant needs except for P and Cu for which supplementation is recommended to meet nutrient requirements.

## REFERENCES

Abat, M., McLaughlin, M.J., Kirby, J.K., Stacey, S.P. (2012) Adsorption and desorption of copper and zinc in tropical peat soils of Sarawak, Malaysia. Geoderma,175-176, 58–63. DOI: https://doi.org/10.1016/j.geoderma.2012.01.024

Ademosun, A.A. (1973) Nutritive evaluation of Nigerian forages. The effect of stage of maturity on the nutritive value of Guinea grass (*Panicum maximum*). Nigerian Agricultural Journal, 10, 170-177.

Adriano, D.C. (2001) Manganese. In: Trace elements in terrestrial environments. Biogeochemistry, bioavailability, and risks of metals 2nd edition. New York, Berlin and Heidelberg: Springer, pp. 547-585.

Ali, A.I.M., Sandi, S., Riswandi, R., Muhakka, M. (2019) Seasonal influence on mineral concentration of forages on flooded pastures in South Sumatra, Indonesia. Tropical Grasslands-Forrajes Tropicales, 7 (5), 527–532. DOI: https://doi.org/10.17138/tgft(7)527-532

Belesky D.P., Turner K.E., Fedders, J.M. (1995) Nitrogen and mineral composition of autumn-grazed pasture. Communications in Soil Science and Plant Analysis, 26 (17-18), 2941-2959. DOI: https://doi.org/10.1080/00103629509369499

Bengtsson, H., Öborn, I., Jonsson, S., Nilsson, I., Andersson, A. (2003) Field balances of some mineral nutrients and trace elements in organic and conventional dairy farming – a case study at Öjebyn, Sweden. European Journal of Agronomy, 20, 101–116. DOI: https://doi.org/10.1016/S1161-0301(03)00079-0

Brady, N.C., Weil, R.R. (2002) The nature and properties of soils. Prentice Hall, New Jersey, 960 p.

Brink, G. E., Sistani, K. R., Oldham, J. L., Pederson, G.A. (2006) Maturity effects on mineral concentration and uptake in annual Ryegrass. Journal of Plant Nutrition, 29 (6), 1143–1155. DOI: https://doi.org/10.1080/01904160600689308

Chang, C., Janzen, H.H., Entz, T. (1994) Long-term manure application effects on nutrient uptake by Barley. Canadian Journal of Plant Science, 74, 327-330. DOI: https://doi.org/10.4141/cjps94-062

Dele, P.A. (2008) Effect of plot management and fertilizer treatments on the growth, biomass yield and seed quality of two guinea grass varieties. M. Agric Dissertation, Department of Pasture and Range Management, University of Agriculture, Abeokuta, 84 p.

Dele, P. A. (2012) Evaluation of dry matter yield and nutritive quality of forage, hay and silage produced from three grasses fertilized with animal manures. Ph.D. Thesis, Federal University of Agriculture, Abeokuta, 263 p.

Dele, P. A., Akinyemi, B. T., Amole, T. A., Okukenu, O. A., Sangodele, O. T., Sowande, O. S., Olanite, J. A., Arigbede, O. M. and Jolaosho, A. O. (2017) Effect of manure type and season of harvest on the forage yield, quality and macro-elements of two *Panicum maximum* varieties. Nigerian Journal of Animal Science, 19 (1), 265-282.

Dele, P., Akinyemi, B., Okukenu, O., Amole, T., Akinlolu, A., Sarumi, G., Salawu, F. and Anotaenwere, C. (2018) Chemical Composition of *Panicum maximum* as Influenced by Poultry Manure Rate and Age at Harvest. Pacific Journal of Science and Technology, 19 (2), 319-325.

Dele, P., Akinyemi, B., Oyeleke, O., Anotaenwere, C., Salawu, F., Onifade, S. O. (2021) Mineral profile of *Panicum maximum* var. Ntchisi as influenced by organic nitrogen rate and age at harvest. In: Mureithi, J.G., Nyangito, M.M., Wamuongo, J.W., Njoka, J., Nyambati, E.M., Miano, D., Mbuku, S., Okoti, M., Martim, F., eds. Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods. Proceedings of the Virtual Joint XXIV International Grassland and XI International Rangeland Congress – Poster Papers, October 25-29, 2021, Nairobi, Kenya, University of Kentucky, pp. 385-388.

Delevatti, L.M., Cardoso, A.S., Barbero, R.P. Leite, R.G., Romanzini, E.P., Ruggieri, A.C., Reis, R.A. (2019) Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. Scientific Reports, 9, 7596.
DOI: https://doi.org/10.1038/s41598-019-44138-x

Dupas, E., Buzetti, S., Rabelo, F.H.S., Sarto, A., Cheng, N.C., Filho, M.C.M.T., Galindo, F.S., Dinalli, R.P., De Niro Gazola, R. (2016) Nitrogen recovery, use efficiency, dry matter yield, and chemical composition of palisade grass fertilized with nitrogen sources in the Cerrado biome. Australian Journal Crop Science, 10 (9), 1330.
DOI: https://doi.org/10.21475/ajcs.2016.10.09.p7854

FAO. (1991) Guidelines, Land evaluation for extensive grazing. [FAO] Soils Bulletin, No. 58, 158 p.

Fardous, A., Gondal, S., Shah, Z. A., Ahmad, K., Khan, Z. I., Ibrahim, M., Ejaz, A., Ahmad, W., Ullah, S., Valeem, E. E. (2010) Sodium, potassium and magnesium dynamics in soil-plant- animal continuum. Pakistan Journal of Botany, 42 (4), 2411–2421.

Fluharty, F.L. (2008) Updating phosphorus supplementation in ruminants to meet the animal's requirement, reduce excess cost, and reduce environmental concerns. Available at: https://agnr.osu.edu/sites/agnr/files/imce/pdfs/Beef/ReTkgPhos.pdf [Accessed 18 March 2023]

Frey, P.A., Reed G.H. (2012). The Ubiquity of Iron. ACS Chemical Biology Journal, 7, 1477–148. DOI: https://doi.org/10.1021/cb300323q

Fritz, J.S., Schenk, G.H. (1979) Quantitative analytical chemistry. 4th Ed., Allyn and Bacon, Inc., Boston, Massachusetts.

Gransee, A., Führs, H. (2013) Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant Soil, 368, 5–21.
DOI: https://doi.org/10.1007/s11104-012-1567-y

Güsewell, S., Koerselman, W., Verhoeven, J.T.A. (2003) Biomass N:P ratios as indicators of nutrient limitation for plant populations in wetlands. Ecological Applications, 13 (2), 372–384. DOI: https://doi.org/10.1890/1051-0761(2003)013[0372:BNRAIO]2.0.CO;2

Harris, B., Shearer, J. (2003) Nitrate, prussic acid (HCN) and grass tetany problems in cattle feeding. Univ. of Florida IFAS. Extension. Available at: https://ufdcimages.uflib.ufl.edu/IR/00/00/47/76/00001/DS16200.pdf [Accessed 05 April 2007].

Herdt, T.H., Hoff, B. (2011) The use of blood analysis to evaluate trace mineral status in ruminant livestock. Veterinary Clinical of North America: Food Animal Practice, 27 (2), 255–283.
DOI: https://doi.org/10.1016/j.cvfa.2011.02.004

Heuzé V., Tran G. (2020) Guinea grass (*Megathyrsus maximus*). Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. Available at: https://www.feedipedia.org/node/416 Last updated on September 15, 2020, 15, 40.

Islam, M.R., Saha, C.K., Sharker, N.R., Jahilil, M., Hasanuzzaman, M. (2003) Effect of variety on proportion of botanical fraction and nutritive value of different Napier grass (*Pennisetumpurpureum*) and relationship between botanical fraction and nutritive value. Asian Australian Journal of Animal Science, 16, 177–188.
DOI: https://doi.org/10.5713/ajas.2003.837

Jefferson, P.G., Mayland, H.F., Asay, K.H., Berdahl, J.D. (2001) Variation in mineral concentration and grass tetany potential among Russian Wildrye Accessions. Crop Science, 41 (2), 543–548.
DOI: https://doi.org/10.2135/cropsci2001.412543x

Jones, G.B., Tracy, B.F. (2013) Evaluating seasonal variation in mineral concentration of cool-season pasture herbage. Grass and Forage Science, 69, 1–8. DOI: https://doi.org/10.1111/gfs.12094

Juknevičius, S., Sabienė, N. (2007) The content of mineral elements in some grasses and legumes. Ekologija, 53 (1), 44–52.

Jumba, I.O., Suttle, N.F., Hunter, E.A., Wandiga, S.O. (1995) Effects of soil origin and composition and herbage species on the mineral composition of forages in the Mount Elgan region of Kenya. 1. Calcium, phosphorus, magnesium and sulfur. Tropical Grasslands, 29, 40–46.

Ketterings, Q.M., Godwin, G., Kilcer, T.F., Barney, P., Hunter, M., Cherney, J.H., Beer, S. (2006) Nitrogen, phosphorus, potassium, magnesium and calcium removal by brown midrib sorghum Sudangrass in the Northeastern USA. Journal of Agronomy and Crop Science, 192, 408—416.
DOI: https://doi.org/10.1111/j.1439-037X.2006.00228.x

Koerselman, W., Meuleman, A.F.M. (1996) The Vegetation N:P Ratio: a new tool to detect the nature of nutrient limitation. Journal of Applied Ecology, 33 (6), 1441–1450.
DOI: https://doi.org/10.2307/2404783

Lamidi, A.A., Ologbose, F.I. (2014) Dry season feeds and feeding: a threat to sustainable ruminant animal production in Nigeria. Journal of Agriculture and Social Research, 14, 17–30.

MacPherson, A. (2000) Trace-mineral status of forages. In: Givens, D.I., Owen, E., Axford, R.F.E., Omed, H.M., eds. Forage evaluation in ruminant nutrition. Wallingford UK: CAB International, pp. 345-371.

McDowell, L. R. (1992) Minerals in animal and human nutrition. Academic Press, San Diego, 524 p.

McDowell, L. R. (1996) Feeding minerals to cattle on pasture. Animal Feed Science and Technology, 60 (3–4), 247–271.
DOI: https://doi.org/10.1016/0377-8401(96)00983-2

McDowell, L.R. (1997) Minerals for grazing ruminants in tropical regions. 3rd Edn. University of Florida Press, Gainesville, FL, USA.

McDowell, L.R., J.H. Conrad, and Ellis, G.I. (1984) Mineral deficiencies and imbalances and their diagnosis. Proc. Symp. on Herbivore Nutrition in Sub-Tropics and Tropics. Pretoria, South Africa, pp. 67-88.

McFarlane, J.D., Judson, J.D., Gouzos, J. (1990) Copper deficiency in ruminants in the south east of Australia. Australian Journal of Experimental Agriculture, 30, 187–193. DOI: https://doi.org/10.1071/EA9900187

Mengel, K., Kirkby, E.A. (1987) Iron. In: Principles of Plant Nutrition. 4th edition. Bern, Worblaufen: International Potash Institute, pp. 493-511.

Minson, D.J. (1981) Nutritional differences between tropical and temperate pastures In: Grazing animals. Disciplinary Approach. World Animal Science 34. Elsevier, Amsterdam, pp. 143-157.

Minson, D.J. (1990) Forage in Ruminant Nutrition. Academic Press, London, 483 p.

Minson, D.J., Norton, B.W. (1982) The possible cause of the absence of hypomagnesemia in cattle grazing tropical pastures. Proceedings of the Australian Society of Animal Production, 14, 357-360.

Mohammed-Saleem, M.A. (1994) Evaluation of Stylosanthes for pasture development: An overview of ILCA's experience in Nigeria. In: De Leeuw, P.N., Mohammed-Saleem, M. A., Nyamu, A.M., eds. Stylosanthes as a Forage and Fallow Crop. Proceedings of the Regional Workshop on the Use of Stylosanthes in West Africa. Kaduna, Nigeria, October 23–31, 1992. International Livestock Centre for Africa, pp. 17–23.

Muraina, T.O., Jimoh, S.O., Ewetola, I.A. Ojo, V.O.A., Amisu, A.A., Okukenu, O.A., Adebisi, Y.A., Muraina, H.A., Olanite, J.A. (2020) Mineral composition of two Stylosanthes species oversown in natural pasture: effect of tillage practice and sowing method. Tropical Animal Health and Production, 52, 2753–2759. DOI: https://doi.org/10.1007/s11250-020-02305-7

National Research Council (1984) Nutrient Requirements of Beef Cattle, Sixth Edition. National Academies Press, Washington, D.C.

National Research Council (1989) Nutrient Requirements of Dairy Cattle, Sixth Edition. National Academies Press, Washington, D.C.

National Research Council (1996) Nutrient requirements of beef cattle, Seventh Edition National Academy Press, Washington, D.C.

Olanite, J.A. (2002) Evaluation of selected grass-legume mixtures as feed for weaner calves under traditional cattle management in Ibadan, Nigeria. Ph. D. Thesis. Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

Olanite, J.A., Jimoh, S.O., Adeleye, O.O., Ojo, V.O.A., Amisu, A.A., Ewetola, I.A., Okuribido, S. (2018) Assessment of some macromineral concentration of a grass/legume sward in relation to livestock requirements. Bulletin of Animal Health and Production in Africa, 66, 95–104.

Onifade, O. S., Olanite, J. A., Jolaosho, A. O., Arigbede, O. M., Tijani, N. K. (2005) Response of Guinea grass (*Panicum maximum*) to application of cow dung in Southwest, Nigeria. In: O'Mara, F. P., Wilkins, R. J., t'Mannetje, L., Lovett, D. K., Rogers, P. A. M., Boland, T. M., eds. Proceedings of the XX International Grassland Congress, Dublin Ireland, 26th June to 1st July 2005. Wageningen Academic, p. 396.

Qian, P., Schoenau, J.J., King, T., Japp, M. (2005) Effect of repeated manure application on potassium, calcium and magnesium in soil and cereal crops in Saskatchewan. Canadian Journal of Soil Science, 85, 397–403. DOI: https://doi.org/10.4141/S04-028

Reid, R.L., Jung, G.A. (1991) Plant/soil interactions in nutrition of the grazing animal. In: McCollum, F.T., Judkins, M.B., eds. Proceedings of 2nd Grazing Livestock Nutrition Conference, Colorado, 2-3 August 1991. Steamboat Springs, CO., pp. 48-63.

Reiné, R., Ascaso, J., Barrantes, O. (2020) Nutritional quality of plant species in Pyrenean hay meadows of high diversity. Agronomy, 10 (6), 883. DOI: https://doi.org/10.3390/agronomy10060883

Sanchez, P.A. (1994) Tropical soil fertility research: towards the second paradigm. In: Etchevers B., J. D., ed. Transactions. 15th World Congress of Soil Science, Acapulco, Mexico, July 1994 (Acapulco, Mexico), 1. Cornell University, pp. 65–88.

SAS Institute (2010) STAT-SAS, Version 9.4. SAS Institute, Cary, North Carolina.

Sleper, D.A., Vogel, K.P., As.y, K.H., Mayland, H.F. (1989) Using plant breeding and genetics to overcome the incidence of grass tetany. Journal of Animal Science, 67 (12), 3456-3462. DOI: https://doi.org/10.2527/jas1989.67123456x

Spears, J.W., Brandao, V.L.N., Heldt, J. (2022) Invited Review: Assessing trace mineral status in ruminants, and factors that affect measurements of trace mineral status. Applied Animal Science, 38, 252–267. DOI: https://doi.org/10.15232/aas.2021-02232

Stewart, L. (2017) Mineral supplements for beef cattle. UGA Cooperative Extension Bulletin 895. Athens, GA: University of Georgia.

Suttle, N.F. (2010) Mineral nutrition of livestock, 4th Edition, CABI Publishing: Cambridge, UK.

Tainton, N.M. (1988) Veld and pasture management in South Africa. Pietermaritzburg, South Africa: Shuter and Shooter/University of Natal Press, 481 p.

Underwood, E.J., Suttle, N.F. (1999) The mineral nutrition of livestock (3rd Ed.). CABI Publishing, New York.

Vallee, B.L., Falchuk, K.H. (1993) The biochemical basis of zinc physiology. Physiological Reviews, 73, 79-118. DOI: https://doi.org/10.1152/physrev.1993.73.1.79

Van Saun, R.J. (2012) Understanding copper nutrition in small ruminants. In: Smith, R. A., eds. Proceedings of the 45th Annual Conference of the American Association of Bovine Practitioners, Montreal, Canada, 20-22 September 2012, VM Publishing Company, pp.155-160.

Villa, Y.B., Khalsa, S.D.S., Ryals, R., Duncan, R.A., Brown, P.H., Hart, S.C. (2021) Organic matter amendments improve soil fertility in almond orchards of contrasting soil texture. Nutrient Cycling in Agroecosystems, 120, 343–361. DOI: https://doi.org/10.1007/s10705-021-10154-5

Warman, P. R., Termeer, W. C. (2005) Evaluation of sewage sludge, septic waste and sludge compost applications to corn and forage yields and N, P and K content of crops and soils. Bioresource Technology, 96 (8), 955–961. DOI: https://doi.org/10.1016/j.biortech.2004.08.003

Zelal, A. (2017) Hypomagnesemia tetany in cattle. Journal of Advances in Dairy Research, 5 (2),1-9. DOI: https://doi.org/10.4172/2329-888X.1000178