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Forage growth, yield and nutritional characteristics of four varieties of napier grass (*Pennisetum purpureum* Schumach) in the west Usambara highlands, Tanzania

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Low pasture biomass production and dry seasons fodder scarcity are among the major challenges affecting productivity of dairy cattle in Tanzania. Field experiments were set to evaluate growth, biomass yields and nutritional contents of four napier grass (*Pennisetum purpureum* Schumach) varieties as feed for ruminants. Experimental napier varieties included Ouma, Kakamega 2 (KK2), Bana and local napier (LN). The study was conducted in the Western Usambara highlands (WUHs) in Tanzania between December 2016 and April 2017 (110 days). The results indicated that the varietal mean stem heights differed significantly ($P<0.001$); whereby LN, Ouma, KK2 and Bana had mean heights of 210.81, 185.72, 177.15 and 145.44 cm respectively. There was a significant difference ($P=0.025$) in the mean total forage biomass production in which KK2, LN, Ouma and Bana yielded 16,551, 14,035, 12,868 and 8954 kg dry matter/ha respectively. The crude protein content averaged 9.92% and did not differ significantly across the varieties ($P=0.83$). The mean metabolizable energy was 7.94 MJ/kg dry matter and did not differ significantly across the varieties ($P=0.11$). The in vitro organic matter digestibility differed significantly ($P=0.03$); 65.87, 59.22, 58.33 and 55.41% for Ouma, Bana, KK2 and LN respectively. This study demonstrates that Ouma and KK2 can be established in the WUHs for forage use due to higher biomass production. Further studies on ensiling and animal feeding would provide valuable information for optimizing forage conservation and animal performance in the WUHs and elsewhere with similar conditions.

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Introduction

Napier grass (*Pennisetum purpureum* Schumach) is a fast growing and the highest biomass yielding tropical forage grass [1,2]. Napier grass is adapted to high rainfall areas including the East African highlands where a practice of smallholder dairy cattle farming is popular [2]. Land shortages and high population growth pressures is forcing the east African highland farmers to diversify production means through farming both crops and livestock in limited units of land [3]. Low pasture biomass production and dry seasons fodder scarcity are among the major challenges affecting productivity of dairy cattle in East Africa [4].

Introduction of high-yielding napier fodder varieties is among the most promising approach for improving forage availability in high rainfall areas under the mixed crop-livestock production systems [2,5]. However, both yields and nutritional values of napier grass have shown to be influenced by a multitude of factors including climatic conditions, edaphic environments, agronomic practices and genotypes [6–8]. Therefore, the knowledge on suitability of different napier varieties, cultivars or hybrids for a particular environment is worth generating towards fostering sustainable production.

In the WUHs, the practice of on-farm establishment of fodder grasses including local napier (LN) was highly promoted by the Soil Erosion Control and Agro-forestry Project (SECAP) from 1981 to 2000 [9]. The goal of the SECAP was to improve conservation of soil and water resources in sloppy farmlands through promotion of tree and perennial grasses establishment along the contour terraces. In concomitant to SECAP, the Tanga Dairy Development Programme (TDDP) supplied Zebu–Friesian crossbred dairy calf heifers to smallholder farmers in the WUHs. Also, TDDP promoted on-farm growing of fodder grasses including napier grass and guatemala grass (*Tripsacum laxum*) in the WUHs [10]. TDDP was implemented from 1985 to 2002 and prompted most smallholder farmers in the WUHs to adopt cattle farming. Cut and carry of fodder (zero grazing) is the predominant method of feeding dairy cattle under smallholder farming in the WUHs. In addition, napier grass and crop residues mainly maize stover are the most important feed resources for dairy cattle in the WUHs [11].

Despite the crucial role of the existing napier grass variety (LN) for providing fodder to dairy cattle in the WUHs, still dry seasons fodder scarcity remains a great challenge [11]. Nevertheless, little information exists on the establishment of alternative high yielding and nutritive novel napier varieties in the WUHs. Three napier varieties namely Bana, Ouma and Kakamega 2 which have been proven superior elsewhere were planted for the first time in the WUHs and compared against the existing local variety. Ouma, KK2 and Bana are widely grown by smallholder farmers in the Central and Western Highlands of Kenya [2,5,12,13]. Moreover, Bana has been reported to perform well in terms of biomass and nutrients in South East Asia and Hawaiian Islands of North America [6,14].

This study was set to evaluate the performances of four napier varieties in terms of growth, biomass yield and nutritional characteristics as feed for ruminants in the WUHs, Tanzania. The overall aim of this study was to generate new information with regard to alternative napier varieties with potential for improving fodder availability in terms of both quantity and quality in the WUHs. This information is deemed essential for enhancing sustainable livestock production in particular smallholder dairy production in the study area and elsewhere with similar conditions.

Methodology

Study area description

The field trials were conducted in the Western Usambara Highlands (WUHs) which are administratively located in Lushoto district, Tanga region, north eastern Tanzania. These highlands lie between latitudes 4° 38′ S and 4° 53′ S and longitudes 38° 14′ E and 38° 22′ E at an altitude ranging from 1200 to 1800 m above sea level (a.s.l). The mean annual rainfall in the WUHs is about 1100 mm and most of it falls between November and May. The mean annual temperature is 17.3 °C whereas the maximum is 20.3 °C (in February) and the minimum is 14.5 °C usually in July [15]. The dominant soil type in the agricultural lands is clay loam with average pH of 5.9 ± 0.84. The total Nitrogen and soil organic carbon contents are highly variable amounting to 3.31±2.18 and 38.5 ± 28.7 g kg^{-1} respectively [16]. The major occupation in the WUHs is farming whereby the dominant crops include maize, beans, potatoes, banana and vegetables (such as cabbages, carrots, eggplants and peppers). Ruminant livestock farming mainly involves cattle (crossbred dairy cattle kept under zero grazing), goats and sheep. The practices of growing napier and guatemala perennial grasses along the contour strips for soil erosion control and as livestock feed are popular [11]. The growing season is between November and May when there is ample rainfall. Monthly total precipitation and average temperatures recorded at the WUHs during the study period are presented in Fig. 1.

Planting materials, experimental design and plant establishment

Mature healthy stem cuttings of Ouma and KK2 were obtained from the Tanzania Livestock Research Institute (TALIRI) located in Tanga city, Coastal Tanzania. While those of Bana grass were sourced from Magadu Dairy Farm found within the Sokoine University of Agriculture (SUA) in Morogoro region, Eastern Tanzania. Moreover, the LN stem cuttings were obtained from smallholder farms in the study area.

Two on-farm experiments were set, including one in lowland and another at an upland site within the study area. The lowland site was located between latitude 4°49′ 45′′ south and longitude 38°18′ 25′′ east and at an altitude of 1206 m

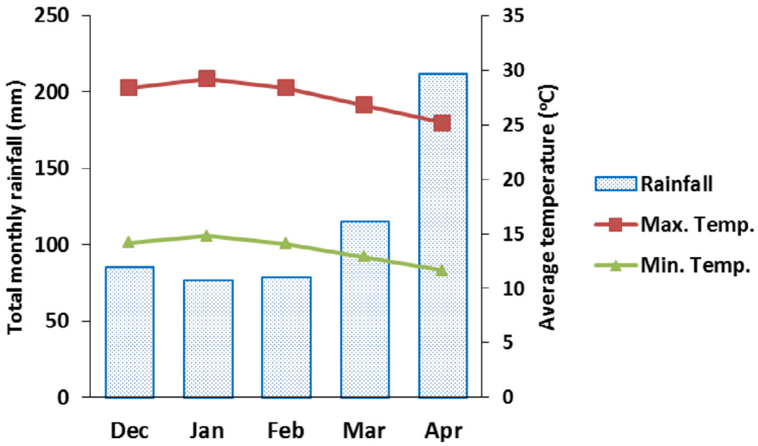

Fig. 1. Total monthly rainfall and average temperature at the study area between December 2016 and April 2017.

a.s.l in Bombo village. The upland site was located between latitude 4°40′ 10′′ south and longitude 38°15′ 28′′ east and at an altitude of 1779 m a.s.l in Hambalawei village. Both villages are administratively found in Lushoto district, Tanga region, Tanzania. Planting was done in 21st December 2016. A Completely randomized block design (CRBD) was adopted whereby the improved napier varieties (Pp cv Ouma, Pp cv KK2 and Pp cv Bana) as well as the LN (control) were replicated thrice. Twelve 2) plots were prepared in each site making a total of 24 plots. The plots had dimensions of 4×3 m^2; spaced 1 m apart and there was a 1 m wide path around the block boundary. In each plot, 3 contour furrows spaced 0.5 m apart and with a length of 4 m, 0.5 m width and 0.4 m depth were prepared.

The furrows were prepared through a sunken seedbed technique commonly called *Tumbikiza* method literally meaning planting in pits or furrows. The *Tumbikiza* method has been proved superior in enhancing napier grass biomass yields, soil moisture and nutrients retention and reducing soil erosion [2,17]. In brief during furrows preparation; the topsoil about 15 cm depth was mixed with pit composted dry cattle manure and returned to the furrow at the manure application rate of 5 kg/m^2. The subsoil (below 15 cm depth) was not returned to the furrows.

Within the furrows two napier stem cuttings about (30–45 cm long) were planted in two 25 cm apart parallel lines at a planting space of 50 cm along the furrow length. At least two nodes were inserted into the soil leaving a single internode at about 45° angle slanted to the ground. Also, dry *Grevilia robusta* tree leaves that were abundantly available were spread into the furrows at a thickness of about 10 cm as mulch. Due to rainfall inadequacy at the onset of the experiment, the furrows were irrigated twice a week at an interval of 3 days within the first three weeks to facilitate robust establishment. Weeding was done manually once.

Measurement of growth characteristics and sampling

Field measurements and sampling were done between 10 and 12th April 2017 when the plants were considered to be mature for forage use. At the time of field measurement each of the two planted stem cuttings had established a bunch of tillers. Number of tillers per bunch was counted in three inner bunches of each plot. In each bunch, three tillers/stems including the tallest, medium and shortest were used for measurement of growth characteristics. The recorded parameters included stem height, leaves per stem, leaf length, leaf width, internodes per stem, basal stem diameter and leaf area index (LAI). The fourth leaf from the stem/tiller's tip was used for measuring leaf length and width measured at the center. Number of leaves and visible internodes were counted for each of the measured stem. The basal diameter of the stem was measured at the lowest internode by means of a vernier caliper. The leaf area index (LAI) was measured using a Samsung Galaxy S4 Smartphone installed with the PocketLAI app (a Smartphone App developed for estimating plant LAI) through non-destructive techniques [18]. A 0.25 m^2 quadrat metal frame was used for destructive sampling in which it was placed once at the center of each of the three furrows within a plot. Within a quadrat, the enclosed bunch of forage was cut at about 15 cm stubble height and total fresh weight was measured. Thereafter, leaves excluding the leaf sheaths were stripped off the stem/cane and both the stem and leaves' fresh weight was measured separately. Leaf and stem sub-samples of about 0.3 kg were packed, labeled and taken to laboratory for nutrients concentration analysis including dry matter percent. The leaf to stem ratio (LSR) was computed by dividing the leaf to stem dry matter yields. The total forage dry matter yield was obtained through summing up the leaf and stem dry matter yields.

Forage sample laboratory analysis

The forage sub-samples were oven dried at 80 °C to constant weight and thereafter ground to pass through a 2 mm sieve. The analyzed nutritive values included dry matter (DM), crude protein (CP), crude fat (EE), neutral detergent fibre (NDF), acid

Table 1
Effects of variety and site on the growth characteristics of four napier varieties.

Variable	Variety				S.E.M	*P*-value		
	Bana	KK2	Ouma	LN		Variety	Site	Variety x Site
Stem height (cm)	145.44[c]	177.15[b]	185.72[b]	210.81[a]	2.88	<0.001	0.936	0.019
Tillers per bunch (no.)	9.96[d]	18.17[b]	28.87[a]	16.33[c]	0.53	<0.001	<0.001	<0.001
Basal stem diameter (cm)	2.19[a]	1.81[b]	1.18[c]	1.73[b]	0.34	<0.001	0.889	0.646
Leaves per stem (no.)	11.17[b]	13.50[a]	11.46[b]	12.65[ab]	0.30	0.015	0.114	0.029
Leaf length (cm)	89.48[a]	84.74[a]	85.72[a]	86.28[a]	1.01	0.322	<0.001	0.621
Leaf width (cm)	3.69[a]	2.74[b]	2.33[c]	2.46[c]	0.05	<0.001	0.006	0.067
Internodes per stem (no.)	4.46[d]	7.28[b]	6.34[c]	8.72[a]	0.19	<0.001	<0.001	0.103
LAI (dimensionless)	2.23[d]	3.37[b]	3.82[a]	2.69[c]	0.08	<0.001	0.086	0.520

Variable means followed by same letter within the same row are not significantly different (P > 0.05); S.E.M = standard error of the mean.

detergent fibre (ADF), ash and mineral element (Ca and P) percentage content. Near-infrared spectroscopy (NIRS) techniques as described by Corson et al. [19] were used in analyzing the nutritive values at the Tanzania Veterinary Laboratory Agency (TVLA), Dar es Salaam, Tanzania. While the in vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD) were estimated using the 2-stage technique of Tilley and Terry [20]. A 0.5 g of ground forage sample was incubated in rumen liquor obtained from a fistulated dairy steer maintained on a mixture of fresh napier and natural grass hay at SUA. The IVDMD and IVOMD analysis were done at the Animal Nutritive Analytical Laboratory of SUA, Morogoro, Tanzania. The metabolizable energy (ME) was computed using the formula (Eq. (1)) by MAFF [21].

$$ME = \frac{(\mathbf{IVDMD} \times (100 - \mathbf{Ash}\%))}{100} \times 0.15 \tag{1}$$

Statistical analysis

Statistics for the above ground growth morphological characteristics, biomass yields and nutritional contents were computed using the STATISTICA 8.0 software package [22]. The 2×4 factorial ANOVA considering two sites and four napier varieties was employed to test the overall effects and interactions between sites and varieties. The following model was used: $Yijk = \mu + Vi + Sj + (VS)ij + eijk$,

Where μ = overall mean, Vi = effects of the *v*th variety, Sj = effects of the *s*th site, (VS)ij = effects of the interaction between the *v*th variety and the *s*th site and eijk = error term.

The Fisher's Least Significant Difference post hoc test was used to do the pairwise comparison of the means. The means were considered to be statistically significant different when $P<0.05$.

Results

Forage growth characteristics

The above ground forage growth characteristics of the 4 napier varieties are presented in Table 1. In general, there was a significant difference in the mean stem height of the 4 napier varieties ($P<0.001$) while site did not have a significant effect ($P=0.936$). But the interaction between varietal height and site was significant (0.019). The varietal stem height was in order of LN>KK2/Ouma>Bana; note no significant difference between KK2 and Ouma ($P>0.05$). The mean number of tillers per bunch varied significantly between varieties and sites ($P<0.001$) and was in order of Ouma>KK2>LN>Bana. All two-way comparisons of the mean tiller number per bunch were significantly different ($P<0.05$). The basal stem diameter varied significantly among the varieties ($P<0.001$) but site did not have a significant effect ($P=0.889$). Bana had the thickest basal stem diameter and Ouma the thinnest ($P<0.05$). However, there was no significant difference between the mean stem basal diameter of KK2 and that of LN ($P>0.05$).

The mean number of leaves per stem varied significantly among the varieties ($P=0.015$) but not sites ($P=0.114$). Concerning mean leaf length, there was no significant difference among the varieties ($P=0.322$), however differed significantly between sites ($P<0.001$). The mean leaf width varied significantly among the varieties ($P<0.001$) and sites ($P=0.006$). The varietal leaf width was in the order of Bana>KK2>Ouma/LN; note no significant difference between Ouma and LN ($P>0.05$).

The number of internodes per stem varied significantly among varieties ($P<0.001$) and sites ($P<0.001$). The mean number of internodes per stem was in the order of LN>KK2>Ouma>Bana. All two-way comparisons of the mean number of internodes per stem were significantly different ($P<0.05$). The mean LAI varied significantly among varieties ($P<0.001$) but not sites ($P=0.086$). The mean LAI was found to be in the order of Ouma>KK2>LN>Bana. All two-way comparisons of the mean LAI for the four napier varieties were significantly different ($P<0.05$).

Table 2
Effects of variety and site on the yield performance of four napier varieties.

Variable	Variety				S.E.M	P-value		
	Bana	KK2	Ouma	LN		Variety	Site	Variety x Site
Leaf DM%	17.44[b]	22.06[a]	22.87[a]	21.81[a]	0.75	0.057	0.035	0.808
Stem DM%	8.29[d]	10.63[cd]	14.7[ab]	11.98[bc]	0.54	<0.001	0.422	0.514
Total DM%	12.87[b]	16.34[ab]	18.78[a]	16.90[ab]	0.84	0.105	0.364	0.972
Leaf DM yield (kg/ha)	4901[b]	7909[a]	6527[ab]	6496[ab]	477	0.141	0.003	0.648
Stem DM yield (kg/ha)	4053[b]	8642[a]	6341[ab]	7539[a]	535	0.009	0.009	0.192
Total biomass yield (kgDM/ha)	8954[b]	16551[a]	12868[ab]	14035[ab]	955	0.025	0.003	0.426
LSR	1.39[a]	0.987[b]	1.19[ab]	0.89[b]	0.064	0.014	0.020	0.029

Variable means followed by same letter within the same row are not significantly different (P > 0.05); S.E.M = standard error of the mean.

Table 3
Effects of variety and site on nutritional values of four napier varieties.

Variable	Variety				S.E.M	P-value		
	Bana	KK2	Ouma	LN		Variety	Site	Variety x Site
CP%	9.73[a]	10.40[a]	9.98[a]	9.58[a]	0.31	0.829	0.649	0.912
NDF%	63.70[ab]	65.24[ab]	62.93[b]	66.63[a]	0.55	0.084	0.231	0.620
ADF%	36.88[ab]	36.60[ab]	35.83[b]	39.40[a]	0.55	0.094	0.187	0.409
EE%	1.95[a]	1.90[a]	2.05[a]	2.04[a]	0.08	0.889	0.900	0.260
Ash%	8.62[a]	9.35[a]	9.38[a]	7.96[a]	0.37	0.174	0.001	0.632
Ca%	0.24[a]	0.26[a]	0.29[a]	0.21[a]	0.02	0.349	0.466	0.476
P%	0.13[a]	0.19[a]	0.15[a]	0.19[a]	0.01	0.191	0.001	0.219
IVDMD%	55.55[ab]	55.28[ab]	60.84[a]	52.09[b]	1.21	0.085	0.793	0.429
IVOMD%	59.22[ab]	58.33[ab]	65.87[a]	55.41[b]	1.27	0.030	0.690	0.677
ME(MJ/KgDM)	7.92[ab]	7.85[ab]	8.57[a]	7.42[b]	0.18	0.109	0.004	0.413

Variable means followed by same letter within the same row are not significantly different (P > 0.05); S.E.M = standard error of the mean.

Forage biomass production

The forage biomass production of the four napier varieties in terms of leaf and stem DM%, leaf and stem DM yields (kg/ha), total biomass yield (kgDM/ha) and LSR are presented in Table 2. Generally, the leaf DM% did not vary significantly among the varieties ($P = 0.057$) but differed significantly between sites ($P = 0.035$). Bana had the lowest leaf DM% and there was no significant difference among the rest of varieties ($P > 0.05$). The stem DM% differed significantly among the varieties ($P < 0.001$) but not between sites ($P = 0.422$).

The leaf DM yield did not vary significantly among the varieties ($P = 0.141$) but varied between sites ($P = 0.003$). The stem DM yield varied significantly between varieties ($P = 0.009$) and sites ($P = 0.009$). Among the four varieties; LN and KK2 had the highest stem DM yields. The forage biomass DM yield varied significantly among the varieties ($P = 0.025$) and between the sites ($P = 0.003$). Among the four varieties; LN and KK2 had higher ($P < 0.05$) stem DM yields than Ouma and bana. The LSR differed significantly among the varieties ($P = 0.014$) and between the sites ($P = 0.02$). The LSR of KK2, Ouma and LN did not differ significantly ($P > 0.05$). Also, the LSR of Bana and Ouma were statistically similar ($P > 0.05$).

The interaction between variety and site was only significant for the LSR ($P = 0.029$) while for the rest of variables it was insignificant ($P > 0.05$).

Nutrient concentrations

The selected nutritional values as forage for ruminants of the four napier varieties were determined and presented in Table 3. In general, neither variety ($P = 0.829$) nor site ($P = 0.649$) had significant effect on the CP concentration. All two-way varietal comparisons of the mean CP were not significantly different ($P > 0.05$). The NDF and ADF did not vary significantly among the varieties and between the sites. The concentrations of EE, Ash, Ca and P did not vary significantly among the varieties but that of Ash and P differed significantly between sites (Table 3). The IVDMD did not differ significantly among the varieties ($P = 0.085$) and between sites ($P = 0.793$). The IVOMD varied significantly among the varieties ($P = 0.03$) but not between the sites ($P = 0.69$). Only the IVOMD% of Ouma differed significantly from that of LN ($p < 0.05$) while that of Bana and KK2 were in between that of Ouma and LN ($P > 0.05$). The ME did not differ significantly across the varieties ($P = 0.109$) but varied significantly between the sites ($P = 0.004$). There was no observed significant interaction between variety and site among all the nutritional value parameters (Table 3).

Table 4
Correlations between forage growth parameters in four napier varieties.

	Leaf yield (kgDM/ha)	Biomass yield	LSR	Stem height	Leaves per stem	Internodes per stem	Tillers per bunch	Leaf length	Leaf width	Basal stem diameter
Biomass yield (kgDM/ha)	0.94*									
Stem yield	0.78*	0.95*								
LSR	0.19	−0.12								
Stem height (cm)	0.14	0.17	−0.1							
Leaves per stem (no.)	0.05	0.08	−0.2	0.19						
Internodes per stem (no.)	−0.03	0	−0.25*	0.26*	0.37*					
Tillers per bunch (no.)	−0.03	0.02	−0.2	0.24*	0.06	0.18				
Leaf length (cm)	0.05	0.11	−0.1	−0.02	−0.15	−0.14	−0.02			
Leaf width (cm)	−0.04	−0.08	0.17	−0.42*	0.03	−0.31*	−0.55*	0.03		
Basal stem diameter (cm)	−0.07	−0.1	0.14	−0.31*	0.05	−0.16	−0.64*	0	0.64*	
LAI	0.06	0.09	−0.1	0.17	0.16	−0.05	0.38*	−0.07	−0.25*	−0.31*

*Correlations marked with * are significant ($P < 0.05$).*

Correlations of forage growth and yield parameters

The correlation matrix of forage growth and yield parameters are presented in Table 4. In general, leaf yield, stem yield and overall biomass yield had strong positive relationship between each other. LSR had weak negative relationship with internodes per stem. Stem height had weak positive relationship with tillers per bunch and internodes per stem, but negatively related to leaf width and basal stem diameter. Leaves per stem were positively associated to number of internodes per stem. Internodes per stem had weak negative relationship with leaf width. Tiller numbers per bunch were found to have strong negative relationship with basal stem diameter and leaf width. Leaf width had strong positive relationship with basal stem diameter while it has weak negative relationship with LAI. Basal stem diameter was found to have negative relationship with LAI.

Discussion

Forage growth characteristics

The four napier varieties varied in growth parameters including stem height, tiller numbers, leaf sizes and LAI. These variations imply that the varieties under study exhibit different adaptation potentials to the cooler and wet conditions of WUHs. There are previous studies with similar findings on wide range of variation of growth parameters among napier grass varieties [5,23,24]. Ouma consistently produced higher number of tillers per bunch followed by KK2 and LN while Bana the least. According to Lafarge and Loiseau [25] tiller production is vital for perennial grasses to sustain forage production through replacing plant parts that are lost through ageing, grazing or cutting. All varieties except Bana achieved the recommended harvesting height of 150 cm within 110 days in WUHs. Also, in comparison to other varieties Bana had the smallest number of leaves and internodes per stem, and this can be attributed to its shorter stems. However, in terms of basal stem diameter and leaf width; Bana outperformed all varieties indicating that it invested more on stem thickness and leaf size rather than other parameters such as number of tillers per bunch and stem elongation. Similarly, Nyambati et al. [5] recorded broader leaves and shorter stems in Bana grass relative to other 12 napier cultivars which were compared in the Western Kenya.

The LAI was significantly higher in Ouma followed by KK2 and LN while Bana had the least. According to Kubota et al. [26] stem elongation and erection is essential for enhancing canopy light penetration and hence photosynthesis efficiency in C4 grasses. Hence, the low LAI in Bana might be attributed to its low tiller number per bunch and the observed slightly decumbent growth habit while the rest of grasses exhibited erect stem growth habit. Nevertheless, the measured LAI values (2.2–3.8) in this study were well below those obtained by Kubota et al. [26] who reported LAI of 12.4 in napier sward aged 75 days and with over 2 m canopy height. Comparable LAI results ranging from 1.7 to 4.1 were reported by Guenni et al. [27] working in five Brachiaria grass species in a tropical environment. The lower LAI values of this study compared to those of previous studies might be attributed to the methodological differences [28]. Similarly, [18] observed that PocketLAI provided low LAI values in comparison to those measured using commercial instruments namely LAI-2000 and Accu-PAR Ceptometer. Nevertheless, based on growth morphological characteristics Bana did not perform well in the WUHs in comparison to Ouma, KK2 and LN varieties.

Forage biomass production

The DM yield results for KK2, LN and Ouma varieties under the present study are in conformity to those reported by Halim et al. [18]. Whereby, they recorded DM yields for a single cut of 12,640, 14,420 and 15,840 kg/ha for tall napier varieties namely Red napier, Common Napier and King grass respectively. Also, in agreement with Nyambati et al. [5] who reported an average yield of 13.5 tDM/ha per cutting for eight napier varieties in Western Kenya. However, in this study

Bana grass which is a tall napier variety was found to have contrasting DM yields (8954 kgDM/ha) comparable to those of dwarf napier varieties. Halim et al. [23] reported single cutting DM yields of 8000 and 8720 kgDM/ha for Australian Dwarf and Dwarf 'Mott' napier varieties, respectively. In contrary to this study, Nyambati et al. [5] recorded an average of 16.2 tDM/ha for Bana in 8 cuttings under Nitrogen and Phosphorus fertilizer application. The significantly higher DM yields of KK2 and Ouma which were comparable to that of LN indicated that they are suitable for enhancing forage production in the WUHs. The observed low DM yields for Bana indicated that it is not suitable for enhancing forage biomass availability in the smallholder farms of WUHs. However, the recorded higher LSR for Bana indicates that it has potential for enhancing leaf availability which is among the key parameters to be considered for high quality fodder production [29]. Similarly, Mwendia et al. [30] reported higher LSR for Bana grass (4.98) compared to that of Kakamega1 (2.49) and KK2 (3.32) in the highlands of Kenya.

Nutrient concentrations

Similar to yields the nutrient content of forage is an essential element to consider on selection of fodder varieties for livestock production. The major nutrients required by ruminant animals are carbohydrates and proteins. In particular, these nutrients are essential for animal body growth, maintenance, reproduction and production e.g. milk, beef and wool [31]. Rusdy [1] asserted that the CP for napier grass ranges from 4.4 to 20.4% with a mean of 12%. Genotypes, harvesting age and environment have been identified as the major sources of variation. In the present study the mean CP concentrations of the napier varieties was 9.92≈10%. Unlike the present study, Gemiyo et al. [32] reported lower CP values ranging between 4.2 and 6.7% across 10 napier accessions at 2 months harvesting interval and unfertilized conditions in Southern Ethiopia. According to National Research Council (NRC) [31] for sustainable production and maintenance a dairy cattle require feeds with a CP between 14 and 16%.

The mean ME values in the present study ranged from 7.4 to 8.5 MJ/KgDM and are comparable to 7.1 MJ/KgDM reported by Turano et al. [33]. However, NRC [31] recommends 10 MJ/KgDM as minimum ME requirement for dairy cattle. This implies that supplementary protein-energy rich feed sources are required for optimal milk production if the napier varieties under the study are to be the basal dairy cattle feed in the WUHs.

The concentrations of fibers (NDF and ADF), crude fat (EE) Ash and minerals (Ca and P), are generally concurring to earlier recorded values in napier grass varieties [1,2,33]. For example, the NDF values followed within the range of 45–65% which is regarded as roughage feed of moderate quality [33]. According to NRC [31] minerals are very essential for ruminant animal reproduction (conception, gestation and calving), growth, maintenance and production (e.g. milk, beef and wool). In this study, mean phosphorus (P) concentrations ranged from 0.13 to 0.19% while calcium (Ca) ranging from 0.21 to 0.29%. The observed values under this study are further below the recommended concentrations of 0.36 and 0.43% for P and Ca respectively. Nonetheless, forage mineral and ash contents are reported to be influenced by edaphic factors, seasons and biomass dry matter proportion [34].

The mean ranges in vitro digestibility values under this study were IVDMD (52.1–60.8%) and IVOMD (55.4–65.9). These results are in agreement with [1] who generally revised IVDMD for napier grass ranging from 55.7 to 81.7% whilst IVOMD ranged from 35 to 66.4%. Moreover, the varietal differences were significant in IVOMD with Ouma being most digestible and LN the least. The observed higher IVOMD of Ouma might be attributed to its low NDF contrary to LN. High NDF contents render forage digestibility and intake by ruminants due to increased fraction of indigestible structural carbohydrates in the feed ration.

Correlations of forage growth and yield parameters

In this study, it was observed that tiller numbers per bunch has significant negative association with basal stem diameter (r=−0.64) as well as with leaf width (r=−0.55). This can be explained by the tiller density versus tiller size compensation theory which states that forage grasses might either adopt a high density of small tillers or low density of bigger tillers as a strategy to maximize canopy light access [35]. Ouma which had the highest number of tillers per bunch had thinnest tillers and leaves. Interestingly, Bana grass which was observed to have broadest leaves and thickest tillers/stems had the smallest number of tillers per bunch. Nevertheless, the stem height tended to be negatively related to basal stem diameter (r=−0.31) and leaf width (r=−0.42). Tiller number per bunch tended to be positively related to stem height ($r = 0.24$) and LAI ($r = 0.38$). This observation can be attributed to the fact that all napier varieties except bana were observed to exhibit erect growth habit and achieved higher heights. This is in agreement to Kubota et al. [26] who affirmed that in napier grass stem elongation and erection has positive association with leaf area index. The observation that LSR had weak negative association with stem height (r=−0.1) might be attributed to the fact that Bana which was the shortest was the most leafy variety.

Conclusion

This study demonstrated that KK2 and Ouma alongside LN performed well in terms of forage biomass production (12–16 t/ha) while Bana the least (≈9 t/ha) in the WUHs of Tanzania. Also, it was established that the nutrient concentrations including CP (≈10%) and ME (7.4 – 8.6 MJ/KgDM) was almost similar for the four napier varieties. Nevertheless, all the effects of interactions between variety and sites on forage biomass and nutrient concentrations parameters were not statistically significant. This implies that similar outcomes for the four varieties can be expected in both lowland and upland sites of the WUHs.

Hence, farmers in the WUHs are advised to cultivate Ouma and KK2 alongside LN. Further studies on ensiling and animal feeding of napier varieties are suggested. This is deemed essential for generating valuable information for optimizing forage conservation and animal performance in the WUHs and elsewhere with similar conditions. Additionally, studies on molecular characterization to discern the genotypes of the WUHs' local napier variety are advised.

Declaration of Competing Interest

The authors declare no conflict of interest.

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References

[1] M. Rusdy, Elephant grass as forage for ruminant animals, Livest. Res. Rural Dev. 28 (4) (2016) Retrieved from http://www.lrrd.org/lrrd28/4/rusd28049.html .
[2] Orodho, A.B., The role and importance of napier grass in the smallholder dairy industry in kenya, Food and Agriculture Organization, Rome, 2006. Retrieved from http://www.fao.org/ag/agp/agpc/doc/newpub/napier/napier_kenya.htm.
[3] Herrero, M., Thornton, P.K., Notenbaert, A., Msangi, S., Wood, S., Kruska, R., … and P.R. Parthasarathy, Drivers of change in crop–livestock systems and their potential impacts on agro-ecosystems services and human wellbeing to 2030, 2012. ILRI Project Report. Nairobi, Kenya. Retrieved from https://cgspace.cgiar.org/handle/10568/3020.
[4] C. Wambugu, F. Place, S. Franzel, Research, development and scaling-up the adoption of fodder shrub innovations in east Africa, Int. J. Agric. Sustain. 9 (1) (2011) 100–109 https://doi.org/10.3763/ijas.2010.0562.
[5] E.M. Nyambati, F.N. Muyekho, E. Onginjo, C.M. Lusweti, Production, characterization and nutritional quality of napier grass [*Pennisetum purpureum* (Schum.)] cultivars in western Kenya, Afr. J. Plant Sci. 4 (12) (2010) 496–502.
[6] K. Rengsirikul, Y. Ishii, K. Kangvansaichol, P. Sripichitt, V. Punsuvon, P. Vaithanomsat, S. Tudsri, Biomass yield, chemical composition and potential ethanol yields of 8 cultivars of napiergrass (*Pennisetum purpureum* schumach.) harvested 3-monthly in central Thailand, J. Sustain. Bioenergy Syst. 3 (2) (2013) 107–112 https://doi.org/10.4236/jsbs.2013.32015.
[7] G. Kebede, F. Feyissa, G. Assefa, M. Alemayehu, A. Mengistu, A. Kehaliew, M. Abera, Chemical composition and in vitro organic matter digestibility of napier grass (*Pennisetum purpureum* (L.) schumach) accessions in the mid and highland areas of ethiopia, Int. J. Livest. Res. 6 (2016) 41–59.
[8] A.T. Negawo, A. Teshome, A. Kumar, J. Hanson, C.S. Jones, Opportunities for napier grass (*Pennisetum purpureum*) improvement using molecular genetics, Agronomy 7 (2) (2017) 28 https://doi.org/10.3390/agronomy7020028.
[9] Mowo, J.G., Mwihomeke, S.T., Mzoo, J.B. and T.H. Msangi, Managing natural resources in the west Usambara mountains: a glimmer of hope in the horizon. In Mountain High Summit Conference for Africa. 6–10 p, 2002. Retrieved from http://lib.icimod.org/record/10929/files/213.pdf.
[10] Food and Agriculture Organization (FAO), Dairy development programme in Tanga, Tanzania. 1992. Retrieved from http://www.fao.org/Wairdocs/ILRI/x5485E/x5485e0p.htm.
[11] D. Maleko, W.T. Ng, G. Msalya, A. Mwilawa, L. Pasape, K. Mtei, Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in western usambara highlands, Tanzania, Trop. Anim. Health Prod. 50 (7) (2018) 1653–1664 https://doi.org/10.1007/s11250-018-1609-4.
[12] M.M. Mulaa, D.J. Bergvinson, S.N. Mugo, J.M. Wanyama, R.M. Tende, H.D. Groote, T.M. Tefera, Evaluation of stem borer resistance management strategies for bt maize in Kenya based on alternative host refugia, Afr. J. Biotechnol. 10 (23) (2011) 4732–4740.
[13] ICIPE (International Centre of Insect Physiology and Ecology)., Solving napier stunt disease to save the smallholder dairy sector in east africa—a success story. ICIPE, Nairobi, Kenya. 2014. Retrieved from https://pdfs.semanticscholar.org/f287/e37c391f5058b0474e9c3e3871e0cac1ecef.pdf.
[14] C.N. Lee, G.K. Fukumoto, M.S. Thorn, M.H. Stevenson, M. Nakahata, R.M. Ogoshi, Bana grass (Pennisetum purpureum): a possible forage for ruminants in hawaii, Pasture Range Manag. (2016) 1–8 PRM-11Retrieved from www.ctahr.hawaii.edu/oc/freepubs/pdf/PRM-11.pdf .
[15] F. Rubel, M. Kottek, Observed and projected climate shifts 1901-2100 depicted by world maps of the köppen-geiger climate classification, Meteorol. Z. 19 (2) (2010) 135–141, doi:10.1127/0941-2948/2010/0430.
[16] L. Winowiecki, T.G. Vågen, B. Massawe, N.A. Jelinski, C. Lyamchai, G. Sayula, E. Msoka, Landscape-scale variability of soil health indicators: effects of cultivation on soil organic carbon in the usambara mountains of Tanzania, Nutr. Cycl. Agroecosyst. 105 (3) (2016) 263–274, doi:10.1007/s10705-015-9750-1.
[17] E.M. Nyambati, C.M. Lusweti, F.N. Muyekho, J.G. Mureithi, Up-scaling napier grass (*Pennisetum purpureum* schum.) production using *tumbukiza* method in smallholder farming systems in northwestern Kenya, J. Agric. Ext. Rural Dev. 3 (1) (2011) 1–7.
[18] C. Francone, V. Pagani, M. Foi, G. Cappelli, R. Confalonieri, Comparison of leaf area index estimates by ceptometer and pocketlai smart app in canopies with different structures, F. Crop. Res. 155 (2014) 38–41, doi:10.1016/j.fcr.2013.09.024.
[19] D. Corson, G.C. Waghorn, M.J. Ulyatt, J. Lee, NIRS: forage analysis and livestock feeding, in: Proceedings of the Conference-New Zealand Grassland Association, 1999, pp. 127–132.
[20] J.M.A. Tilley, R.A. Terry, A two-stage technique for the in vitro digestion of forage crops, Grass Forage Sci. 18 (2) (1963) 104–111, doi:10.1111/j.1365-2494.1963.tb00335.x.
[21] MAFF (Ministry of Agriculture, Fisheries and Food)., Energy allowances and feeding systems for ruminants. department of agriculture and fisheries for scotland and department of agriculture for northern Ireland, Technol. Bull. 33 (1975) Her Majesty's Stationery Office.
[22] C.H. Weiß, Inc. StatSoft, O.K. Tulsa, STATISTICA, version 8, Adv. Stat. Anal 919 (3) (2007) 339–341, doi:10.1007/s10182-007-0038-x.
[23] R.A. Halim, S. Shampazuraini, A.B. Idris, Yield and nutritive quality of nine napier grass varieties in Malaysia, Malays. J. Animal Sci. 16 (2) (2013) 37–44.
[24] L. Khairani, Y. Ishii, S. Idota, R.F. Utamy, A. Nishiwaki, Variation in growth attributes, dry matter yield and quality among 6 genotypes of napier grass used for biomass in year of establishment in southern Kyushu, Japan, Asian J. Agric. Res. 7 (1) (2013) 15–25, doi:10.3923/ajar.2013.15.25.
[25] M. Lafarge, P. Loiseau, Tiller density and stand structure of tall fescue swards differing in age and nitrogen level, Eur. J. Agron. 17 (3) (2013) 209–219, doi:10.1016/S1161-0301(02)00011-4.

[26] F. Kubota, Y. Matsuda, W. Agata, K. Nada, The relationship between canopy structure and high productivity in napier grass, Pennisetum purpureum Schumach. F. Crop. Res. 38 (2) (1994) 105–110, doi:10.1016/0378-4290(94)90004-3.
[27] O. Guenni, J.L. Gil, Y. Guedez, Growth, forage yield and light interception and use by stands of five brachiaria species in a tropical environment, Trop. Grassl. 39 (1) (2005) 42–53.
[28] R. Confalonieri, M. Foi, R. Casa, S. Aquaro, E. Tona, M. Peterle, T. Guarneri, Development of an app for estimating leaf area index using a smartphone: trueness and precision determination and comparison with other indirect methods, Comput. Electron. Agric. 96 (2013) 67–74, doi:10.1016/j.compag.2013.04.019.
[29] A.J. Smart, W.H. Schacht, L.E. Moser, J.D. Volesky, Prediction of leaf/stem ratio using near-infrared reflectance spectroscopy (NIRS), Agron. J. 96 (1) (2004) 316–318.
[30] S.W. Mwendia, D.M. Mwangi, R.G. Wahome, M. Wanyoike, Assessment of growth rate and yields of three napier grass varieties in central highlands of Kenya, East Afr. J. Agric. Res. 74 (3) (2008) 211–217.
[31] NRC (National Research Council), Nutrient Requirements of Dairy Cattle, 7th revised ed. 542 National Academy Press, Washington, DC., USA, 2001.
[32] D. Gemiyo, A. Jimma, S. Wolde, Biomass yield and nutritive value of ten napier grass (Pennisetum purpureum) accessions at areka, southern Ethiopia, World J. Agric. Sci. 13 (5) (2017) 185–190 https://doi.org/10.5829/idosi.wjas.2017.185.190.
[33] B. Turano, U.P. Tiwari, R. Jha, Growth and nutritional evaluation of napier grass hybrids as forage for ruminants, Trop. Grasslands-Forrajes Trop. 4 (3) (2016) 168 https://doi.org/10.17138/TGFT.
[34] E.J. Mtengeti, E.C.J.H. Phiri, N.A. Urio, D.G. Mhando, Z. Mvena, R. Ryoba, T. Lørken, Forage availability and its quality in the dry season on smallholder dairy farms in Tanzania, Acta Agric. Scand. Sect. A Anim. Sci. 58 (4) (2008) 196–204, doi:10.1080/09064700802492362.
[35] S.G. Assuero, J.A. Tognetti, Tillering regulation by endogenous and environmental factors and its agricultural management, Am. J. Plant Sci. Biotechnol. 4 (2010) 35–48.