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Productivity nutritive value and economic potential of irrigated fodder in two regions of Ghana

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Abstract

An on-farm study was conducted in the northern and Upper East regions of Ghana to investigate the productivity and nutritive value of irrigated ruzi grass [*Urochloa ruziziensis* (R. Germ. and C.M. Evrard) Crins] (syn. *Brachiaria ruziziensis* (R. Germ. and C.M. Evrard)] and forage sorghum (*Sorghum almum*) grasses as options against dry season feed scarcity and to understand associated market opportunities. Sixty participating farmers each established 100-m^2 plots which were sown at 15 kg ha^{-1} drilled in 60-cm rows in the dry season of 2016 and 2017. Irrigation was by flooding of soil surface every alternate day throughout the period of the trial. At both regions, herbage accumulation and nutritive value of forage species were determined at four harvesting stages: 4, 8, 12, and 16 weeks after planting (WAP) followed by 4-wk intervals between harvests. At the end of the trial, fresh biomass was weighed, bundled, and sold in major livestock feed markets to estimate market price. Allowing forages to establish for only 8 wk resulted in two 4-wk regrowth harvests with dry matter accumulation (DMA) ranging from 4.5 to 8.1 Mg DM ha^{-1} from both species and in both regions. Generally, herbage nutritive values in terms of crude protein, metabolizable energy (ME) concentration, and in vitro digestible organic matter (IVDOM) declined ($P < .05$) while DMA increased linearly with delay in harvest. While both grasses adapted well in the regions under irrigation, 8 WAP harvests provided the best balance between nutritive value and DMA. Irrigated fodder must be marketed more effectively since currently market prices are not closely related to nutritive value.

1 | INTRODUCTION

In tropical Africa, livestock have been reported to improve the stability and resilience of farm enterprises, serve as a store of wealth, provide ready cash, provide secondary income during periods of crop failure, and help farmers to purchase inputs for improved crop yields (Adam et al., 2010; Karbo & Agyare, 2002). In the semi-arid regions of West Africa, especially in northern Ghana, feed is a major constraint to livestock production, particularly during the dry season due to the scarcity and decreasing quality of natural pasture (Ademosum, 1994). Natural pasture is characterized by seasonal, inter- and intra-annual, and spatial variations, which are key limiting factors to its productivity (Hiermaux, 1996). This is associated with both the temporal and spatial distribution of rainfall

Abbreviations: CP, crude protein; DM, dry matter; DMA, dry matter accumulation; IVDOM, in vitro digestible organic matter; ME, metabolizable energy; NDF, neutral digestible fiber; WAP, weeks after planting.

(Bayala et al., 2014), resulting in an abundance of good quality material during the rainy season, and scarcity and poor-quality material during the dry season. Crop residues, such as groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L.) haulms, pigeon pea (*Cajanus cajan* L.) straw, maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.) and millet (*Pennisetum glaucum* L. R. Br.) stovers, constitute the bulk of ruminant feed during the dry season in northern Ghana (Karbo & Agyare, 2002; Smith, 2010). Other available feed resources are agro-industrial by-products (AIBPs) from households and agro-processing industries. Besides the possible conflicting demands for use of cereal crop residue as livestock feed or as soil mulch, the challenge of collection, transportation, and conservation limit its efficient utilization in smallholder livestock production systems (Pathak et al., 2012)

Irrigated farming as a supplement to rainfed production has been recommended to increase cropping intensity, and crop and fodder productivity. Pasture irrigation has been described as a promising technique that increases forage resource availability (Arya et al., 2011) and livestock productivity by maintaining forage crops during periods of drought, which is reflected in livestock production (Ferreira et al., 2020; Mochel Filho et al., 2016).

Irrigated agriculture is not new in most countries in Africa, especially in the West African subtropics, though it is usually associated with rice (*Oryza sativa* L.), maize, and vegetable production, and not forage production. Elsewhere, irrigation has been used extensively in dairy production (ABS, 2006). Previous work has shown that irrigation provided an increase of about 288% in forage production, corresponding to 3,000 kg ha^{-1}, in four cuts carried out in a period of about 4 mo in Brazil (Dantas et al., 2016). Work in Morroco indicates that irrigated forages can supply 40–50% of total livestock energy requirements, mainly from perennial alfalfa (*Medicago sativa* L.), berseem (*Trifolium alexandrinum L.*), and maize (Alaoui, 2009). In Ethiopia, small-scale irrigation supports intensification of the crop–livestock system in the highlands (Getnet et al., 2014; Hagos & Mamo, 2014).

Research and development work on irrigated forage production in West Africa is virtually nonexistent, even though the necessary components are all in place (dams, rivers, fodder species, etc.). There is very limited previous experience of irrigated fodder production, for example in Ghana, though a number of opportunities exist for its development. These include an emerging fodder market in the Upper East Region and a recent growing demand for feed for the increasing number of livestock in the peri-urban areas of Ghana, where livestock were not historically common and where conditions are less suitable for grazing. Therefore, an opportunity exists for spatial integration of fodder production into irrigated cropping systems in northern Ghana.

As climate variation is expected to become more frequent (Martin et al., 2016) impacting forage availability and quality, promotion of high-yielding forage species with improved nutritive value that are also better adapted to drought and low fertility soils is a promising approach for improving animal productivity in arid and semi-arid zones. Urochloa is one of the important tropical forage grasses of African origin. It is widely cultivated in South America, Australia, and East Asia and has demonstrated success in transformation of beef and dairy industries (Ghimire et al. 2015). It produces large amounts of biomass and has a vigorous and deep root system, (Rosolem et al., 2017). It tends to be drought resistant and resilient in infertile soils and produces well with relatively low levels of fertilizer inputs and is sometimes referred to as a "climate smart" forage species (Ngila et al., 2016). Forage sorghum has been reported as another example of a pasture species with resistance to drought stress, which reduces the effects of the forage production seasonality and ensures the maintenance of animal production throughout the year (Lima et al., 2017). It is a short-lived perennial forage species, easily established from seed with rapid growth and fodder yield accumulation within the year of establishment. Forage sorghum is a prominent crop in the Brazilian agricultural sector for being a high energy grass, with high digestibility, productivity and adaptation to dry and warm environments (Lima et al., 2017). These two forage species were considered based on their ease of establishment through seeds, reported herbage yield and ability to thrive with minimal soil moisture in areas with limited annual rainfall such as the northern area of Ghana.

Harvesting at different weeks after planting (WAP) has been reported to impact both quantitative and qualitative traits of forages (Buxton, 1996; Buxton & O'Kiely, 2003). Many authors had reported different suitable WAPs when yield and quality were most stable for harvesting forage grasses especially Urochloa and forage sorghum in different parts of the world and under different seasons and fertilizer regimes (Perazzo et al., 2017; Ramírez de la Ribera et al., 2008; Zemene et al., 2020). Beyond the first harvest, ability to regrow under different conditions is considered desirable (Afzal et al., 2012; Foloni et al., 2008). For semiarid regions, where the rainy season is short (3–4 mo) regrowth capacity with high

Core Ideas

- Productivity of ruzi grass and forage sorghum was evaluated under irrigation.
- Plant age at harvests affected regrowth ability of ruzi grass and forage sorghum.
- Harvest at 8 wk allowed two 4-wk regrowth, best nutritive value and herbage accumulation.
- Market potential for irrigated fodder varies spatially and is demand dependent.
- Market prices of feeds and irrigated fodder is not always a reflection of the quality.

productivity, will reduce production costs and maximize the production system (Ahmeda et al., 2016; Rao et al. 1996). Botelho et al. (2010) had demonstrated such potential in Forage sorghum (*Sorghum almum*) in Brazil. Respati et al. (2018), observed similar potential of Urochloa in Indonesia. Repetitive defoliation of forage regrowth has been reported to have either negative or positive effects on the yield due to several factors such as the availability of nutrients in the soil, meristem, the length of growing season, the frequency and intensity of defoliation (Ferraro & Oesterheld, 2002). The current study builds on previous work and explores the effects on timing of harvest on irrigated Urochloa and forage sorghum in northern Ghana to assess possible impact on regrowth yield and other phenotypic traits, which might consequently modify the nutritional value.

The objective of study was to assess the potential of irrigated fodder in the West Africa subtropics through a case study in the northern and Upper East regions of Ghana, by quantifying the productivity and nutritive value of ruzi grass [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins] and forage sorghum under irrigation. A further objective was to evaluate the economic potential of irrigated forages in the region by exploring the market opportunities and profitability of irrigated fodder as well as farmer motivation for production via market responses.

2 | MATERIALS AND METHODS

2.1 | Study area

Northern Ghana is located in the Guinea Savannah ecological zone of Ghana which is largely characterized by lowland and grassland areas. The area has a relatively dry climate characterized by a prolonged dry season between November and March/April and a single rainy season that begins in May and ends in October, with an annual rainfall that ranges between 750 and 1,050 mm (Ghana Statistical Service, 2013). The monthly mean temperature ranges between 22 and 34 °C (Acheampong et al., 2014). The two specific communities where the study was conducted were Bihinayili in Savelugu district in the northern region and Zanlerigu in Nabdam district in Upper East region. Bihinayili is located about 10 km North of Tamale, the regional capital (9˚36′06.2“N 0˚51′44.4″W) and is 162 m above sea level (masl). Zanlerigu is located about 15 km Northeast of Bolgatanga, the regional capital for the Upper East (10˚ 48 22.3′N and 0˚ 44 10 .9′W) and is 206 masl.

The vegetation consists mainly of grassland, especially savanna, with clusters of drought-resistant trees. The temperatures vary between 14 ˚C at night and 40 ˚C during the day. Much of the production of crops takes place in small-scale and rainfed systems (Månsson, 2011).

Both communities are located in the Guinea Savannah agro-ecological zone, Zanlerigu (Upper East) is relatively closer to the Sudan and Sahel agro-ecological zones than Bihinaayili (northern region), and the former receives less rainfall than the latter (Balana, et al., 2020).

The study sites were characterized by mixed crop–livestock production systems. The livestock reared are goats, sheep, pigs, donkeys, cattle, and poultry (Adzitey, 2013). The major crops cultivated are millet [*Cenchrus americanus* (L.) Morrone], maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], bean (*Phaseolus vulgaris* L.), tomato (*Solanum lycopersicum* L.), and vegetables, grown during the rainy season from May to September. The weather patterns restrict rainfed cropping to a single cropping season; therefore, irrigation is practiced during the off-season. Tomato, onion (*Allium cepa* L.), okra [*Abelmoschus esculentus* (L.) Moench], and other vegetables are occasionally planted during the off season for consumption and income with supplemental irrigation (Blümmel et al., 2018). Vegetable plots are irrigated by watering-can and surface irrigation methods and water lifted using buckets and motorized pumps from the shallow wells.

Irrigated land areas in both communities are in a particular low-land area of the communities which in total are <2 ha. These irrigated land sites in both communities are usually waterlogged and therefore unused during the rainy season. Each household with access to the irrigated land area map out individual plots and cultivate according to local agreement. Access to the limited irrigated area is by inheritance, or allocation through the local chiefs who act as the custodians of community land. Other criteria may be the ability to own small reservoirs or availability of vacant plots (Acheampong et al., 2018).

2.2 | Land preparation and plot establishment

The study involved on-farm agronomic trials of two forage species under surface irrigation carried out on farmers' fields. The selected forage species were ruzi grass known for drought tolerance, adaptability to poor quality soil, and soil conservation properties; and forage sorghum, also known for its drought tolerance. Sixty farmers (30 from each region) who participated in the Feed the Future Innovation Lab on Small Scale Irrigation (ILSSI) project were selected based on willingness and readiness to allocate at least 100 m^2 of their irrigated land for the fodder trials for 2 yr. A total of 0.3 ha from the entire irrigated land area was used in each community. The field trials were carried out in October–April (dry season) for two consecutive years, in 2016 and 2017. Land preparation, field layout, plot irrigation, and sowing were performed manually in both regions.

TABLE 1 Physico-chemical characteristics of the composite soil samples in study sites[a]

Parameters	Northern region	Upper East region	Method
pH (1:2.5 H_2O)	6.35	6.67	Laboratory pH meter following 1:5 dilution of soil/water
Percentage organic C	0.23	0.01	Walkley–Black chromic acid wet
Nitrogen, mg kg^{-1}	200	100	Kjeldahl method
Available P, mg kg^{-1}	4.52	4.49	Olsen's method
Exchangeable K, mg kg^{-1}	67.88	86.34	Flame Photometric Methods
Exchangeable cations, cmol kg^{-1}			
Ca	2.67	3.93	Single-step extraction with LiEDTA
Mg	1.02	1.34	
K	0.17	0.22	
Na	0.06	0.01	
Exchangeable acidity, cmol kg^{-1}	0.76	0.54	Differential potentiometric titration
Total exchangeable bases, cmol kg^{-1}	3.93	5.59	Extraction Methods
Cation exchangeable capacity, cmol kg^{-1}	4.69	6.13	
Base saturation, %	75.19	97.82	
Particle size distribution, %			
Sand	51.25	57.94	Sieve-pipette
Silt	41.57	35.30	
Clay	7.18	6.67	

[a]*Source*: Field data, 2016.

Nine representative soil samples were taken at 0-to-15-cm depth, three each from the top, middle, and lower slope of the experimental site in each region before the commencement of the trial, using soil auger. Composite soil samples from each slope per region were air-dried and passed through a 2-mm sieve before being analyzed. In addition to this, meteorological data of rainfall and temperature for the years of the field trials were provided upon request from the Ghana central meteorological station.

2.3 | Soil physico-chemical characteristics

The physico-chemical characteristics of composite soil samples from the experimental sites showed that average total N recorded from northern and Upper East regions of Ghana was 200 and 100 mg kg $^{-1}$), respectively (Table 1). The soil analysis in the northern region showed that soil contained 0.76 cmol kg^{-1} of exchangeable acidity, total exchangeable base of 3.93 cmol kg^{-1} and cation exchangeable capacity of 4.69 cmol kg^{-1}. The proportions of 0.54, 5.59, and 6.13 cmol kg^{-1} were respectively recorded at the Upper East region for exchangeable acidity, total exchangeable base, and cation exchangeable capacity. The rainfall distributions are presented in Figures 1 and 2. As presented, there was no rainfall in January and December for the 2 yr of measurement. Rainfall started in March and increased gradually to reach its peak between July and September 2015, after which it started to diminish. The rainfall pattern was largely unimodal. It should be noted that 3 of the 12 mo were completely dry for 2016 and 2017. The region had moisture to sustain vegetation growth throughout the year, but probably not sufficient for all year-round dryland forage production. Total rainfall in the northern region (1,084 and 919 mm in 2016 and 2017, respectively) were lower than that recorded (1,176 and 926 mm in 2016 and 2017, respectively) in the Upper East region.

2.4 | Experimental design

The experiment was a factorial arrangement in a randomized complete block design (RCBD), comprised of the two regions: northern and Upper East regions of Ghana; two forage species: ruzi grass and forage sorghum; and four stages of harvest: 4, 8, 12, and 16 WAP. In each region, 30 plots were randomly selected for the trial with a total land area of 100 m^2 each, totaling 60 plots (30 per region). Each plot was marked out, cleared, and tilled manually in October 2016. Average cost of land preparation was determined for each region. Both ruzi grass and forage sorghum were established from seed by sowing at 15 kg per hectare, each on half of the plots. Ruzi grass was planted by row drilling at 60-cm spacing while forage sorghum was planted at 30-cm intervals in rows at 50-cm spacing. Each farmer's plot represented a replicate to account for the effect of land variation within the irrigated area. Acquisition of irrigation materials and equipment (pumps set up

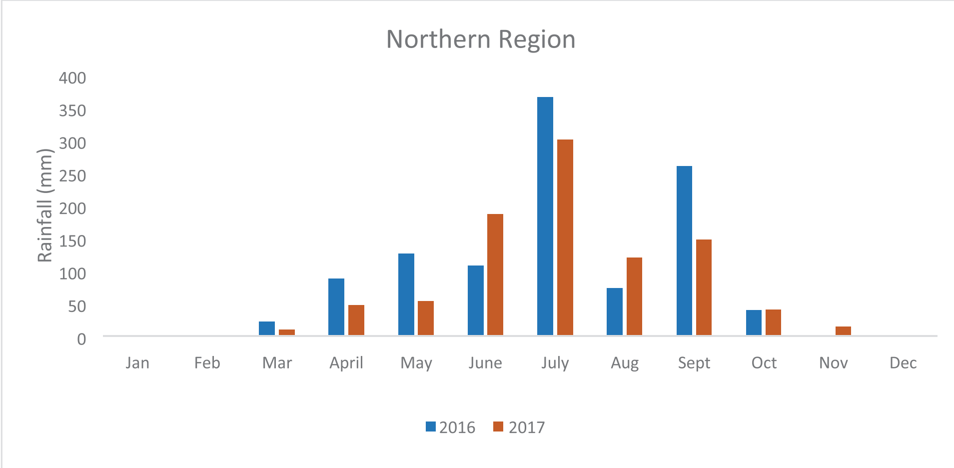

FIGURE 1 Mean monthly rainfall distribution in millimeters for 2016–2017 in the northern region of Ghana

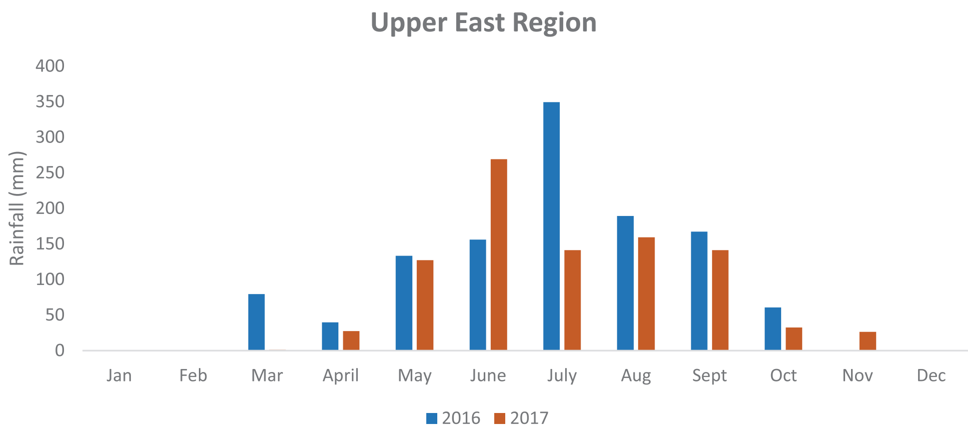

FIGURE 2 Mean monthly rainfall distribution in millimeters for 2016–2017 in the Upper East region of Ghana

with inlet and outlet hoses) were arranged for both sites by the project. Cost of seeds, fertilizer, and fueling of water pumps were documented for each region.

2.5 | Plot management

Weeding was carried out manually 3–4 WAP and as the need arose, using hoes and handpicks. The plots were fenced using locally available materials (Gliricidia poles and chain-link wires) in both districts. The cost of fencing was estimated and included in the total production costs. A compound fertilizer was applied to the forage grass plots at a rate of 20 kg N, 20 kg P, and 20 kg K ha^{-1} 2 WAP. Irrigation was performed by flooding the soil surface following farmers' practice, using a 5-cm hose for 20–30 min every other day, using a shallow well as a water source. As the dry season progressed, hose size was increased to 10 cm. In each year, experimental design, seed rate, and plot allocation were the same and re-sowing was repeated only where necessary.

2.6 | Agronomic data collection

Agronomic data including plant height, number of leaves per plant, leaf area, and number of tillers were collected in 2016 and 2017 seasons, in both regions at 4 and 8 WAP until when it was impossible to measure, especially Urochloa. Plant height of each forage species from the ground surface to apical meristem was measured using a meter rule graduated in centimeters. Leaf area was calculated manually using a nondestructive method by measuring leaf length x width x 0.75 (Oosterom et al., 2001).

2.7 | Herbage accumulation

Herbage accumulation of each forage species was determined at four harvesting stages: 4, 8, 12, and 16 WAP. For each harvesting stage, regrowth at 4-wk intervals was additionally harvested until no substantial biomass from the plot could be recorded. Dry matter accumulation (DMA) at each harvesting stage and regrowth period were determined separately by harvesting the fresh forage 15 cm above the ground level within a 1-m^2 quadrat using a hand sickle. The fresh forage was weighed, and a random subsample of 300 g oven dried at 65 ˚C for 48 h reweighed and used to estimate DMA by multiplying fresh forage biomass by the respective DM concentration of the samples.

2.8 | Laboratory analysis

Nutrient analysis of herbage was conducted at the nutrition laboratory of the International Livestock Research Institute (ILRI), Hyderabad, India. Subsamples from each harvested sample were dried at 65 ˚C for 72 h and then ground to pass through 1-mm sieve for the determination of N, ash, neutral detergent fiber (NDF) concentrations, in vitro digestible organic matter (IVDOM), and metabolizable energy (ME) using near infra-red spectroscopy (NIRS) equations developed for both grasses from conventional analysis of proximate chemical fractions (AOAC, 1990; Van Soest et al., 1994). The NIRS instrument used was FOSS Forage Analyzer 2500 with software package WinISI II.

2.9 | Irrigated fodder market price

After the 16th weeks of the field trial (March 2017), forages were harvested from a 10-m^2 area, randomly selected from within the grass plots and from three different farmers' plots each, for both species, in both regions, for each year. Harvested material was weighed and bundled for the market to assess buyers' estimated market price for each forage species daily for 5 d. At the market, the forages were rebundled according to the weight of fresh natural pasture available at the livestock feed market in Tamale, in the northern region and Bolgatanga in the Upper East region. Each bundle of irrigated forage was sold by the feed seller on the same day and the selling price per weight was recorded. Feeds available at the market during January–April 2017and their market prices were inventorized and categorized using a structured survey tool through personal interview with feed sellers. The sellers and buyers were also interviewed at the markets to assess their motivation to sell or buy irrigated fodder. Available feed samples sold at the market were bought from three to four different sellers. The price per kilogram DM of the purchased feeds was determined using at least three samples of each feed. Subsamples were later weighed and then air dried for nutrient analysis. Irrigated fodder farmers were also interviewed to assess their "willingness to continue".

2.10 | Statistical analysis

Analysis of variance and Duncan's Multiple Range Test for mean separation using the general linear model of Statistical Analysis System (SAS, 2009) were used to analyze the phenological, DMA, and nutritive value variables. Each species was analyzed separately. Alpha level .05 was used where means are separated. The model for the statistical analysis included fixed variables (Region and WAP) and dependent variables. Significant interaction was determined using R statistical software (V 4.1).

2.11 | Experimental model

$$\text{Yijk} = \mu + Ai + Bj + (AB)\text{ij} + \sum \text{ijk}$$

μ = Population means

Ai = Main effects of the region (A)

Bj = Main effects of the WAP (B)

(AB)ij = A × B interaction effects

$\sum$ijk = Random error

Descriptive statistics were employed to present the qualitative variables obtained from the household survey. Ranking in the order of importance was done using normalized ranking.

$$\text{Normalized rank} = \frac{1 - (\text{Raw rank} - 1\ )}{\text{Total number of ranked items}}$$

3 | RESULTS

3.1 | Phenological characteristics

The mean plant heights, number of leaves and tillers, and the leaf area in both years increased from the 4 WAP to the 8 WAP (Table 2). At the 4 WAP, all measured phenological parameters, except the number of leaves in ruzi grass, were greater in the northern region than in the Upper East region. Conversely, the number of tillers of forage sorghum recorded in the Upper East region were greater than in the northern region, both at 4 WAP (5.9) and 8 WAP (6.5) while leaf area in both 4 and 8 WAP was significantly greater in the northern region than in the Upper East. It was observed that the plant heights in both species was consistently higher in the northern region than in the Upper East.

3.2 | Herbage accumulation

When harvest was initiated at 4 WAP, regrowth allowed two subsequent 4-wk harvests both for ruzi grass and forage sorghum, in both regions, for both years. The DMA at each

TABLE 2 Average phenological characteristics of ruzi grass and forage sorghum in the northern and Upper East regions of Ghana in 2016 and 2017

Parameters	Age	Ruzi grass Northern region	Ruzi grass Upper East region	Ruzi grass Average	Ruzi grass P values	Ruzi grass SEM	Forage sorghum Northern region	Forage sorghum Upper East region	Forage sorghum Average	Forage sorghum P values	Forage sorghum SEM
Leaf area per plant, cm^2	4 WAP	35.4	19.8	27.6	.000*	2.6	141.8	39.5	90.6	.001*	24.5
	8 WAP	53.4	87.9	71.1	.107	9.9	261.6	175.7	218.7	.121	33.3
Number of leaves	4 WAP	8.1	4.3	6.2	.009*	0.8	5.6	4.4	5.0	.020	0.3
	8 WAP	11.3	12.3	11.8	.157	0.9	12.7	8.3	10.5	.000*	1.3
Number of tillers	4 WAP	6.6	5.6	6.1	.083	0.7	2.8	5.9	4.4	.000*	0.9
	8 WAP	10.6	8.6	9.6	.064	0.5	3.4	6.5	4.9	.000*	0.9
Plant height, cm	4 WAP	36.7	14.4	25.6	.000*	2.9	69.1	56.9	63.0	.220	7.1
	8 WAP	89.4	58.0	73.7	.005*	5.8	193.8	130.4	162.1	.003*	11.6

Note. WAP, weeks after planting; SEM, standard error of mean.
*Significant level based on *P* values at .05.

TABLE 3 Average dry matter accumulation at each harvest (Mg DM ha^{-1}) and total accumulation (Mg DM ha^{-1}) of ruzi grass and forage sorghum in northern and Upper East regions of Ghana in 2016 and 2017

Age	Cutting regime	Ruzi grass Northern region	Ruzi grass Upper East region	Ruzi grass SEM	Forage sorghum Northern region	Forage sorghum Upper East region	Forage sorghum SEM
4 WAP	First harvest	2.5	1.5	0.2	2.5	1.9	0.2
	First regrowth	1.9	1.2	0.1	1.8	1.4	0.1
	Second regrowth	1.9	1.4	0.1	1.8	1.4	0.1
	Total accumulation	6.4	4.1		6.1	4.7	
8 WAP	First harvest	7.9	6.8	0.2	8.1	6.5	0.5
	First regrowth	5.8	4.5	0.4	6.3	5.0	0.4
	Total accumulation	13.7	11.6		14.4	11.5	
12 WAP	First harvest	13.7	11.6	0.5	13.6	11.0	0.9
	Total accumulation	13.7	11.6		13.6	11.0	
16 WAP	First harvest	18.0	15.3	0.7	18.0	14.5	1.2
	Total accumulation	18.0	15.3		18.0	14.5	
	Effect of factors	*P* values			*P* values		
	Region	<.001***			.00034***		
	Age	<.001***			<.001***		
	Region × age	<.001***			.037*		

Note. WAP, weeks after planting; SEM, standard error of mean.
*Significant at .05. **Significant .01. ***Significant .001.

regrowth was similar to the first harvest, indicating that early harvest could produce similar productivity for at least two subsequent harvests at 4 wk cutting interval (Table 3). Harvesting both grass species at 8 WAP could only produce one further regrowth, no substantial yield could be recorded following a second regrowth period, in both regions with a lower DMA than the first harvest. Similarly, when harvesting was delayed until 12 and 16 WAP, it resulted in one harvest time with no substantial regrowth.

Total cumulative DMA was lowest when the repeated harvests were initiated at 4 WAP (Table 3). Generally, ruzi grass gave greater ($P < .05$) DMA in the northern region than in the Upper East region across all the treatments. Dry matter accumulation of ruzi grass and forage sorghum were significantly ($P < .05$) affected by age at harvest, region, and their interactions.

3.3 | Nutritional value

Crude protein(CP), ME, and IVDOM at different harvest stages were relatively similar between northern and Upper

TABLE 4 Mean of nutritive values of ruzi grass at the northern and Upper East regions of Ghana in 2016 and 2017 (g kg^{-1})

Age	Cutting regime	CP		NDF		ME		IVDOM	
		Northern	Upper East	Northern	Upper East	Northern	Upper East	Northern	Upper East
4 WAP	First harvest	186 ± 1.4[a]	196 ± 2.3	512 ± 2.1	549 ± 3.0	8.3 ± 0.3	4.3 ± 0.6	653 ± 3.4	597 ± 2.0
	First regrowth	158 ± 0.7	111 ± 4.7	558 ± 2.2	564 ± 11.5	7.0 ± 1.0	6.5 ± 0.7	616 ± 1.0	551 ± 5.5
	Second regrowth	142 ± 4.6	107 ± 4.1	575 ± 30.1	555 ± 0.5	7.9 ± 4.3	7.2 ± 0.6	590 ± 3.2	541 ± 3.6
8 WAP	First harvest	89 ± 0.6	78 ± 0.8	582 ± 0.5	617 ± 2.2	7.5 ± 0.5	6.5 ± 0.8	469 ± 1.7	479 ± 1.8
	First regrowth	90 ± 1.0	75 ± 1.6	588 ± 0.8	607 ± 3.1	7.4 ± 0.5	6.4 ± 0.4	471 ± 4.7	468 ± 2.4
12 WAP	First harvest	83 ± 0.6	67 ± 1.2	642 ± 3.1	657 ± 0.9	7.1 ± 0.3	6.2 ± 1.4	411 ± 0.8	436 ± 6.0
16 WAP	First harvest	67 ± 1.3	53 ± 0.4	678 ± 2.4	670 ± 0.2	6.7 ± 0.5	5.6 ± 0.6	327 ± 0.8	355 ± 5.3
Factor's effect		*P* values							
Region		.03*		.005*		.710NS		.235NS	
Age		<.001*		<.001*		<.001*		<.001*	
Region × age		.208NS		.001*		.002*		.004*	

Note: CP, crude protein; NDF, neutral detergent fiber; ME, metabolizable energy (MJ kg^{-1} DM); IVDOM, in vitro digestible organic matter; WAP, weeks after planting; NS, not significant.

[a]± represents standard error.

*Significant at .05. **Significant .01. ***Significant .001.

TABLE 5 Average nutritive values of forage sorghum at the northern and Upper East regions of Ghana in 2016 and 2017(g kg^{-1})

Age	Cutting regime	CP		NDF		ME		IVDOM	
		Northern	Upper East	Northern	Upper East	Northern	Upper East	Northern	Upper East
4 WAP	First harvest	197 ± 0.68[a]	193 ± 0.3	566 ± 5.12	601 ± 0.2	7.4 ± 0.46	7.0± 0.4	629 ± 1.01	572 ± 3.7
	First regrowth	104 ± 0.58	87 ± 1.36	594 ± 0.63	590 ± 2.6	7.8 ± 0.40	6.7 ± 0.4	607 ± 0.51	531 ± 6.3
	Second regrowth	77 ± 0.68	75 ± 3.8	556 ± 5.10	589 ± 2.7	7.8 ± 0.49	6.4 ± 3.7	555 ± 0.47	569 ± 2.5
8 WAP	First harvest	89 ± 1.05	75 ± 1.05	603 ± 2.95	639 ± 1.9	7.5 ± 0.49	6.6 ± 0.6	468 ± 1.85	452 ± 1.3
	First regrowth	89 ± 0.59	73 ± 1.50	602 ± 2.27	654 ± 1.3	7.4 ± 0.39	6.5 ± 0.6	471 ± 1.65	461 ± 2.7
12 WAP	First harvest	92 ± 0.56	64 ± 2.54	668 ± 0.87	668 ± 0.87	6.0 ± 0.48	5.6 ± 1.2	401 ± 0.73	407 ± 1.7
16 WAP	First harvest	69 ± 1.1	50 ± 0.13	694 ± 0.63	709 ± 3.2	6.5 ± 0.63	5.3 ± 0.4	323 ± 1.25	353 ± 6.5
Factor's effect		*P* values							
Region		<.001***		.440NS		<.001***		.014*	
Age		<.001***		<.001***		<.001***		<.001***	
Region × age		.162NS		.380NS		.004**		.025*	

Note. CP, crude protein; NDF, neutral detergent fiber; ME, metabolizable energy (MJ kg^{-1} dry matter); IVDOM, in vitro digestible organic matter; WAP, weeks after planting; NS, not significant.

[a]± represents standard error.

*Significant at .05. **Significant .01. ***Significant .001.

East regions in 2016 and 2017. The CP concentration, ME concentration, and IVDOM declined with increased age of first harvest after seeding in both grasses in both regions while neutral digestible fiber (NDF) increased linearly with increasing age (Tables 4 and 5). Furthermore, CP and NDF means for ruzi grass were greater in the northern region than the Upper East although the regional differences was not significant for ME and IVDOM. This regional difference was also evident in the results for forage sorghum, except in the NDF concentration. Generally, 4-wk regrowth, whether after 4 or 8 WAP, had higher quality than either the first harvests at 8, 12, or 16 WAP.

3.4 | Market values of irrigated fodder

The cost of production for each grass species was similar except for the cost of the seeds. Market prices for both grass species were also similar in each of the two regions in April, though lower in the Upper East compared with the northern

TABLE 6 Cost of production, sales, and economic benefit of irrigated fodder in the northern and Upper East regions in Ghana Cedi (GH¢ yield^{-1} unit area^{-1})

	Northern region		Upper East region	
Cost of production	**Ruzi grass**	**Forage sorghum**	**Ruzi grass**	**Forage sorghum**
Fixed cost				
Shared cost of irrigation pump	1,000	1,000	1,000	1,000
Variable cost[a]				
Land preparation	525	525	375	375
Seed cost	480.3	430.3	480.3	430.3
Fuel for irrigation pump	996.5	996.5	996.5	996.5
Fertilizer	260	260	234.3	234.3
Transportation to market	30.5	30.5	23	23
Total cost of production, GH¢ ha^{-1}[b1]	3,292.3	3,242.3	3,109.1	3,059.1
Dry matter yield, Mg ha^{-1}	18.0	18.0	15.3	14.5
Cost/yield, GH¢ kg^{-1} DM	0.18	0.18	0.20	0.21
Estimated market price, GH¢ kg^{-1} DM	0.5	0.5	0.3	0.3
Profit margin, GH¢ kg^{-1} DM	0.32	0.32	0.10	0.09
Profit margin, GH¢ ha^{-1}	2,467.7	2,517.7	1,530	1,754.1

Note. DM, dry matter.

[a]No cost of labor and fencing materials.

[b]1 GH¢ = US$0.22.

region, which anecdotally correlates with the differences in nutritive values. Cost per kilogram of DM was different resulting from currency per yield per unit area of land and cost of the seeds (Table 6). Irrigated forages were priced lower in the Upper East region than in the northern region. The estimated market price of the irrigated fodder by the buyers at the livestock market showed that it has similar market value per unit kilogram DM relative to other available feeds in the market and with better nutritive value than cereal straw (Table 7).

The predominant livestock feeds available in the regions were groundnut haulm, cowpea haulm, soybean haulm, maize bran, cassava peel, pigeon pea straw, and rice bran (Table 7). In both markets, cowpea haulm is priced higher among the legume crop residues. There were fewer feed trading activities in the Upper East fodder market during this study as indicated by the types of feed resources available as well as lower prices (Table 7).

3.5 | Relationship between the price and nutritional parameters of livestock feed resources

A scatterplot was used to determine the relationship between price (GHC/kg^{-1} DM) and N, ME, and IVDOM concentration of available feed resources sold at the Upper East and northern markets in Ghana in 2016 and 2017 (Figures 3, 4, and 5). The results showed a positive though weak linear relationship between price and all the nutritional parameters examined. The relationship between the price and the N concentration, and ME were not significant ($P > .05$), but a significant relationship was recorded between the price and the IVDOM

3.6 | Factors for selling and buying irrigated fodder

According to the livestock feed sellers in both markets, the leading motivational factors for selling irrigated fodder from both regions were high demand, regular supply of irrigated fodder in the market, and a high likelihood of profit (Figure 6). According to the respondents, provision of storage facility and access to credit were mentioned as factors that could stimulate their interest in selling the fodder. From the buyers interviewed, evidence of good performance of the animals fed irrigated fodder, regular supply of irrigated fodder in the market, and capacity building in conservation techniques of fodder were the major factors to stimulate buying irrigated fodder (Figure 7).

3.7 | Factors that will promote irrigated fodder production

More than 40% of the farmers who participated in the irrigated fodder production from the Upper East region confirmed that guaranteed fodder market and evidence of profitability will

TABLE 7 Available feed resources and average price per unit of the feed in both regions

Crop residues	Northern region	Upper East region
	GH¢ kg^{-1} dry matter[a]	
Cowpea haulm	2.6	1.3
Soybean haulm	1.0	na
Groundnut haulm	0.7	0.7
Pigeon pea haulm	0.5	na
Maize straw	0.1	na
Rice straw	0.1	na
Sorghum straw	0.1	0.1
Household by-products		
Cassava peel	0.4	na
Sorghum bran	na	0.2
Maize bran	0.6	0.6
Millet bran	0.5	na
Maize mill waste	na	0.1
Industrial by-products		
Rice bran	0.3	0.2
Wheat bran	na	0.9
Irrigated forage estimated		
Ruzi grass	0.5	0.3
Forage sorghum	0.5	0.3

Note. na, not available at the site.
[a]1 Ghana Cedi (GH¢) = US$0.22.

motivate them to practice irrigated fodder production. Other factors include availability of forage seed, access to credit or financial services (e.g., subsidized inputs and building technical capacity). Fewer farmers suggested resolving issues surrounding land tenure security and availability of household labor as additional factors in promoting the production of irrigated fodder (Table 8). In the northern region, more than 60% of respondents chose guaranteed market for irrigated fodder and evidence of profitability as their motivation to continue in the production of irrigated fodder. A wide range of other factors were considered important in promoting the production.

4 | DISCUSSION

4.1 | Agronomic phase

The establishment and growth of both ruzi grass and forage sorghum under irrigation revealed their potential in the two regions of Ghana. Differences in the plant heights of both crops could be attributed to several factors among which could be differences in soil profiles in both regions. Soil texture at the Upper East region is a sandy-loam and neutral soil, while greater organic C and N content in the soil of the northern region is expected to support better crop production (Musinguz et al., 2013). The productivity of forage sorghum at 12 WAP was greater than what was reported for the same growth period in northern Nigeria by Ishiaku et al. (2016), but similar to the result of Olanite et al. (2010). Balole and Legwaila (2006) reported that forage sorghum yield annually about 20 Mg green matter ha^{-1}, which is similar to the DMA recorded at 8 WAP from the present study. The total DMA of irrigated forage sorghum in the Upper East was similar to that reported for forage sorghum when irrigated in the late dry season in the Sudan Savannah of Nigeria (Muhammad et al., 2005).

4.2 | Cutting management and its effects on fodder yield and nutritive value

The result of the cutting management showed that both grasses responded to cutting management, both in quality and quantity. Nevertheless, the accumulated herbage DMA increased from 8 WAP and plateaued in ruzi grass but declined in forage sorghum beyond 8 WAP with advancement in maturity. As plants grew taller, they had more tillers per plant and more leaves per plant, resulting from accumulation of biomass components. This corroborates the report of Spitaleri et al. (1995), that herbage accumulation of grass increases with maturity, though the nutritive value declines. The results show that early harvesting promotes multiple regrowth but lowers total DMA. Multiple harvests may still be beneficial to forage farmers who target fresh fodder sales in the dry season at regular fodder markets in both regions of Ghana. Lower DMA might not sustain commercial livestock production especially in zero-grazing system in land-constrained areas. Delaying harvest until 8 WAP which produced single 4-wk regrowth that provided good yield of higher quality forage in both species may be desirable by livestock farmers.

The biomass productivity differences between the two sites can be partly explained by the growth habit and adaptation of each of the grass species. Generally, ruzi grass performed better in the northern region in both years of study than in the Upper East region. Rao et al. (1996) suggested that Brachiaria species can adapt to a wide range of soil types from low-fertility acid soils to high-fertility neutral soils. They perform much better on acid soils (pH range of 5.0–6.8) than other grasses as the soils in this study from the northern region are more acidic. It is of paramount importance that high-yielding and palatable grass species should be established in suitable eco-sites (Mohammad & Naqvi, 1987).

Similar to DMA, the nutrient concentrations of forage are important to consider in selection of fodder varieties for livestock production (Maleko et al., 2014). Greater CP of the grass before 8 WAP is expected. Harvested grasses at 4 and 8 WAP resulted in younger plant regrowth material, which led to the

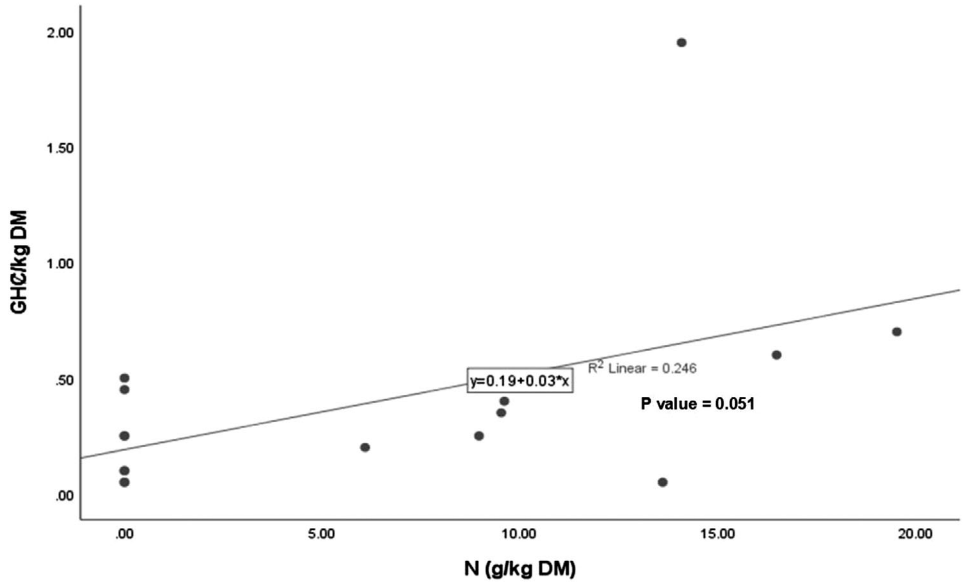

FIGURE 3 Relationship between price and N concentration of feeds sold in the feed markets of the northern and Upper East regions of Ghana in 2016 and 2017

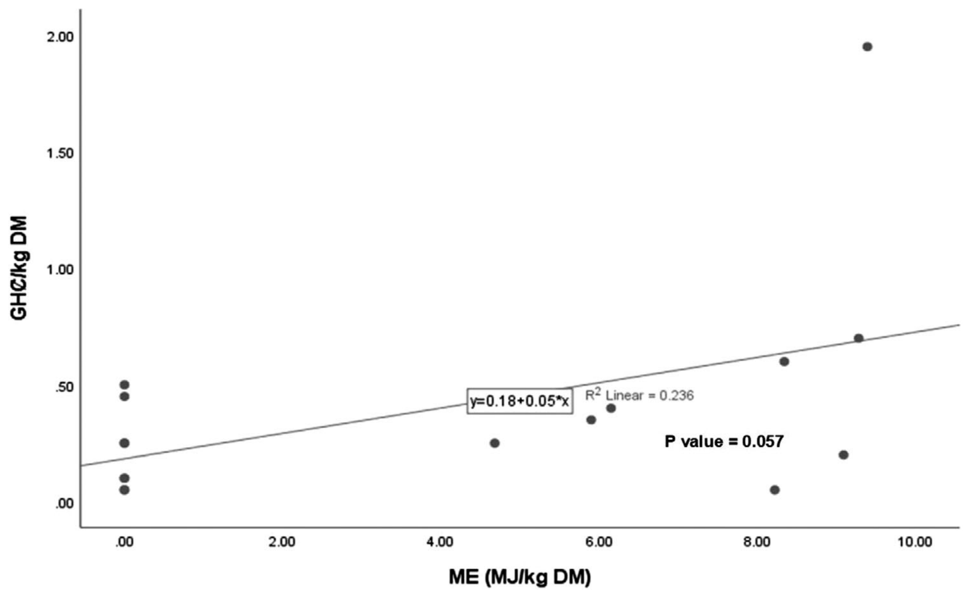

FIGURE 4 Relationship between price and metabolizable energy (ME) of feeds sold in the feed markets of the northern and Upper East regions of Ghana in 2016 and 2017

greater CP and lower fiber concentrations. Late harvesting has been reported to significantly reduce CP concentrations of herbage species (Daniel, 1996; Teshome et al., 1994). In the 12 WAP treatment, the CP concentration of both grasses in Upper East region in both years of the study was below 75 g kg^{-1} which is the minimum level of CP for optimal rumen function (Adugna & Said, 1994; Van Soest, 1994). The implication is that supplementary protein-rich feed sources are required for optimal production if grasses harvested after 12 WAP are to be used as the basal diet for livestock in the region. Irrigated ruzi grass and forage sorghum harvested at an early growth/regrowth stage could be an alternative to continuous purchase of concentrate feeds by poor-resourced livestock farmers in the northern part of Ghana.

The NDF values fell within the range of 450–650 g kg^{-1} which is regarded as roughage feed of moderate quality (Turano et al., 2016). The trend of increasing NDF concentration with older harvesting age is a common phenomenon

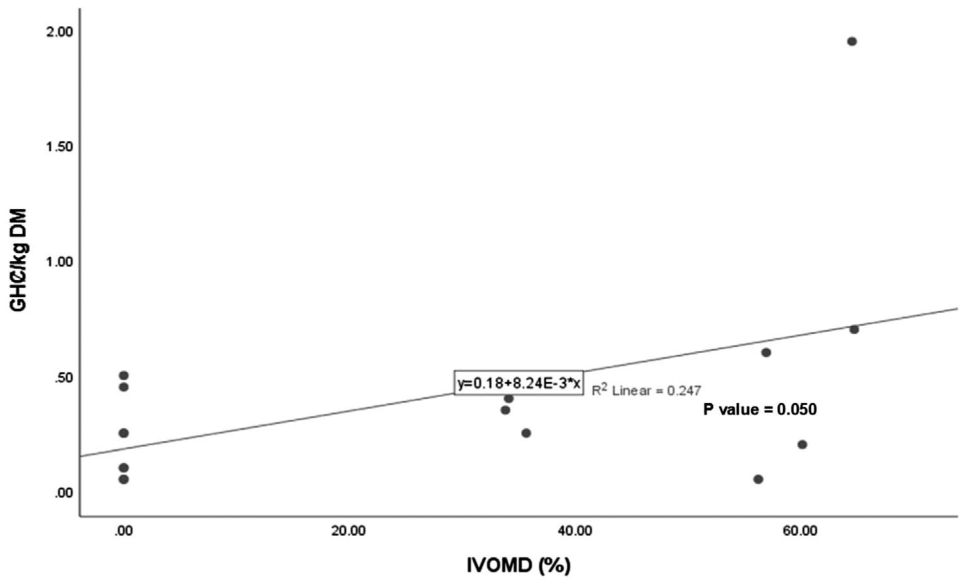

FIGURE 5 Relationship between price and in vitro digestible organic matter (IVDOM) of feeds sold in the feed markets of the northern and Upper East regions of Ghana in 2016 and 2017

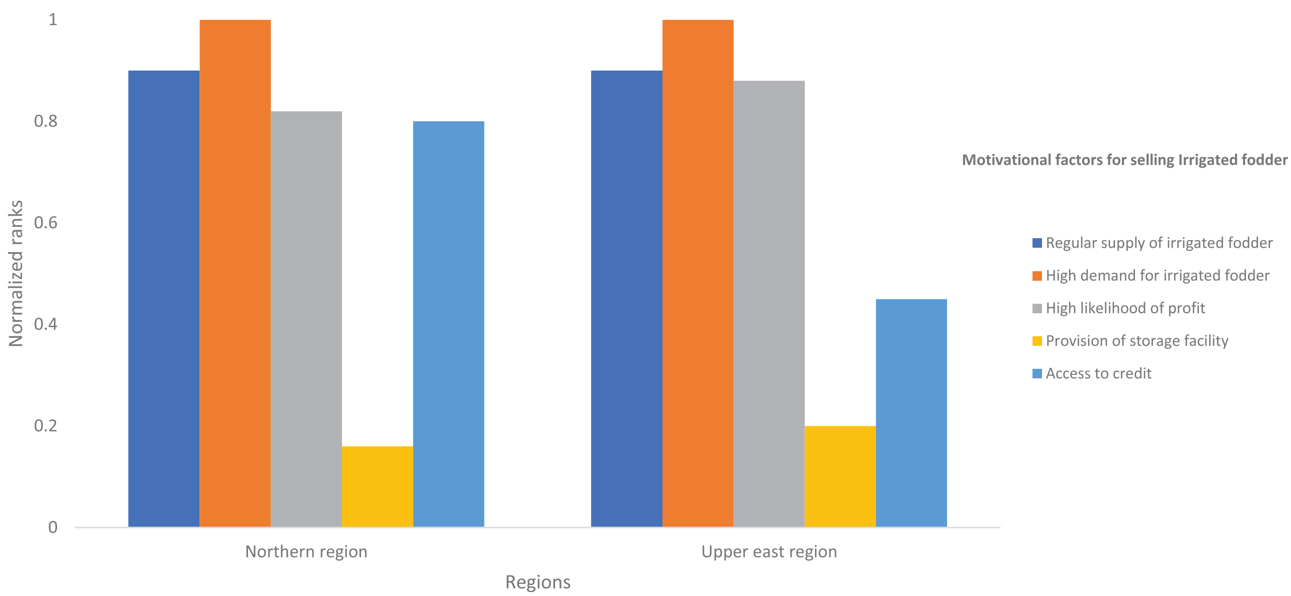

FIGURE 6 Respondents' perceived extent of importance of motivational factors for selling irrigated fodder by fed sellers in the northern and Upper East regions of Ghana

(Amole et al., 2013; Asmare, 2016). The NDF concentration in tropical forages beyond which the DM intake of animals is negatively affected is considered to be around 650 g kg^{-1} (Van Soest et al., 1994). Higher NDF concentration occurs during later harvests, resulting in decreased DM digestibility (Mirza et al., 2002). The IVDOM concentration of the fodders was observed to decrease with age of the fodder. This corresponded with concomitant reductions in CP, ash, and ME and an increase in fiber proportions. Moore and Mott (1973) and Mugeriwa et al. (1978) reported that digestibility values >650 g kg^{-1} indicate a better forage quality and that intake may be reduced below this. The values obtained at advanced harvest age (12 and 16 WAP) in the present study were by far lower than this critical level. It is important to note that decisions on the optimal time to harvest both ruzi grass and forage sorghum will depend on a compromise between productivity and nutritive value of the forage. Despite the reduction in CP concentration as harvest age increased, the CP yield increased as harvesting was delayed. The higher forage CP yield obtained for ruzi grass shows the potential

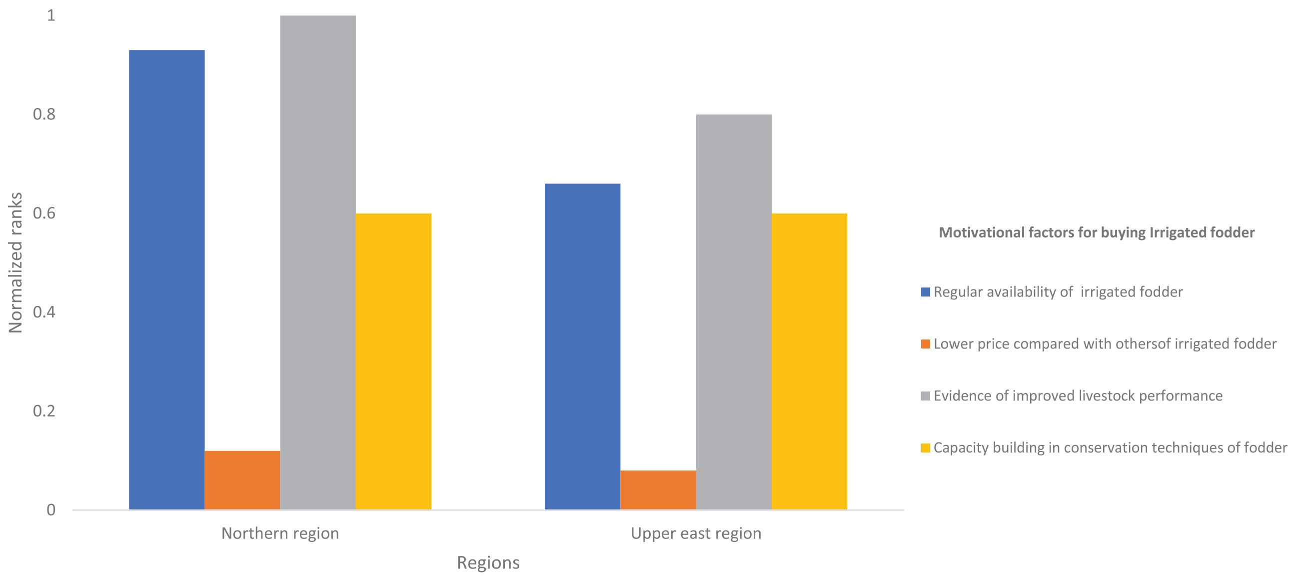

FIGURE 7 Respondents' perceived extent of importance of motivational factors for buying irrigated fodder in the northern and Upper East regions of Ghana

TABLE 8 Factors that will promote irrigated fodder production of livestock feed by the producer ($N = 30$ in each region)

Factors	Extent of importance	
	Northern region	Upper East region
	%	
Guaranteed fodder market	73.3	46.7
Evidence of profitability	60	40
Availability of forage seed	43.3	30
Access to irrigation facilities	40	33.3
Building technical capacity	40	23.3
Access to credit or financial services (subsidized inputs)	36.7	13.3
Availability of household labor	36.7	10
Land tenure security	3.3	6.7

protein benefits to be realized from allowing ruzi grass to grow until 16 WAP before it is harvested. This could possibly be a result of its late flowering as a perennial grass which kept the quality higher until this time. A relative reduction in the quality, especially CP concentration, once reproductive phase starts has been reported in most grasses (Amole et al., 2016). This phase is generally earlier in forage sorghum, consequently the CP yield declined earlier (12 WAP). Early reproductive development in forage sorghum leading to reduction in CP concentration, accumulation of cellulose and other complex carbohydrates, and lignification has been reported (Hazim & Ates, 2018). Asmare (2016) reported similar findings for desho grass (*Pennisetum pedicellatum* Trin.) when harvest was delayed until the 16th week after planting.

In any forage evaluation situation, compromises between quality and productivity must be made when deciding at what stage to harvest or graze a crop or pasture (Tilahun et al., 2017). In this study, harvesting at the early stage allowed multiple harvests, though lower total DMA. However, accumulated CP yield and ME yield were highest when both grasses were harvested twice (first harvest and one regrowth) and before the CP concentration and ME declined. In both regions this happened when ruzi grass and forage sorghum were harvested at 8 WAP, confirming that accumulation of CP is a function of total DM and CP concentration (Bayble et al., 2007). Though DMA and nutritive value are inversely related, technically evaluating CP and ME yields in relation to DMA provided the best harvesting time of the grasses. It therefore follows that farmers could use this information to assist in making decisions based on the relative importance of forage yield and quality in their operations.

The absence of cultivated fodder in the markets is an indication that commercial forage production is not routinely practiced in the study sites (Lukuyu et al., 2016) whereas there is a growing need for fodder especially during the dry season (Konlan et al., 2015). The scarcity of natural pastures has created a high demand for feed and has motivated feed sellers to collect browses, crop residues, and agro-industrial by-products (AIBPs) for small ruminant farmers (Husseini et al., 2011). Low feed trading activity and feed price in the Upper East region may be influenced by low demand, contrary to the report of Konlan et al. (2015). This study observed that demand and prices for fodder are higher in areas with limited access to free natural pasture due to urban development than in areas where livestock are raised mostly on free range (Tegegne et al., 2013). Differences in availability of feeds in fodder market and prices have been attributed to existing alternative feed resources in the same areas (Konlan et al., 2015).

An increment in the nutrient coefficients for IVDOM produced similar incremental increases in the price of the feed resources. Some have argued that there was no relationship between price and quality for all feed types in the fodder market survey peri-urban areas of Bamako in Mali (Ayantunde et al., 2014). However, this result is consistent with the report of Samireddypalle et al. (2017) suggesting that haulm fodder quality is the guiding principle for pricing in feed markets in northern Nigeria, especially with reference to digestible organic matter. Generally, pricing may be based on units of measure, physical appearance, and indigenous knowledge of acceptability by the animal and not actual quality analyses. Livestock keepers are not yet well informed on the nutritional quality of feeds (Ayantunde et al., 2014). Consequently, when feed prices are based on indigenous knowledge, quality fodder may be priced less than it could be, resulting in unequal pricing. The irrigated fodder harvested at 16 WAP for the market potential may affect its pricing as older or stemmy material may be priced lower based on indigenous knowledge. The linear relationship between price and quality in this study is an indication that any changes in the quality attributes may result in a corresponding change in the price. Creating opportunities for improving the quality of the feed resources in regions can lead to increases in the profit derived.

Attempts to market the harvested irrigated fodder demonstrated the potential demand for fresh fodder and its market acceptability. Regarding the market value of irrigated fodder, it was observed that this could serve as means of diversifying household income sources from the sale of fodder for producers having access to water source and available land. Yield per unit area and the market price at different location influence the cost benefit of engaging in irrigated forage production as demonstrated in this study. Grass species with greater yield per unit area, lower cost of production and higher return on investment, may be the irrigated farmers' preference especially in the northern region.

Although the market value of irrigated fodder is relatively higher than those of dry crop residues and bran, making it economically viable, the return on investment needs to be compared with other options with little or no cost of investment (roadside natural pasture, crop residues etc.). Similarly, where irrigated fodder production competes with more traditional irrigated commodities for land, water, labor, cash and other resources, farmers make decisions by considering their comparative advantages. With this situation in mind, capacity development in terms of awareness of the nutritional values of irrigated fodder, economic potential and technical support will be initial steps in promoting irrigated fodder trading in regions where it does not exist. Land size is one of the major limiting or enhancing factors. Especially in the Upper East region, available land areas for irrigated farming are located in the lowlands and are usually small as a result of fragmentation due to population growth.

Other limiting factors observed during the study were the farmers' livestock production targets in both regions which were not market oriented. In most studies where the profitability of irrigated fodder has been reported and is well established, livestock production is market oriented–mostly dairy production, even at the smallholder level (SNV, 2013). Others also report on the profitability of irrigated forage in eastern Africa (Getnet et al., 2014; Bezabih et al., 2016). Integrating fodder into irrigated production practices in both regions will require a change of mind-set of smallholder farmers into business-oriented livestock management. This is because for a successful adoption of irrigated fodder, farmers need sufficient land, water, and productive animals, and proper input and output market linkages (Gebrehaweria & Haileslassie, 2014).

5 | CONCLUSION

As the demand for feed continues to grow with prolonged dry seaosn especially in the semi-arid regions, this trial showed greater potential for cultivation and marketing of irrigated fodder in places where such practices are uncommon. Ruzi grass and forage sorghum evaluated in this study showed great potential as feed resources in view of their high yields and quality especially under irrigation. Finding balance between DMA and nutritive values of forages requires targeting harvest at the optimum time. Harvesting at 8 WAP appear as the best time as it resulted into two harvests with reasonable quality materials.

Market potential for irrigated fodder during the dry season varies spatially and is demand dependent. Feed pricing in this region is based on indigenous knowledge and not on determined nutritive value which may result in unequal pricing of the irrigated fodder. There is need for capacity development on informed nutritional quality of feeds and forages in region. This is important to accelerate the market value for irrigated fodder when harvested at the optimum time (8 WAP) in term of quality and quantity as evidence of good performance of the animals fed irrigated fodder could stimulate higher demand for irrigated fodder. However, where pricing is not a reflection of the forage quality, delaying harvesting till 16 WAP to generate higher DMA may be advisable.

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AUTHOR CONTRIBUTIONS

T. Adegoke Amole: Conceptualization; Investigation; Project administration; Writing-original draft; Writing-review & editing; Emmaunel Panyan: Investigation; Supervision; Adetayo Adekeye: Data curation; Writing-review & editing; Augustine Ayantunde: Conceptualization; Methodology; Supervision; Validation; Writing-review & editing; Alan Duncan: Conceptualization; Methodology; Supervision; Validation; Writing-review & editing; Michael Blummel: Conceptualization; Methodology; Project administration.

CONFLICT OF INTEREST

Authors declare no conflict of interest in relation to this publication.

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REFERENCES

ABS. (2006). *Australian Water Resources 2005 (AWR 2005) project. Water account Australia 2004–05 4610.0*. ABS. http://www.water.gov.au/

Acheampong, D., Balana, B. B., Nimoh, F. & Abaidoo, R. C., (2018). Assessing the effectiveness and impact of agricultural water management interventions: The case of small reservoirs in northern Ghana. *Agricultural Water Management*, *209*, 163–170. https://doi.org/10.1016/j.agwat.2018.07.009

Acheampong, E. N., Ozor, N., & Owusu, E. S. (2014). Vulnerability assessment of northern Ghana to climate variability. *Climatic Change*, *126*, 31–44. https://doi.org/10.1007/s10584-014-1195-z

Adam, H., Atengdem, P. B., & Al-hassan, S. (2010). Innovation adoption levels of small ruminant farmers in Tolon-Kumbungu district of Ghana. *Ghana Journal of Development Studies*, *7*(2), 39–66. https://doi.org/10.4314/gjds.v7i2.66880

Ademosum, A. A. (1994). Constraints and prospects for small ruminant research and development in Africa. In S. H. B. Lebbie, Rey, B & Irungu, E.K et al. (Eds.), *Proceedings of the Second Biennial Conference of the African Small Ruminants Research Network* (pp. 1–9). AICC

Adugna, T., & Said, A. N. (1994). Assessment of feed resources in Wolayita Sodo: Quantity estimation and laboratory evaluation. *Ethiopian Journal of Agricultural Sciences*, *14*, 69–87.

Adzitey, F. (2013). Animal and meat production in Ghana–An overview. *The Journal of World's Poultry Research*, *3*(1), 1–4. https://jwpr.science-line.com/attachments/article/16/J.%20World's%20Poult.%20Res.%203(1)%2001-04,%202013.pdf

Afzal, M., Ahmad, A., & Ahmad, A. u. H. (2012). Effect of nitrogen on growth and yield of sorghum forage (*Sorghum bicolor* (L.) Moench cv.) Under three cuttings system. *Cercetări Agronomice în Moldova*, *45*, 57–64. https://doi.org/10.2478/v10298-012-0065-y

Ahmed, I. A. M., Eltilib, A. M. A., Ganawa, F. H. S., Erenoglu, E. B., & Islam, K. R. (2016). Utilization of industrial waste aqueous ammonia for irrigated forage sorghum production. *Archives of Agronomy and Soil Science*, *62*, 93–107. https://doi.org/10.1080/03650340.2015.1039523

Amole, T. A., Odeyemi, A. J., Dele, P. A., Lawal, A. E., Oyaniran, D. K., Odunuga, A. O., Sofela, T. O, & Oshundara, O. F. (2016). Yield and quality evaluation of five tropical legumes in pure and mixed sward in the moist savanna of West Africa. *Tropical Agriculture*, *93*, 165–177. https://journals.sta.uwi.edu/ojs/index.php/ta/article/view/878

Alaoui, S. B. (2009) *Irrigated fodder crops production in Morocco*. FAO regional expert consultation on irrigated fodder crops in the near east region: Forage production, conservation and utilization for sustainable animal production IAV Hassan II, 15–19 June 2009. https://doi.org/10.13140/RG.2.2.11309.69601

Amole, T. A., Oduguwa, B., Shittu, O., Nkwelum, N., Dele, P. A., Ojo, V. O. A., Odeyemi, B., Toviesi, P., & Famakinde, A. (2013). Preference of Muturu cattle to either fresh forage or pelleted hay of *Panicum maximum* and *Pennisetum purpureum* cut at four and eight weeks. *Slovak Journal of Animal Science*, *46*(2), 68–74. https://sjas.ojs.sk/sjas/article/view/248

Arya, S. L., Panwar, P., & Yadav, R. P. (2011). Role of watershed management in bridging demand – Supply gap of fodder for enhancing livestock production in Shivaliks. *Haryana Agricultural Economics Research Review*, *24*, 225–233. https://www.semanticscholar.org/paper/Role-of-Watershed-Management-in-Bridging-Demand-%E2%80%93-Arya-Panwar/8412668ab26620f7010f4f5159f936fd3db087a1

Asmare, B. (2016). *Evaluation of the agronomic, utilization, nutritive and feeding value of desho grass (Pennisetum pedicellatum)* (Doctoral dissertation, Ph.D Dissertation. Jimma University Ethiopia). http://hdl.handle.net/10568/77741

Association of Official Analytical Chemists (AOAC). (1990). *Official methods of analysis of the AOAC*. 15th, AOAC.

Ayantunde, A. A., Blummel, M., Grings, E., & Duncan, A. J. (2014). Price and quality of livestock feeds in sub-urban markets of West African Sahel: Case study from Bamako, Mali. Revue d'elevage et de medecine veterinaire des pays tropicaux. *Ressources Alimentaires*, *67*, 13–21. https://doi.org/10.19182/remvt.10155

Balana, B. B., Bizimana, J.-C., Richardson, J. W., Lefore, N., Adimassu, Z., & Herbst, B. K. (2020). Economic and food security effects of small-scale irrigation technologies in northern Ghana. *Water Resources and Economics*, *29*, 100141. https://doi.org/10.1016/j.wre.2019.03.001

Balole, T. V., & Legwaila, G. M. (2006). *Sorghum bicolor (L.) Moench. Record from protabase*. Plant Resources of Tropical Africa/Ressources Végétales de l'Afrique Tropicale. http://www.prota4u.org

Bayala, J., Ky-Dembele, C., Kalinganire, A., Alain, O., & Hamidou, N. (2014). *A review of pasture and fodder production and productivity for small ruminants in the Sahel* (ICRAF Occasional Paper no. 21). World Agroforestry Centre. https://www.researchgate.net/publication/262943657_A_review_of_pasture_and_fodder_production_and_productivity_for_small_ruminants_in_the_Sahel

Bayble, T., Melaku, S., & Prasad, N. K. (2007). Effects of cutting dates on nutritive value of Napier *(Pennisetum purpureum)* grass planted sole and in association with Desmodium *(Desmodium intortum)* or Lablab (*Lablab purpureus*). *Livestock Research for Rural Development*,*19*(1). http://www.lrrd.org/lrrd19/1/bayb19011.htm

Bezabih, M., Duncan, A. J., Mekonnen, K., Adie, A., Khan, A. K., & Thorne, P. J. (2016). The role of irrigated fodder production to supplement the diet of fattening sheep by smallholders in Southern Ethiopia. *Tropical and Subtropical Agroecosystems*, *19*(3), 263–275.

Blümmel, M., Derseh, M., Adie, A. & Amole, T. (2018). Feed the Future Innovation Lab on Small Scale Irrigation (ILSSI): Ethiopia, Ghana, and Tanzania ILRI final report. Nairobi, Kenya. https://hdl.handle.net/10568/100485

Botelho, P. R. F., Pires, D. A. A., Sales, E. C. J., Rocha Júnior, V. R., Jayme, D. G., & Reis, S. T. (2010). Avaliação de Genótipos de Sorgo em primeiro corte e rebrota para produção de silagem. *Revista Brasileira de Milho e Sorgo*, *9*, 287–297. https://doi.org/10.18512/1980-6477/rbms.v9n3p287-297

Buxton, D. R. (1996). Quality-related characteristics of forages as influenced by plant environment and agronomic factors. *Animal Feed Science Technology*, *59*, 3749.

Buxton, D. R., & O'Kiely, P. (2003). Preharvest plant factors affecting ensiling. In D. R. Buxton, R. E. Muck, & J. H. Harrison (Eds.), *Silage science and technology* (pp. ASA, CSSA, and SSSA, 199–250) 42. https://acsess.onlinelibrary.wiley.com/doi/book/10.2134/agronmonogr42

Daniel, K. (1996). Effects of nitrogen application and stages of development on yield and nutritional value of Rhodes grass (*Chloris gayana*). *Ethiopia Journal of Agricultural Science*, *15*, 86–101.

Dantas, G. D.e F., Faria, R. T. D.e, Santos, G. O., Dalri, A. B., & Palaretti, L. F. (2016). Herbage yield and quality of irrigated brachiaria in autumn and winter. *Engenharia Agricola*, *36*(3), 469–481. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n3p469-481/2016

Ferraro, D. O., & Oesterheld, M. (2002). Effect of defoliation on grass growth. *Oikos*, *98*, 125–133. https://doi.org/10.1034/j.1600-0706.2002.980113.x]

Ferreira, L., Sanches, A., Mendonça, F., Gomes, P., Pezzopane, M., Couto, R., Biconi-Pacheco, A., Lisboa, C. & Gomes, R. (2020). Yield parameters and water productivity of tropical and overseeded winter forages. *International Journal for Innovation Education and Research*, *8*, 760–774.

Foloni, J. S. S., Tiritan, C. S., Calonego, J. C., & Dundes, L. R. (2008). Rebrota de soqueiras de sorgo em função da altura de corte e da adubação Nitrogenada. *Ceres*, *55*, 102–108.

Gebrehaweria, G. & Haileslassie, A. (2014). Assessments of key small-scale irrigation technologies, agricultural water management options and integrated irrigated fodder in Ethiopia Feed the Future Innovation Lab for Small-Scale Irrigation: Ethiopia Discussion Paper for Stakeholder Consultation January 2014. https://cgspace.cgiar.org/rest/bitstreams/64157/retrieve

Getnet, M., Hengsdijk, H., & Van Ittersum, M. (2014). Disentangling the impacts of climate change, land use change and irrigation on the Central Rift Valley water system of Ethiopia. *Agricultural Water Management*, *137*, 104–115. https://doi.org/10.1016/j.agwat.2014.02.014

Ghana Statistical Service. (2013). 2010 population and housing census *(Regional Analytical Report, northern region)*. Ghana Statistical Service.

Ghimire, S., Njarui, D., Mutimura, M., Cardoso, J., Johnson, L., Gichangi, E., Teasdale, S., Odokonyero, K., Caradus, J., Rao, I. & Djikeng, A. (2015). Climate-smart Brachiaria for improving livestock production in East Africa: emerging opportunities. Vijaya, D., Srivastava, M., Gupta, C., Malaviya, D., Roy, M., Mahanta, S., Singh, J., Maity, A. & Ghos, P., *Sustainable use of grassland resources for forage production, biodiversity and environmental protection. Proceedings of 23rd International Grassland Congress, 20–24 Nov. 2015*. Range Management Society of India, 361–370.

Hagos, F. & Mamo, K. (2014) Financial viability of groundwater irrigation and its impact on livelihoods of smallholder farmers: The case of eastern Ethiopia. *Water Resources and Economics*, *7*, 55–65.

Hazim, S. T., & Ates, E. (2018). Chemical composition of six grass species (*Poaceae* sp.) from protected forest range in northern Bulgaria. *Asian Journal of Applied Sciences*, *11*, 71–75.

Hiernaux, P. (1996). *The crisis of Sahelian pastoralism: Ecological or economic?* (ODI Pastoral Development Network Paper no. 39a). Overseas Development Institute.

Husseini, R., & Belko, R. (2011). Survey of browse plants trade in the Upper East Region of Ghana. *Agricultural and Biology Journal of North America*, *2*, 546–551. https://doi.org/10.5251/abjna.2011.2.3.546.551

Ishiaku, Y. M., Hassan, M. R., Tanko, R. J., Amodu, J. T., Abdu, S. B., Ahmed, S. A., Abubabakar, S. A., Lasisi, O. T., Bala, A. G., Bello, S. S., & Ibrahim, H. (2016). Effect of plant spacing on yield and quality of Columbus grass (*Sorghum almum*) under rainfed in Shika. *Nigeria Journal of Animal Production Research*, *28*(1), 318–328.

Karbo, N., & Agyare, W. A. (2002). Improving livestock systems in the dry Savannas of West and Central Africa. In G. Tarawali & P. Hiernaux (Eds.), *Crop-livestock systems in the dry Savannas of West and Central Africa. Reports from the Workshop on livestock systems in the dry savannas of West and Central Africa* (pp. International Institute of Tropical Agriculture, 022–027).

Konlan, S. P., Ayantunde, A. A., Addah, W., Dei, H. K., & Karbo, N. (2015). Emerging feed markets for ruminant production in urban and peri-urban areas of northern Ghana. *Tropical Animal Health Production*, *50*, 169–176. https://doi.org/10.1007/s11250-017-1418-1

Lima, M. H. M., Pires, D. A. A., Moura, M. M. A., Costa, R. F., Rodrigues, J. A. S. & Alves, K. A. (2017). Nutritional characteristics of Sorghum hybrids hay (Sorghum sudanense vs. Sorghum bicolor). *Acta Scientiarum*, *39*, 229–234. https://doi.org/10.4025/actascianimsci.v39i3.32524

Lukuyu, M., Njehu, A., Mwilawa, A., Lukuyu, B., Omore, A., & Rao, J. (2016). *A study to understand fodder markets and fodder trading patterns in MoreMilkiT sites and other selected regions in Tanzania* (pp. 35–46). International Livestock Research Institute.

Maleko, D., Mwilawa, A., Msalya, G., Pasape, L., & Mtei, K. (2014). Forage growth, yield and nutritional characteristics of four varieties of napier grass (*Pennisetum purpureum* Schumach) in the west Usambara highlands Tanzania. *Scientific African*, *6*. https://doi.org/10.1016/j.sciaf.2019.e00214

Månsson, H. (2011). *Small-scale agriculture in Bolgatanga Ghana–A case study of how to make small-scale sustainable agriculture more profitable* (A seminar presentation in Göteborgs Universitet).

Martin, R., Linstädter, A., Frank, K. & Müller, B. (2016) Livelihood security in face of drought – assessing the vulnerability of pastoral households. *Environmental Modelling & Software*, *75*, 414–423. https://doi.org/10.1016/j.envsoft.2014.10.012

Mirza, S. N., Muhammad, N., & Qamar, I. A. (2002). Effect of growth stages on the yield and quality of forage grasses. *Pakistan Journal Agriculture Research*, *17*, 145–14.

Mochel Filho, W., Carneiro, M., Andrade, A., Pereira, E., Andrade, A., Cândido, M., Magalhães, J., Rodrigues, B., Santos, F., & Costa, N. (2016). Yield of Mombaça grass under irrigation and nitrogen fertilization. *Revista de Ciências Agrarias*, *39*(1), 81–88. https://doi.org/10.19084/RCA14154

Mohammad, N. & Naqvi, A. H. (1987). Dry matter yield of promising grasses in tropical arid rangelands of Sind, Pakistan. *Tropical Agriculture*, *61*, 70–71.

Moore, J. E., & Mott, G. O. (1973). Structural inhibitors of quality in tropical grasses. In A. G. Matches (Ed.), *Antiquality components of forages* (pp. 53–98). CSSA.

Mugeriwa, J. S., Christianson, J. A., & Ochetim, S. (1978). Grazing behaviour of exotic dairy cattle in Uganda. *East Africa Agriculture and Forestry Journal*, *19*, 1–11.

Muhammad, I. R., Abdullahi, B., Mohammed, A. K., Tanko, R. J., Kallah, M. S., & Alawa, J. P. (2005). Influence of irrigation intervals on dry matter yield, concentration of crude protein, calcium and phosphorus in Lablab purpureus and *Sorghum almum* fodder in the Sudan Savannah zone of Nigeria. *Nigerian Journal of Animal Production*, *32*, 280–286. https://doi.org/10.51791/njap.v32i2.1094

Ngila, P., Njarui, D. M., Musimba, N. K. & Njunie, M. N. (2016). Performance of Galla goats fed different cultivars of Brachiaria in the coastal lowlands of Kenya. *Journal of Fish and Livestock Production*, *5*, 210. https://doi.org/10.4172/2332-2608.1000210

Olanite, J. A., Anele, U. Y., Arigbede, O. M., Jolaosho, A. O., & Onifade, O. S. (2010). Effect of plant spacing and nitrogen fertilizer levels on the growth, dry-matter yield and nutritive quality of Columbus grass (*Sorghum almum* stapf) in southwest Nigeria. *Grass and Forage Science*, *65*(4), 369–375. https://doi.org/10.1111/j.1365-2494.2010.00755.x

Pathak, S., Jain, N., & Bhatia, A. (2012). *Crop residues management with conservation agriculture: Potential, constraints and policy needs* (pp. 7–32). Indian Agricultural Research Institute.

Patrick, M., Tenywa, J. S., Ebanyat, P., Tenywa, M. M., Mubiru, D. N., Basamba, T. A., & Leip, A. (2013). Soil organic carbon thresholds and nitrogen management in tropical agroecosystems: Concepts and prospects. *Journal of Sustainable Development*, *6*, 31–43. https://doi.org/10.5539/jsd.v6n12p31

Perazzo, A. F., Carvalho, G. G. P., Santos, E. M., Bezerra, H. F. C., Silva, T. C., Pereira, G. A., Ramos, R. C. S., & Rodrigues, J. A. S. (2017). Agronomic evaluation of sorghum hybrids for silage production cultivated in semiarid conditions. *Frontier in Plant Science*, *8*, 1088. https://doi.org/10.3389/fpls.2017.01088

Ramírez de la Ribera, J. L., Kijora, C., Acosta, I. L., Cisneros López, M., & Tamayo Soza, W. (2008). *Effect of age and growing season on DM yield and leaf to stem ratio of different grass species and varieties growing in Cuba* (Article 148). http://www.lrrd.org/lrrd20/9/rami20148.htmVolume20

Rao, I. M., Kerridge, P. C., & Macedo, M. (1996). Nutritional requirements of Brachiaria and adaptation to acid soils. In J. W. Miles, Maass, B. L, Valle, C. B & Kumble, V. et al. (Eds.), *Brachiaria: Biology, agronomy, and improvement* (pp. CIAT, 53–71)https://hdl.handle.net/10568/54881

Respati, A. N., Umami, N., & Hanim, C. (2018). Growth and production of *Brachiaria brizantha* cv. MG5 in three difference regrowth phase treated by gamma radiation dose. *Tropical Animal Science Journal*, *41*(3), 179–184. https://doi.org/10.5398/tasj.2018.41.3.179

Rosolem, C., Ritz, K., Cantarella, H., Galdos, M., Hawkesford, M., Whalley, W. & Mooney, S. (2017). Enhanced plant rooting and crop system management for improved N use efficiency. *Advances in Agronomy*, *146*, 205–239. https://doi.org/10.1016/bs.agron.2017.07.002

Samireddypalle, A., Boukar, O., Grings, E., Fatokun, C. A., Kodukula, P., Devulapalli, R., Okike, I., & Blümmel, M. (2017). Cowpea and groundnut haulms fodder trading and its lessons for multidimensional cowpea improvement for mixed crop livestock systems in West Africa. *Frontiers in Plant Science*, 08. https://doi.org/10.3389/fpls.2017.00030

SAS Institute Inc. (SAS). (2009). *SAS/STAT 9.2 user's guide*. 3nd, SAS.

Smith, T. (2010). *Some tools to combat dry season nutritional stress in ruminants under African conditions* (pp. Development and field evaluation of animal feed supplementation packages. International Atomic Energy Agency (IAEA), 145–152). https://inis.iaea.org/collection/NCLCollectionStore/_Public/33/032/33032982.pdf

SNV. (2013). *Study on the Kenyan animal feed and fodder sub-sector* (pp. 19–38). SNV/Kenya Netherlands Development Organisation. https://cowsoko.com/programs/kmdp/publications/11/item

Spitaleri, R. F., Sollenberger, L. E., Staples, C. R., & Schank, S. C. (1995). Harvest management effects on silage nutritive value of seeded *Pennisetum hexaploid* hybrids. *Postharv Biology and Technology*, *5*, 353–362. https://doi.org/10.1016/0925-5214(94)00033-O

Tegegne, A., Gebremedhin, B., Hoekstra, D., Belay, B. & Mekasha, Y. (2013). *Smallholder dairy production and marketing systems in Ethiopia: IPMS experiences and opportunities for market-oriented development* (Working paper 31). International Livestock Research Institute,

Teshome, S., Beyene, C., & Reed, J. D. (1994). Effect of days of maturity and fertilizer on composition and *in vitro* digestibility of indigenous pasture in the eastern high lands of Ethiopia. *Ethiopia Journal of Agricultural Science*, *14*, 60–68.

Tilahun, G., Asmare, B., & Mekuriaw, Y. (2017). Effects of harvesting age and spacing on plant characteristics, chemical composition and yield of desho grass (*Pennisetum pedicellatum* Trin.) in the highlands of Ethiopia. *Tropical Grasslands-Forrajes Tropicales*, *5*, 77. https://doi.org/10.17138/TGFT(5)77-84

Turano, B., Tiwari, U. P., & Jha, R. (2016). Growth and nutritional evaluation of Napier grass hybrids as forage for ruminants. *Tropical Grasslands-Forrajes*, *4*(3), 168168–178. https://doi.org/10.17138/TGFT(4)168-178

Van Oosterom, E. J., Carberry, P. S., & Muchow, R. C. (2001). Critical and Minimum N contents for development and growth of grain sorghum. *Field Crop Research*, *70*, 55–73. https://doi.org/10.1016/S0378-4290(00)00152-0

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant* (2nd ed.). Cornell University Press.

Zemene, M. Mekuriaw, Y. &Asmare, B. (2020). Effect of plant spacing and harvesting age on plant characteristics, yield and chemical composition of Para grass (*Brachiaria mutica)* at Bahir Dar, Ethiopia. *Journal of Microbiology, Biotechnology and Food Sciences*, *53*, 137–145. https://spasb.ro/index.php/spasb/article/view/2669

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