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# Forage yields and quality of *Cenchrus ciliaris* and *Panicum maximum* ecotypes under varied harvest intervals in a semi-arid environment in Kenya

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**Abstract.** *Kisambo BK, Wasonga OV, Kipchirchir OK, Karuku GN, Kirwa EC. 2023. Forage yields and quality of* Cenchrus ciliaris *and* Panicum maximum *ecotypes under varied harvest intervals in a semi-arid environment in Kenya. Intl J Trop Drylands 7: 102-111.* Livestock production in Kenya typically relies on native pastures for nutrition and efforts are ongoing to develop varieties adapted to semi-arid conditions. A field experiment was conducted in a semi-arid environment to evaluate harvest intervals' influence on the yield and nutritional attributes of selected grass ecotypes of two native grasses used in reseeding and fodder production. The grasses included Buffel grass ecotypes {*Cenchrus ciliaris* Kilifi (KLF), *C. ciliaris* Magadi (MGD)} and Guinea grass ecotypes *{Panicum maximum* Isinya (ISY) and *P. maximum* Taveta (TVT)}. They were planted in a randomized-complete block design in a split-plot arrangement and maintained under rain-fed conditions. Forage harvests were performed at 3 harvest intervals i.e., 14, 28 and 84 days, simulating different utilization regimes in semi-arid Kenya. Biomass yield, forage accumulation and quality of the grasses were determined. The highest yields were obtained at 28-day harvest intervals and were 74% higher than the 14-day interval, although almost similar to the 84-day interval harvests. Forage accumulation rates varied significantly ($p$ <0.005) between ecotypes and harvesting intervals. Crude Protein (CP) declined significantly with maturity, from a mean of 11.67% for the 14-day harvesting interval to 5.22% at the end of the season and varied among treatments. In Vitro Dry Matter Digestibility (IVDMD) increased with increasing harvest interval. However, fiber components-Nutrient Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL) increased with plant age. Harvest intervals had a significant ($p$ <0.05) influence on the yield and qualitative attributes of the grass ecotypes. *C. ciliaris* ecotype MGD and *P. maximum* ecotype TVT are viable options for further performance evaluation in semi-arid environments as efforts to develop new range fodder varieties are accelerated.

**Keywords:** Biomass, crude protein, digestibility, dry matter; grazing, livestock feed, reseeding

## INTRODUCTION

Natural pastures are critical feed sources for livestock across the globe (Michalk et al. 2018) and constitute 48% of the total biomass used by livestock (Herrero et al. 2013). Indigenous perennial grasses in particular play a key role in livestock nutrition in dryland environments. With changing land use patterns, overgrazing, and climate change, most of these grasses are on the decline (Boone et al. 2018; Greiner et al. 2021), compromising the sustainability of livestock production. The lack of sufficient feed of good quality has been a major drawback in dryland production systems resulting in reduced livestock productivity (Koech 2014; Mganga et al. 2019; Balehegn et al. 2022).

In semi-arid Kenya, besides natural pastures, there is an unexploited potential for forage cultivation using indigenous grasses for hay production to bolster feed security and sustain livestock production. This is widely pronounced especially under increasing pasture scarcity, mainly occasioned by frequent droughts and diminishing grazing land. Many pastoralists and agro-pastoralists have ventured into fodder production not only for feed provision for feed provision and other co-benefits such as range grass seed production (Omollo 2017; Wasonga et al. 2017). Some of the key grasses used for reseeding and grown for fodder include African foxtail grass (*Cenchrus ciliaris*), Guinea grass (*Panicum maximum*), Masaai love grass (*Eragrostis superba*), Bush rye (*Enteropogon macrostachyus*), Horsetail grass (*Chloris roxburghiana*) among others (Koech 2014; Mganga et al. 2021) among others. The demand for better forage species that are more productive and able to cope with changing climatic conditions exists and will continue to increase (Wasonga et al. 2017).

Determining yields and nutritional attributes of livestock feeds is critical to the growth, well-being and productivity of livestock. Some of the factors affecting the productivity and nutritional profiles of grasses include: species, soil types growing environment, stage of utilization and management interventions. For instance, research has shown that as the harvesting interval increases, the feed quality attributes declines (Schnellmann et al. 2020; Gilo et al. 2022). For successful fodder production, management interventions must aim at optimizing production. One key management intervention involves harvesting or grazing grasses at appropriate intervals which has implications not only on the reproductive potential, persistence and quality of grasses (Capstaff and Miller 2018; Venter et al. 2021), but also on ruminant production.

Two grass species, *C. ciliaris* and *P. maximum* are key forage species in arid and semi-arid rangeland ecosystems in Kenya and elsewhere. In Kenya, these species are commonly preferred for various reasons including drought tolerance, high biomass production and the ability to thrive in varied environments (Mganga et al. 2015; Njarui et al. 2015). Currently, these grasses are commonly grazed or harvested as fodder. In semi-arid regions, the onset of rain normally results in rapid grass regrowth which grazers rapidly consume. At this point, the grasses are rich in nutrients such as Crude Protein (CP) but low in biomass yields. Fodder harvesting and utilization should coincide with the flowering stage when grasses are at their peak nutritional status. On the other hand, harvesting grass seeds for sale and reseeding, which has become common in Kenya's drylands is normally done after seed maturity (Omollo 2017). This has implications for the quality of grasses, mostly a decline (Koech 2014; Gilo et al. 2022).

Limited studies have considered within-species variability concerning biomass and nutritional aspects in semi-arid Kenya. Many local accessions or ecotypes of these grasses have been collected and preserved at the national genebank and in ex-situ field genebanks in Kenya. Kirwa (2019), investigated the performance of various accessions for reseeding in Kenya and found wide variability in yield attributes. No further studies have been done to evaluate the species based on responses to management interventions such as defoliation or harvesting intervals. Knowledge of grass responses and sensitivity to defoliation is crucial in designing grazing and harvesting regimes under semi-arid conditions and is critical for pasture-based systems' sustainability. With the development of fodder value chains and growth of the livestock sector, evaluating available forage germplasm and selecting high-yielding varieties is necessary. This is for breeding, multiplication and promotion of improved livestock productivity particularly under a changing climate.

This study was therefore conducted to evaluate the effects of harvesting intervals on cumulative forage yields and nutritional attributes of 4 selected grass ecotypes of two range grasses (*C. ciliaris* and *P. maximum*) commonly used in reseeding and fodder production in semi-arid Kenya. It complements efforts to identify new indigenous dryland varieties based on biomass yield and nutritional attributes which are key traits of forage crop (Capstaff and Miller 2018).

## MATERIALS AND METHODS

### Description of the study site

The study was conducted from October 2019 to September 2020 at the Kenya Agricultural and Livestock Research Organization (KALRO)-Kiboko Research Station in South-east Kenya (02°151S, 37°43E). The station lies at an altitude of 1024 m above sea level. The average annual rainfall is 534.3±66.2 mm, distributed in a bimodal pattern with the long rains received between March and May. The short rains are normally received between October and December and are more reliable for agricultural production within the study site. Temperatures vary from a minimum of 22°C to a maximum of 32°C (Ndathi 2012). The mean monthly rainfall and temperature data recorded during the study period are illustrated in Figure 1.

The vegetation at the station is mainly bushed grassland with a diverse mix of native tree and shrub species with an understory of various grasses. The common tree species include *Acacia, Commiphora*, and *Combretum* spp. The dominant grasses include Bush rye (*E. macrostachyus*), Foxtail grass (*C. ciliaris*) Horsetail grass (*C. roxburghiana*) and Maasai love grass (*E. superba*). The soils in the experimental site are classified as Acri-rhodic ferralsols (CIMMYT 2013) and the physiochemical composition at the beginning of the study is shown in Table 1.

### Experimental grasses

The study used 4 range grass ecotypes: *P. maximum* Taveta (TVT), *P. maximum* Isinya (ISY), *C. ciliaris* Magadi (MGD) and *C. ciliaris* Kilifi (KLF). These were obtained from the KALRO Kiboko farm which serves as a field genebank for some accessions collected from different parts of semi-arid Kenya. The selection of the 4 ecotypes was based on previous work characterizing the ecotypes at the Centre (Kirwa 2019).

### Land preparation, planting and experimental design

Land that had been left fallow for two seasons was plowed and prepared to a fine tilth in September 2019 in readiness to plant the grass ecotypes. A total area of 885 $m^2$ was divided into 3 blocks with each having 12 plots measuring 10.5 $m^2$. A 2-metre alley separated the blocks while a 1-metre alley separated the plots. The experiment was laid out as randomized blocks with three replicates as a split-plot design. The main plots were 4 grass ecotypes while the harvest intervals represented the sub-plots.

**Table 1.** Soil physiochemical properties of the experimental site at two depths (0-15 and 15-30 cm) at the beginning of the study

| Soil Property | Value (0-15 cm) | Value (15-30 cm) |
|---|---|---|
| Texture grade | Sandy loam | Sandy loam |
| pH | 7.66 | 7.17 |
| Total nitrogen (%) | 0.12 | 0.09 |
| Total organic carbon (%) | 1.11 | 0.76 |
| Phosphorus (ppm) | 23 | 13 |
| Potassium (milliequivalents %) | 0.68 | 0.66 |
| Calcium (milliequivalents %) | 2.2 | 2.2 |
| Manganese (milliequivalents %) | 0.33 | 0.33 |
| Copper (ppm) | 2.00 | 2.57 |
| Zinc (ppm) | 4.33 | 0.96 |

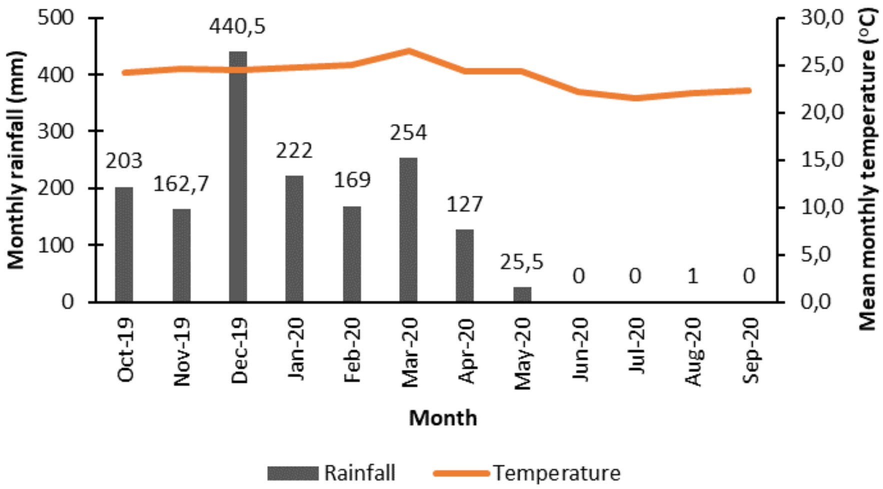


**Figure 1.** Monthly rainfall and temperature data of the study site during the experimental period

The 3 harvesting intervals included cutting once every 14 days; once every 28 days and a one-off harvesting at 84 days. The harvesting intervals represented a high-frequency regime; moderate/intermediate regime and low-frequency regime of utilization respectively. These utilization regimes are commonly practiced within arid and semi-arid areas by livestock keepers and farmers, with the latter being mainly adopted for hay production (Omollo 2017). The 4 grass ecotypes were uprooted from the field genebank and the vegetative root splits were transplanted immediately into prepared plots in holes measuring 10 cm in diameter. The spacing between rows and between plants was 50 cm. Plants were maintained under rain-fed conditions over the experimental period. A standardization cut was carried out at the end of the establishment phase of 30 days where the grasses were all clipped at 10 cm stubble height and top-dressed with Calcium Ammonium Nitrate (CAN) fertilizer at the rate of 50 $KgNha^{-1}$. This was done as per recommendations by Boonman (1993) for cultivated grasses to ensure optimal crop growth, even though few farmers fertilize their grasses with manure or fertilizer in semi-arid Kenya. The grasses were regularly weeded whenever weeds emerged, manually.

**Data collection**

Harvesting treatments commenced in February 2020 and data was collected through two regrowth cycles up to September 2020. Forage production was determined for each treatment by harvesting all plant tissues above ground within a 1 $m^2$ quadrat at the center of each plot, at a stubble height of 10 cm from the ground level. A hand sickle was used to clip the grasses. The harvested material was weighed in the field using a portable balance, for each treatment and a subsample was taken, weighed and taken to the laboratory for oven drying at 65°C for 48 hrs. This was then weighed and dry matter yields per hectare were determined by extrapolating to per hectare level. After harvesting, the whole plot was clipped to the same residual height, depending on the treatment. Total yields per treatment were calculated as the cumulative yields obtained from the plots by adding up individual yields at each harvest. Forage Accumulation Rate (FAR) was measured as the amount of accumulated forage mass (DM $Kgha^{-1}$) between harvesting intervals for every treatment divided by the number of days, i.e. 14, 28 and 84 days. Weather data, mainly rainfall and temperature were obtained from a nearby weather station at 500 m from the experimental site.

**Laboratory feed quality determination**

The oven-dried samples were ground using an electric mill and analyzed for Dry Matter (DM), Crude Protein (CP), ash, Nutrient Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL) and In Vitro Dry Matter Digestibility (IVDMD) following procedures of AOAC (2010). Dry matter was determined through a forced air oven desiccator where a sample was oven-dried at 105°C overnight and the difference in mass was recorded. Crude protein was determined using the Kjeldahl method while ash content was determined using the dry combustion method where a sample was ignited in a furnace at 600°C for four hours to oxidize organic matter. Fiber components were analysed following the procedures of Van Soest et al. (1991) where samples were boiled for an hour in neutral detergent and a further hour in acid detergent to determine neutral detergent fiber (NDF) and Acid Detergent Fiber (ADF) respectively. In Vitro Dry Matter Digestibility (IVDMD) was determined following the two-stage procedure by Tilley and Terry (1963), where dried samples were incubated anaerobically at 38°C for 48 hrs with rumen fluid in a buffered solution. The samples were then digested in pepsin and hydrochloric acid at 38°C for 48 hrs.. Three samples were used for each analysis, which was done at the Animal Nutrition Laboratory at the University of Nairobi, Kenya.

**Statistical analysis**

Data was checked for normality under the Shapiro-Wilk test in Genstat software version 21 (VSN International). Analysis of variance (ANOVA) was carried out using The General Linear Model (GLM) in Genstat software to determine the effects of harvesting intervals on cumulative forage yield, forage accumulation rate, and nutritive attributes of the grass ecotypes.

The model adopted was

$$Y = \mu + E_i + H_j + B_k + EH + \varepsilon_{ijk}$$

Where Y was the observed value (yield and nutritive parameter) of ecotype i in interval j and block k, next μ was the overall mean effect, $E_i$ was the effect of ecotype, $H_j$ was the effect of the harvest interval, $B_k$ was the block effect- and EH the interaction between ecotype and harvest interval. Then $\varepsilon_{ijk}$ was the random error effect. Means were compared using Tukey tests whenever significance was detected and differences were considered statistically significant at $p$ <0.05. Additionally, the Pearson correlation was usedto determine the relationships between the nutritional; attributes of the grasses.

## RESULTS AND DISCUSSION

### Forage production

Generally, harvesting intervals significantly affected cumulative forage biomass yields ($p$ <0.05). Each ecotype responded differently to clipping with higher yields obtained as the harvest interval increased from 14 days to 84 days especially during the wet season. However, during the dry season, yields were only greater during the 28-day clipping interval and reduced at the 84-day harvest interval. Harvesting the grasses at 14-day intervals resulted in the lowest cumulative yields during the dry season period. Overall, *C. ciliaris* MGD harvested at 28-day intervals produced the highest cumulative biomass (12,017.69 $KgDMha^{-1}$) while the lowest biomass was recorded at the 14-day harvest interval in *C. ciliaris* KLF (3,726.28 $KgDMha^{-1}$) as shown in Table 2. Mean yields produced at 28-day intervals were significantly higher at 7,829.66 $KgDMha^{-1}$ than the 14-day (4,479.64) and 84-day (7,167.30) $KgDMha^{-1}$ harvest intervals. Generally, a 32% yield decline was also reported during the dry season.

### Forage Accumulation Rate (FAR)

The Forage Accumulation Rate (FAR) differed significantly ($p$ <0.05) among the grass ecotypes across the harvest intervals. The highest mean FAR was realized in *C. ciliaris* MGD and *P. maximum* TVT at 90.66 and 86.86 82.61 $KgDMha^{-1}$ respectively. The highest accumulation rates were realized while harvesting the grass ecotypes at 28-day intervals followed by 84-day intervals and the lowest at 14-day intervals. The *C. ciliaris* MGD accumulated more biomass 241.51 $KgDMha^{-1}day^{-1}$ over 28-day intervals than all the other treatments. Among the grass ecotypes, forage accumulation rates declined during the subsequent dry season as illustrated in Table 3.

### Forage quality

*Dry matter, crude protein and ash content*

The percentage of dry matter was above 96% for all the grass ecotypes and differed significantly ($p$ <0.05) with *C. ciliaris* KLF having the highest DM. Overall, the mean crude protein among the grass ecotypes was between 8.25% and 9.01%. Ash content also significantly varied with values between 12.21% and 15.59% obtained. The *C. ciliaris* MGD had the highest ash content of 15.59%.

Harvesting interval had a highly significant ($p$ <0.01) effect on CP and ash content, but not in DM. Ecotypes harvested at 14-day intervals had the highest CP with a mean of 11.67% followed by the 28-day interval at 8.78% while the 84-day interval had the lowest value of 5.22%. The highest CP value of 12.82% was found in *P. maximum* ISY, harvested at 14-day intervals while the lowest value of 4.49% was determined in the same species harvested after 12 weeks.

The ash content varied between 11.21%-16.93% with *C. ciliaris* MGD harvested at 14 day interval having the highest ash content (16.93%), followed by the same ecotype harvested at 28 day interval at 15.50%. The lowest ash content of 11.21% was determined in *P. maximum* TVT harvested at 28-day intervals (Table 4). Ecotypes clipped at 14-day intervals had the highest mean ash content (14.83) while those clipped at 84-day interval had the least (12.91%). Ash content generally decreased with increased harvest interval, with C. *ciliaris* grasses generally having a higher percentage than *P. maximum* ecotypes.

*Fiber fractions (NDF and ADF) and Lignin content (ADL)*

Table 5 indicates the Nutrient Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL) and In Vitro Dry Matter Digestibility (IVDMD) of the grass ecotypes at different harvest intervals.

The NDF values obtained were between 71% and 74% and significantly differed (p = 0.011) among the grass ecotypes. Harvest interval also significantly (p <0.001) influenced NDF in the grass ecotypes, with grasses subjected to 14-day interval having a lower mean NDF (70.51) than the 28-day and 84-day harvest intervals which were 74.35% and 73.72% respectively. The highest NDF value was reported in *C. ciliaris* KLF (76.76%) harvested at the 84-day interval.

The highest ADF value of 43.26% was found in *P. maximum* TVT harvested after 84 days while the lowest was *C. ciliaris* KLF (29.79%) harvested after 14 days. The effects of harvest interval on ADF were highly significant (p <0.001) with lower values obtained at 14-day intervals increasing with harvest interval.

Variation in ADL values among the grass ecotypes was very minimal ($p$ = 0.08) with mean values of 5.39%, 5.38%, 4.94% and 4.68%obtained for *C. ciliaris* MGD, *C. ciliaris* KLF, *P. maximum* TVT and *P. maximum* ISY respectively. The harvesting period significantly (p <0.001) influenced ADL with the highest ADL found among ecotypes harvested at the 84-day intervals. Finally, the IVDMD for the grass ecotypes ranged between 47% and 68% with the grasses harvested at 84-day intervals having significantly lower values than those harvested at shorter intervals.

**Table 2.** Effects harvesting interval on cumulative dry matter forage yields in $KgDMha^{-1}$ of 4 grass ecotypes in semi-arid Kenya over 2 growing seasons

| Harvest Interval | *C. ciliaris* MGD | | *C. ciliaris* KLF | | *P. maximum* TVT | | *P. maximum* ISY | |
|---|---|---|---|---|---|---|---|---|
| | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** |
| 14 days | 5,294.00 $^{cHIJ}$ | 4,627.18 $^{cHIJ}$ | 3,726.28 $^{cJ}$ | 4,311.19 $^{cHIJ}$ | 5,352.08 $^{deHIJ}$ | 3,934.42 $^{eIJ}$ | 5,676.39 $^{cGHI}$ | 4,295.98 $^{cHIJ}$ |
| 28 days | 12,017.69 $^{aA}$ | 8,271.43 $^{bCD}$ | 7,729.81 $^{aDEF}$ | 6,174.77 $^{bEFGH}$ | 9,811.90 $^{bBC}$ | 7,776.62 $^{cDE}$ | 7,282.06 $^{bDEFG}$ | 5,427.54 $^{cGHIJ}$ |
| 84 days | 10,624.17 $^{aAB}$ | 5,575.77 $^{cGHIJ}$ | 8,544.38 $^{aCD}$ | 5,556.16 $^{bGHIJ}$ | 11,419.05 $^{aAB}$ | 5,817.66 $^{dFGHI}$ | 10,651.17 $^{aAB}$ | 4,900.59 $^{cHIJ}$ |
| *p*-value | <0.001 | | <0.001 | | <0.001 | | <0.001 | |
| LSD | 658.4 | | 652.8 | | 970.8 | | 1,048.5 | |
| CV (%) | 18.1 | | 11.4 | | 13.9 | | 17.3 | |

Note: Different lower case letter after the number denotes significant difference at $p < 0.05$ between harvest intervals and season. Different uppercase letter denotes significant differences between ecotypes at $p < 0.05$

**Table 3.** Effects of harvest interval on forage accumulation rate ($Kg\ DM\ ha^{-1}\ day^{-1}$) of 4 grass ecotypes in tropical semi-arid Kenya during two growing seasons

| Harvest Interval | *C. ciliaris* MGD | | *C. ciliaris* KLF | | *P. maximum* TVT | | *P. maximum* ISY | |
|---|---|---|---|---|---|---|---|---|
| | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** | **Wet Season** | **Dry Season** |
| 14 days | 75.63 $^{cEFGH}$ | 58.08 $^{cHIJ}$ | 53.22 $^{cIJ}$ | 61.87 $^{cGHIJ}$ | 56.20 $^{dHIJ}$ | 76.03 $^{cEFGH}$ | 81.09 $^{bcDEFG}$ | 61.36 d $^{GHIJ}$ |
| 28 days | 143.06 $^{aA}$ | 98.47 $^{bBCD}$ | 92.01 $^{aCDE}$ | 73.50 $^{bEFGHI}$ | 116.80 $^{aB}$ | 92.57 $^{bCDE}$ | 86.70 $^{bDEF}$ | 64.61 $^{cdGHIJ}$ |
| 84 days | 110.66 $^{bBC}$ | 58.08 $^{cHIJ}$ | 89.00 $^{aDE}$ | 57.02 $^{cHIJ}$ | 118.95 $^{aB}$ | 60.59 $^{dGHIJ}$ | 110.95 $^{aBC}$ | 51.04 $^{dJ}$ |
| *p*-value | <0.001 | | <0.001 | | <0.001 | | <0.001 | |
| LSD | 15.17 | | 7.29 | | 10.61 | | 11.51 | |
| CV (%) | 17.4 | | 10.8 | | 12.9 | | 16.0 | |

Note: Different lower case letter after the number denotes significant difference at $p < 0.05$ between harvest intervals and season. Different uppercase letter denotes significant differences between ecotypes at $p < 0.05$

**Table 4.** Effects of harvesting interval on dry matter, crude protein and ash contents of 4 grass ecotypes in tropical semi-arid Kenya

| Harvest Interval | *C. ciliaris* MGD | *C. ciliaris* KLF | *P. maximum* TVT | *P. maximum* ISY |
|---|---|---|---|---|
| Dry matter (%) | | | | |
| 14 days | 96.15 $^{aBC}$ | 97.50 $^{bABC}$ | 98.95 $^{aAB}$ | 96.87 $^{aABC}$ |
| 28 days | 95.77 $^{aC}$ | 99.31 $^{aA}$ | 97.44 $^{abABC}$ | 95.44 $^{aC}$ |
| 84 days | 96.84 $^{aABC}$ | 98.09 $^{abABC}$ | 96.40 $^{bABC}$ | 96.89 $^{aABC}$ |
| *p*-value | 0.270 | 0.008 | 0.022 | 0.486 |
| LSD | 1.37 | 1.06 | 1.73 | 2.94 |
| Crude protein (%) | | | | |
| 14 days | 11.19 $^{aAB}$ | 11.54 $^{aAB}$ | 11.12 $^{aAB}$ | 12.82 $^{aA}$ |
| 28 days | 10.13 $^{aABC}$ | 8.08 $^{bCD}$ | 7.25 $^{bCDE}$ | 9.64 $^{bBC}$ |
| 84 days | 5.11 $^{bEF}$ | 5.39 $^{cDEF}$ | 5.90 $^{cDEF}$ | 4.49 $^{cF}$ |
| *p*-value | <0.001 | <0.001 | <0.001 | <0.001 |
| LSD | 2.76 | 1.78 | 0.97 | 1.16 |
| Ash content (%) | | | | |
| 14 days | 16.93 $^{aA}$ | 15.34 $^{aABC}$ | 13.52 $^{aCDEF}$ | 13.52 $^{bcdeBCDEF}$ |
| 28 days | 15.50 $^{bAB}$ | 15.03 $^{bABCD}$ | 11.21 $^{bG}$ | 12.50 $^{defBCDE}$F |
| 84 days | 14.26 $^{cBCDE}$ | 12.27 $^{cEFG}$ | 11.91 $^{abFG}$ | 13.19 $^{cdeDEFG}$ |
| *p*-value | <0.001 | <0.001 | 0.054 | 0.216 |
| LSD | 1.1 | 0.98 | 1.89 | 1.194 |

Note: Different lower letters after the number denote significant differences between harvest intervals at p <0.05 while uppercase letters denote differences between ecotypes at p <0.05

**Table 5.** Effects harvest interval on fiber components and in vitro dry matter digestibility of 4 grass ecotypes in tropical semi-arid Kenya

| Harvest Interval | *C. ciliaris* MGD | *C. ciliaris* KLF | *P. maximum* TVT | *P. maximum* ISY |
|---|---|---|---|---|
| Nutrient detergent fiber (%) | | | | |
| 14 days | 70.47 $^{bBCD}$ | 67.61 $^{dD}$ | 71.58 $^{b}$ | 72.32 $^{abBC}$ |
| 28 days | 73.78 $^{aAB}$ | 73.79 $^{abAB}$ | 76.43 $^{aABCD}$ | 73.49 $^{aAB}$C |
| 84 days | 74.03 $^{aAB}$ | 76.74 $^{aA}$ | 74.40 $^{abAB}$ | 69.69 $^{bCD}$ |
| *p*-value | <0.001 | <0.001 | 0.033 | 0.012 |
| LSD | 1.53 | 2.04 | 3.53 | 2.37 |
| Acid detergent fiber (%) | | | | |
| 14 days | 37.97 $^{bAB}$ | 29.79 $^{bC}$ | 35.88 $^{bB}$ | 35.97 $^{aB}$ |
| 28 days | 42.96 $^{aA}$ | 38.89 $^{aAB}$ | 42.01 $^{aA}$ | 35.99 $^{aB}$ |
| 84 days | 40.29 $^{abAB}$ | 38.73 $^{aAB}$ | 43.26 $^{aA}$ | 38.98 $^{aAB}$ |
| *p*-value | 0.016 | <0.001 | 0.004 | 0.185 |
| LSD | 3.22 | 3.64 | 4.19 | 3.84 |
| Acid detergent lignin (%) | | | | |
| 14 days | 5.72 $^{aAB}$ | 4.24 $^{aAB}$ | 4.30 $^{abAB}$ | 3.96 $^{bB}$ |
| 28 days | 5.18 $^{aAB}$ | 5.83 $^{aAB}$ | 4.57 $^{abAB}$ | 4.52 $^{abAB}$ |
| 84 days | 5.28 $^{aAB}$ | 6.06 $^{aA}$ | 5.95 $^{aA}$ | 5.57 $^{aAB}$ |
| *p*-value | 0.467 | 0.075 | 0.002 | 0.031 |
| LSD | 0.93 | 1.71 | 0.85 | 1.17 |
| In vitro dry matter digestibility (%) | | | | |
| 14 days | 66.68 $^{aAB}$ | 66.31 $^{aAB}$ | 68.08 $^{aA}$ | 67.42 $^{aAB}$ |
| 28 days | 63.16 $^{aABC}$ | 60.93 $^{bBC}$ | 63.10 $^{abcABC}$ | 64.84 $^{abABC}$ |
| 84 days | 50.58 $^{bD}$ | 47.23 $^{cD}$ | 49.94 $^{dD}$ | 58.08 $^{bC}$ |
| *p*-value | <0.001 | <0.001 | <0.001 | 0.024 |
| LSD | 4.53 | 1.73 | 3.31 | 6.43 |

Note: Lowercase letters after the number denote significant differences between harvest intervals at p <0.05 while uppercase letters denote differences between ecotypes at p <0.05

## Discussion

### *Climatic conditions*

The total precipitation recorded over the two seasons of the evaluation was 1604 mm of rain annually. This was 3 times heavier than the long-term mean of the study region. The highest rain amount was received during December (440.5 mm). The mean monthly temperature was also lower than long-term averages. Unlike previous seasons, no short dry season was experienced in February highlighting the high intra and inter-annual variability in climate experienced in semi-arid Kenya (Kisaka 2015). The heavy rainfall in November and December 2020 also highlighted potential precipitation anomalies in semi-arid East Africa, likely influencing forage productivity in these regions under future climate change scenarios (Wainwright et al. 2021).

*Forage production*

Biomass yield is a critical indicator of pasture productivity determining the amount of forage available to animals. All the studied grasses were morphologically different and a distinction can be noted in the yields of the ecotypes at the different harvesting intervals over the two seasons. For instance, *C. ciliaris* KLF is a short grass variety of less than 30 cm tall, unlike *C. ciliaris* MGD which is taller. The *C. ciliaris* MGD also has a higher tiller density than *C. ciliaris* KLF, contributing to the differences in biomass yields (Kirwa 2019). The *P. maximum* TVT had thicker stems and larger leaves than *P. maximum* ISY. These structural attributes and individual inherent genetic attributes contribute to the eventual differences in yields and dry matter production.

Cumulatively higher yields were recorded at 28-day and 84-day harvesting interval compared to the 14-day harvest interval. This was attributed to the sufficient resting period before the subsequent harvest, which allowed the grass ecotypes to accumulate as much biomass as possible. In *P. maximum* and *Urochloa* hybrids, Mwendia et al. (2022) also found a 28-day harvesting regime to promote cumulative biomass yields. These frequent harvests help ameliorate the frequent forage demands common in semi-arid regions. In this study, an even shorter grazing regime or harvest interval, 14 days, would benefit small stock or calves that consume less forage. From this study, the 28-day harvesting intervals can enhance feed availability for livestock without compromising animal productivity in dryland environments. This finding is consistent with investigations in an enclosure system in Ethiopia with similar harvest frequencies to this study, where Gilo et al. (2022), reported low yields at higher harvest frequencies. The overall mean of 6,007.10 KgDM $ha^{-1}$ obtained for *C. ciliaris* ecotypes in this study is superior but comparable to the mean value (5,358 $KgDMha^{-1}$) reported by Kirwa (2019), in semi-arid Kenya for the ecotypes and several accessions. Overall, the mean values obtained for the two *P. maximum* ecotypes are almost 50% higher than those reported for local *P. maximum* ecotypes in the same study region (Njarui et al. 2015). The probable influence of seasonal rainfall, which was higher during the study period, site and management practices could explain the differences in the study.

Overall, biomass yields in the dry season dropped by almost 32%. The notable decline of biomass production for individual ecotypes in the dry season was due to drier conditions experienced from May through September 2020. Such responses are common for grass plants in semi-arid environments as reduced precipitation and soil moisture may not have been sufficient for plant growth and development. These findings corroborate those reported for *P. maximum* grass ecotypes by Njarui et al. (2015) in a multi-location study in eastern Kenya. These seasonal variations in yields will continue to be experienced with increased climate variability in arid and semi-arid lands (Godde et al. 2020) since rainfall is a primary driver of forage productivity. This highlights the need for fodder bulking in the form of hay to deal with forage scarcity brought about by climatic uncertainties. This is already happening in East African rangelands where the preserved grasses of poor quality (Balehegn et al. 2022). Even though there was a decline in cumulative biomass in the dry season among the grass ecotypes, an exception was found in *C. ciliaris* KLF under a 14-day harvest regime, probably due to the variety's grazing and dry conditions tolerance. It is a rhizomatous ecotype and most of the nodal tillers are found below the defoliation level adopted for this study.Hence the frequent clipping yield effects on the ecotype were minimal. A farmer evaluation exercise of *C. ciliaris* ecotypes in this region found this variety preferred over other robust and taller ecotypes by pastoral and agropastoral communities (Kirwa 2019). This was attributable to its persistent nature and drought tolerance characteristics. Such ecotypes may require different management strategies and should be further evaluated for other attributes other than yields. These attributes may include the role of soil and moisture conservation, drought tolerance, persistence, and carbon sequestration. These aspects are key to grasslands and the resilience of agropastoral and pastoral ecosystems.

*Forage accumulation rate*

The likely prolific nature of *C. ciliaris* MGD resulted in more regrowth per harvest interval than the other ecotypes. Overall, higher biomass accumulation rates were realized at 28-day and 84-day intervals. This is because physiologically, the plants' growth rates were not interrupted as frequently as in the 14-day harvesting intervals, hence more energy was invested in plant growth. Frequent harvesting (14-day) intervals resulted in lower yields as most carbohydrate reserves were depleted faster by removing vegetative parts. This removal can impact the leaf area influencinglight capture and subsequent regrowth characteristics. This is consistent with results obtained in *Chloris gayana* grass species by Ruolo et al. (2019). Frequent defoliation regimes can also result in the death of some plant tissues, diminishing the regrowth potential of grasses and subsequent rangeland deterioration. During the dry season, FAR declined significantly due to inadequate precipitation. This demonstrates that soil water availability can significantly affect forage accumulation rate and subsequent availability. Similar results have been reported for elephant grass genotypes by de Almeida Souza et al. (2021). Remarkably during the dry season, FAR for *C. ciliaris* MGD and *P. maximum* TVT under the 28-day harvest intervals were higher than other ecotypes' FAR for the wet season. This demonstrates the capacity of the ecotypes to continue growing despite precipitation limitations and their potential adaptability to semi-arid conditions.

Species and ecotypes that accumulate more biomass quickly can generally be recommended for fodder production and rangeland restoration. This is because they maximize the use of soil nutrients and rainfall use at the onset of the rainy season, growing faster and yielding higher biomass. Considering the variability and unpredictable rainfall patterns in semi-arid areas, it is critical to take advantage of any precipitation events as early as possible and grow varieties that mature early and accumulate forage quickly.

*Forage quality*

The results presented in this study on quality attributes are consistent with general observations by Koech (2014), Njarui et al. (2015), Kirwa (2019) and Mganga et al. (2021) and for grass ecotypes and key African indigenous rangeland grasses found in Kenya. The findings also fall within the range of values as reviewed by Lee (2018) for forages grown in contrasting environments.

**Crude Protein (CP)**

The crude protein values obtained at the 28-day regime for *C. ciliaris* ecotypes (8.08 and 10.13%), though higher, closely relate to 6.6 and 9.6 for *C. ciliaris* KLF and *C. ciliaris* MGD ecotypes respectively as reported by Kirwa (2019) at a 42-day harvesting interval. The difference could be due to the harvest period since the grasses were harvested two weeks earlier for this study. With increasing harvest interval, the CP of the grasses is expected to decline. This is demonstrated in the highly significant drop in CP values of grasses harvested at 84-day intervals. Similar results have been reported for common rangeland grasses by Koech (2014) in semi-arid Kenya and Keba et al. (2013) in southern Ethiopia. However, no ecotypic or within-species variability was considered but the trends of reduced CP with a maturity of the grasses were confirmed. As the harvest interval increases, the number and amount of senescent leaves increasingly become prevalent particularly in the lower parts of the stem. Typically, these are low in protein as nitrogen is remobilized to other parts of the plant (Yang and Udvardi 2018). This contributed to lower CP in the grasses at 84-day cutting intervals. The higher proportion of young leaves and the decreased stem component within the 14-day harvest intervals contributed to higher CP values.

Crude protein is an essential nutrient for livestock and feeding animals on these grasses, especially at maturity (i.e. over 8 week-old pastures) may not meet livestock nutritional requirements (Erickson and Kalscheur 2020). This study obtained less than 8% CP values, considered poor quality for grasses (Leng 1990) at the 84-day harvest intervals. Feeding livestock on such material may only be beneficial for maintenance purposes and not to improve performance.

**Ash content**

The amount of ash generally represents the number or amount of minerals in a plant. For this study, the ash content varied significantly among the grass ecotypes, with *C. ciliaris* ecotypes having a higher ash content. Kirwa (2019), reported 11.2 and 15.2% ash with a mean of 13.7% in a study of 11 *C. ciliaris* grass ecotypes in semi-arid Kenya. The mean of 14.82 for *C. ciliaris* obtained in this study falls within this range. Similarly, Njarui et al. (2015) reported a mean of 12.2% for *P. maximum* ecotypes, which compares favourably with the value of 12.6% in this study. The slight differences are attributed to variables such as experimental sites and seasons. Shorter harvesting intervals (14 days) resulted in grasses with higher ash content than longer harvest intervals (28 and 84 days). As plants age, they continue to utilize minerals at vegetative stages for growth, resulting in less mineral content in the final harvests due to the translocation of minerals from the vegetative parts to the roots (Kitaba and Tamir 2007). Younger plants are therefore anticipated to have higher ash contents. These differences in ash content, attributable to harvesting interval have also been observed by Gilo et al. (2022) in the Borana rangelands of Ethiopia.

**Fiber fractions (NDF, ADF and ADL)**

As hypothesized, varietal and species differences explain the differences in NDF and ADF components. The harvesting stage significantly ($p$ <0.05) influenced the fiber components of the grass ecotypes and showed a corresponding linear response where an increase in harvest interval resulted in higher fiber components. Similarities have been observed in *C. ciliaris* and *P. maximum* grasses used in range restoration and fodder production in South Africa (Msiza et al. 2021). The slight discrepancies and variability in results could be attributable to site differences and weather parameters. The effects of harvesting interval on NDF are also demonstrated by Gilo et al. (2022) in natural pastures, where shorter cutting intervals led to lower NDF concentrations. Similarly, ADF within the grass ecotypes also increased as the cutting interval as Wassie et al. (2018) showed in a study involving *Brachiaria* ecotypes in Ethiopia. In addition, harvest interval also affected ADL in the grasses. The low NDF, ADF and ADL at shorter cutting intervals agree with values Lee (2018) reported from global studies on forage grasses. These trends of increasing NDF, ADF and ADL values as the harvest interval increased have been observed in the King Napier grass (*Pennisetum purpureum*) variety in Thailand (Lounglawan et al. 2014) and *P. maximum* in Argentina (Schnellmann et al. 2020). Harvesting these grass ecotypes late at maturity (after 84 days) resulted in highly lignified material which may lead to low intake by livestock and decreased productivity.

**In Vitro Dry Matter Digestibility (IVDMD)**

The differences in IVDMD between the grass ecotypes showed a pronounced decrease with increasing harvest interval. As plants mature, they require stronger support tissues producing lignification enzymes that promote lignin accumulation and deposition in cell walls. This tends to make the grasses less digestible (Getachew et al. 2018). Lower IVDMD values were observed at the 84-day harvest interval since the grasses had matured resulting in decreased digestibility. This contrasts with the 14-day and 28-day harvest intervals with higher digestibility values.

**Table 6.** Correlation matrix for nutritional characteristics of the grass ecotypes

| | DM | CP | ASH | NDF | ADF | ADL | IVDMD |
|---|---|---|---|---|---|---|---|
| DM | - | | | | | | |
| CP | -0.1412 | - | | | | | |
| ASH | -0.0953 | 0.419*** | - | | | | |
| NDF | 0.1288 | -0.3754** | -0.4631*** | - | | | |
| ADF | 0.1254 | -0.4167 | -0.2637 | 0.5848*** | - | | |
| ADL | 0.0413 | -0.3629** | 0.1453 | 0.1253 | 0.4641*** | - | |
| IVDMD | -0.2311* | 0.8169*** | 0.444*** | -0.4713*** | -0.4835*** | -0.4037*** | - |

Note: ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$. DM: Dry matter, CP: Crude protein, NDF: Nutrient detergent fiber, ADF: Acid detergent fiber, ADL: Acid detergent lignin, IVDMD: In vitro dry matter digestibility

In most cases in semi-arid Kenya, grass cultivation for hay production and utilization is a common practice and strategy to mitigate feed shortages (Omollo 2017). However, the need to harvest grass seeds after grass maturity results in highly lignified pastures of poor digestibility. Grazing enclosures where grasses are left ungrazed for longer periods may also result in grasses with lower digestibility due to a decrease in leaf: stem ratio as shown by Gilo et al. (2022) in Ethiopian rangelands. IVDMD figures of the grass ecotypes harvested at 84-day intervals in this study ranged between 47% and 58%. In vitro dry matter digestibility values of less than 50% in forages are considered poor quality and of hardly any feeding value to livestock (Ball 2001).

**Correlation of nutritive attributes among the grass ecotypes**

Table 6 shows a correlation matrix for nutritive traits among the 4 grass ecotypes. Crude protein was positively and strongly correlated to ash content and IVDMD. However, CP negatively correlated with NDF, ADF and ADL components. Negative correlations were also observed between IVDMD and the fiber components

With the advancement in age, the CP of the grass ecotypes is expected to decline while fibercomponents' increase (Lee 2018). Younger plants,exhibit high CP and hence are of higher quality, as demonstrated by the strong correlation between CP and IVDMD. Such significant correlations have also been reported between IVDMD and fiber components in some tropical grasses of semi-arid north western Australia (Mahyuddin 2008). Similar relationships were observed in indigenous grass ecotypes by Kirwa (2019) in semi-arid Kenya.

This study reveals that the defoliation interval significantly effects cumulative yields, forage accumulation rates and the nutritional attributes of the selected grass ecotypes. The *C. ciliaris* MGD and *P. maximum* TVT yielded the highest cumulative biomass regardless of the harvest intervals. Shorter harvest intervals (14 days) resulted in the lowest biomass in all the grasses and should be discouraged as this may impact animal performance. Forage nutritional value was variable across the grass ecotypes at different harvest intervals. More frequently clipped grasses indeed have higher crude protein values, but this may not be an advantage in practice because concurrently, it lowered yields thus compromising animal productivity. Therefore, it is better to harvest these grasses at 28-day intervals, to obtain more biomass, with better forage quality. Among the 4 grass ecotypes evaluated, *C. ciliaris* MGD and *P. maximum* TVT can be options for further performance evaluation for fodder production and rangeland restoration.

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