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From Practice

Morphoecological characteristics of grasses used to restore degraded semi-arid African rangelands

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Abstract

1. Progressive loss of productivity and plant diversity is a concern in global rangelands. In African rangelands, this process is partly attributed to heavy and uncontrolled grazing by livestock and wildlife, leading to land degradation. Therefore, restoring such degraded rangelands is critical for enhancing ecosystem health and securing the livelihoods of millions of people.
2. Active restoration strategies, for example, reseeding using indigenous perennial grasses, have been identified as a viable ecological solution for restoring degraded African rangelands. Grass species indigenous to African rangelands *Cenchrus ciliaris* L. (African foxtail grass), *Eragrostis superba* Peyr. (Maasai love grass), *Enteropogon macrostachyus* (Hochst. Ex A. Rich.) Monro ex Benth. (Bush rye grass), *Chloris roxburghiana* Schult. (Horsetail grass) and *Chloris gayana* Kunth. cv Boma (Rhodes grass) were established in a semi-arid rangeland in Africa under natural conditions to compare their morphoecological characteristics and suitability for use in ecological restoration. Biomass dry matter yields, plant densities, basal cover, seed production, tiller densities and plant height were measured.
3. *Chloris gayana* cv Boma and *E. superba* produced significantly higher dry matter biomass yields and attained higher seed production than other species. High biomass and seed production indicate their suitability to support livestock production and replenish depleted soil seed banks, respectively.
4. *Enteropogon macrostachyus* and *C. ciliaris* displayed significantly higher values for components of establishment and ecological restoration success, that is, plant densities, tiller densities and basal cover. Overall, *C. roxburghiana* ranked lowest in the measured morphoecological characteristics.
5. Successful restoration of degraded African semi-arid rangelands using indigenous grass reseeding can best be achieved through careful selection of grasses to take advantage of their specific morphoecological characteristics. This selection should

primarily be informed by the intended use of the rangeland and the specific challenges of restoring each site.

KEYWORDS
aboveground biomass, basal cover, plant density, plant structure, reseeding, seed production, tillers

1 | INTRODUCTION

In Africa, arid and semi-arid rangelands cover about 41% of the continent's landmass and are characterized by low, erratic annual rainfall (300–600 mm), high temperatures and nutrient poor soils (Sanchez, 2002; Vohland & Barry, 2009). Pastoralists are arguably the primary human users of African rangelands. Native perennial grasses, for example, *Themeda triandra* Forssk., *Cynodon dactylon* (L.) Pers., *Chloris roxburghiana* Schult., *Cenchrus ciliaris* L., *Enteropogon macrostachyus* (Hochst. Ex A. Rich.) Monro ex Benth., *Eragrostis superba* Peyr., *Chloris gayana* Knuth., *Sorghum sudanense* (P.) Stapf., *Panicum maximum* Jacq. and *Panicum coloratum* L., provide a rich source of forage for grazing livestock and wildlife (Koech et al., 2016; Mnene et al., 2005).

Degradation caused by heavy grazing causes major ecological transformation and negatively impacts the three broad attributes of rangeland health, that is, soil and site stability, hydrologic function and biotic integrity (Duniway & Herrick, 2013; Herrick et al., 2017 ; Whisenant, 1999). Depending on the severity of degradation, recovery of denuded rangeland landscapes by means of natural succession and passive methods is very slow and often less effective (Kinyua et al., 2010; van den Berg & Kellner, 2005). Consequently, more active restoration procedures, for example, reseeding using native perennial grasses, have been incorporated into rangeland restoration (Kimiti et al., 2017; Kinyua et al., 2010; Koech et al., 2016; Mganga et al., 2015; Mnene et al., 2005). Use of native grass seeds for reseeding is advantageous because of their better survival and growth, reduced risk of restoration failure due to poor adaptation to local environmental conditions, limiting 'pollution' of local gene pools and outbreeding depression (Broadhurst et al., 2008).

Active restoration methods can help counteract soil erosion by increasing vegetation cover, enhancing primary productivity, increasing the carrying capacity and replenishing the native seed banks of semi-arid African rangelands. For example, in a previous study, low-cost grass restoration using erosion barriers in a degraded African rangeland has been achieved by seeding with *C. ciliaris* (Kimiti et al., 2017). This resulted in higher herbaceous cover even when other grasses failed to establish. Enclosures reseeded with *C. ciliaris* and *E. superba* have increased biomass production up to 10 times in a semi-arid rangeland in Kenya (Verdoodt et al., 2010). Use of perennial grasses native to African rangelands for ecological restoration is beneficial because they are: (1) preadapted to the environment (Wright et al., 2021), (2) prolific seeders and efficient in seed dispersal (Marshall et al., 2012), (3) characterized by extensive tillering and nutrient translocation to escape or tolerate herbivory and fires (Stuart-Hill and Mentis, 1982) and (4) are an additional source of income through the sale of hay and seeds (Kimiti et al., 2017; Koech et al., 2016; Mureithi et al., 2016; Mureithi et al., 2014). African rangelands perennial grasses are C4 species and drought tolerant, adaptations that results to grazing exaptation (Coughenour, 1985). The mechanisms of drought tolerance are an extensive fine root system and greater root rhizosheath thickness (Hartnett et al., 2013). High concentration of roots in the upper 0–30 cm soil depth supports the efficient utilization of the low and sporadic rains (Marshall et al., 2012). *C. ciliaris*, with a deeper rooting depth of up to 2.4 m, facilitates its water uptake at deeper soil layers (Marshall et al., 2012).

Active ecological restoration using perennial grasses native to African rangelands has demonstrated great potential (Kimiti et al., 2017; Mganga et al., 2019; Mureithi et al., 2016). However, studies to determine multiple morphoecological attributes of perennial grasses native to African rangelands for ecological restoration under rainfed conditions for more than one growing season remain limited. Therefore, in this study we evaluated six attributes considered to be good indicators of restoration success (i.e., plant height, biomass production, plant density, tiller density, basal cover and seed production; Kimiti et al., 2017; Ruiz-Jaen & Aide, 2005; Verdoodt et al., 2010). These indicators also serve as proxy of plant productivity, which constitutes an important measurement in these agropastoralists environments. The overall objective of this study was to measure the selected morphoecological traits of the grasses to determine the most suitable species for reversing damaged primary processes in semi-arid rangelands in southeastern Kenya.

2 | MATERIALS AND METHODS

2.1 | Study area

This reseeding study was conducted in a typical semi-arid African rangeland in Kitui County, southeastern Kenya (site GPS coordinates latitude S 1° 22′ 33.329′′ and longitude E 38° 0′ 34.771′′) under rainfed conditions. Akamba agropastoralists are the main inhabitants in the area. They primarily rear local breeds of livestock notably small East African shorthorn zebu, Red Maasai sheep and small East African goats and cultivate drought-tolerant varieties of maize, millet, sorghum, pigeon peas and beans (Mganga et al., 2015). The rainfall pattern is bimodal with two rainy seasons. The long and intense rains between March and May are characterized by a rain peak in April while the short and less intense rains between October and December, have a rain peak in November. Total annual rainfall ranges between 300 and 800 mm and the monthly temperatures ranges between 14 and 34°C, with a mean of 24°C (Schmitt et al., 2019). Rainfall and temperature during the study fell within these ranges (Figure S1).

Soils in the study area are shallow, deficient in nitrogen and phosphorus, with little organic matter. The basic soil chemical and physical characteristics of the experimental site were 0.08% nitrogen, 0.8% carbon, 165 mg kg^{-1} soil phosphorus, and a loamy soil texture of 22% clay, 31% silt and 47% sand. Surface sealing properties and low infiltration rates make the soils vulnerable to erosion, particularly since intense rains come early in the growing season when the ground is bare. No fertilizer was applied during the seeding study. Common tree and shrub species include *Lannea triphylla* (Hochst. ex A. Rich.) Engl., *Commiphora africana* (A.Rich.) Endl., *Acacia mellifera* (M. Vahl) Seigler & Ebinger and *Acacia senegal* (L.) Britton (Hayashi, 1996). The herbaceous layer is dominated by *C. roxburghiana*, *E. superba*, *C. ciliaris*, *E. macrostachyus* and *Rhynchelytrum repens* (Willd.) Zizka (Hayashi, 1996; Mganga et al., 2015).

2.2 | Seed viability test, experimental layout and site preparation

Seed viability tests were conducted under controlled laboratory conditions (22°C, 14 days) before sowing. At the end of the 14 days, all seeds that had germinated in the petri dishes were expressed as a percentage of the total number of seeds.

The experimental site was flat with minimal patches of native overstorey and understorey vegetation. Experimental design was a randomized complete block design with five experimental blocks with an area of 150 m^2 (10 × 15 m) laid horizontally adjacent to each other, and with a 2 m buffer between blocks. Each block was further subdivided into five smaller experimental plots, each with an area of 30 m^2 (10 × 3 m). Each grass species was sown in one experimental plot selected at random across the five blocks.

Selected grasses were established from local seeds in early October, 2017, before the onset of the short rains. Local seeds, collected within a radius of 500 m of the site, were used because locally adapted seeds deliver superior ecological restoration outcomes (O'Brien et al., 2007). Seeds were hand-sown at a constant density as monocultures along shallow (20 cm deep) ox-ploughed microcatchments at a depth of 2 cm and lightly covered. Spacing between the created microcatchments was approximately 15 cm. Shallow microcatchments were created to trap sufficient rainwater to prolong moisture availability and promote better germination of seeds and subsequent growth and development of the seedlings (Mganga et al., 2015; Visser et al., 2007). We used Kenya Agricultural and Livestock Research Organisation (KALRO) recommended and desired seeding rate (5 kg ha^{-1}) for indigenous rangeland grasses in semi-arid lands for all the species. However, seeding rates were adjusted for seed viability based on germination rate. Therefore, seeding rates used were 8.62, 6.09, 10.87, 15.63 and 6.52 kg ha^{-1} for *C. ciliaris*, *E. macrostachyus*, *E. superba*, *C. roxburghiana* and *C. gayana*, respectively.

2.3 | Measurement of plant morphoecological attributes

Seedling emergence, that is, the point when cotyledonary leaves are unfolded, was recorded in each plot as the number of days from sowing to 50% emergence. Plant indices and morphometric characteristics were measured after four (4) months (biomass production, plant height) and nine (9) months (biomass production, plant height, plant density, tiller density, basal cover and seed production). All the grasses were sampled during early reproductive stage. Destructive sampling was done to determine aboveground biomass production, an important variable used to determine the carrying capacity of grasslands. To do so, three randomly placed 0.25 m^2 quadrats were used per grass species and clipped to a stubble height of 2 cm in each plot. Harvested aboveground biomass was placed in paper bags and oven dried at 60°C for 24 h to determine dry matter (DM) yield.

Plant densities and average tiller densities per plant species were estimated in three 0.25 m^2 quadrats within each plot (Cox, 1990). Percentage basal cover was estimated using the step-point method due to its suitability for valid analysis of field-based ecological research (Evans & Love, 1957). Three 10 m long parallel line transects (1 m apart) were used in each of the five plots in all five blocks. Ten measurements were taken along each transect (1 m interval) to give a total of 30 measurement points in each plot. Plant densities, tillers and basal cover facilitate regrowth after disturbance and trap sediments and as such are important to ecological restoration (Erkossa et al., 2020). Seed production was estimated from the biomass harvested by separating it from the stem and leaf biomass by hand stripping. Plant height to the tip of the top leaf was determined using a 2 m ruler to the nearest cm and was used to estimate the growth per day.

2.4 | Statistical analysis

Statistical analyses were performed using STATISTICA 10.0 (StatSoft Inc). One-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of the measured parameters. Tukey's HSD post hoc test was used to separate significant differences of plant parameters among species, at $\alpha = 0.05$. Additionally, a correlation analysis between the measured morphoecological characteristics was conducted using R version 4.0.3 (2020-10-10) (R Core Team, 2020) within RStudio (RStudio, 2018) and the correlation matrix was generated using the *corrplot* package (Wei et al., 2017).

3 | RESULTS

3.1 | Plant morpho-ecological characteristics

Enteropogon macrostachyus and *C. roxburghiana* had the highest and lowest percent seed viability, respectively (Table 1). Furthermore, seedling emergence was fastest in *E. macrostachyus* (after 3 days) and slowest in *C. roxburghiana* (after 9 days) (Table 1). Overall, *C.*

TABLE 1 Selected characteristics of the grasses used in the reseeding trial

Grass species	Seed viability (%)	Seedling emergence (days)	Growth (height) (cm day^{-1})
Cenchrus ciliaris	58a	7a	0.09a
Enteropogon macrostachyus	82b	3b	0.15b
Eragrostis superba	46c	7a	0.13b
Chloris roxburghiana	32d	9a	0.17b
Chloris gayana	76b	4b	0.27c

Different lower case letters indicates statistically significantly differences at $\alpha = 0.05$.

gayana and *E. superba* had significantly higher aboveground biomass yields (F (4, 70) = 2343.0, $p < 0.001$) (Figure 1(b)), plant height (F (4, 70) = 711.9, $p < 0.001$) (Figures 1(c) and 1(d)), and seed production (F(4, 70) = 1605.9, $p < 0.001$) (Figure 2(d)), than *E. macrostachyus*, *C. ciliaris* and *C. roxburghiana*. Additionally, *C. gayana* had the highest tiller density (F (4, 70) = 277.6, $p < 0.001$) (Figure 2(b)). *E. macrostachyus* and *C. ciliaris* had significantly higher plant densities (F (4, 70) = 40, $p < 0.001$) (Figure 2(a)) and percent basal cover (F (4, 70) = 177.39, $p < 0.001$) (Figure 2(c)) than *C. gayana*, *E. superba* and *C. roxburghiana*. *C. roxburghiana* had the lowest biomass yields (Figure 1(b)), tiller densities (Figure 2(b)), seed production (Figure 2(d)).

Measured morphoecological characteristics displayed different patterns of correlation. Plant height after 9 months was negatively correlated with plant density ($R = 0.72$, $p < 0.001$) and basal cover ($R = 0.73$, $p < 0.001$), but positively correlated with seed production ($R = 0.66$, $p < 0.001$) and dry matter biomass yields ($R = 0.83$, $p < 0.001$) (Figure 3). Additionally, plant density was positively correlated with biomass yields after 4 months ($R = 0.65$, $p < 0.001$) and basal cover ($R = 0.93$, $p < 0.001$), but negatively correlated with dry matter biomass yields after 9 months ($R = 0.48$, $p < 0.05$) (Figure 3). Basal cover was also negatively correlated with dry matter biomass yields after 9 months ($R = 0.40$, $p < 0.05$) (Figure 3).

4 | DISCUSSION

Biomass production and plant height are used as predictors of performance in ecological restoration (Erkossa et al., 2020; Vundla et al., 2020). Sowing *C. gayana* and *E. superba* was clearly more successful in terms of providing ecosystem services (e.g., biomass production and erosion control) than the other selected species. Faster growth rate contributed the significantly taller culms in *C. gayana* and *E. superba*,

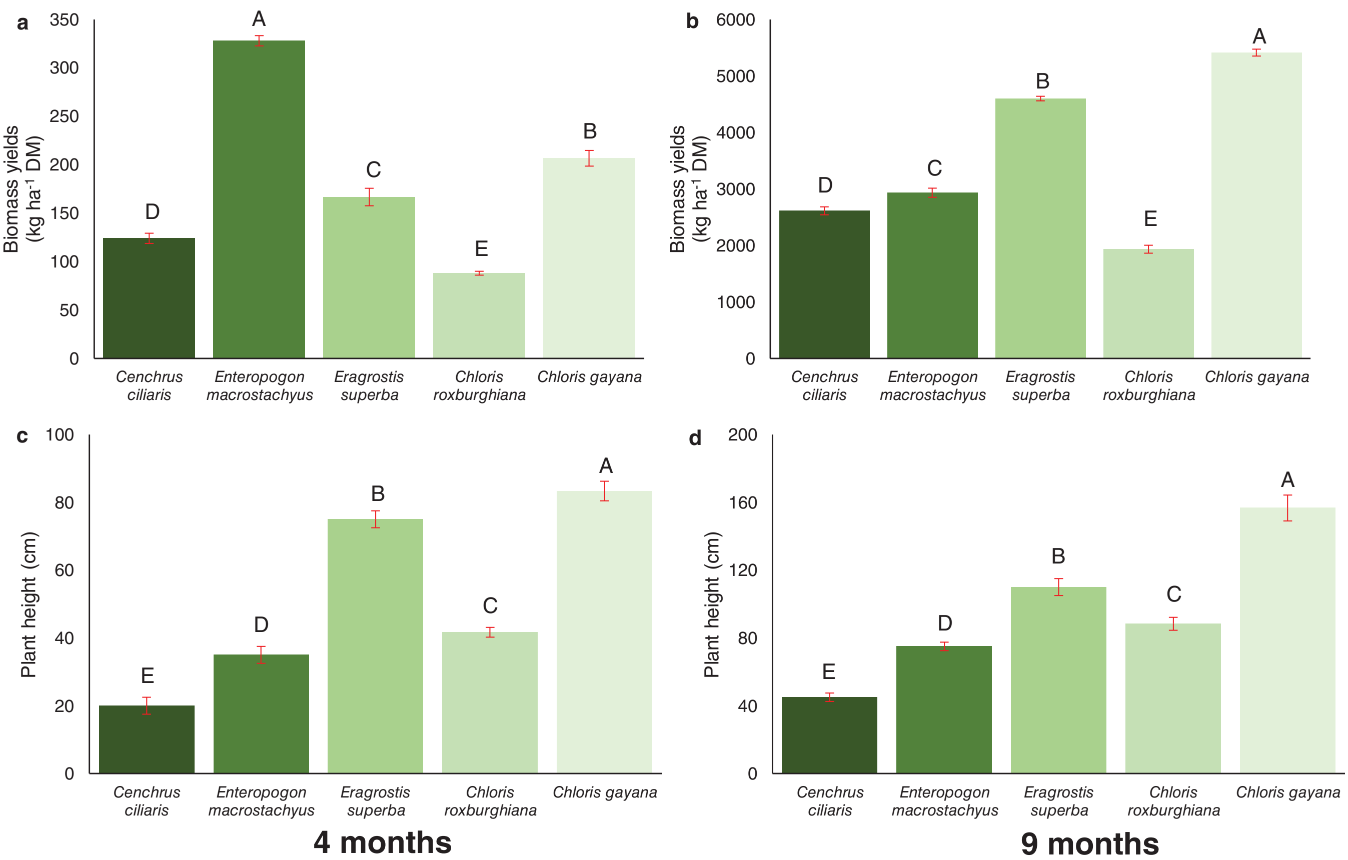

FIGURE 1 Biomass yields (a and b) (kg ha^{-1} DM) and plant height (c and d) (cm) of the selected grasses four and nine months after sowing. Error bars represent standard error of means (±SE). Bars with different lowercase letters indicate statistically significant differences at $\alpha = 0.05$

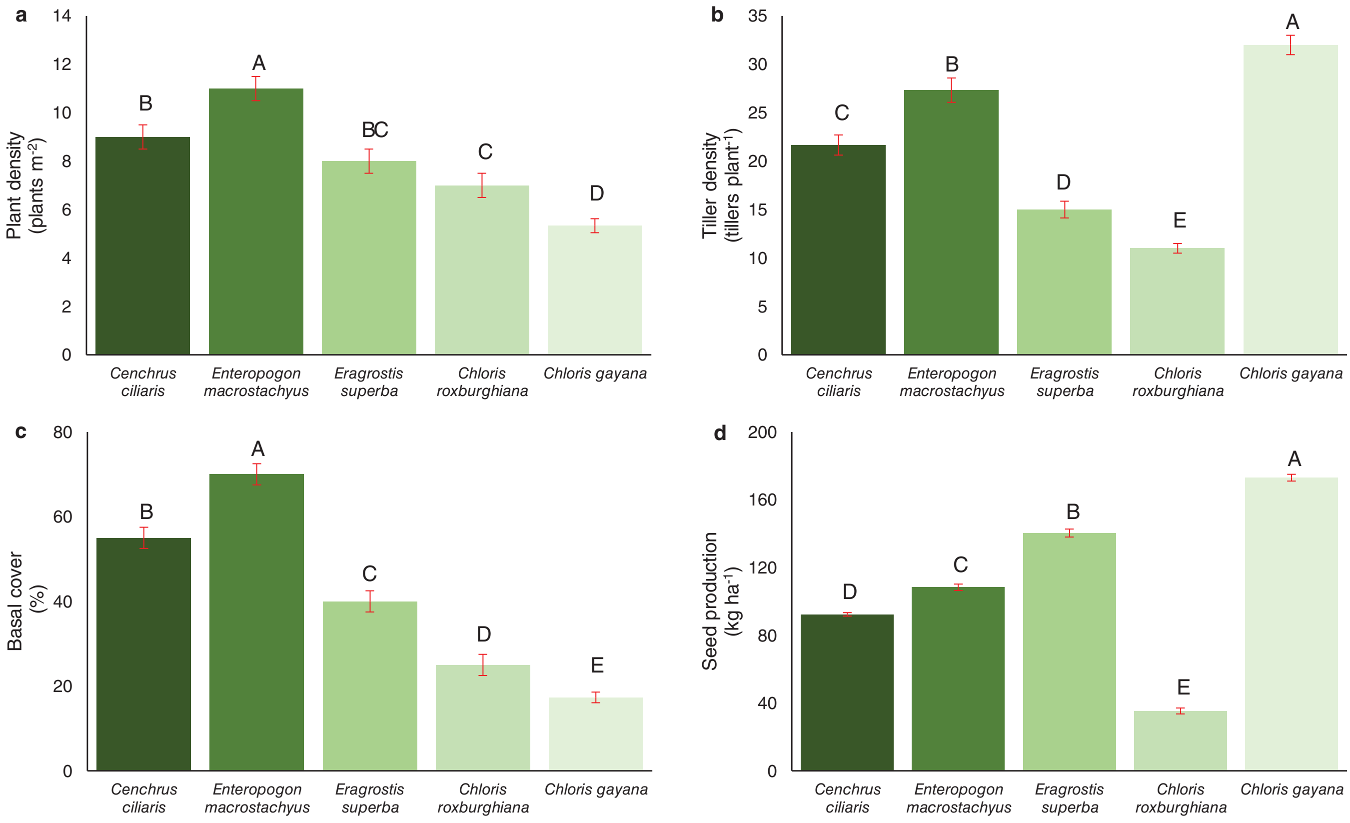

FIGURE 2 Plant density (a), tiller density (b), basal cover (c) and seed production (d) of African rangeland grasses after nine months. Error bars represent standard error of means (±SE). Bars with different lowercase letters indicate statistically significant differences at $\alpha = 0.05$

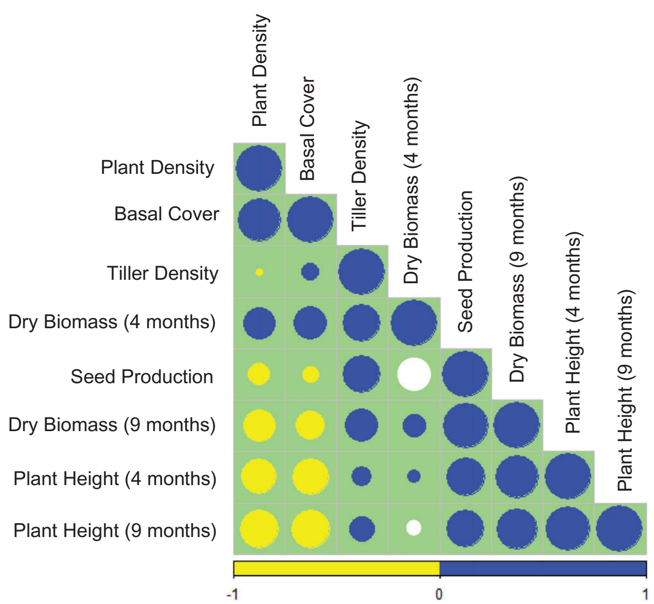

FIGURE 3 Correlogram of morphoecological parameters of selected perennial grasses indigenous to African rangelands. Significant correlation coefficients are displayed in blue (positive) and yellow (negative) coloured circles, respectively. Insignificant positive correlation coefficients are displayed in white circles. The size of the circles is proportional to the correlation coefficients

compared to *C. ciliaris*. *C. gayana* cv Boma is known to establish easily, grow quickly and mature early (Ponsens et al., 2010). High biomass produced by *C. gayana* and *E. superba* (Figure 1(b)), implies that they are suitable for enhancing productivity, forage availability and increasing the carrying capacity of southeastern Kenya semi-arid rangelands for grazing herbivores. Plant height is a major factor controlling soil erosion in grassy biomes because it determines the potential maximum falling height and kinetic energy of raindrops (Senn et al., 2020). Thus, taller culms of *C. gayana* (150 cm) and *E. superba* (110 cm) (Figures 1(c) and 1(d)), indicate that they have a great potential in intercepting raindrops and thus minimize soil disturbance. Moreover, our results also imply that taller African rangeland grasses like *C. gayana* and *E. superba* are suitable for reducing grazing pressure on other shorter species because they are more accessible to grazing herbivores. Thus, incorporating *C. gayana* and *E. superba* in reseeding diverse semi-arid rangelands in southeastern Kenya should indirectly promote a vegetation cover consisting of shorter grasses and contribute to restoration success.

Our results suggest that *E. macrostachyus* is suitable for increasing vegetation cover and subsequently improve soil hydrological properties and facilitate successful ecological restoration processes, for example, plant growth and vegetation succession, in degraded semi-arid rangeland landscapes in southeastern Kenya. Perennial grasses native to African rangelands characterized by high basal cover, tiller and plant densities, such as *E. macrostachyus* (Figures 2(a), 2(b) and 2(c)), regenerate and persist in environments dominated by fire, drought and herbivory (Moore et al., 2019). High basal cover, tiller and plant densities exhibited by *E. macrostachyus* indicate that it is a suitable species to reduce soil loss by enhancing infiltration and reducing surface flow velocity.

Reintroduction of plant species and thus higher diversity in restored landscapes depends largely on the presence of viable seed in the soil and the ability of the established plant species to replenish the seed bank (Bakker et al., 2005). Seeds of perennial grasses native to African rangelands may lay dormant retaining the original seed viability in the ground for up to 8 months and remain at 10% viability for about two years (Winkworth, 1963). Long-term rangeland ecological restoration is more feasible if the density of persistent seeds in the soil seed bank is sufficient (Kalamees et al., 2012). High seed production by *C. gayana* and *E. superba* (Figure 2(d)) suggest that they are the best suited for replenishing southeastern Kenya semi-arid rangelands characterized by depleted soil seed bank. Moreover, prolific native grass seeders like *C. gayana* and *E. superba* indicate that they have a great potential contribution to seed rain, a process that plays a key role in recruitment and regeneration in plant communities in grasslands (Arruda et al, 2018). The poor establishment *C. roxburghiana*, on the other hand, could be attributed to the genetic differences between ecotypes occurring as a result of adaptation to unique environmental factors specific rangeland sites (Mnene et al., 2005). Therefore, based on our results, we cannot recommend it as a promising species for reversing degradation in southeastern Kenya semi-arid rangelands.

The grasses selected in this study do not occur in isolation in their natural semi-arid rangeland environment in Kenya. Thus, it is expected that interspecific interactions will play a role in influencing vegetation structure and cover when established in different combinations. Incorporating perennial grass mixtures consisting of taller and shorter species in reseeding semi-arid rangelands in Kenya could be used as a strategy promote a continuous vegetation cover. This is because herbivores preferentially graze taller species (Santos et al., 2013). Therefore, long-term and robust studies using multiple grass combinations established in different ecological sites would generate valuable information to better assess the suitability of the grasses for the restoration of semi-arid rangelands in Kenya.

5 | MANAGEMENT RECOMMENDATIONS

Chloris gayana cv Boma or *E. superba* combined with *E. macrostachyus* offers the best species combination for enhancing productivity and potentially reversing degradation during restoration process in southeastern Kenya semi-arid rangelands. Perennial grasses indigenous to African rangelands used here displayed a variety of attributes suitable for ecological restoration. *C. gayana* cv Boma and *E. superba* are best suited for enhancing forage production and replenishing depleted seed bank. *E. macrostachyus* and *C. ciliaris* displayed a greater potential for restoring and rejuvenating denuded semi-arid rangelands in Kenya. *C. roxburghiana* was consistently ranked lowest in all the measured morphoecological characteristics. Considering that *C. ciliaris* is aggressive, we recommend a careful assessment of its potential negative impact prior to its selection for seed-based ecological restoration programmes, especially those targeting to enhance plant biodiversity in an African rangeland landscape.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

K. M., F. S. and N. M. conceived the ideas and designed methodology; E. K., N. K., T. K. and A. N. collected the data; K. M., L. B. and S. W. analyzed the data; K. M. and L. B. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.sxksn031p (Mganga et al., 2020).

PEER REVIEW

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REFERENCES

Arruda, A. J., Buisson, E., Poschlod, P., & Silveira, F. A. O. (2018). How have we studied seed rain in grasslands and what do we need to improve for better restoration? *Restoration Ecology*, *26*, S84–S91. https://doi.org/10.1111/rec.12686

Bakker, C., de Graaf, H. F., Ernst, W. H. O., & van Bodegom, P. M. (2005). Does the seed bank contribute to the restoration of species-rich vegetation in wet dune slacks? *Applied Vegetation Science*, *8*, 39–48. https://doi.org/10.1111/j.1654-109X.2005.tb00627.x

Broadhurst, L. M., Lowe, A., Coates, D. J., Cunningham, S. A., McDonald, M., Vesk, P. A., & Yates, C. (2008). Seed supply for broadscale restoration: Maximizing evolutionary potential. *Evolutionary Applications*, *1*, 587–597. https://doi.org/10.1111/j.1752-4571.2008.00045.x PMID: 25567799

Coughenour, M. B. (1985). Graminoid responses to grazing by large herbivores: Adaptation, exaptations and interacting processes. *Annals of the Missouri Botanical Garden*, *72*, 852–863. https://doi.org/10.2307/2399227

Cox, G. (1990). *Laboratory manual of general ecology*, 6th edn. Dubuque, Iowa: William C. Brown.

Duniway, M. C., & Herrick, J. E. (2013). Assessing impacts of roads: Application of a standard assessment protocol. *Rangeland Ecology and Management*, *66*, 364–375. https://doi.org/10.2111/REM-D-11-00130.1

Erkossa, T., Geleti, D., Williams, T. O., Laekemariam, F., & Haileslassie, A. (2020). Restoration of grazing land to increase biomass production and improve soil properties in the Blue Nile basin: Effects of infiltration trenches and *Chloris gayana* reseeding. *Renewable Agriculture and Food Systems*, 1–9. https://doi.org/10.1017/S1742170519000425

Evans, R. A., & Love, R. M. (1957). The step-point method of sampling. A practical tool in range research. *Journal of Range Management*, *10*, 208–212. https://doi.org/10.2307/3894015

Hartnett, D. C., Wilson, G. W. T., Ott, J. P., & Setshogo, M. (2013). Variation in root system traits among savanna grasses: Implications for drought tolerance. *Austral Ecology*, *38*, 383–392. http://doi.org/10.1111/j.1442-9993.2012.02422.x

Hayashi, I. (1996). Five years experiment on vegetation recovery of drought deciduous woodland in Kitui, Kenya. *Journal of Arid Environments*, *34*, 351–361. https://doi.org/10.1006/jare.1996.0115

Herrick, J. E., van Zee, J. W., McCord, S. E., Courtright, E. M., Karl, J. W., & Burkett, L. M. (2017). *Monitoring manual for grassland, shrubland and savanna ecosystems*, 2nd edn.. Volume, *I*: Las Cruces, New Mexico: Core Methods. USDA-ARS Jornada Experimental Range. https://jornada.nmsu.edu/files/Core_Methods.pdf

Kalamees, R., Püssa, K., Zobel, K., & Zobel, M. (2012). Restoration potential of the persistent soil seed bank in successional calcareous (alvar) grasslands in Estonia. *Applied Vegetation Science*, *15*, 208–218. https://doi.org/10.1111/j.1654-109X.2011.01169.x

Kimiti, D. W., Riginos, C., & Belnap, J. (2017). Low-cost grass restoration using erosion barriers in a degraded African rangeland. *Restoration Ecology*, *25*, 376–384. https://doi.org/10.1111/rec.12426

Kinyua, D., McGeoch, L. E., Georgiadis, N., & Truman, P. Y. (2010). Short-term and long-term effects of soil ripping, seeding and fertilisation on the restoration of a tropical rangeland. *Restoration Ecology*, *18*, 226–233. https://doi.org/10.1111/j.1526-100X.2009.00594.x

Koech, O. K., Kinuthia, R. N., Karuku, G. N., Mureithi, S. M., & Wanjogu, R. K. (2016). Irrigation levels affects biomass yields and morphometric characteristics of range grasses in arid rangelands of Kenya. *Springer Plus*, *5*, 1640. https://doi.org/10.1186/s40064-016-3309-8 PMID: 27722058

Marshall, V. M., Lewis, M. M., & Ostendorf, B. (2012). Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: A review. *Journal of Arid Environments*, *78*, 1–12. https://doi.org/10.1016/j.jaridenv.2011.11.005

Mganga, K. Z., Kaindi, E., Ndathi, A. J. N., Bosma, L., Kioko, T., Kadenyi, N., Wambua, S., van Steenbergen, F., & Musimba, N. K. R. (2020). Data from: Morphoecological characteristics of grasses used to restore degraded semi-arid African rangelands. *Dryad Digital Repository*, https://doi.org/10.5061/dryad.sxksn031p

Mganga, K. Z., Nyariki, D. M., Musimba, N. K. R., & Mwang'ombe, A. W. (2019). Indigenous Grasses for Rehabilitating Degraded African Drylands. In: Bamutaze, Y., Kyamanywa, S., Singh, B., Nabanoga, G., & R, Lal (Eds), *Agriculture and Ecosystem Resilience in Sub Saharan Africa. Climate Change Management* (pp. 53–68). Cham: Springer. https://doi.org/10.1007/978-3-030-12974-3_3

Mganga, K. Z., Musimba, N. K. R., Nyariki, D. M., Nyangito, M. M., & Mwang'ombe, A. W. (2015). The choice of grass species to combat desertification in semi-arid rangelands is greatly influenced by their forage value for livestock. *Grass and Forage Science*, *70*, 161–167. https://doi.org/10.1111/gfs.12089

Mganga, K. Z., Musimba, N. K. R., & Nyariki, D. M. (2015). Competition indices of three perennial grasses used to rehabilitate degraded semi-arid rangelands in Kenya. *The Rangeland Journal*, *37*, 489–495. https://doi.org/10.1071/RJ15023

Mnene, W. N., Hanson, J., Ekaya, W. N., Kinyamario, J. I., Mweki, P., Lall, G., Stuth, J. W., & Jamnadass, R. H. (2005). Genetic variation between ecotypic populations of *Chloris roxburghiana* grass detected through RAPD analysis. *African Journal of Range and Forage Science*, *22*, 107–115. https://doi.org/10.2989/10220110509485868

Moore, N. A., Camac, J. S., & Morgan, J. W. (2019). Effects of drought and fire on resprouting capacity of 52 temperate Australian perennial native grasses. *New Phytologist*, *221*, 1424–1433. https://doi.org/10.1111/nph.15480

Mureithi, S. M., Verdoodt, A., Njoka, J. T., Gachene, C. K. K., & van Ranst, E. (2016). Benefits derived from rehabilitating a degraded semi-arid rangeland in communal enclosures, Kenya. *Land Degradation and Development*, *27*, 1853–1862. https://doi.org/10.1002/ldr.2341

Mureithi, S. M., Verdoodt, A., Gachene, C. K. K., Njoka, J. T., Wasonga, V. O., de Neve, S., Meyerhoff, E., & van Ranst, E. (2014). Impacts of enclosure management on soil properties and microbial biomass in a restored semi-arid rangeland. *Kenya. Journal of Arid Land*, *6*, 561–570. https://doi.org/10.1007/s40333-014-0065-x

O'Brien, E. K., Mazanec, R. A., & Krauss, S. L. (2007). Provenance variation of ecologically important traits of forest trees: Implications for restoration. *Journal of Applied Ecology*, *44*, 583–593. https://doi.org/10.1111/j.1365-2664.2007.01313.x

Ponsens, J., Hanson, J., Schellberg, J., & Moeseler, B. M. (2010). Characterization of phenotypic diversity, yield and response to drought stress in collection of Rhodes grass (Chloris gayana Kunth) accessions. *Field Crops Research*, *118*, 57–72. https://doi.org/10.1016/j.fcr.2010.04.008

R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

RStudio Team. (2018). *RStudio: Integrated Development for R. RStudio, PBC*, Boston, MAURL: http://www.rstudio.com/

Ruiz-Jaen, M. C., & Aide, T. M. (2005). Restoration success: How is it being measured? *Restoration Ecology*, *13*, 569–577. https://doi.org/10.1111/j.1526-100X.2005.00072.x

Sanchez, P. A. (2002). Ecology – soil fertility and hunger in Africa. *Science*, *295*, 2019–220. https://doi.org/10.1126/science.1065256 PMID: 11896257

Santos, M. E. R., Silveira, M. C. T., Gomes, V. M., da Fonseca, D. M., Sousa, B. M. L., & Santos, A. D. (2013). Pasture height at the beginning of deferment as a determinant of signal grass structure and potential selectivity by cattle. *Acta Scientiarum Animal Science*, *35*, 379–385. https://doi.org/10.4025/actascianimsci.v35i4.20421

Schmitt, C. B., Kisangau, D., & Matheka, K. W. (2019). Tree diversity in a human modified riparian forest landscape in semi-arid Kenya. *Forest Ecology and Management*, *433*, 645–655. https://doi.org/10.1016/j.foreco.2018.11.030

Senn, J. A., Fassnacht, F. E., Eichel, J., Seitz, S., & Schmidtlein, S. (2020). A new concept for estimating the influence of vegetation on throughfall kinetic energy using aerial laser scanning. *Earth Surface Processes and Landforms*, *45*, 1487–1498. https://doi.org/10.1002/esp.4820

Stuart-Hill, G. C., & Mentis, M. T. (1982). Coevolution of African grasses and large herbivores. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa*, *17*, 122–128. https://doi.org/10.1080/00725560.1982.9648969

Van den Berg, L., & Kellner, K. (2005). Restoring degraded patches in a semi-arid rangeland of South Africa. *Journal of Arid Environments*, *61*, 497–511. https://doi.org/10.1016/j.jaridenv.2004.09.024

Verdoodt, A., Mureithi, S. M., & van Ranst, E. (2010). Impacts of management and enclosure age on recovery of the herbaceous rangeland vegetation in semi-arid Kenya. *Journal of Arid Environments*, *74*, 1066–1073. https://doi.org/10.1016/j.jaridenv.2010.03.007

Visser, N., Morris, C., Hardy, M. B., & Botha, J. C. (2007). Restoring bare patches in the Nama-Karoo of South Africa. *African Journal of Range and Forage Science*, *24*, 87–96. https://doi.org/10.2989/AJRFS.2007.24.2.5.159

Vohland, K., & Barry, B. (2009). A review of in situ rainwater harvesting (RWH) practices modifying landscape functions in African drylands. *Agriculture, Ecosystems and Environment*, *131*, 119–127. https://doi.org/10.1016/j.agee.2009.01.010

Vundla, T., Mutanga, O., & Sibanda, M. (2020). Quantifying grass productivity using remotely sensed data: An assessment of grassland restoration benefits. *African Journal of Range and Forage Science*, *37*, 247–256. https://doi.org/10.2989/10220119.2019.1697754

Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y., & Zemla, J. (2017). Corrplot package: visualization of a correlation matrix. Version 0.84. https://github.com/taiyun/corrplot

Whisenant, S. G. (1999). *Repairing damaged wildlands: A process-oriented, landscape-scape approach*. Cambridge: Cambridge University Press, UK. ISBN 0-521-47001-3.

Winkworth, R. (1963). The germination of buffel grass (*Cenchrus ciliaris*) seed after burial in a Central Australian soil. *Australian Journal of Experimental Agriculture and Animal Husbandry*, *3*, 326–328. https://doi.org/10.1071/EA9630326

Wright, B. R., Latz, P. K., Albrecht, D. E., & Fensham, R. J. (2021). Buffel grass (*Cenchrus ciliaris*) eradication in arid central Australia enhances native plant diversity and increases seed resources for granivores. *Applied Vegetation Science*, *00*, e12533. https://doi.org/10.1111/avsc.12533

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