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Pastoralists' perceptions of forage value and productivity of pasture grasses under different reseeding technologies in Upper Ewaso Nyiro Basin rangelands, Kenya

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Over 80% of Kenya's landmass falls under arid and semi-arid lands, where harsh environmental conditions hinder efforts to restore degraded rangelands. Rangeland degradation is a gradual process in which the natural environment is compromised through reduced biological diversity and weakened ecosystem functioning due to anthropogenic and natural causes. This study identified farmers' preferred pasture grass species and evaluated the effects of different reseeding technologies on growth parameters and dry matter yield of prioritized grasses in Kenya's Upper Ewaso Nyiro Basin rangelands. Cross-sectional survey results from respondents ($n = 118$) indicated that broadcasting was the most common reseeding technology (80.8%) while inadequate rainfall was the main critical challenge (73.4%). Based on ranking scores, *Cenchrus ciliaris* (33.4%), *Chloris gayana* (20.0%) and *Eragrostis superba* (18.6%) cumulatively ranked highest for yield, forage yield, ground cover, increased milk production and weight gain. The grasses were subjected to an on-farm randomized complete block design experiment with drilling and broadcasting reseeding technologies under mono- and mixed-cropping systems. Experimental data was subjected to general analysis of variance (ANOVA) using GENSTAT and Tukey's HSD used to separate significant means ($p < 0.05$). The total annual rainfall was 741.7 mm while that received from January - June (season 1) and July - December 2021 (season 2) was 316.8 mm and 424.9 mm respectively. Plant density, tiller density, basal cover, dry matter, ash and dry matter yields varied significantly ($P < 0.05$) across treatments and seasons. Mono-cropped *Chloris gayana* and its mixed crop with *Cenchrus ciliaris* consistently achieved higher plant densities, tiller densities and better basal cover. Broadcasted monocropped *Eragrostis superba* had the lowest productivity (4.55 and 7.51 tons/ha/year), while drilled mixed cropped *Cenchrus ciliaris* and *Chloris gayana* had the highest (11.17 and 15.96 tons/ha/year) across the treatments and seasons. These findings indicate that drilling combined with mixed cropping, particularly involving *Cenchrus ciliaris* and *Chloris gayana*, should be prioritized in community reseeding initiatives to enhance pasture productivity in arid and semi-arid lands of Upper Ewaso Nyiro Basin.

KEYWORDS

pastoralists' perceptions, productivity, reseeding technologies, cropping systems, plant density

1 Introduction

1.1 Background information

Rangeland degradation is a gradual process where the natural environment is compromised through reduction in biological diversity, grassland productivity and soil nutrients and the general health by anthropogenic and natural causes (Bolo et al., 2019; Wiethase et al., 2023). It is a major global challenge affecting grazed rangelands, ecological resilience, forage availability, and livestock productivity (Belay and Mammo, 2024). Degradation reduces the ability of ecosystems to sequester carbon and regulate the water cycle, exacerbating climate change and creating a vicious cycle that further accelerates land degradation (Unger and Marjan, 2014; Christian et al., 2021). In addition, degraded rangelands are marked by reduced biological and economic productivity due to unsustainable human land use, affecting hydrology, soil processes, and vegetation composition. The causes and drivers of degradation vary with geographic characteristics and grassland types (Zhang et al., 2024). Natural drivers such as climate change and variability, aridity and desertification, invasive/alien species and bush encroachment and drought intensify degradation pressures worldwide (Bolo et al., 2019; Lutta et al., 2020; GoK, 2021a). Human-induced factors including unsustainable agricultural expansion, overgrazing, weakened traditional governance, and ineffective land policies further exacerbate deterioration (Ji et al., 2022; Ayuba et al., 2025).

The United Nations' (UN) Sustainable Development Goals (SDGs) 15, "Life on Land", aims to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" and achieve Land Degradation Neutrality (LDN) by 2030 (United Nations, 2015). One of the ways of achieving LDN in land that is already degraded is through interventions to reverse degradation through restoration or rehabilitation, which actively assist in the recovery of ecosystem functions (Kust el al. 2017). However, the success of SDG 15 could be hindered by absence of unified definitions and assessment standards for grassland degradation worldwide so far (Lutta et al., 2020; Zhang et al., 2024).

Restoration measures can both be natural restoration or artificial recovery. In artificial recovery reseeding practices, perennial grasses are seeded into degraded grasslands and it's one of the most commonly used measures the artificial restoration of degraded grassland. Reseeding increase degraded grassland aboveground biomass, improves soil conservation, enhances water infiltration, and boosts forage availability (Guo et al., 2021) and inhibits rangeland vegetation degradation (Mi et al., 2024). In sub-Saharan Africa, restoration methods include reseeding, natural regeneration, soil/water conservation, water harvesting, dryland forestry, and addressing degradation causes (Ouled et al., 2019). In arid areas of Tunisia, *gdel* based on the principle of leaving the rangeland in rest (without grazing) to reconstitute its plant cover has been newly established in response to widely fluctuating rainfall and declining productivity in communal rangelands.

Droughts have become more frequent and severe globally due to climate change, leading to soil moisture depletion, reduced river flows, and long-term ecological stress (Chen et al., 2025). It is one of the most damaging disasters worrying African pastoralists (Umer, 2024; Sintayehu et al., 2025). In addition, poverty and poor land use can increase vulnerability to droughts and intensify their impacts on degradation (Shiferaw et al., 2014). These impacts are most severe in vulnerable regions, where drought undermines livelihoods, livestock production, food security and nutrition, environment and local economies (WHO, 2024; Toromade et al., 2024).

The Horn of Africa is among the world's most drought-prone regions, with historical events such as the 1973 and 1983 droughts causing massive livestock losses and famine (ISS, 2011; Ondiko and Karanja, 2021; ACAPS, 2022; Mati et al., 2023; WMO, 2023). In Kenya, drought occurrences have increased over the past three decades, severely affecting pastoral and agro-pastoral households (GoK, 2022). However, pastoralists apply diverse coping strategies such as mobility, herd diversification and water harvesting, prolonged droughts continue to undermine resilience (Opiyo et al., 2015; Ndiritu, 2021; Kirui et al., 2022).

Kenya's arid and semi-arid lands (ASALs) occupy over 80% of the country, support more than 60% of the national livestock herd, host the majority of wildlife populations and approximately 10 million persons live there (KNBS, 2010). Despite their socioeconomic importance, ASALs face low agricultural potential, poor soils, increasing population pressure, and land-use conflicts driven by resource scarcity and poor rangeland governance (Mohammed et al., 2016; GoK, 2022). In addition, water scarcity, pasture shortages, livestock deaths, and conflict over limited resources are common (Kimaro et al., 2018; Gebremeskel Haile et al., 2019). Pastoral households frequently experience livestock losses, reduced herd sizes and heightened vulnerability during prolonged dry periods (Mati et al., 2023). These challenges are pronounced in Laikipia County, where drought occurs every 2–3 years, rainfall is highly variable, and only 20% of land is arable (Njeru et al., 2024). The county has a climate vulnerability index of 0.384 (MoALF, 2018) with significant impacts on the region's ecosystems, agriculture, and livelihoods.

The key reseeding grasses species in Kenya's ASALs include drought-tolerant natives like Red oat grass (*Themeda triandra*), Maasai Love Grass (*Eragrostis superba*), African Foxtail (*Cenchrus ciliaris*), Bush Rye (*Enteropogon macrostachyus*), Rhodes Grass (*Chloris gayana*), Guinea Grass (*Panicum maximum*), Fingergrass (*Digitaria macroblephara*), Mopane grass (*Enteropogon macrostachyus*), Horsetail Grass (*Chloris roxburghiana*) and their mixed crops alongside legumes (Lrrd.org, 2015; Mganga et al., 2021). The common legumes for soil fertility improvement and animal nutrition include Stylo (*Stylosanthes spp.*), Butterfly Pea (*Clitoria ternatea*) and Tropical Kudzu (*Pueraria phaseoloides*). The pasture grass species and their mixed crops alongside legumes are reseeded under different methods such as controlled grazing, micro-catchments/bunds, conservation tillage (e.g., trenches for water), and potentially combining drilling with broadcasting. Another

Abbreviations: ACAPS, Assessment Capacities Projects; AOAC, Association of Official Analytical Chemists; ASALs, Arid and Semi-Arid Lands; DM, Dry matter; GoK, Government of Kenya; ILCA, International Livestock Centre for Africa; ISS, Institute for Security Studies; KNBS, Kenya National Bureau of Statistics; LDN, Land Degradation Neutrality; MoLAF,. Ministry of Agriculture, Livestock and Fisheries, RCBD, Randomized Complete Block Design; SDGs, Sustainable Development Goals; WHO, World Health organization of United Nations; WMO, World Meteorological Organization.

emerging reseeding method in some of the ranches in Upper Ewaso Nyiro Basin, e.g., Ol Jogi Conservancy reseeding via livestock manure (feacal reseeding) where seeds harvested at the ripe, hard stage can pass through livestock digestive systems intact (Ol Jogi Wildlife Conservancy, 2024). The reseeding methods focus on species adapted to heavy grazing and drought for better biomass and seed production.

Several drought mitigation strategies, such as climate-smart agriculture, water harvesting, and community resilience programs, have been implemented (County Government of Laikipia, 2023). However long-term, ecosystem-based interventions such as rangeland reseeding are essential for restoring productivity and enhancing resilience. As a result, there is need for concerted efforts to halt any further degradation which will further aggravate the already precarious ecological and socio-economic challenges. Reseeding interventions should therefore, halt degradation and improve the functional capacity of rangelands. This study aimed to identify pastoralists' preferred grass species based on perceptions on forage yield, ground cover, increased milk production and weight gain and evaluate their performance under different reseeding technologies and cropping systems to inform evidence-based rangeland restoration strategies in Kenya's Upper Ewaso Nyiro Basin rangelands.

2 Materials and methods

2.1 Description of study area

The study was conducted in Upper Ewaso Nyiro Basin of Laikipia County which are prone frequent droughts. The basin lies between latitudes 0°15′South and 1°00′North, and longitudes 36°30′East and 37°45′East with a grassland plateau of unpredictable altitude of 1,500 to 2,611 m above sea level at the Ewaso Nyiro basin in the north and Marmanet forest. It has two main rainy seasons: the long rains (March - June) and short rains (October - December) with mean annual rainfall ranging from 400–1,200 mm (MoALF, 2018). The mean annual temperatures range from 16 °C to 26 °C. Most of the residents in Ewaso Nyiro basin are pastoralists who move from one area to another in search of water and pasture during the dry season.

2.2 Research design

A cross-sectional survey involving 118 households assessed preferred grass species, reseeding technologies and challenges. Based on pastoralists perceptions, three grass species *Cenchrus ciliaris*, *Chloris gayana*, and *Eragrostis superba* were selected because they ranked highest for forage yield, basal ground cover, contribution to increased milk production and weight gain and adaptations to ASAL conditions.

The grass species were sourced from an Agro-Vet in Nanyuki town, Laikipia County and subjected to an on-farm randomized complete block design (RCBD) experiment for two seasons. Two reseeding technologies (drilling and broadcasting) were evaluated under mono- and mixed-cropping systems which lead to 12 treatment combinations, Each treatment was replicated three times.

2.3 Experimental treatments and layout

The 12 treatment combinations were randomly assigned within blocks to reduce positional effects. Plot size was 3 × 3 m with 1 m spacing. Drilling was done at 1–2 cm depth with 30 cm row spacing; broadcasting involved surface application followed by raking. Mixed cropping system involved alternating rows under drilling and equal amounts of seed mixing under broadcasting. Seeding rate was 5–8 kg/ha. Land was manually cleared, harrowed and leveled to a fine tilth suitable for uniform seed placement. All plots were subjected to the same agronomic practices under rain-fed agriculture. No watering, inorganic or organic fertilizers were added to simulate actual pastoralist's practices and reflect natural soil conditions in ASALs. The grasses were established in mid-February before the onset of long rains in March (season 1) and mid-August before the onset of short rains September 2021(season 2). A trained agronomist was in-charge of field agronomic practices and data collection.

2.4 Experimental data collection

Plant density (number of plants/m^2) and above ground standing biomass (%) from each plot was determined by 1 m^2 quadrat method. For tiller density (number of tillers/crown), reference plants were randomly selected and tagged for subsequent measurements. Tiller density was determined by counting the numbers tillers from base of a grass plant. Each tiller consisted of a leaf, stem node, stem inter-node, and bud. Measurements were conducted according to standard procedures adapted from ILCA (1990) and Brummer et al. (1994). Vegetation biomass and standing crop were harvested at 20 weeks to determine the DM and ash of plant material available. Samples were collected from 1 m^2 quadrat randomly located within each experimental plot. DM was determined using AOAC oven-drying, which removes all moisture. For ash, AOAC method of incinerating samples were for 3 h at 550 °C was used (AOAC, 1990). All samples were analyzed in triplicates. Subsamples with unusually high readings were re-analyzed, confirming consistency. Then dry matter yield (t/ha) was calculated by (Etefa and Dibaba, 2011) formula.

The dry matter yield (t/ha/year) = TFW × (DWss/HA × FWss) ×10 x 3.
Where TFW = total fresh weight kg/plot,
DWss = dry weight of subsample in grams,
FWss = fresh weight of subsample in grams,
HA = Harvest plot area in square meters,
10 is a constant for conversion of yields in kg/m to t/ha and 3 is assuming a minimum of 3 harvests per year.

2.5 Data analysis

The cross-sectional survey data was analyzed using the SPSS for descriptive statistics to identify the challenges, preferred pasture grass species and reseeding practices. Experimental data was subjected to general analysis of variance (ANOVA) using GENSTAT. Mean separation was done using the Tukey's HSD

TABLE 1 Common challenges faced by pastoral and agro-pastoralists.

Main challenges	Proportion (%)
In adequate rainfall	53.4
Insecurity	17.8
Disease outbreaks	11.8
Overgrazing	5.9
Inadequate market access for livestock and their products	5.3
Fire outbreaks	4.0
Wild animals attack	1.7

TABLE 2 Land reclamation strategies.

Reclamation strategies	Respondent answer (%)
Grass reseeding	36
No reclamation and rehabilitation	25
Destocking	16
Controlled grazing	15
Planting trees	8

TABLE 3 Reseeding technologies used.

Reseeding technologies	Proportions (%)
Broadcasting	35.3
Drilling	34.1
Combination of broadcasting and drilling	30.6

test at $p < 0.05$. In the analysis, while cropping systems and grass species affected the results, they were not the primary focus of the research. They were treated as blocking factors to account for systematic variation. However, the general ANOVA factored the possible interactions between them.

3 Results

3.1 Identification of the most preferred grass species

The common challenges faced by pastoral and agro-pastoralists are presented in Table 1.

The main challenge faced by pastoral and agro-pastoralists was inadequate rainfall (53.4%) followed by insecurity (17.8%) with wild animals attack the least (1.7%).

Table 2 shows the rangeland reclamation strategies used by pastoralists.

The most used rangeland restoration practice was grass reseeding (36%) while 25% did not not practice any. Others used destocking (16%) and controlled grazing (15%).

The pasture grasses reseeding technologies used in the area are shown in Table 3.

Out of 36% of the pastoral and agro-pastoralists who practiced grass reseeding (Table 2), 35.3% preferred broadcasting while 30.6% used a combination of broadcasting and drilling methods.

The ranks of grasses in relation to abundance, forage yield (Table 3), milk yield, weight gain, and ground cover are presented in Table 4.

Based on respondents' experience, exposure and perceptions, *Chloris gayana* was most preferred in terms of abundance (32.2%), forage yield (33.9%), milk yield (34.7%) and weight gain (35.6%). *Eragrostis superba* was ranked first in terms of ground cover (30.5%). *Chloris gayana* had the highest cumulative weighted score of 33.4% while *Pennisetum clandestinum* had the lowest with 12.2%.

3.2 Effects of reseeding technologies on growth parameters and yields of selected grass species

3.2.1 Rainfall distribution

Over the last 13 years from 2009–2021, the mean annual rainfall was 770.22 mm (Figure 1).

During the study period in 2021, rainfall distribution in the area varied across the year as shown in Figure 2.

The total annual rainfall was 741.7 mm while that received from January - June 2021 and July - December 2021 was 316.8 mm and 424.9 mm respectively. The highest and lowest amounts of rainfall were received in May (132.0 mm) and June (10.3 mm) and October (111.1 mm) and September (45.9 mm) during the long and short rains respectively. The onset of long rains of March - May 2021 was late and most parts of the county received average rains which constituted 91%–110% of normal rains (GoK, 2022). Ewaso Nyiro basin received 76%–90% of normal rains whose temporal distribution was poor and spatial distribution was uneven. During the short rains season, most parts of the county received below normal rains ranging from 51% to 90% of the normal rains (GoK, 2021b). The rainfall was characterized by uneven spatial and poor temporal distribution.

3.2.2 Growth parameters and dry matter yield

The interaction effects of reseeding technologies, cropping systems and grass species on mean plant density (plants/m^2), tiller density (number of tillers/crown) and foliage basal cover (%) at week 4, 8, 12, 16 and 20 during long- (season 1) and short-rains (season 2) 2021 varied as shown in Tables 5, 6. Despite the variations in rainfall during the year, growth parameters and dry matter yields between the season 1 and 2 followed a similar trend.

At week 4 and 8, plant density had significant differences ($P < 0.05$) between treatments across the two seasons. At week 4, season 1, P2C2G4 (10.08 plants/m^2) was significantly different with P1C1G3 (5.42 plants/m^2), P1C2G6 (6.0 plants/m^2) and P2C2G6 (5.71 plants/m^2) only. During season 1, at week 4, 8, 12 and 16, P1C1G3 had the lowest plant density of 5.42, 10.79, 12.96 and 67.50 plants/m^2 while P2C2G4 had the highest at 10.08, 14.96, 19.00 and 78.96 plants/m^2 respectively. During season 2, P1C1G3 and P2C2G4 had the same trend of having the lowest

TABLE 4 Ranks of grasses in relation to abundance, forage yield, milk yield, weight gain and ground cover.

Parameter	Rank	Grasses	Frequency	Percentage (%)
Abundance	1	*Chloris gayana*	38	32.2
	2	*Cenchrus ciliaris*	29	24.6
	3	*Eragrostis superba*	25	21.2
	4	*Themeda triandra*	15	12.7
	5	*Penisetum clandestinum*	11	9.3
Forage yield	1	*Chloris gayana*	40	33.9
	2	*Themeda triandra*	27	22.9
	3	*Cenchrus ciliaris*	19	16.1
	4	*Eragrostis superba*	18	15.3
	5	*Penisetum clandestinum*	14	11.9
Milk yield	1	*Chloris gayana*	41	34.7
	2	*Eragrostis superba*	26	22.0
	3	*Cenchrus ciliaris*	18	15.3
	4	*Themeda triandra*	17	14.4
	5	*Penisetum clandestinum*	16	13.6
Weight gain	1	*Chloris gayana*	42	35.6
	2	*Eragotis superba*	21	17.8
	3	*Cenchrus ciliaris*	19	16.1
	4	*Pennisetum clandestium*	18	15.3
	5	*Themeda triandra*	18	15.3
Ground cover	1	*Eragrostis superba*	36	30.5
	2	*Cenchrus ciliaris*	28	23.7
	3	*Chloris gayana*	25	21.2
	4	*Themeda triandra*	16	13.6
	5	*Pennisetum clandestium*	13	11.0
Weighted score	1	*Chloris gayana*	197	33.4
	2	*Eragrostis superba*	118	20.0
	3	*Cenchrus ciliaris*	110	18.6
	4	*Themeda triandra*	93	15.8
	5	*Pennisetum clandestium*	72	12.2

and highest plan density across the seasons. At week 16, plant density was greater than 50.0 plants/m^2 in all the treatments ranging from 67.50–7.96 in season 1 to 52.78–59.71 plants/m^2 in season 2 in P1C1G3 and P2C2G4 respectively. During the 20th week, the grasses were fully grown and was not necessary to establish the plant density.

During the 4th week, the tillers were not fully developed. In season 1, tiller density had no significant differences at 8, 12 and 16. At week 8, tiller density varied between 7.71 and8.42 tillers per crown in season 1 to 6.46–9.54 in season 2 in P1C1G3 and P2C1G2 respectively. At week 12, tiller density had significant differences (P < 0.05) between treatments during season 2. Across the seasons and weeks, P1C1G3 had the lowest tiller density of 6.45, 16.75 and 128.80 and 7.71, 28.17 and 128.9 tillers/crown. Except P1C1G3, all other treatments had tiller densities of more than 20 and 25 tillers/crown at week 12 in seasons 1 and 2. At week 16, tiller density ranged from 128.80 (P1C1G3) - 141.00 (P2C1G2) tillers per crown during season 2. During the 20th week, some tillers had started developing new plants from their nodes, therefore not possible to determine the density from the initial plant.

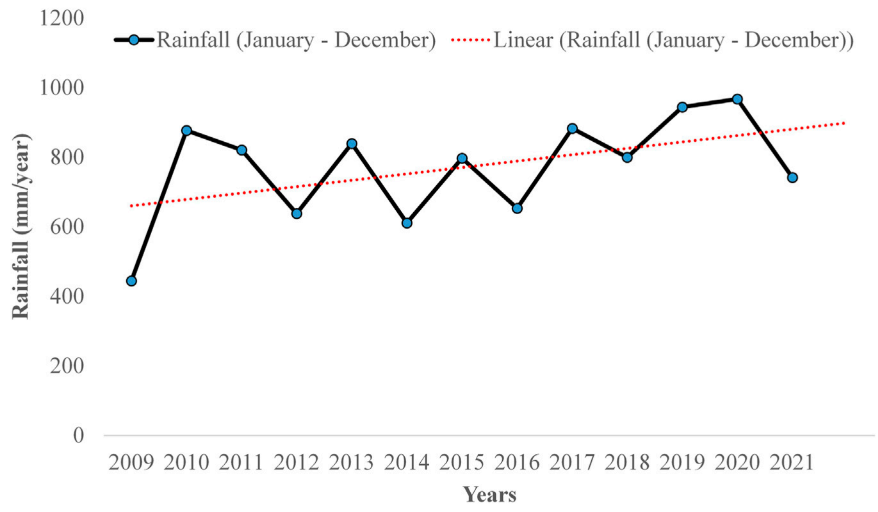

FIGURE 1
Rainfall distribution in Ewaso Nyiro Basin for the last 13 years (Source: Kenya Meteorological Department, 2022).

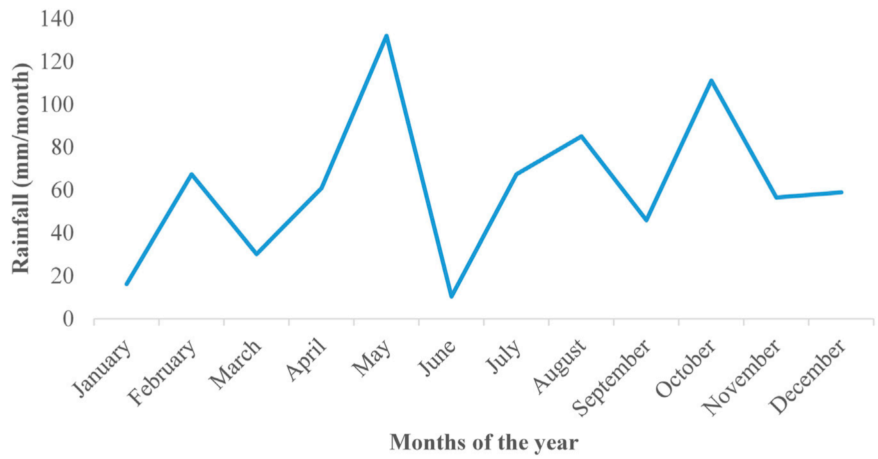

FIGURE 2
Rainfall distribution in the area throughout the year (Source: Kenya Meteoroloical Department, 2022).

There were significant differences ($P < 0.05$) between treatments for foliage basal cover only at week 16 during season 1. However, during season 2, there were significant differences at week 8, 12 and 16. At week 8 and 12, P1C1G3 had the lowest cover of 8.12% and 47.50% while P2C1G2 had the highest at 62.08% and 91.67% during season 2. At week 16, all treatments exceeded 90% cover except P2C1G3. At 20th week, all the treatments had achieved 100% coverage.

The interaction effects of reseeding technologies, cropping systems and pasture grass species on mean dry matter and ash content and dry matter yield at 20th week of growth varied as shown in Table 7.

There were significant differences ($P < 0.05$) between treatments for dry matter (%), ash (%) and dry matter yields (ton/ha/year). DM ranged from 94.04% (P1xC2xG6) to 98.50% (P2xC2xG4). The ash content varied from 12.19% (P1xC1xG1) to 14.90% (P2xC2xG5). The dry matter yield was highest in P2xC2xG4 (11.17 and 15.96 ton/ha/year) and lowest in P1xC2xG5 (4.55 and 7.51 ton/ha/year) in seasons one and two respectively.

4 Discussion

This study integrated pastoralists' perceptions with experimental results to identify suitable grasses and reseeding practices for ASALs. Pastoralists consistently preferred *Chloris gayana*, reflecting its adaptability, regrowth capacity, and productivity; findings supported by the field experiment, which showed strong establishment and high biomass yields. Drilled mixed plots of *Cenchrus ciliaris* and *Chloris gayana* outperformed other treatments, demonstrating the benefits of drilling (enhanced seed–soil contact) and mixed cropping (resource-use complementarity). High DM and ash values reflected late harvesting, natural senescence, and environmental conditions typical of semi-arid ecosystems. Although the present results represents establishment performance, rather than grazing resilience or long-term pasture behaviour, they align with global studies showing superior performance of mixed swards in ASAL systems subject to further research.

TABLE 5 Interaction effects of reseeding technologies, cropping systems and grass species on plant density, tiller density and foliage basal cover at week 4, 8, 12, 16 and 20 during long rains 2021.

Treatment	Plant density (plants/m^2)					Tiller density (numbers of tillers/crown)					Foliage basal cover (%)				
	Week 4	Week 8	Week 12	Week 16	Week 20	Week 4	Week 8	Week 12	Week 16	Week 20	Week 4	Week 8	Week 12	Week 16	Week 20
P1xC1xG1	8.12^{bc}	12.79^{a}	18.33^{a}	70.42^{ab}	—	—	8.21^{a}	29.04^{a}	130.3^{a}	—	—	59.42^{a}	82.27^{b}	99.17^{b}	100
P1xC1xG2	8.41^{c}	14.42^{ab}	19.12^{a}	73.67^{ab}	—	—	8.33^{a}	29.08^{a}	137.0^{a}	—	—	59.83^{a}	83.62^{a}	100^{b}	100
P1xC1xG3	5.42^{a}	11.83^{a}	17.29^{a}	67.50^{a}	—	—	7.71^{a}	28.17^{a}	128.6^{a}	—	—	54.75^{a}	77.58^{a}	89.58^{a}	100
P1xC2xG4	9.08^{c}	14.33^{ab}	19.62^{a}	72.79^{ab}	—	—	7.83^{a}	30.00^{a}	131.6^{a}	—	—	63.54^{a}	78.83^{a}	100^{b}	100
P1xC2xG5	8.25^{c}	13.12^{a}	18.88^{a}	70.92^{ab}	—	—	8.00^{a}	30.12^{a}	133.6^{a}	—	—	57.83^{a}	82.48^{b}	97.92^{b}	100
P1xC2xG6	6.00^{ab}	12.33^{a}	18.42^{a}	73.58^{ab}	—	—	8.21^{a}	30.13^{a}	136.1^{a}	—	—	60.38^{a}	78.31^{a}	98.33^{b}	100
P2xC1xG1	9.29^{c}	13.67^{ab}	18.04^{a}	75.46^{ab}	—	—	7.79^{a}	30.04^{a}	130.8^{a}	—	—	62.21^{a}	83.42^{b}	99.17^{b}	100
P2xC1xG2	8.71^{c}	12.12^{a}	17.62^{a}	73.92^{ab}	—	—	8.42^{a}	31.42^{a}	141.0^{a}	—	—	66.04^{a}	84.46^{b}	100^{b}	100
P2xC1xG3	6.04^{ab}	12.00^{a}	17.88^{a}	76.33^{ab}	—	—	8.33^{a}	31.33^{a}	132.6^{a}	—	—	61.67^{a}	83.1^{b}	91.25^{a}	100
P2xC2xG4	10.08^{c}	16.71^{b}	19.75^{a}	78.96^{b}	—	—	8.33^{a}	32.83^{a}	139.1^{a}	—	—	60.08^{a}	80.4^{a}	99.58^{b}	100
P2xC2xG5	9.292^{c}	13.5^{ab}	19.12^{a}	78.71^{a}	—	—	8.29^{a}	31.54^{a}	133.0^{a}	—	—	63.46^{a}	83.52^{b}	97.08^{b}	100
P2xC2xG6	5.71^{c}	13.58^{ab}	17.29^{a}	74.58^{ab}	—	—	8.29^{a}	32.04^{a}	137.0^{a}	—	—	62.00^{a}	83.21^{b}	98.75^{b}	100
S.E.D	0.666	1.015	1.173	3.198	—	—	0.253	2.223	6.26	—	—	4.345	2.417	1.314	—
P-value	<0.001	<0.001	0.382	0.017	—	—	0.04	0.676	0.718	—	—	0.526	0.039	<0.001	—

P1- Broadcasting method, P2 - Drilling method, C1- Mono cropping, C2 - Mixed cropping, G1- *Cenchrus ciliaris*, G2 - *Chloris gayana*, G3 - *Eragrostis superba*, G4- *Cenchrus ciliaris* + *Chloris gayana*, G5 - *Cenchrus ciliaris* + *Eragrostis superba*, G6 - *Choloris gayana* + *Eragrostis superba*.

Means with different letter superscripts (a. b.& c) within a column are significantly diffident ($P < 0.05$).

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TABLE 6 Interaction effects of reseeding technologies, cropping systems and grass species on plant density, tiller density and foliage basal cover at week 4, 8, 12, 16 and 20 during short rains 2021.

Treatment	Plant density (plants/m^2)					Tiller density (numbers of tillers/crown)					Foliage basal cover (%)				
	Week 4	Week 8	Week 12	Week 16	Week 20	Week 4	Week 8	Week 12	Week 16	Week 20	Week 4	Week 8	Week 12	Week 16	Week 20
P1xC1xG1	8.13^{bc}	13.83^{ab}	16.38^{abc}	54.01^{a}	—	—	7.54^{a}	34.96^{cd}	130.30^{a}	—	—	58.70^{c}	79.17^{bc}	99.17^{b}	100
P1xC1xG2	8.40^{c}	14.88^{b}	18.12^{bc}	53.24^{a}	—	—	8.38^{a}	39.32^{de}	137.00^{a}	—	—	59.58^{c}	88.75^{d}	99.37^{b}	100
P1xC1xG3	5.42^{a}	10.79^{a}	12.96^{a}	52.78^{a}	—	—	6.46^{a}	16.75^{a}	128.80^{a}	—	—	18.12^{a}	47.50^{a}	90.42^{a}	100
P1xC2xG4	9.08^{c}	14.21^{ab}	16.92^{bc}	58.96^{a}	—	—	7.36^{a}	30.18^{bc}	131.60^{a}	—	—	38.75^{b}	78.75^{b}	97.08^{b}	100
P1xC2xG5	8.25^{c}	13.04^{ab}	16.29^{abc}	57.17^{a}	—	—	8.04^{a}	22.12^{b}	133.60^{a}	—	—	39.17^{b}	76.67^{bc}	97.92^{b}	100
P1xC2xG6	6.00^{ab}	14.29^{ab}	17.29^{abc}	55.42^{a}	—	—	7.63^{a}	23.33^{b}	129.90^{a}	—	—	21.87^{a}	48.33^{a}	98.33^{b}	100
P2xC1xG1	9.29^{c}	13.96^{ab}	17.52^{bc}	54.38^{a}	—	—	8.00^{a}	46.04^{e}	136.64^{a}	—	—	60.00^{c}	90.42^{d}	99.57^{b}	100
P2xC1xG2	8.71^{c}	13.62^{ab}	18.21^{bc}	54.75^{a}	—	—	9.54^{a}	46.67^{e}	141.00^{a}	—	—	60.42^{c}	91.67^{d}	100.00^{b}	100
P2xC1xG3	9.04^{ab}	12.08^{ab}	14.96^{ab}	57.83^{a}	—	—	7.21^{a}	41.13^{de}	132.63^{a}	—	—	36.67^{b}	78.70^{b}	89.58^{a}	100
P2xC2xG4	10.08^{c}	14.96^{b}	19.00^{c}	59.71^{a}	—	—	8.46$_{a}$	46.29^{de}	139.13^{a}	—	—	62.08^{c}	90.43^{d}	99.60^{b}	100
P2xC2xG5	9.29^{c}	14.71^{b}	17.25^{bc}	58.38^{a}	—	—	7.67^{a}	22.04^{b}	133.04^{a}	—	—	59.58^{c}	85.83^{cd}	99.58^{b}	100
P2xC2xG6	5.71^{a}	14.25^{ab}	17.71^{bc}	54.88^{a}	—	—	7.57^{a}	24.42^{b}	136.96^{a}	—	—	40.83^{b}	79.58^{bc}	98.75^{b}	100
S.E	0.470	0.75	0.838	2.505	—	—	0.65	1.933	4.424	—	—	2.026	1.730	0.962	—
P-value	0.01	0.04	0.001	0.564	—	—	0.183	0.001	0.675	—	—	0.001	0.001	0.001	—

P1- Broadcasting method, P2 - Drilling method, C1- Mono cropping, C2 – Mixed cropping, G1- *Cenchrus ciliaris,* G2 - *Chloris gayana*, G3 - *Eragrostis superba*, G4- *Cenchrus ciliaris* + *Chloris gayana*, G5 - *Cenchrus ciliaris* + *Eragrostis superba*, G6 - *Choloris gayana* + *Eragrostis superba*.
Means with different letter superscripts (a. b., c, d & e) within a column are significantly diffident ($P < 0.05$).

TABLE 7 Interaction effects of reseeding technologies, cropping systems and pasture grass species on dry matter and ash content and dry matter yield at 20th week of growth.

Treatment	Dry matter (%)	Ash (%)	Dry matter yield (ton/ha/year)	
			Season 1 (long rains)	Season 2 (short rains)
P1xC1xG1	96.96^{bc}	12.19^{a}	8.19^{c}	9.86^{ab}
P1xC1xG2	96.04^{b}	14.48^{bc}	11.09^{d}	11.97^{abc}
P1xC1xG3	97.33^{cd}	12.83^{ab}	4.55^{a}	7.51^{a}
P1xC2xG4	98.29^{de}	13.56^{abc}	7.63^{c}	14.37^{bc}
P1xC2xG5	97.33^{cd}	14.9^{c}	5.46^{a}	9.23^{ab}
P1xC2xG6	94.04^{a}	14.26^{bc}	7.89^{c}	10.64a^{bc}
P2xC1xG1	98.00^{de}	13.86^{abc}	10.60^{d}	13.56^{bc}
P2xC1xG2	97.58^{cde}	14.42^{abc}	8.32^{c}	11.27^{abc}
P2xC1xG3	97.92^{cde}	13.13^{abc}	5.87^{ab}	8.03^{a}
P2xC2xG4	98.5^{e}	13.6^{abc}	11.17^{d}	15.96^{a}
P2xC2xG5	97.58^{cde}	13.52^{abc}	7.25b^{c}	9.48^{ab}
P2xC2xG6	97.75^{cde}	12.66^{ab}	5.94^{ab}	9.4^{ab}
S.E.D	0.304	0.558	1.648	0.447
P-value	<0.001	<0.001	<0.001	<0.001

P1 - Broadcasting method, P2 - Drilling method, C1- Mono cropping, C2 - Mixed cropping, G1- *Cenchrus ciliaris*, G2 - *Chloris gayana*, G3 - *Eragrostis superba*, G4- *Cenchrus ciliaris* + *Chloris gayana*, G5 - *Cenchrus ciliaris* + *Eragrostis superba*, G6 - *Choloris gayana* + *Eragrostis superba*.
Means with different letter superscripts (a. b., c, d & e) within a column are significantly diffident (P < 0.05).

4.1 Agro-pastoralist perceptions on abundance, forage yield, milk yield, weight gain and ground cover on some grasses

Eragrostis superba was ranked first in terms of ground cover followed by *Cenchrus ciliaris* and *Chloris gayana*. For abundance, *Eragrostis superba* was ranked third while it was fourth for contribution to forage yield. Despite being ranked third in ground coverage, *Chloris gayana* was number one overall indicating that it was the most preferred grass species in the area. This concurs with Mganga et al. (2016) that the choice of grass for rehabilitation programs to combat desertification is much more influenced by their forage value for livestock than their contribution for rehabilitation purposes.

4.2 Plant densities

Drilling reseeding technology consistently resulted in higher plant densities than broadcasting (Tables 5 and 6). For instance, P2C2G4 had 10.08 plants/m^2 while P1C2G4 had 9.08 plants/m^2 at week 4 in season 1. This difference can be attributed to more controlled seed placement and depth associated with drilling. This ensures better seed-to-soil contact leading to higher germination rates and initial seedling establishment (Lamichhane and Soltani, 2020; Aime et al., 2021; Bellangue et al., 2024). Optimal seed-soil contact ensures moisture absorption, oxygen availability, and protection from environmental stresses, leading to higher germination rates and greater plant density. In addition, the improved plant density observed with drilling methods may be attributed to the more controlled and deeper seed placement, which can lead to better moisture and nutrient access (Zhang et al., 2021).

Mixed cropping tended to produce higher plant densities than mono cropping within the same reseeding technology. For example, P2C2G4 (10.08 plants/m^2) had higher density than P2C1G1 (9.29 plants/m^2) and P2C1G2 (8.71 plants/m^2). Mixed cropping lead to better resource utilization (light, water, and nutrients) and reduced competition among plants of different species, promoting overall plant density (Lithourgidis et al., 2011; Zhang et al., 2021). *Chloris gayana* under drilling (P2C1G2) or broadcasting (P1C1G2) reseeding technology exhibited the high plant densities under mixed cropping systems from 4th - 16th week regardless of season. *Chloris gayana* is known for its robust growth and adaptability, which likely contributed to its superior performance (Feedipedia, 2017; Jayasinghe et al., 2022). *Chloris gayana* and *Cenchrus ciliaris* mixed crop (P2C2G4) had high densities indicating the potential benefits of mixing species to enhance overall density. This demonstrates the advantages of mixed cropping by utilizing available resources more efficiently and promoting optimal plant density. Mixed cropping fosters rich biodiversity, enhancing below-ground interactions that promote soil health and fertility (Toker et al., 2024). Therefore, mixed cropping enhance light interception, nutrient uptake, and water use efficiency, leading to better plant growth and yield (Li et al., 2020; Moreira et al., 2024; Akchaya et al., 2025). Despite the variations at weeks 4, 8 and 12, no statistically significant differences were found in plant density at week 16, suggesting that both reseeding technologies may provide similar results at later stages of growth once the grasses are fully establishment.

Mixed cropping systems create a more balanced and productive ecosystem, which is essential for sustainable grassland management. This aligns with literature suggesting that mixed cropping can improve resource use efficiency by maximizing light capture and reducing competition among plants (MacLaren et al., 2023; Melkamu, 2023; Toker et al., 2024). Further, Mganga et al. (2021) highlight that the choice of grass species in mixed cropping systems is crucial, as it can influence the effectiveness of these systems in combating desertification and improving forage value. The synergistic effects of different species in mixed cropping systems contribute to higher overall productivity and better soil health, making these systems a viable option for sustainable grassland management.

The results at week 12 emphasize the effectiveness of the drilling over broadcasting reseeding technology for enhancing plant density, tiller density, and basal cover. This in line with the advantages of drilling for seed placement precision and soil contact, leading to better seedling establishment and increased plant density (Yechale et al., 2021). Drilling methods reduce seed wastage and provide a more consistent seedling emergence compared to broadcasting, contributing to improved ground cover and overall productivity (Aime et al., 2021). This underscores the importance of the reseeding technology in influencing plant density outcomes. At week 16, the result supports the idea that once established, the density of grass plants does not significantly vary with the reseeding technology used.

4.3 Tiller density

The variations in tiller density highlights how treatments affected tiller growth and development which is essential for overall plant growth and productivity. Treatment P2C1G2 and P2C2G4 exhibited the highest tiller density at week 8, (8.52 and 8.33 tillers/crown) during season 1, and week 12 and 16 of 46.67 and 46.29 tillers/crown and (141.0 and 139.13 tillers/crown) during season 2 respectively. At week 16, *Chloris gayana* emerged as particularly effective species in terms of tiller density either under broadcasting or drilling under mono cropping. This is consistent with *Chloris gayana* robust growth characteristics (Feedipedia, 2017; Jayasinghe et al., 2022). Therefore, tiller density can be influenced more by species characteristics than by reseeding technologies (Ashraf et al., 2011; Mmbando, 2025). However, mixed cropping systems had lower tiller density than mono cropping which was not significantly different. Therefore, the grass species and cropping systems could be used to support high tiller production regardless of the reseeding technology.

4.4 Foliage basal cover

Treatments involving mixed cropping and specific grass species combinations showed higher ground basal coverage compared to mono cropping systems (Table 5). High basal cover is essential for soil conservation, enhancing ground stability, moisture retention and suppression of weeds, emphasizing the effectiveness of certain species and cropping systems in achieving optimal ground coverage (Quintarelli et al., 2022; Mmbando, 2025). High foliage basal cover values were generally observed in treatments involving *Chloris gayana* and *Cenchrus ciliaris* under broadcasting or drilling either as mono- or their mixed-crop. The P2C1G2 achieved the highest basal cover at week 12 and 16 of 91.67% and 100.0% respectively indicating superior ground cover and potential soil erosion control benefits associated with *Chloris gayana*.

The significant differences suggest that the choice of reseeding technology and crop combination plays a crucial role in determining plant density outcomes. *Chloris gayana* shows superior performance in terms plant density and basal cover. Mono- and mixed-cropped treatments of *Chloris gayana* (P1C1G2 and P2C1G2) and its mixed crop with *Cenchrus ciliaris* (P1C2G4 and P2C2G4) consistently achieved higher plant densities, tiller densities and better basal cover. Tiller density enhances ground coverage which lead to reduced run-off during heavy rains. This supports findings from previous studies that have documented the robustness and adaptability of *Chloris gayana* in various environments (Feedipedia, 2017; Allah, 2019; Belete et al., 2024). *Cenchrus ciliaris* is recognized for its vigorous growth and adaptability to various conditions, while *Chloris gayana* is noted for its excellent ground cover and erosion control properties (Feedipedia, 2017; Mganga et al., 2021). Their ability to establish a dense ground cover makes them effective choice of grass species for grassland enhancement initiatives such as erosion control and forage production. This shows their inherent potential roles in restoring vegetation cover in degraded arid and semi-arid rangeland landscapes. As result *Chloris gayana* and *Cenchrus ciliaris* as mono-crops and/or mixed crops should be prioritized in grassland management practices.

4.5 Dry matter and ash content and dry matter yield

The results suggest that dry matter and ash contents can be influenced by the reseeding technology (Table 7). Mixed cropping and certain grass species combinations had better performance. The drilling method had higher dry matter content than broadcasting, but the differences not as pronounced as in ash content. Dry matter content was generally high across all treatments, indicating that the grasses were well-matured and contained a substantial proportion of non-water material. The highest dry matter content was observed in the P2C2G4 (98.50%), suggesting that mixed cropping with *Cenchrus ciliaris* and *Chloris gayana* under the drilling reseeding technology promotes high dry matter accumulation. Although high for fresh plant material, these values reflect sampling of mature grasses at 20 weeks, when moisture content is naturally low (Feedipedia, 2017).

Ash values reflect maturity-related increases at 20 weeks and minor soil contamination noted in senescent tillers. Ash content, reflects the mineral content of the grasses and varied across the treatments. The variation in ash content could be attributed to differences in soil mineral availability and grass species' ability to accumulate minerals (Wróbel et al., 2025). High ash content can indicate better mineral uptake from the soil, which is beneficial for livestock nutrition. The variability in ash content among different species and treatments underscores the importance of selecting appropriate species and management practices to optimize the nutritional quality of grass for both soil health and livestock feed.

The choice of reseeding method and species combination influenced the dry matter yield across treatments. The high yield of *Chloris gayana* under broadcasting (P1C1G2 and P2C1G2) aligns with previous findings that this species is well-suited for high-density planting and can thrive under less intensive management practices (Allah, 2019). The highest yields were achieved in P2C1G1 (11.09 and 16.97 tons/ha/year), P2C1G2 (10.60 and 13.56 tons/ha/year) and P2C2G4 (11.17 and 15.96 tons/ha/year) indicating potential of *Cenchrus ciliaris, Chloris gayana* and *Cenchrus ciliaris* and *Chloris gayana* in biomass production under drilling method. The same grasses also outperformed other grasses even under broadcasting method. The lowest yield was recorded for the combination of *Chloris gayana* and *Eragrostis superba* (P1C2G6 and P2C2G6) could be due to competition among species for resources, which often leads to reduced individual biomass production. In addition, fodder crops can have their nutritional value increased by using appropriate agronomic techniques like timing of planting and harvesting, mixed cropping, and nutrient management (Rai, 2024). This suggests that some species and reseeding methods are more efficient in maximizing biomass production.

The findings underscore the importance of selecting appropriate grass species and reseeding technologies to enhance both yield and nutritional quality. Effective grassland management is crucial for optimizing pasture productivity and sustainability. One of the key factors in successful grass establishment is the choice of reseeding technology and cropping system. These choices significantly influence plant density outcomes, which in turn impact overall pasture health and productivity. The results suggest that drilling should be preferred over broadcasting for grass establishment due to its higher plant density outcomes. Additionally, mixed cropping system enhances plant density and potentially improving pasture productivity. However, pasture restoration effectiveness requires multi-year assessment in order to evaluate the persistence, grazing tolerance, competition dynamics and long-term productivity monitoring.

This study has potential limitations. Although overgrazing was identified as the central contextual challenge, grazing response, regrowth capacity, and defoliation are central to pasture suitability and long-term productivity. In addition, the findings reflects early establishment responses and do not long-term performance and are specific to Kenya's Upper Ewaso Nyiro Basin rangelands. Therefore, requires further validation across multiple Kenya rangelands agro-ecological zones.

5 Conclusion and recommendations

1. This study identified *Chloris gayana*, *Cenchrus ciliaris*, and *Eragrostis superba* as the most preferred and suitable species for reseeding in Kenya's Upper Ewaso Nyiro Basin rangelands based on both farmer perceptions. To some extent, the choice of species for a majority of livestock keepers in the region is greatly influenced by the forage value for livestock.
2. Drilling reseeding technology consistently outperformed broadcasting, and mixed cropping; particularly *Cenchrus ciliaris* + *Chloris gayana* produced the highest yields. For practical applications, drilling combined with mixed cropping should be prioritized in community reseeding programs. High DM and ash values reflected maturity at sampling, highlighting the importance of timing in forage quality assessment. This information is valuable for grassland management and forage production, where maximizing yield is a key objective.
3. Policy implications should prioritize drilling technologies and mixed cropping in pastoralist communities reseeding programs, enhancing access to quality seeds, training on establishment techniques through strengthening extension services and seed distribution networks to enhance adoption. Integrated rangeland management; combining reseeding, controlled grazing, soil conservation and climate-smart practices are essential for long-term resilience.
4. Future studies should incorporate grazing or harvesting regimes and assess long-term species persistence, grazing impacts, and reseeding performance across ecological zones.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

LM: Formal Analysis, Writing – review and editing, Methodology, Validation, Conceptualization, Supervision, Visualization, Software, Data curation. AL: Investigation, Software, Funding acquisition, Resources, Conceptualization, Data curation, Project administration, Formal Analysis, Writing – original draft. BD: Conceptualization, Writing – review and editing, Supervision, Software, Visualization, Data curation, Validation.

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The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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