Sokoine University of Agriculture

MSc Dissertation

Participatory Establishment of *Cenchrus ciliaris* Among Pastoralists Using Different Seedbed Types and Manure Levels in Semi-Arid Area, Mvomero, Tanzania

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May 2024

PARTICIPATORY ESTABLISHMENT OF *Cenchrus ciliaris* AMONG PASTORALISTS USING DIFFERENT SEEDBED TYPES AND MANURE LEVELS IN SEMI-ARID AREA, MVOMERO, TANZANIA

Dissertation Submitted to Sokoine University of Agriculture in Partial Fulfilment of the Requirements for the Degree of Master In Tropical Animal Production

By

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May 2024

EXTENDED ABSTRACT

Ruminant livestock species such as cattle, sheep, and goats in tropical countries including Tanzania to a large extent depend on natural pasture found in semi-arid rangelands as the major feed resource. Among the major challenges in the communal semi-arid rangelands in Tanzania is the seasonal fluctuations in availability of forages in terms of both quantity and quality. Natural forages are plenty and nutritious during wet seasons but become scarce and with less protein content during dry seasons, hence; inability to meet nutritional requirements of ruminants throughout the year. There are incidences of dry season loss of conditions and even mortalities of cattle reared in the semi-arid rangelands. Various efforts are employed to improve the situation, in particular towards improving feed availability during dry seasons. The pastoralists practice nomadism, the movement with animals to other potential places with substantial pasture and water. The livestock mobility are accompanied with serious consequences including conflicts with crop farmers and conservation agencies, animal deaths, and environment damage such as soil erosion and pollution of surface water resources. Improving the utilisation and productivity of grazed semi-arid areas under the pastoral system is crucial. *Cenchrus ciliaris* forage could be cultivated to ensure feed availability for sustainable dry-season livestock feeding. However, forage cultivation is new among pastoralists, and there is a need for participatory cultivation through Farm Field School (FFS). The research project was conducted to evaluate the growth and nutritional value of *C. ciliaris* cultivated under not-tilled (NT), tilled flat (TF), and tilled sunken (SN) land preparation methods and different manure levels (0 t/ha, 5 t/ha, 10 t/ha, and 15 t/ha). Quantitative and qualitative data were collected in a semi-arid village in Mvomero district, eastern Tanzania. The qualitative data involved information on livestock importance and breeds, milk production and marketing, livestock production challenges, and manure management. Other qualitative data were grazing land conditions, improvement

practices, and dry-season feeding strategies. Quantitative data included *C. ciliaris* establishment rate, grass cover, agronomic characteristics, and nutritional values. Pastoralists were keeping local cattle, goat, and sheep breeds, which they depend upon as a source of income, food, insurance during emergencies, and other socio-cultural values. The FFS members had a smaller average herd size (35 cattle, 14 goats, and 8 sheep per household) than the non-members (52 cattle, 30 goats, and 12 sheep per household). The attitude of FFS members to keep fewer number of livestock compared to non-members was attributed to awareness on safe livestock caring capacity. Daily milk yield was low in both FFS members and non-members (0.5 - 1.4 litres/cow/day) and varied seasonally ($p < 0.05$), in dry season was lower than wet season, which led to poor market access in the studied area. Many respondents (68%) were not collecting or using manure for either food crops or pasture production. Moreover, most respondents in FFS member and non-member groups perceived grazing land to be poor because it took their livestock a long time and distance to find forage. Also, there were limited grazing land improvement practices because of the communal grazing, limited privately owned land and large herd sizes. Migration and use of crop residues were the main dry-season feeding strategies in both groups. Few individuals had established private forage reserves in the grazing land, which were smaller ($p < 0.05$) in FFS members (0.8 ha per houehold) than non-members (2 ha per household). The Tilled flat seedbed in different manure levels had higher ($p < 0.05$) establishment rate (97%), grass cover (66 - 78%), and biomass yields (10 – 12.6 t/ha) than no tilled and sunken seedbeds. The responding FFS members perceived TF as a better land preparation method because of its high yields and grass cover at the study site. There were variations in biomass yield and grass cover among manure levels, whereby a manure level of 10 t/ha resulted in the optimum return comparing to other manure levels in the current study. The protein values (104 - 132 g/kg DM) in cultivated forage were sufficient to meet the daily nutritional requirements of ruminants. However, the estimated energy intake

(7 - 15 MJ ME/day) was insufficient for optimum cattle performance and would require other feed supplementation, such as treated maize stover and bean haulm with molasses or urea during the dry-season. Lack of effective dry-season feeding strategy, poor grazing land conditions, and low milk yield showed the importance of *C. ciliaris* cultivation at the study site. Based on the results from this study, the TF and manure 10 t/ha are the recommended land preparation method and manure level for *C. ciliaris* cultivation at study site and similar areas due to better agronomic performance.

Keywords: Farmer field school (FFS); land preparation methods; dry-season feeding; agronomic characteristics; nutritional values; Feed fluctuation, Grazing, Rangelands,

IKISIRI KUU

Mifugo kama vile ng'ombe, kondoo na mbuzi kwa kiasi kikubwa huchungwa katika nyanda za malisho zilizopo kwenye maeneo kame katika nchi za ukanda wa Kitropiki ikiwemo Tanzania. Maeneo kame mengi yanaathiriwa na mabadiliko ya tabianchi, hivyo mifugo hulazimika kutembea umbali mrefu hasa wakati wa kiangazi kutafuta malisho. Aidha, hali hiyo imekuwa ikisababisha kutokea kwa migogoro ya matumizi ya ardhi baina ya wafugaji na watumiaji wengine, uharibifu wa mazingira, kupungua kwa uzalishaji na vifo vya mifugo. Katika kukabiliana na changamoto hiyo jitihada mbalimbali zimekuwa zikifanyika kama vile kuhamasisha wafugaji, kupunguza vichaka na magugu vamizi katika maeneo ya malisho. Upandaji wa majani ya mkia wa mbweha ni miongoni mwa suluhisho kwa kuwa yanaweza kuwezesha upatikanaji wa malisho kwa kipindi chote cha mwaka kwa ufugaji endelevu. Hata hivyo, upandaji malisho ni shughuli mpya miongoni mwa wafugaji wa jadi na hawana ujuzi wa kutosha. Utafiti huu ulilenga kufanya kilimo shirikishi na kutathmini uzalishaji wa malisho aina ya mkia wa mbweha katika Kijiji cha Mela, Wilaya ya Mvomero, Tanzania. Kazi ya ulimaji na upandaji wa malisho kupitia shamba darasa ilitanguliwa na tathmini ya usimamizi wa maeneo ya malisho na mifugo katika eneo hilo kame miongoni mwa wafugaji wa jadi. Tathmini ilifanyika kupitia dodoso kwenye kaya za wafugaji wanachama wa kikundi cha ufugaji bora na wale wasio wanachama. Takwimu nyingine zilizokusanywa kupitia dodoso ni pamoja na uzalishaji wa maziwa na soko lake, changamoto zinazoikabili mifugo, hali ya maeneo ya malisho na matumizi ya samadi katika uzalishaji wa malisho. Aidha, malisho ya mkia wa mbweha yalipandwa kwa kutumia vipando vyenye mizizi kwenye vitalu ambapo njia mbalimbali za uandaaji wa shamba na kiasi cha samadi ya ng'ombe vilitumika. Mbinu hizo za uandaaji wa shamba ni bila kukwatua (BK), kukwatua (KA) na tumbukiza (TA); wakati samadi ikiwekwa kwa vipimo vya tani 0/hekta, tani 5/hekta, tani 10/hekta na tani 15/hekta. Matokeo yalionyesha kuwa wafugaji wengi walikuwa wanamiliki ng'ombe,

mbuzi, na kondoo wa asili kama chanzo cha kipato na chakula, bima wakati wa dharura na kwa ajili ya shughuli nyingine za kijamii. Wanachama wa kikundi cha ufugaji walikuwa na mifugo michache (ng'ombe 35, mbuzi 14 na kondoo 8 kwa kaya) ikilinganishwa na wale ambao hawakuwa wanachama (ng'ombe 52, mbuzi 30 na kondoo 12 kwa kaya). Uzalishaji maziwa ulikuwa ni mdogo kwa wafugaji wote (wastani wa lita 0.5 - 1.4 kwa siku kwa ng'ombe mmoja) na ulibadilika kulingana na msimu hali iliyopelekea kutokukidhi mahitaji ya familia na soko. Wafugaji wengi (68%) hawakuwa wakikusanya na kutumia samadi ya ng'ombe kwa ajili ya uzalishaji wa mazao na malisho. Wafugaji wote waliripoti hali ya uwepo wa uhaba wa malisho haswa vipindi vya viangazi. Hii ilisababishwa pia na kutokuwepo kwa shughuli za uboreshaji maeneo ya malisho kutokana na mfumo usiothabiti wa umiliki ardhi na idadi kubwa ya mifugo kwa kaya. Hivyo, wafugaji walikuwa wakihamisha mifugo na kutumia mabaki ya mavuno mashambani kama chakula cha mifugo huku wachache wakimiliki akiba ya malisho kwenye maeneo yao binafsi ambayo yalikuwa na wastani wa ukubwa wa hekta 0.8 kwa wanakikundi na hekta 2 kwa wasiokuwa wanakikundi. Uchipuaji wa mimea (97%), kutanda kwa malisho (66-78%) na uzalishaji (tani 10 - 13 kwa hekta) ulikuwa mkubwa zaidi katika KA. Pia, wafugaji wanachama wa kikundi cha ufugaji bora ambao walishiriki kwenye shamba darasa walipendelea zaidi vitalu vya KA kwakuwa vilizalisha kiasi kikubwa cha malisho. Kulikuwa na tofauti katika kutanda kwa malisho katika kiasi tofauti tofauti cha samadi kilichotumika ambapo tani 10/hekta za samadi zilizalisha kiasi kingi zaidi cha malisho. Kiwango cha protini (104 – 132 gramu/kilogramu majani makavu) kilichokuwepo kwenye malisho ya mkia wa mbweha kilikuwa kinatosha kukidhi mahitaji ya mifugo. Hata hivyo, kiasi cha nishati (7 - 15 MJ ME/siku) kilikuwa kidogo sana kisichotosheleza ukuaji wa ng'ombe, hivyo kuhitajika kwa vyakula vya ziada kama vile mabaki ya mazao katika kipindi cha kiangazi. Kutokuwepo kwa mkakati madhubuti wa ulishaji mifugo kipindi cha kiangazi, kutokuwepo kwa shughuli za uboreshaji eneo la malisho na uzalishaji mdogo wa maziwa vilionyesha

umuhimu wa kupanda malisho katika eneo la utafiti. Uandaaji wa vitalu kwa njia ya kutifua ardhi na kutumia tani 10 za samadi ya ng'ombe kwa hekta vilikuwa njia bora zaidi za kuzalisha malisho ya mkia wa mbweha katika utafiti huu.

Maneno muhimu: Shamba darasa malisho; Uandaaji wa vitalu malisho; Kurutubisha malisho; Malisho kiangazi; Hali ya malisho; Viinilishe katika malisho.

DECLARATION

I, **Onesmo Damian Ngenzi**, declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work within the registration period and has neither been submitted nor concurrently submitted for a degree award in any other institution.

_________________________ _________________________

Onesmo Damian Ngenzi Date
(MSc. Tropical Animal Production)

The above declaration is confirmed by;

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Prof. G. M. Msalya Date
(Supervisor)

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Dr. D. D. Maleko Date
(Supervisor)

LIST OF PUBLICATIONS

I. **Ngenzi, Onesmo Damian**, Peter Rogers Ruvuga, Msalya, George Mutani and Maleko, David Dawson (2024). Participatory establishment of *Cenchrus ciliaris* forage grass among pastoralists in a semi-arid rangeland area of eastern Tanzania. *African Journal of Range and Forage Science* 41(1): 29-38 https://doi.org/10.2989/10220119.2023.2219700

II. **Ngenzi, Onesmo Damian**, Msalya, George Mutani and Maleko, David Dawson (2023). Influence of seedbed type and cattle manure level on herbage characteristics and forage nutritive value of *Cenchrus ciliaris* in a semi-arid area. *Tropical Agriculture* 100(3): 191-205. https://journals.sta.uwi.edu/ojs/index.php/ta/article/view/8427

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ACKNOWLEDGEMENTS

I am thankful to the Almighty God for the gift of life, good health, and the capacity to undertake and complete the current research project. Also, I am grateful to the Ministry of Livestock and Fisheries (MLF) and Sustainable Agriculture Tanzania (SAT), who made the research project possible by providing financial support. I thank my employer, the Permanent Secretary of MLF, for granting me permission to undertake the masters' study. Furthermore, I would like to thank my research supervisors, Prof. G. M. Msalya and Dr. D. D. Maleko of the Department of Animal, Aquaculture, and Range Sciences (DAARS), Sokoine University of Agriculture (SUA) for their mentorship and support which made the current academic milestone possible. Likewise, I am grateful to all academic and non-academic staff members at the DAARS, SUA, for their guidance, technical and administrative support. My fellow postgraduate students at SUA are also thanked for extending a helping hand and assistance whenever needed. Similarly, Mela village officials and pastoralists who gave permission to undertake the current study and participated in the research project, respectively, are highly appreciated, and I am indebted to them. Otherwise, I would like to take this opportunity to thank my parents, the late Damian Ngenzi and Mrs. Fauster Kifulwime, for their upbringing, moral and social lessons. Moreover, I am grateful to my wife Mrs. Frida Ombay, and our daughter Isabella Ngenzi, whose sacrifices knew no bounds to ensure I had all I needed to complete my education successfully. Also, I am grateful to my siblings, Kibadeni Mduda, Asunta Ngenzi, Yuster Ngenzi, Fadhili Ngenzi, and Baraka Ngenzi for their social support. I would be ungrateful for not mentioning some of my friends for their help in one way or another including Khatib Luvanda, Peter Kiwuyo, Charles Lugamala and Francis Ndumbaro.There is no way I can repay each of you for all you have done for me except to express my eternal gratitude.

DEDICATION

To my daughter Isabella O. Ngenzi, whom I am a first teacher, may this dissertation be a lesson and a foundation you can build upon.

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LIST OF ABBREVIATIONS AND ACRONYMS

&	and
<	Less than
≈	Approximation
ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CBPP	Contagious Bovine Pleuropneumonia
CP	Crude Protein
DM	Dry-matter
DMD	Dry-matter Digestibility
DMI	Dry-matter Intake
ECF	East Coast Fever
et al.	and others
FAO	Food and Agriculture Organisation
FFS	Farmer Field Schools
FPC	Farmers and Pastoralists Collaboration
FPC	Farmers and Pastoralists Collaboration project
IVDMD	*in-vitro* Dry-matter Digestibility
kg	Kilogram
m	Meter
ME	Metabolisable Energy
MEI	Metabolisable Energy Intake
MJ/kg	Megajules per Kilogram
mm	Millimetre
NDF	Neutral Detergent Fiber
NGO	None-governmental Organization
NT	Not tilled
^{o}C	Degree Centigrade
OECD	The Organization for Economic Cooperation and Development
pH	Expressing the acidity or alkalinity or neutral state of a solution
SAT	Sustainable Agriculture Tanzania

SDGs	Sustainable Development Goals
SN	Tilled Sunken
SPSS	Statistical Package for Social Science
SSA	Sub-Saharan Africa
t/ha	Tan per Hectare
TF	Tilled Flat
TLU	Tropical Livestock Unit
TZS	Tanzanian Shillings
UN	United Nations
USD	United States Dollar

CHAPTER ONE

1.0 Introduction

1.1 Background Information

Globally human population is projected to reach 9.7 billion by 2050 (United Nations, UN, 2022). The population growth would increase animal-source food demand, such as meat and milk, especially in developing countries (Wang *et al.,* 2022). The increase in livestock production is necessary to ensure food security, meaning that all people have access to nutritious, safe, and sufficient food at all times to meet their food preferences and nutritional needs for a healthy life without any economic, social, or physical barriers (Galiè *et al.,* 2019). However, most developing countries, especially those in Sub-Saharan Africa (SSA), have low livestock production due to lack of solid agrarian policies and institutions, and climate change effects (Cedrez *et al.,* 2020; Ntali & Lyimo, 2022). This is because most SSA livestock keepers (~250 million) are pastoralists who operate in a low input system by grazing their livestock extensively in large collectively owned grazing areas (Filho *et al.,* 2020; Ruvuga *et al.,* 2020). The decline in available grazing land for livestock production has led to conflicts between farmers and pastoralists which affects pastoral livelihoods (Benjaminsen *et al.,* 2009; Woodhouse & Mccabe, 2018). Cropland expansion has limited pastoralism to the marginal drylands, semi-arid areas unsuitable for crop farming due to unreliable rainfall, high evapotranspiration, and long dry periods (Espeland *et al.,* 2020). These semi-arid areas are characterised by seasonal differences in native pasture quality and quantity, which are abundant and of high quality during rainy periods while limited during dry periods (Ruvuga *et al.,* 2021; Selemani *et al.,* 2013b). The pastures seasonal differences cause poor livestock performance, for instance, <250kg mature live weight and <2litres/day milk yield in cattle among Tanzanian pastoralist (Michael *et al.,* 2018; Mushi, 2020).

The livestock kept including cattle, camel, goats, and sheep are essential sources of food, income, insurance, and other socio-cultural values, e.g., rituals, dowry, and ceremonies (Ruvuga *et al.,* 2022). These livestock species are mostly local breeds, the like of Bos indicus cattle, e.g., Ankole, Nguni, and short horned Zebu, small East African goats, and Red Maasai sheep, which are resilient to droughts and diseases in semi-arid areas, though some keep few crossbred livestock breeds for their relatively high performance (Ruvuga *et al.,* 2020; Yaro *et al.,* 2016). Socially, pastoralists like Maasai have the division of labour and asset ownership based on gender and age. Adult males own all ruminants in the household and make decisions related to grazing and animal management (Mwacharo & Rege, 2002; Sangeda & Maleko, 2018). Females can own poultry and milk from lactating animals; however, the decisions on how to spend household income from milk sales are made by adult males only. Young males and females are responsible for grazing sick, old, or young animals (calves and kids) around the homestead and assisting with household chores, respectively (Galiè *et al.,* 2019; Truebswasser & Flintan, 2018).

Land reallocation for infrastructure development and settlements have limited pastoral mobility and overall livestock production system (Godde *et al.,* 2018). Limited pastoral mobility can cause excessive grazing in a small area due to overstocking and lack of sufficient resting period for pasture regeneration (di Virgilio *et al.,* 2019; Godde *et al.,* 2018). Overstocking and continuous livestock grazing can lead to reduced ability of grazing land (grazing land degradation) to support livestock production by replacing palatable pasture species with weeds, increase bush encroachment, soil erosion, and biodiversity losses (Dunne *et al.,* 2011; Macharia & Ekaya, 2005; Solomon *et al.,* 2007). This led to the transition of open grazing land into either shrub land or desert. Also, grazing land degradations contribute significantly to climate change by releasing previously soil-stored carbon into the atmosphere and increasing greenhouse gas emissions per unit of land and animal product due to the long period it takes livestock to attain mature weight and/or lower yields (Abdalla *et al.,* 2018; Kihoro *et al.,* 2021). Grazing land degradation, environment protection, poor livestock performance, and projected increase in animal source food demand in SSA dictate an improvement of the current pastoral production system (Komarek *et al.,* 2021). Pastoralists have extensive knowledge of grazing land and livestock management due to their experience utilising semi-arid areas for animal production (Liao *et al.,* 2016; Ruvuga *et al.,* 2020).

1.2 Grazing Land Management Among Pastoralists in Sub-Saharan Africa

Grazing lands and their resources (forage and water) are collective property under the pastoral system whereby only pastoralists residing permanently in the respective area or village have rights to the grazed lands within their boundaries (Meshesha *et al.,* 2019; Ruvuga *et al.,* 2020; Sangeda & Maleko, 2018). By-laws or social agreements govern these grazing lands depending on the existing political or social structure (Glowacki, 2020; Kilawe *et al.,* 2018; Mccabe *et al.,* 2021). The pastoral grazing land tenure is affected by dry season emigration of “other livestock keepers” coming from locations outside of the respective area or village (Mccabe *et al.,* 2014; Ruvuga *et al.,* 2021; Treydte *et al.,* 2017). Pastoralists mainly adult males migrate with their livestock to other locations (>80km from the permanent residence area) where temporary residents are established until the pasture conditions become favourable in their customary land (Adriansen & Nielsen, 2005). The pastoralists' migration is a good practice for pasture regeneration in the customary land, but it has various challenges and limitations. These include excessive grazing in the area of destination which could degrade grazing land and cause conflicts between different pastoral groups (Dunne *et al.,* 2011; Ruvuga *et al.,* 2021). Another challenge is related to food security since adult males are the ones who migrate with the herd, leaving behind few livestock or none at all for the remaining household members such as old, children and pregnant women who lack access to nutritious animal source food (Mengistu *et al.,* 2017; Ripkey *et al.,* 2021).

The grazing land degradation and food insecurity mitigation require a shift in the pastoral system from transhumance to sedentary. Some Maasai pastoralists in Tanzania keep large herd sizes of cattle (105 - 600), goats (53 - 108), and sheep (50 - 106) per household, hoping that not all animals would die during severe droughts in case livestock migration is limited (de Glanville *et al.,* 2020; Kimaro *et al.,* 2018b). Similarly, pastoralists establish traditional forage reserves (Olalili or Ngitiri in Tanzania and Kallos in Ethiopia) in their collectively owned grazing areas (Ruvuga *et al.,* 2020; Tefera *et al.,* 2007). These forage reserves intend to limit grazing within the reserves during the rainy season to allow pasture regeneration and forage accumulation for dry-season livestock feeding (Nyberg *et al.,* 2019; Verdoodt *et al.,* 2010). The communal forage reserves can be between 42 - 179ha in size and are established through a deferred grazing system facilitated by social agreements and monitored by traditional institutions (Safari *et al.,* 2019; Selemani *et al.,* 2012; Solomon *et al.,* 2007). The traditional institutions are established to address dry season feed shortage among pastoral communities whereby elders make grazing decisions, and youth enforce them (Sangeda & Maleko, 2018; Wainaina *et al.,* 2021). Also, individual pastoralists establish private forage reserves by using thorn bushes as fences. These private reserves are relatively small (2.2 - 54.9ha) and located around or closer to the homesteads (Selemani *et al.,* 2012; Safari *et al.,* 2019).

However, forage reserves consist of native pasture species with relatively low biomass, energy, and protein values for sufficient livestock performance (Ruvuga *et al.,* 2021; Safari *et al.,* 2011). Also, forage reserves do not always result in high forage biomass yields due to alternative steady state influenced by soil erosion, available plant species, and management (Seymour *et al.,* 2010; Verdoodt *et al.,* 2010). These forage reserves challenges have led some pastoralists to use other grazing resources, e.g., miombo woodlands and feed, e.g., concentrates and crop residues for dry-season feeding (Mtimbanjayo & Sangeda, 2018; Mushi, 2020; Ruvuga *et al.,* 2022). However, miombo woodlands are protected, have tsetse flies (Glossina species), and grazing is forbidden in most SSA except for some parts of Tanzania. The concentrates use is limited by accessibility, high price, and large volume required by ruminants, while crop residues have poor digestibility due to high hemicellulose and lignin levels (Ruvuga *et al.,* 2022; Subudhi *et al.,* 2020). The forage reserves, alternative grazing land, and feed resources challenges affect livestock performance during dry periods and pastoral livelihoods (Woodhouse & Mccabe, 2018). There are reports of some traditional sedentary pastoralists shifting to agro-pastoralism by engaging in crop cultivation for livelihood diversification (Mccabe *et al.,* 2010; Zampaligré *et al.,* 2014). Crop cultivation would be futile in semi-arid areas due to high aridity; although crop cultivation can yield an energy-rich diet, it can end up limiting the intake of protein-rich animal-source foods, which would affect household nutrition and food security (Mengistu *et al.,* 2017; Ripkey *et al.,* 2021; Woodhouse & Mccabe, 2018). It is, therefore, essential to find effective means of utilising available grazing lands, like introducing improved grass pastures, e.g., *Cenchrus ciliaris*, to ensure sustainable livestock production in semi-arid areas.

1.3 Problem Justification

Cenchrus ciliaris is a native perennial grass species highly preferred by grazing livestock species in African semi-arid areas (Selemani *et al.,* 2013a; Tefera *et al.,* 2007). It has high drought resilience and above-ground biomass of 1.1 - 6.0 t DM/ha in drylands which is relatively higher than 0.3 - 5.1 t DM/ha in other native grass forage species (Mganga, Ndathi *et al.,* 2021; Mishra *et al.,* 2010; Patidar & Mathur, 2017; Ruvuga *et al.,* 2021; Selemani *et al.,* 2013b; Verdoodt *et al.,* 2010). Similarly, C. ciliaris has good nutritional values with crude protein (CP), metabolisable energy (ME), and dry-matter digestibility (DMD) of 47 - 109 g/kg DM, 7.7 - 9.2 MJ/kg DM, and 51 - 61%, respectively (Mero & Udén, 1998; Mganga *et al.,* 2021; Mishra *et al.,* 2010; Ruvuga *et al.,* 2022). These nutritional values are relatively higher than 41 - 107 g/kg DM for CP, 3.5 - 8.1 MJ/kg DM for ME, and 48 - 59% for DMD within native grass forage species (Mganga *et al.,* 2021; Ruvuga *et al.,* 2021; Safari *et al.,* 2011; Selemani *et al.,* 2013b). Drought resilience, decreasers status, high biomass yield, and good nutritional values are ideal C. ciliaris qualities as the candidate grass forage species for livestock feeding during the dry season in semi-arid areas.

However, most of the semi-arid grazing lands receive insufficient rainfall with compacted and eroded soil due to climate change effects and excessive livestock grazing, respectively (Dunne *et al.,* 2011; Kimaro *et al.,* 2018a; Zampaligré *et al.,* 2014). These factors would lead to failure in establishing C. ciliaris or result in low biomass yields due to poor soil- moisture, fertility, aeration, and root penetrations (Ji *et al.,* 2013; Pfeiffer *et al.,* 2019). Land tillage is suggested to break soil compaction on the cultivated plots to improve root development and plant nutrient uptake (Ji *et al.,* 2013). Additionally, some scholars suggest sunken plot preparation, “tumbukiza” (Figure 1.1), to ensure the collection and retention of water, which would yield good biomass as was the case in cultivated Pennisetum puerperium (Gogoi *et al.,* 2022; Nyambati *et al.,* 2011). Moreover, there is a need to apply fertilisers in the cultivated plots to restore soil fertility and ensure that grown pasture receives nitrogen, phosphorus, and potassium in a sufficient amount for plant growth (Kumar et al., 2005; Silcock, 2022). However, industrial fertilisers are limited by high prices in SSA and have lower organic matter contents required to bind together soil particles in the leached semi-arid areas (Holden, 2018).

Therefore, organic fertilisers are recommended instead due to their easy availability and to facilitate a circular bioeconomy (Bader *et al.,* 2021). Cattle manure is among the commonly used organic fertilisers due to the broader distribution of cattle in SSA and the large fecal matter produced by them (Carbonell *et al.,* 2021). Cattle manure has 1.1% nitrogen, 0.3% phosphorus, and 2.4% potassium, sufficient to promote grass forage growth and high biomass yield (Landon, 1991; Lekasi *et al.,* 2003). There is no standard rate for manure application in semi-arid areas as the rate would depend on the grass forage type, soil fertility, and intended management or production level (Maleko *et al.,* 2015; McRoberts *et al.,* 2018). Most pastoralists are not aware of the existing plot tillage practices and manure application rates since improved grass forage cultivation is not a common practice in their grazing lands and livestock extension services are poorly delivered in SSA (Mangesho *et al.,* 2021; Sala *et al.,* 2020). Participatory forage establishment is recommended through Farmer Field Schools (FFS), which would educate pastoralists through practices to use the diverse resources for forage cultivation (van den Berg *et al.,* 2020, 2021).

Figure 1.1: Sunken seedbed with ability to retain water and nutrients.

The Sustainable Agriculture Tanzania (SAT) established FFS in 2019 to introduce C. ciliaris cultivation to the Maasai pastoralists in eastern Tanzania (SAT, 2017). A total of 34 Maasai households joined the Farmers and Pastoralists Collaboration (FPC) project. However, C. ciliaris cultivation attempts in 2019 and 2020 in the private forage reserves within the grazing land failed. The failures were due to unreliable rainfall and poor-quality pasture seeds (personal communication with project field attendant, June 15, 2021). Also, there is no updated information regarding the relevance of C. ciliaris introduction in the area since the pastoralists could not adopt grass forage cultivation under their current system. Therefore, there is a need to investigate existing grazing land and livestock management practices to assess the relevance of C. ciliaris cultivation in eastern Tanzania. Also, it is imperative to change C. ciliaris establishment methods by using vegetative propagation, different land preparation methods, and manure. Generally, this work would provide insight into the strategies for cultivating improved forage and their practicality to the pastoralists in the semi-arid areas.

1.3 Study objective

1.3.1 General objective

The general objective of the study was to improve dry-seasons forage availability for livestock in the degraded semi-arid grazing land in Morogoro, Tanzania.

1.3.2 Specific objectives

To achieve the overall objective, the following were the specific objectives :

i. To describe the existing grazing land and ruminant livestock management at the study site;
ii. To evaluate performance of *C. ciliaris* established under different land preparation methods and cattle manure application levels at the study site; and
iii. To determine the pastoralists’ preference/s among the different land preparation methods and cattle manure application levels at the study site.

1.4 Methodology Overview

1.4.1 Study design and data collection

House hold survey (Paper I) and on-farm forage establishment (Paper I and II) studies were conducted in Mela village found in the Mvomero district located at latitude 8°0'-10°0'S and longitude 28°22'-37°0'E, eastern Tanzania. Mvomero, the area is semi-arid with mean annual rainfall and temperature ranging from 300 – 800 mm and 18-30^{o}C, respectively (Magita and Sangeda, 2017). The Maasai pastoralists in the study area were the only individuals sampled for the household survey due to their large number and participation in livestock production activities. The stratified sampling techniques were employed whereby respondents were grouped into the Farmer Field School members and non-members strata. The two sets of questionnaires were developed and pretested. The first questionnaire had open and close-ended questions about grazing land and livestock management. This questionnaire was administered face to face to FFS members (18 households) and non-members (22 households). The second questionnaire was administered at the end of *C. ciliaris* cultivation to all 34 FFS members and had questions related to the preferred land preparation method and the motivation behind the selected method. The respondents were asked for their consent to participate in the survey. Similarly, the household head was chosen for the two surveys, and if not available, the another sinior member of the household was interviewed.

An on-farm/field forage planting experimental study (Paper I and II) was conducted on the 0.04 ha experimental plot found in Mela village. The plot was part of a larger 3.2 ha private forage reserve fenced using thorn bushes. One FFS member donated the site, and all members participated at every stage of establishment to facilitate learning. The plot was first divided into 36 smaller 2m x 3m sub-plots with 1m space in-between sub-plots and around the main plot. Individual sub-plots were prepared by using three different methods: not tilled (NT), tilled flat (TF), and tilled sunken (SN). The NT was prepared by clearing only the top vegetation using the hand-hoe, and TF involved tilling the topsoil using hand-hoe in addition to vegetation clearing. The SN included raising soil bunds (~3cm high) around the sub-plot after vegetation clearance and soil tillage. Cattle manure was collected around the village, composted for 63 days, and applied on the respective sub-plot. The manure was used at 0 g/plant (0 t/ha), 200 g/plant (5 t/ha), 400 g/plant (10 t/ha) and 600g/plant (15 t/ha) levels per plant. The land preparation method and manure level combination were replicated three times and assigned randomly following a complete randomised design. The *C. ciliaris* was established using splits with roots collected from one-year-old plants cultivated in the pasture research farm at the Sokoine University of Agriculture. A total of 15 splits were planted per treatment with 50cm space between and within the rows.

The *C. ciliaris* was cultivated for 12 weeks, and individual sub-plots were irrigated manually at 5 litres of water per m^2. The irrigation was throughout the experiment except during week 2, 3, 4, and 9 because it rained for four consecutive days. Overall, irrigation was conducted because *C. ciliaris* was cultivated at the end of the short rainy season (January - April 2022). The cultivated *C. ciliaris* was evaluated for establishment rate on week three after planting of splits. Basal cover, above-ground biomass, plant height, leaf length and width, tiller numbers, and leaves per tiller were evaluated at the end of the cultivation period (week 12) without cut-back since planting. The *C. ciliaris* from each treatment was sampled for chemical analysis following the standard protocols (AOAC, 1990; Mganga *et al.*, 2021; Tilley & Terry, 1963; Van Soest *et al.,* 1991). The analysed components were dry-matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), *in-vitro* dry-matter digestibility (IVDMD), metabolisable energy (ME), dry-matter intake (DMI) and metabolisable energy intake (MEI).

1.4.2 Statistical analysis

Statistical Package for Social Science (SPSS 20) and Statistical Program R (4.2.3) were used to analyse house hold survey and on-farm forage establishment data. The house hold survey data were grouped into FFS members and non-members; then descriptive statistics were calculated in percentage or mean values. The mean and percentage differences between the two groups were compared using the Student t-test and Pearson's *chi-square* test at the 95% confidence interval in the SPSS. On-farm forage establishment data, namely agronomic parameters, establishment rate, and chemical composition were analysed using analysis of variance (ANOVA) in R. The two-way ANOVA model with interaction was used with the preparation method, and manure levels were set as independent variables, while the parameters mentioned above were dependent variables. The mean pairwise comparison among independent variables was conducted using Tukey's test, and Pearson correlation test was used for the correlation test among agronomic parameters at $p < 0.05$.

1.5 Study Limitations

The study was limited by a small sample size of the surveyed population, and the experimental plot used for *C. ciliaris* cultivation lacked replication. This was because a single village (Mela) was selected because it had FFS and land use plan, but the results can be applied to other semi-arid areas provided they have similar social and physical characteristics. Furthermore, *C. ciliaris* was cultivated for one season without cut-back for growth standardisation among different treatments. This could be misleading as it only showed treatments' effects at the beginning of the experiment and did not capture the long-term impact of particular interventions under variable rainfall conditions due to climate change. However, it is crucial to understand the study's main objective was to test if *C. ciliaris* can be established successfully in the semi-arid area of eastern Tanzania in light of the previous failure. Also, there was no sufficient rainfall during *C. ciliaris* cultivation and manual irrigation was conducted in selected weeks. Irrigation could be limited by water scarcity in semi-arid areas, raising the question about its practicality among pastoralists. Therefore, future studies should time cultivation around the long rainy seasons instead of the short ones, which are unreliable.

1.6 Organisation of the Dissertation

The work is organised into five chapters, and the first chapter provides background information related to the current status of global food insecurity, livestock production in Tanzania, study justification, and research objectives. Chapters two and three are based on papers published in reputable international journals. Also, they answer individual research questions and specific objectives raised in this dissertation following the standard research procedures. Chapter four covers a general discussion and analysis of the key results from the two published papers. The analysis includes the interpretation and implications of the key findings. Also, it raises the research questions that are yet to be answered by the current work. Finally, Chapter five provides a detailed conclusion and recommendation based on the key findings and how these findings could be of significance to different stakeholders for sustainable livestock production and improved food security in semi-arid areas.

CHAPTER TWO

2.0 Participatory *Cenchrus ciliaris* Forage Establishment among Pastoralists Grazing Livestock on Rangeland in a Semi-arid Area of Eastern Tanzania*

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* The material contained in this chapter has been published in **African Journal of Range and Forage Science** https://doi.org/10.2989/10220119.2023.2219700

African Journal of Range & Forage Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tarf20

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To cite this article: Onesmo Damian Ngenzi, Peter Rogers Ruvuga, George Mutani Msalya & David Dawson Maleko (2024) Participatory establishment of *Cenchrus ciliaris* forage grass among pastoralists in a semi-arid rangeland area of eastern Tanzania, African Journal of Range & Forage Science, 41:1, 29-38, DOI: 10.2989/10220119.2023.2219700

To link to this article: https://doi.org/10.2989/10220119.2023.2219700

Published online: 13 Jul 2023.

African Journal of Range & Forage Science 2024, 41(1): 26–38

AFRICAN JOURNAL OF RANGE & FORAGE SCIENCE
ISSN 1022-0119 EISSN 1727-9380

Participatory establishment of *Cenchrus ciliaris* forage grass among pastoralists in a semi-arid rangeland area of eastern Tanzania

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In the semi-arid areas of Africa many pastoralists move their livestock to find better grazing when forage is scarce during the dry season. However, the practice of forage cultivation can sustain fodder supply for effective livestock feeding during these times. This study was undertaken to (1) assess grazing land management, and perception among Maasai pastoralists, and 2) evaluate *Cenchrus ciliaris* L. (Buffel grass) establishment and biomass yield under four levels of fertilisation and three seedbeds in a semi-arid area of eastern Tanzania. The seedbeds were not tilled (NT), tilled flat (TF) and tilled sunken (SN) with manure applied at rates of 0, 5, 10 and 15 t ha^{-1}. The 2 m × 3 m subplots were replicated three times per seedbed-manure treatment. Communal grazing land was perceived to be in poor condition by pastoralists due to the long time spent by their livestock in search of forage. Private forage reserves for dry-season feeding were present and could be used for forage cultivation. The TF, manure at 10 and 15 t ha^{-1} treatments had significantly higher ($p < 0.001$) *C. ciliaris* establishment rates (97%) and biomass than other treatments. The TF10 and TF15 t ha^{-1} treatments had biomass values of 9.8 and 10.1t DM ha^{-1}, respectively, by Week 10. Pastoralists preferred the TF method because of its high forage yield and low cost. Cultivation of *C. ciliaris* is important for livestock production and it can be established on privately owned forage reserves.

Keywords: biomass change, cattle manure level, dry-season feeding, establishment rate, farmer field school, seedbed type

Introduction

Grazing lands constitute 40% of Africa's land surface and support the livelihoods of approximately 250 million pastoralists, which is equivalent to 25% of the continent's population (Filho et al. 2020). These grazed lands are mostly located in semi-arid areas with erratic rainfall and utilised by pastoralists whose indigenous practices sustain their livelihoods in harsh conditions (Liao et al. 2016). Mobility is a common practice whereby pastoralists migrate with their livestock as dictated by seasonal changes in pasture availability (Treydte et al. 2017). Individual livestock herds are moved by male adults and youth to other areas (usually > 80 km away) where temporary camps are established, while any sick or weak animals are left behind with other household members e.g. women, children and elders (Adriansen and Nielsen 2005) Pastoralists have large numbers of cattle (up to 600/household), combined with goats and/or sheep as an adaptation measure against severe droughts, with the anticipation that not all animals would die during droughts (Liao et al. 2016; Kimaro et al. 2018).

Pastoralists also establish forage reserves using enclosures, known as *Olalli* among Maasai pastoralists in Kenya and Tanzania. These enclosures can be communal, forming part of common-property rangeland in a deferred grazing system. These systems are managed by traditional institutions via social agreements/contracts in which elders make grazing decisions and the youth enforce them (Nyberg et al. 2019; Safari et al. 2019). Some pastoralists establish a private pasture reserve enclosure near their homesteads (*boma*) using thorny bushes as fences (Safari et al. 2019). Enclosure establishments and livestock mobility are useful for maintaining good grazing land conditions, i.e. the ability to support optimum livestock performance. However, these practices are affected by issues such as changes in land-use, cover and/or tenure, and effects of climate change and variability, which can lead to rangeland degradation (Godde et al. 2018). Furthermore, depending on degradation intensity, enclosure establishment does not usually restore native palatable grass species and an alternative steady state ensues (Seymour et al. 2010). We propose that grass cultivation in the forage reserves could improve biomass yield for effective and sustainable livestock feeding during the dry-seasons in semi-arid areas (Patidar and Mathur 2017).

Cenchrus ciliaris L. (Buffel grass) is a perennial grass species with potential as dry-season fodder. This is because *C. ciliaris* produces 2–6 t DM ha^{-1} yields in semi-arid areas with nutritional values of 7.6–9.2 MJ kg^{-1} DM energy and 80–109 g kg^{-1} DM protein (Bwire et al. 2003; Mishra et al. 2010; Patidar and Mathur 2017; Ruvuga et al. 2022). Ecologically, *C. ciliaris* is a native species of African semi-arid areas and is highly preferred by grazing livestock (a 'decreaser' species) which reduces its potential of becoming invasive rangeland vegetation and replacing other valuable

African Journal of Range & Forage Science is co-published by NISC (Pty) Ltd and Informa UK Limited (trading as Taylor & Francis Group)

native grass species (Tefera et al. 2007). These factors have led some scholars to advocate for its wider introduction into semi-arid grazing areas (Patidar and Mathur 2017; Mganga et al. 2021). However, pastoralists including the Maasai in East Africa are not traditional crop farmers and lack the skills required to establish and manage high-yielding forage grasses (Omollo et al. 2018). The Farmer Field School (FFS) is seen as a suitable instrument to impart these skills to pastoralists because it makes use of available field resources and diverse farm conditions to ensure successful intervention (van den Berg et al. 2020; 2021).

Sustainable Agriculture Tanzania (SAT), a non-governmental organisation, established FFS in some villages of eastern Tanzania, aiming to encourage pastoralists to engage in forage cultivation (SAT 2017). However, most semi-arid grazing lands have compacted soils with poor fertility as a result of erosion, excessive livestock grazing, and trampling (Dunne et al. 2011). Successful *C. ciliaris* establishment would require manure application and top-soil tillage to replenish soil nutrients and facilitate root growth, respectively (Nyamba et al. 2011; Ji et al. 2013; McRoberts et al. 2018). Also, FFS were employed in eastern Tanzania where grazing land is communally managed (Magita and Sangeda 2017) and previous attempts to establish *C. ciliaris* in protected private enclosures by using seeds failed. Failure was due to the poor quality of seeds sown, insufficient rainfall, and a lack of irrigation (personal communication). Therefore, it is imperative to assess the relevance of grass forage introduction on this site in the context of the existing grazing land and livestock management practices. This study was conducted (1) to assess local knowledge and perception among pastoralists on forage cultivation, grazing land management and condition in eastern, Tanzania; (2) to evaluate *C. ciliaris* establishment and growth in a semi-arid area under four levels of fertilisation (0, 5, 10 and 15 t ha^{-1} of manure) and three tillage practices, namely not tilled (NT), tilled flat (TF) and tilled sunken (SN). This study was designed to help inform decision- and policy-makers on the best approaches to engage with pastoralists in improved grass forage cultivation.

Methodology

Study area description

The study was carried out in Melа village, located in Mvomero district (latitude 8°0′–10°0′ S and longitude 28°22′–37°0′ E), eastern Tanzania. It is situated in the south-west part of Mvomero district, covering 7 745.7 ha at an elevation of 600–1200 m a.s.l. Generally, the area is semi-arid with a mean annual rainfall of 300–800 mm and temperatures ranging from 18–30 °C (Magita and Sangeda 2017). The topography is generally flat with Neogene alluvium soil of diverse origins which has a well-drained silt loam texture (Msanya et al. 2003). The soil in the grazing lands had a pH value of 7.7, 0.9% organic content, 0.09% total nitrogen, 8.24 mg kg^{-1} available phosphorus and 0.41 mg kg^{-1} potassium. The vegetation is defined as open grassland with scattered trees and bushes such as *Commiphora africana* Engl., *Combretum collinum* Fresen. and *Piliostigma thonningii* (Schumach.) Milne-Redh. The dominant forage grass species found in natural grazing lands included *Aristida stipoides* Lam., *Bothriochloa bladhii* (Retz.) S.T.Blake, *Enteropogon macrostachyus* (Hochst. Ex A.Rich.) Munro ex Benth. and *Heteropogon contortus* Beauv. Ex Roem. & Schult. (Mdegela et al. 2022).

There were 227 households in the study village in 2021 and Maasai pastoralists were the dominant ethnic group. The village has a long history of livestock grazing throughout the year (Magita and Sangeda 2017). Grazing land makes up 61% (≈4 724.9 ha, Figure 1) of the village land. It was in poor condition, showing early signs of deterioration such as loss of palatable grass species, weed infestation, bush encroachment and soil erosion. In addition, dry season forage scarcity is a common occurrence and the reason behind regular conflicts between farmers and pastoralists in the area (Magita and Sangeda 2017; Ripkey et al. 2021). Some Maasai pastoralists in the village (34 households) joined a Farmers and Pastoralists Collaboration (FPC) project inaugurated in 2019 by SAT. The project aimed to improve farmer–pastoralist relationships and engage Maasai pastoralists in forage production through FFS (SAT 2017). However, initial efforts to establish *C. ciliaris* grass failed, which warranted selection of the village for the current study.

Study design and data collection

Household interviews

Two surveys were conducted separately, aiming to evaluate rangeland management and to assess pastoralists' perception of *C. ciliaris* establishment. Purposive sampling was used to select households for the first survey so that only FFS members and non-member pastoralists who were residing permanently in the village were interviewed. A total of 40 households were sampled, of which 18 were FFS members (representing 52.9% of FFS households), and 22 were non-FFS members (representing 11.4% of non-member households). Sampled households were asked for their permission to participate in the interview, all accepted and were included in the survey. Only the household head was interviewed, using a structured questionnaire containing both open- and close-ended questions. The questions were related to forage shortage and mitigation strategies, grazing management, and grazing land improvement challenges. Other questions included livestock species and breed reared, herd composition, livestock product marketing, manure management, and livestock production challenges. Respondents were allowed to discuss questions and answers with other household members (children and partners) because Maasai pastoralists have a division of labour based on age and gender (Mwacharo and Rege 2002). The second survey involved only FFS members (all 34) who participated during *C. ciliaris* establishment (see the following section). The FFS members were asked to rate the seedbed types using a prepared checklist at the end of the *C. ciliaris* establishment study. They were asked to choose their preferred seedbed type and give reasons for selecting respective seedbed methods, based on biomass yield and managerial cost (labour required during seedbed preparation to forage biomass produced).

Cenchrus ciliaris establishment and change in biomass

Cenchrus ciliaris was established on a 0.04 ha experimental

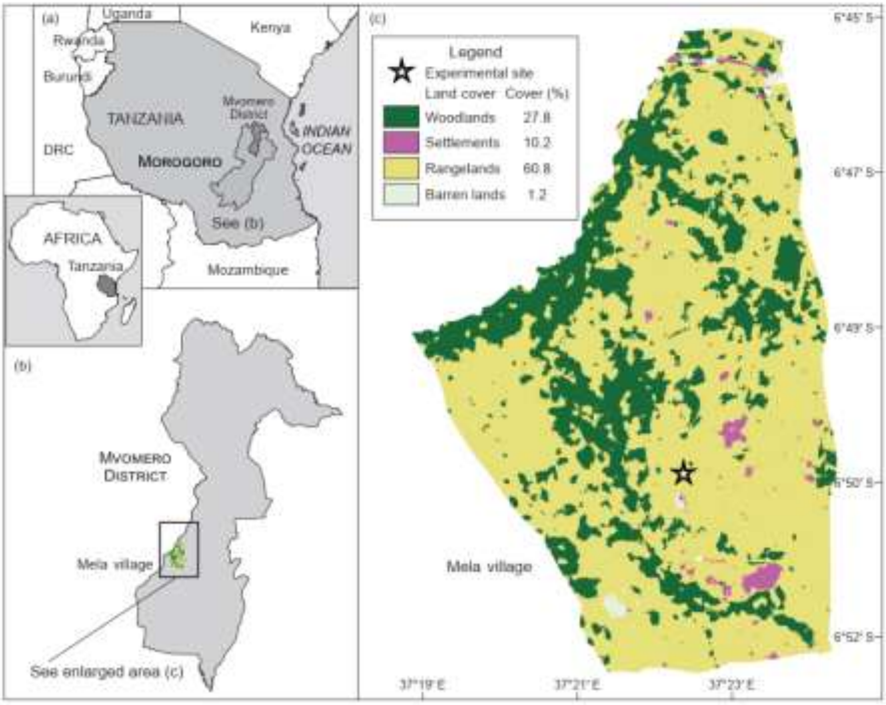

Figure 1: Map of the study area showing Mela village and the existing land covers

plot which was part of a larger private enclosure (3.2 ha) owned by one FFS member. The enclosure was selected because of the owner's willingness to participate, large size and ease of accessibility for other FFS members. A total of 36 subplots (2 m × 3 m, with 1 m distance between subplots and along main plot borders) were demarcated within the experimental plot and prepared for *C. ciliaris* establishment using no till (NT), tilled flat (TF) and sunken till (SN) preparation methods. There was no intervention done on NT seedbeds except digging furrows of ~10 cm deep using a hand-hoe for planting *C. ciliaris* and cattle manure application. There was tilling and harrowing of top soil (0–20 cm) using a hand-hoe when preparing TF seedbeds. The SN treatment involved tilling and harrowing followed by erecting water barriers approximately 3 cm high using soil bunds around the individual subplot in order to trap water and nutrients inside the subplot. Cattle manure was composted for 63 days as described by Kajiya et al. (2014) and applied at rates of 0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1} and 15 t ha^{-1}. The applied cattle manure was mixed with topsoil for TF and SN but it was simply placed in the furrows dug for NT. Manure chemical analysis was carried out using the acid digestion method as described by Gorsuch (1959). The manure had a pH of 8.3, 10.9% organic content, 1.5% total nitrogen, 0.7% phosphorus and 0.3% potassium.

Individual seedbed-manure levels were assigned randomly and replicated three times per treatment. It was decided that cultivated *C. ciliaris* would be irrigated due to insufficient rainfall in the area and from the lessons learnt in previous establishment failures. Similarly, splits were used instead of seeds due to the lack of a reliable supply of quality forage seeds in the country. Splits, which were approximately 15 cm-long sections of plant containing both main stem and roots, were collected from one-year-old *C. ciliaris* plants cultivated in a pasture research farm at Sokoine University of Agriculture, eastern Tanzania. The splits were planted in each treatment at the rate of 15 splits per subplot with 50 cm spacing between and within rows. The *C. ciliaris* splits were planted during the short rainy season (January 2022) and were irrigated manually early in the morning three times a week using cans at the rate of approximately 5 l m^{-2}. Individual subplots were irrigated throughout the experimental period except in Weeks 2, 3, 4 and 9, when it rained for four consecutive days (see Figure 2). The study lasted 10 weeks in order to assess the establishment rate. This was determined in the third week by counting planted splits that were alive and had developed top flag leaves. Established plants were monitored for their preliminary growth parameters such as height and basal cover weekly, from Weeks 4 to 10. A tape measure was used to determine the height of three randomly sampled plants in each subplot which were measured from the ground to the furthest leaf tip.

The basal cover was determined in percentage using Canopeo mobile application (1.1.7) following the procedures in Patrignani and Ochsner (2015). This involved placing a 1 m^2 quadrat in the middle of the subplot and taking an aerial photograph approximately 0.6 m above the quadrat using a Samsung Galaxy A71 cell phone. Plant height and basal cover were used to determine weekly changes in biomass yield (t DM ha^{-1}) using Equation 1. The equation was derived from an open data set obtained from a *C. ciliaris* growth performance study in African semi-arid rangeland (Mganga et al. 2020):

$$\text{Above ground biomass} = 93.8 \times \text{plant height (cm)} + 3.6 \times \text{basal cover (\%)} - 1876\ [R^2 = 0.93] \quad (1)$$

Data analysis

Survey data were categorised and coded into FFS members and non-members. The coded data were then analysed using Statistical Package for Social Sciences (SPSS 20). Data on livestock production, grazing land management and FFS members' perceptions of *C. ciliaris* establishment were analysed and reported in either mean or percentage values. Case percentages were reported on multiple response questions which resulted in a total percentage exceeding 100%. Student *t*-test and Pearson's chi-square test were used to compare mean and percentage differences between FFS members and non-members, and were declared significant at $p < 0.05$. The two tests were used because of the differences in data type, i.e. numerical versus nominal.

The *C. ciliaris* establishment rate, basal cover and weekly biomass yield were analysed using R-statistical program (4.2.3). A two-way ANOVA model was used to analyse establishment rate, basal cover and biomass yield (Week 10). The model was defined as:

$$Y = \text{Seedbed type} + \text{Manure level} + \text{Residual error}$$

The establishment rate was run on ANOVA-type I while basal cover and biomass yield were run on ANOVA-type III. The weekly biomass yield was analysed using the analysis of covariance (ANCOVA) model:

$$Y = \text{Establishment rate}_{\text{covariate}} + \text{Week} + \text{Independent variable (Seedbed type or Manure level)} + \text{Residual error}$$

The establishment rate was set as covariate because it varied significantly among independent variables. Mean values were compared among independent variables by using Tukey's method at the 95% confidence interval.

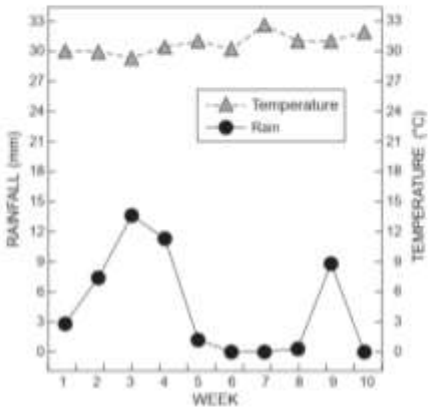

Figure 2: Weekly temperature and rainfall distribution during the experimental period, 28 January 2022–8 April 2022 (unpublished data provided by Tanzania Meteorological Agency, 2022)

Results

Livestock production survey

Interviewed respondents were 47.5% male and 52.5% female with an average age of 43 years. Most respondents (62.5%) did not have formal education and all kept livestock as their main economic activity. Most respondents (73%) kept cattle, goats and sheep, while 15% kept cattle only and 10% kept cattle and goats. These livestock species were local breeds such as Short Horned Zebu cattle, small East African goats and red Maasai sheep. There were no differences ($p > 0.05$) in herd composition between FFS members and non-members, as shown in Table 1. However, non-members had a relatively higher number of cattle, goats and sheep compared to members. Respondents depended on livestock for food, income, insurance during emergencies and socio-cultural activities (dowry, ceremony and ritual), in order of greatest to least importance. Milk was the common livestock product marketed by the two pastoral groups and was sold at a local market at 600 TZS shillings (≈ 0.26 USD) per litre during the wet season and 1 000 TZS shillings (≈ 0.43 USD) in the dry season. Relatively more milk was produced per cow and available for sale during the wet than in the dry season (Table 1).

The majority of respondents (68%) did not collect nor dispose of manure. A third (33%) collected manure and burnt it as a source of fuel (cooking), used it for crop cultivation, or for making bedding materials. Livestock disease was mentioned by all respondents as the major challenge facing their livestock. Contagious Bovine Pleuropneumonia (CBPP) and tick-borne diseases such as East Coast Fever (ECF) were said to have high levels of occurrence. Forage seasonal variability was mentioned by many pastoralists (90%) as a livestock production challenge followed by the communal land tenure system (73%) since rangeland was collectively owned. Also, more than one-third of the interviewed pastoralists (38%) mentioned facing livestock marketing challenges as they were unable to access markets during the rainy season and received low prices for their milk when they did access them.

Grazing land management

There were no variations ($p > 0.05$) in pastoralists' perceptions of grazing land conditions; both pastoral groups mentioned that it was of poor quality because they had to travel long distances and spent a long time (> 9 hr day^{-1}) in search of pasture. More than half of the respondents in the two groups were not carrying out any rangeland improvement practices (56% for FFS members and 55% for non-members). Some FFS members (25%) and non-members (46%) were creating forage reserves (*Olalili*). This was done by setting aside their privately owned land and using it for grazing during the dry seasons. These privately owned forage reserves had an average size of 0.8 ha for FFS members and 2 ha for non-members.

Respondents were also engaged in other measures aimed at mitigating forage shortage. These included migrating part of their herds to other areas (89% of FFS members and 91% of non-members) and feeding crop residues (maize stovers), carried out by 72% of FFS members and 81% of non-members. The crop residues were purchased from the crop owners and fed to livestock on the purchase site. All interviewed FFS members and non-members were willing to cultivate forage as a means of mitigating forage shortages. However, they faced challenges (Figure 3) such as a lack of technical knowledge, unclear land tenure systems (communal ownership, disregard for private property, and emigration of other livestock keepers during the dry season), access to planting materials and large herd size, in descending order of importance. There were no statistical differences in pasture establishment challenges between FFS members and non-members.

Table 1: Herd composition and milk production by Farmer Field School (FFS) member and non-member pastoralists in a semi-arid area of eastern Tanzania

	Herd composition (numbers)	
Livestock species	FFS members (n = 18)	FFS non-members (n = 22)
Cattle	35.2	51.9
Goats	13.6	30.4
Sheep	7.9	12.1
	Milk: litres day^{-1}	
Milk production	FFS member	FFS non-member
Yield per cow, wet season	1.4	1.4
Milk sold/household, wet season	6.4	4.2
Yield per cow, dry season	0.5	0.5
Milk sold/household, dry season	2.0	3.0

Pastoral perception of seedbed type and *Cenchrus ciliaris* establishment

Many respondents (53%) selected TF as their preferred seedbed type for establishing *C. ciliaris* followed closely by NT (45%); SN (3%) was the least preferred. The respondents selected TF because it was perceived to result in high biomass yield (96% of respondents) with low managerial cost (5% of respondents). Those who selected NT mentioned that it was an easy method of establishment (less labour required) despite low biomass returned, while SN was not preferred because it was labour intensive and had low biomass yield. Overall, the *C. ciliaris* cultivation study showed

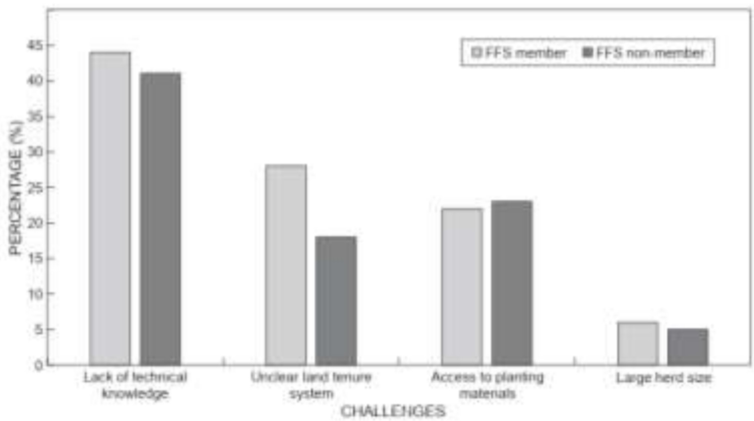

Figure 3: Challenges limiting pasture establishment as expressed by Farmer Field School (FFS) members (n = 18) and non-members (n = 22) in a semi-arid area, eastern Tanzania

that there were significant differences in establishment rate among seedbed types ($p < 0.001$) but not in manure levels ($p = 0.413$). The establishment rate was lowest in SN (87%) while it was similar in NT (95%) and TF (97%).

Cenchrus ciliaris biomass and basal cover

The weekly biomass changes of *C. ciliaris* established in three different seedbed types and four levels of manure application are shown in Figure 4 and Figure 5, respectively. There was a positive biomass change in all seedbed types and manure levels, with TF showing the greatest increase, followed by NT, and SN having the least. Biomass increased with an increase in manure levels as follows: 0 <5 < 10 < 15t ha^{-1}. The biomass variations in seedbed types and manure levels were significantly different ($p < 0.001$).

There were significant variations ($p < 0.001$) in basal cover and biomass yield by Week 10 between manure levels and seedbed types (Table 2). Biomass yield was at the highest in TF and lowest in SN which was similar to NT. Manure 0 t ha^{-1} had lower biomass yield in comparison to 15 t ha^{-1} whilst others in between. On the other hand, basal cover was higher in TF than SN while NT did not vary with either of the seedbeds. Manure 10 t ha^{-1} and 15 t ha^{-1} had higher basal cover than manure 0 t ha^{-1} while manure 5 t ha^{-1} was intermediate.

Discussion

Livestock and grazing land management

The majority of pastoralists (73%) keep indigenous breeds of cattle, goats and sheep because they are resilient to harsh semi-arid conditions, e.g. forage and water shortage (Filho et al. 2020). As reported in this study, multi-species livestock herds are also important for effectively utilising grazing land. This is because cattle and goats have different forage preferences, and goats' small size enables them to forage easily in bush-encroached areas (Liao et al. 2016). However, cattle remain a prominent livestock species among both FFS members and non-members (Table 1) as they made up the largest portion of the herd structure, which was also noted by Kimaro et al. (2018). The FFS members had relatively fewer cattle, sheep and goats compared to non-members possibly due to their lower socio-economic status. This was also evident in the smaller size of their private forage reserves, and may have made members more inclined to join the Farmers and Pastoralists Collaboration (Woodhouse and Mccabe 2018). Another reason for small herd size among FFS members could be concealment of actual herd size in fear of relocation or destocking campaigns by the government. Pastoralists do not trust the government because of the use of environmental protection as the pretext for pastoral relocation and demands to reduce livestock number in the past (Nindi et al., 2014; Weldemichel, 2021). Nonetheless, the two pastoral groups in this study had herd sizes of 105–600 for cattle, and not more than 108 for goats and 106 for sheep, per household, as reported by Kimaro et al. (2018) and de Glanville et al. (2020), for pastoralists in Tanzania. The variations in herd size per household between the studies could be due to livestock migration since the survey was conducted during the dry season, or the impact of climate change, rangelands degradation and diseases

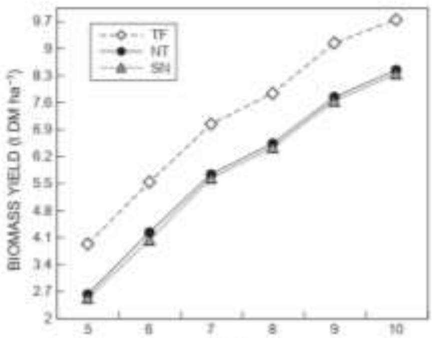

Figure 4: Weekly change in above-ground biomass of *Cenchrus ciliaris* established on three seedbed types (Treatment: not tilled = NT, tilled flat = TF and tilled sunken = SN)

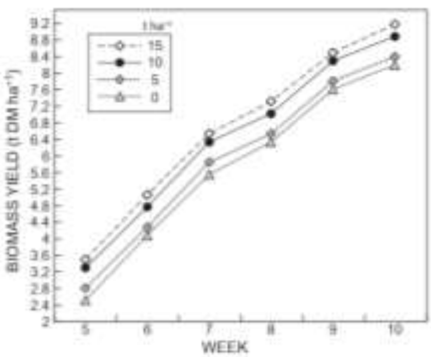

Figure 5: Weekly change in above-ground biomass of *Cenchrus ciliaris* established on four manure levels (0, 5, 10 and 15 t ha^{-1})

causing deaths (Adriansen and Nielsen 2005; Mccabe et al. 2014).

Cow's milk was a source of food and a commonly marketed livestock product for household income generation in the study area. These findings are similar to those found in studies by Filho et al. (2020), Omollo et al. (2018) and Ripkey et al. (2021) which indicated the central role of livestock in pastoral household nutrition and as a source of income. Pastoralists were selling milk at a local market, which showed their lack of integration into the formal dairy value chain, as was also noted by Bayiyana et al. (2018). Twine et al. (2017) argued that pastoralists are not integrated into the formal market because of seasonal milk yield variations as shown in Table 1, which make an investment in milk collection facilities

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Table 2: Above-ground biomass yield and basal cover (Week 10) of *Cenchrus ciliaris* established on three seedbed types (not tilled = NT, tilled flat = TF and tilled sunken = SN) and four manure levels (0, 5, 10 and 15 t ha^{-1})

Seedbed type	Manure level (t ha^{-1}) 0	5	10	15
	Above-ground biomass (t DM ha^{-1})			
NT	7.8^{a*}	8.1$^{ab\#}$	8.5$^{b\#}$	8.9$^{b\#}$
TF	9.1^{a*}	9.4$^{a*\#}$	9.8$^{a*\#}$	10.1$^{a\#}$
SN	8.2^{a*}	8.5$^{a*\#}$	8.9$^{a*\#}$	9.2$^{a\#}$
	Basal cover (%)			
NT	59.7^{a*}	62.6$^{ab*\#}$	67.8$^{ab\#}$	69.2$^{ab\#}$
TF	64.1^{a*}	66.9$^{a*\#}$	72.1$^{a\#}$	73.6$^{a\#}$
SN	56.8^{a*}	59.7$^{b*\#}$	64.9$^{b\#}$	66.3$^{b\#}$

Means in the same column and row with different letters and symbols, respectively, were different at $p = 0.05$

unfeasible. This also explains the low milk prices in the local market during the rainy season because of market saturation and a higher price in the dry season due to reduced supply. Pastoralists need to secure sufficient livestock feed so as to maintain a high milk yield throughout the year. However, this might not be possible in the study area, where livestock spent a long time searching for fodder, indicating the inability of grazing land to support optimum livestock performance, i.e. poor rangeland condition. It is also worth noting that when livestock tends to spend a long time foraging on poor-condition grazing land, this can lead to lower livestock performance, weight loss and even death (Jung et al. 2002).

The presence of other rangeland users and the prevailing communal land tenure system in the study area are management challenges that can lead to a tragedy of commons scenario as described by Moritz et al. (2015). We believe that grazing land improvement practices in the study area should take individual instead of group approaches, and rights to private forage reserves need to be enforced. Many survey respondents were setting aside forage reserves on their privately owned land, which was also observed by Selemani et al. (2013). This practice secures a forage resource for the livestock owner but some native grass species that grow in these reserves are of poor quality and cannot meet livestock nutritional requirements for satisfactory production (Safari et al. 2011). The livestock migration as an alternative is unsustainable because of increased climate change effects and land use changes which could lead to conflicts between different users (Godde et al. 2018). The FFS members (72%) and non-members (81%) were using crop residues, e.g. maize stovers, as dry season feed. Maize stovers have low digestibility due to high structural carbohydrate contents, hence they cannot provide enough of the nutrients required for high milk production during dry periods (Nazli et al. 2018).

Lack of an effective dry season feeding strategy, seasonal milk yield fluctuations, and the central role of livestock in pastoral livelihoods indicated the relevance and importance of improved forage cultivation for livestock nutrition in this semi-arid area. However, survey respondents observed that forage availability needs to be addressed in conjunction with other livestock production challenges such as marketing and livestock diseases. High levels of livestock disease occurrences among pastoralists are due to a lack of effective disease control programmes, e.g. vaccination, parasite control and biosecurity measures, exacerbated by the mixing of herds from different households in communal rangelands (Mangesho et al. 2021). Livestock diseases and marketing issues can be addressed through the establishment of dairy marketing hubs, as it has been done previously in eastern and northern Tanzania (Pham et al. 2015; Rao et al. 2019).

Forage production and pastoralists perceptions

Interviewed pastoralists were all willing to participate in pasture-grass production but were limited by the lack of technical skills (Figure 3), similar to the findings of Omollo et al. (2018). This emphasises the importance of the FFS in imparting the required pasture cultivation skills among pastoralists. However, the lack of technical skills did not vary between FFS members and non-members (Figure 3) because FFS was only established in 2019 and the previous attempt to establish *C. ciliaris* in the study area failed. However, *C. ciliaris* was successfully established in the current study at a rate of 87–97%, which was higher than the 60% reported by Bhatt et al. (2020) in other semi-arid areas. The contrast is due to differences in the establishment methods, irrigation and planting materials between the two studies. The sunken seedbed (SN) technique had the lowest establishment rate (87%) compared to not tilled (NT) and tilled flat (TF), despite its ability to collect water and reduce nutrient runoffs (Nyambati et al. 2011). This is because the SN seedbeds flooded (Weeks 2–4, Figure 2) due to heavy rainfall as it was designed to collect and retain water and *C. ciliaris* is unable to tolerate waterlogged soil (Koech et al. 2016). Waterlogging can also explain the low biomass increase observed in SN compared to NT and TF (Figure 4). Therefore, SN is not a suitable seedbed preparation for the establishment of *C. ciliaris* in conditions where waterlogging can occur. The data suggest that TF is the best seedbed preparation method for *C. ciliaris* establishment in the semi-arid zone of eastern Tanzania.

Final (Week 10) biomass yields (SN 8.1 to TF 10.1 t DM ha^{-1}) reported in this study were higher than 2–6 t DM ha^{-1} reported for *C. ciliaris* in semi-arid areas (Mishra et al. 2010; Patidar and Mathur 2017). The differences are extreme considering *C. ciliaris* was cultivated for a very short time in this study, which implies that Equation 1, used to estimate biomass yields, skewed the results despite its high adjusted R2 (0.93). We recommend that Equation 1 should be re-examined and modified before being used to estimate *C. ciliaris* biomass in other studies. Biomass yield increased with an increase in manure levels, which was expected due to input of nutrients and organic matter (McRoberts et al. 2018). It can be further deduced that a manure application level of 10 t ha^{-1} or 15 t ha^{-1} is better than 0 or 5 t ha^{-1} for *C. ciliaris* cultivation in semi-arid areas. There is an opportunity to obtain the required manure since most pastoralists (68%) in the study area were not using manure for other purposes. Dung is usually deposited by cattle directly onto the grazed land; alternatively, pastoralists rotate their livestock corral holding facilities as a means of creating nutrient-dense patches which support forage regeneration (Huruba et al. 2018). The pastoralists' manure use in *C. ciliaris* cultivation requires further studies to determine its effects, cost and trade-offs on overall grazing land health in semi-arid areas.

The basal cover reported in this study (Table 2) was within 51–75% which is categorised as good in drylands, and was higher than the 19–47% reported in grazed rangelands in eastern Tanzania (Ruvuga et al. 2021). Basal cover can protect the soil surface against erosion agents such as wind, surface runoffs and livestock trampling (Dunne et al. 2011). The good basal cover in the current study emphasises the importance of cultivating improved forage species for high biomass yields and healthy semi-arid rangelands in Africa. The basal cover did not vary between NT and SN despite the observed differences in biomass in the current study. This could be due to the soil compaction in NT which limited water infiltration, soil aeration and root development that can then affect inter-space plant growth (Ji et al. 2013). Lack of soil compaction and seedbed flooding are attributing factors to the higher basal cover observed in TF. As TF10 and TF15 had basal cover values in the upper limits of 51–75% for good rangeland condition in the drylands, they are recommended as the best seedbed-manure treatments for *C. ciliaris* establishment. Treatment TF10 is thought to be ideal because high manure levels would demand more labour in terms of handling and would risk environmental pollution due to the nutrients leaching.

The NT treatment was selected by some respondents (45%) due to its simplicity despite its lower biomass yield. This was probably because hand-hoeing is a familiar tillage technique for TF and SN preparation in the area. In the future, draught power could be introduced through FFS as an alternative land-tillage method. Pastoralists rejected SN seedbed preparation because it was thought to be labour-intensive. In small-scale horticulture production, SN fields are common and are more relevant to forage seed production (Mtengeti et al. 2001; Maleko et al. 2015).

It is clear that the FFS achieved its intended objectives of establishing *C. ciliaris* successfully and imparting forage cultivation skills using available resources, e.g. cattle manure, to all members in this study. The FFS should be used as the means for horizontal knowledge and technology transfer to pastoralists in semi-arid areas (van den Berg et al. 2020; 2021). Generally, our survey suggested that *C. ciliaris* cultivation is potentially valuable to the pastoralists in the study area and this perennial grass can be established on their privately owned forage reserves.

Conclusion

Pastoralists keep indigenous livestock breeds which are an important source of food and income. Grazing land condition was perceived to be poor by both FFS members and non-members since livestock spent a long time in search of forage. An unclear land tenure system limited options for land improvement; hence grazing-land improvement should be done individually to take advantage of already existing, privately owned forage reserves. Pastoralists were willing to cultivate forages on their private land; however, both FFS members and non-members were limited by a lack of technical knowledge. In this study, *C. ciliaris* was successfully established, with TF having the highest establishment rate, basal cover and weekly biomass change compared to SN and NT. These results indicate that TF seedbeds are suitable for *C. ciliaris* cultivation in this semi-arid site. Manure application levels of 10 t ha^{-1} and 15 t ha^{-1} led to the highest biomass yield and basal cover but 10 t ha^{-1} level was recommended for grass cultivation since there was no added benefit in using an extra 5 t ha^{-1}. The *C. ciliaris* cultivation was relevant to pastoralists in the study area and could be planted and grown successfully in the privately owned forage reserves.

Acknowledgements — The authors are grateful to Ministry of Livestock and Fishery Development via Department of Grazing Land and Animal Feed Resources Development, and the NGO, Sustainable Agriculture Tanzania (SAT) for funding this work. We are indebted to all pastoralists in Mela village, Tanzania, who set aside their valuable resources and time to participate in this study. Finally, we are grateful to the two anonymous reviewers who provided very constructive comments that led to the improvement of this work.

Declaration of interest — The authors declare no conflict of interest.

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Received 28 November 2022; revised 15 May 2023; accepted 26 May 2023
Associate Editor: Solomon Tefera

CHAPTER THREE

3.0 Influence of Seedbed Type and Cattle Manure Level on Herbage Characteristics and Forage Nutritive Value of *Cenchrus ciliaris* in a Semi-arid Area†

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† The material contained in this chapter has been published in **Tropical Agriculture Journal**
https://journals.sta.uwi.edu/ojs/index.php/ta/article/view/8427

Influence of seedbed type and cattle manure level on herbage characteristics and forage nutritive value of *Cenchrus ciliaris* in a semi-arid area

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Cenchrus ciliaris **(African foxtail grass) is one of the perennial grass species with high drought and grazing tolerance, biomass yields and nutritional values. These factors emphasize its potential to improve livestock production in drylands. The study was conducted to investigate effects of seedbed types and manure levels on *C. ciliaris* herbage characteristics and nutritional values in a semi-arid area of eastern Tanzania. *C. ciliaris* was cultivated for 12 weeks on three seedbed types, namely not tilled (NT), tilled flat (TF) and sunken (SN), with cattle manure applied at 0, 5, 10 and 15 t/ha rates. Forages were evaluated for biomass yield, grass cover, seed production potential, and nutritional values. Forage biomass yield and grass cover were affected by seedbed type and manure level. The combination of TF seedbed and 10 or 15 t/ha cattle manure had the highest forage biomass yields of 12.4 and 12.6 t/ha, respectively. Similarly, TF seedbed with manure 10 and 15 t/ha had highest vegetative covers of 76.0% and 78.2%, respectively. Inflorescence density did not vary among seedbeds and manure levels. Forage energy and protein contents were not affected by seedbed. Energy intake was affected by manure level whereby it was higher in manure 10 and 15 t/ha for all seedbeds. It was concluded that TF and 10 t/ha are the best seedbed and manure level to establish *C. ciliaris* for sustainable livestock feeding in semi-arid areas of eastern Tanzania and similar environment.**

Keywords: Tillage type, buffel grass, African foxtail grass, forage biomass yield, inflorescence

African grazing lands are facing an increased rate of degradation due to climate change effects and reduced livestock mobility as a result of land use changes (Abdalla et al. 2018). Also, native grass species in these grazed lands have low digestibility and vary seasonally in terms of biomass yields and energy content (Ruvuga et al. 2021). These limitations affect livestock production and livelihoods of the households that depend on these resources (Dunne et al. 2011; Ruvuga et al. 2021). The introduction of new grass species is seen as a viable solution to improve grazing lands and enhance forage quality and quantity during dry periods. This would lead to effective utilisation of grazing lands through improved animal production (Opiyo et al. 2011; Patidar and Mathur 2017). *Cenchrus ciliaris* (African foxtail grass or buffel grass) is among the perennial grass species with drought resilience, high biomass yields (up to 13 t DM/ha) and nutritional values e.g. energy of 7.6 - 9.2 MJ/kg DM and protein up to 103 g/kg DM (Bwire et al. 2003; Mishra et al. 2010; Ruvuga et al. 2022). These factors make *C. ciliaris* an ideal candidate for grazing land restoration and livestock dry season feeding in semi-arid areas.

However, *C. ciliaris* production is faced with various challenges in grazed semi-arid regions such as the need for fertiliser application because of poor soil fertility (Kizima et al. 2014; Koech et al. 2016). Recommended synthetic fertilisers are not easily accessible by the majority of resource-poor farmers in developing countries because they are expensive (Lekasi et al. 2003). Organic fertilisers e.g. cattle manure can be used as an alternative to synthetic fertilisers due to high nitrogen (1.1%), phosphorus (0.3%) and potassium (2.4%) contents that are required for optimum plant growth (Lekasi et

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al. 2003; McRoberts et al. 2018). Also, cattle manure is abundant in African drylands due to the presence of large populations of cattle that produce a huge volume of faeces. The manure application rate depends on soil fertility, the type of forage cultivated and farm management (McRoberts et al. 2018). It is therefore important to evaluate different manure application rates at a specific site so that to determine the optimal levels with the best outcomes in terms of *C. ciliaris* herbage characteristics.

Furthermore, soil physical properties such as bulk density can affect forage establishment and growth in semi-arid areas due to soil compaction because of historical livestock overgrazing (Dunne et al. 2011). Establishing forage on non-tilled soil can preserve soil organic matter and limit carbon escape which can contribute to climate change mitigation through carbon sequestration (Abdalla et al. 2018). However, compacted soil can affect water infiltration, soil aeration, root development and penetration thus reduce biomass yield (Opiyo et al. 2011). Tillage is widely used to break soil compaction in agricultural lands to enhance plant yields. Sunken seedbed (*Tumbukiza*) is gaining recognition in semi-arid areas as an alternative technique for establishing forages because it can retain water and nutrients as was evident in *Pennisetum puerperium* cultivation study (Nyambati et al. 2011). This study was therefore set to compare the effects of not tilled (NT), tilled flat (TF) and tilled sunken (SN) seedbeds at different manure levels on herbage characteristics and nutritive value of *C. ciliaris*. It was hypothesised that NT seedbed and lower levels of manure will result in poor herbage characteristics and nutritional values compared to other seedbed types and higher manure levels.

Methodology

Study area description

The study was conducted in Mela village (Figure 1) located in Mvomero district (8°0' - 10°0' S and 28°22' - 37°0' E), Eastern Tanzania. The village is in the southwest of the Mvomero district at an altitude of 600 - 1200 m. The region receives annual rainfall ranging between 300 - 800 mm distributed into two rainy seasons, the highly variable short rainy periods (October-January) and the long rainy periods (March-May); temperatures range from 18 - 30°C (Magita and Sangeda 2017). The area around Mela is mostly flat with well-drained soil and semi-arid vegetation characterised by scattered bushes and grasses, which makes it ideal for livestock grazing. Understory herbaceous vegetation is dominated by *Bothriochloa intermedia*, *Enteropogon macrostachyus*, *Heteropogon contortus* and *Aristida stipoides* grasses while *Combretum collinum*, *Commiphora africana*, *Dichrostachys cinerea* and *Piliostigma thonningii* are common woody plants (Mdegela et al. 2022). The selected village has a land use plan in which 60.8% of the land was allocated exclusively for grazing at a stocking rate of 9.3 Tropical Livestock Unit (TLU)/ha/year in 2021. Maasai pastoralists are the major ethnic group occupying the area allocated for grazing which is communally owned but with limited improvement practices. These pastoralists are highly affected by seasonal forage variations and grazing land degradation leading to poor livestock performance and increased conflicts with other land users (Magita and Sangeda 2017). Presence of land use plan and increased signs of grazing land degradation such as soil erosion, weed invasion, and loss of palatable grass species led to the selection of Mela village for the current study.

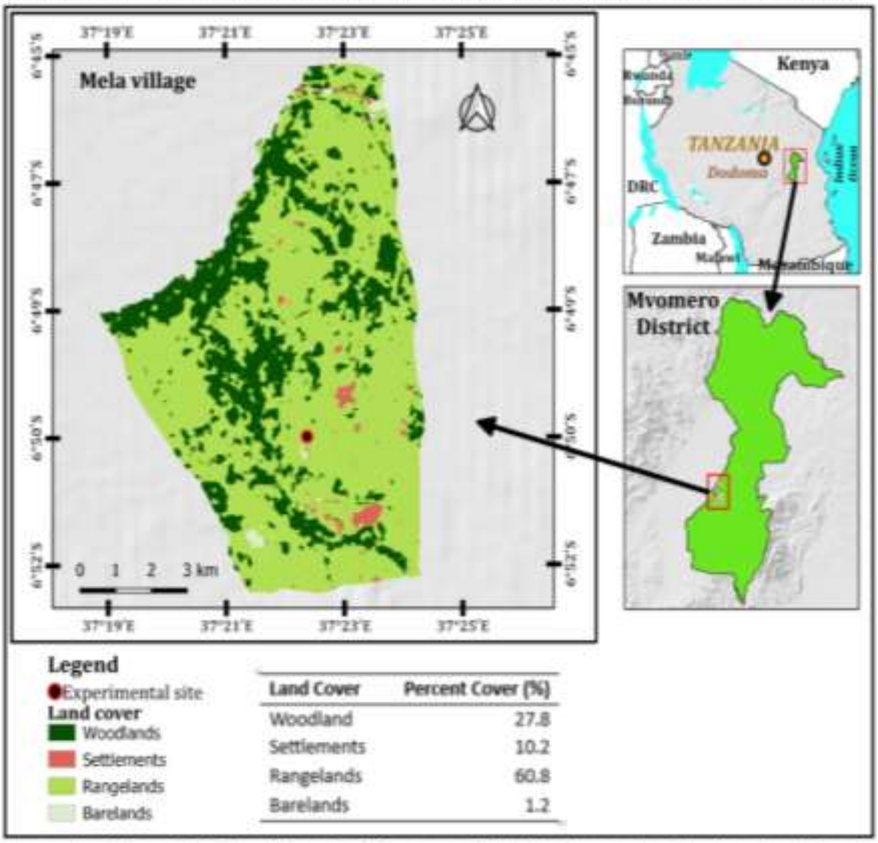

Figure 1: Map of Mela village in Mvomero district, Tanzania showing location of experimental site and land cover types

Experimental design

A 0.1 acre (0.04 ha) area of land within allocated grazing land was used in the *C. ciliaris* cultivation experiment. Selected top soil (0 - 20 cm) properties of the experimental plot are shown in Table 1. The *C. ciliaris* was established using splits containing stems and roots which were sourced from a pasture research farm at Sokoine University of Agriculture, eastern Tanzania. Dry cattle manure used in the study was collected around Maasai settlements (*bomas*) and in the facilities where cattle were kept overnight (kraals). Collected manure was composted for 63 days following the procedures of Kajiya et al. (2014); its properties are shown in Table 1.

Table 1: Selected properties of the experimental area topsoil (0 - 20cm) and composted manure used during forage establishment

Parameter	Soil		Manure	
	Amount	**Remarks**	**Amount**	**Remarks**
pH	7.7	Slightly alkaline	8.26	Mildly alkaline
Soil texture	Silt loam	Suitable	-	
Organic content (%)	0.91	Low	10.89	High
Total nitrogen (%)	0.09	Very low	1.47	Very high
Extractable phosphorus (mg/kg)	8.24	Low	0.74%	Sufficient
Calcium (Ca^{2+})	6.55	High	-	
Magnesium (Mg^{2+})	1.58	Medium	-	
Ca/Mg	4.16	Favourable	-	
Potassium	0.41	Medium	0.31	High
Sodium	0.76	High	-	

Soil and manure remarks are based on soil nutrients requirements for forage growth as detailed by Landon (1991)

The experimental area was divided into 36 plots of 2 x 3 m with 1 m space in between them. A completely randomised design with three replications and three seedbed types (NT, TF and SN) each at four manure levels was used. The NT did not include any land preparation except burrowing during grass splits planting with manure applied on the same pit. The TF method involved tilling and harrowing of topsoil with hand-hoe while SN involved tilling, harrowing and erecting ground roughly 3 cm high on the margins to create water barriers. Cattle manure was applied at the rate of 0, 200, 400 and 600 g/plant equivalent to 0, 5, 10 and 15 t/ha, respectively. During forage establishment composted cattle manure was applied to the TF and SN plots surface, whilst it was applied in the NT plots burrowed pit.

The *C. ciliaris* splits were planted in rows with 50 cm spacing within lines and between each row. The *C. ciliaris* was cultivated for 12 weeks counting from planting day without cut-back and manually irrigated using cans at a rate of 5 L/m^2 three times in the selected weeks (1, 5, 6, 7, 8 and 10) during the experiment. There was irrigation in the respective weeks because it did not rain for four consecutive days and maximum daily temperature exceeded 30°C. The rain was overall high from week 2 - 4 during experimental period, then decreased abruptly with sporadic distribution (Figure 2). Also, forages were hand weeded whenever weeds were observed in the plots. The *C. ciliaris* was evaluated for different herbage characteristics, nutritional values and potential to produce seeds at the end of the study.

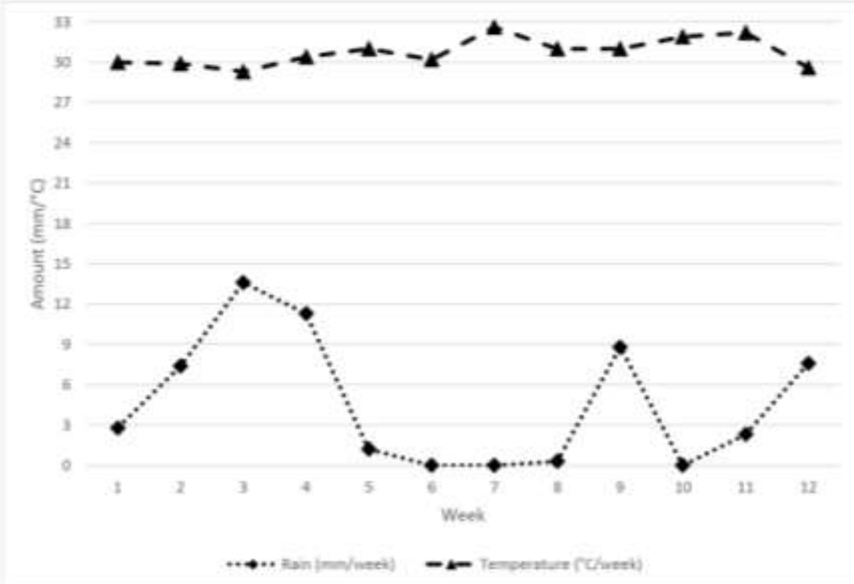

Figure 2: Mean weekly temperature and rainfall distribution in the study area during the study period, 28 January to 28 March 2022 (Tanzania Meteorological Agency 2022)

Data collection

A 1 x 1m quadrat frame was used to sample plants whereby it was placed randomly two times within each plot avoiding the edges. Three plants (tallest, medium and shortest) were sampled within the quadrat. Sampled plants were measured for height, leaf length and width using a tape measure. Plant height was recorded by measuring from the ground to the plant tip excluding inflorescence. Leaf length and width were consistently measured on the third matured leaf from the top and were measured from the leaf collar to the tip for length and across the middle of the leaf for width. The tiller number was determined by counting all tillers within the quadrat frame (1 m^2). Leaves were counted in one tiller from each sampled plant in the quadrat to determine leaf numbers per tiller.

Percentage plant cover was measured using the Canopeo mobile application version 1.1.7 for Android devices by taking a quadrat's aerial picture about 0.6 m above the ground (Patrignani and Ochsner 2015). Inflorescence density was determined by counting all inflorescence found in the individual plot and averaging over plot size to determine density per m^2. Five inflorescences were sampled randomly and measured for length and diameter using a Vernier calliper. Above-ground forage biomass was obtained by cutting forage about 10 cm above the ground in each plot. Harvested forages were weighed separately using a scale and a sample was taken to the laboratory for chemical analysis. Above-ground biomass was determined as the product of complete dry matter (DM) and harvested forage per area.

The *C. ciliaris* samples were air dried individually at 60 - 65°C for 48 – 72 h until constant weights were achieved so as to determine partial DM. Thereafter, individual samples were ground separately to pass through a 1 mm screen. Full DM (ID 930.15) and ash (ID 942.05) contents were analysed following the Association of Official Analytical Chemists (AOAC 1990) standard methods. The complete DM (product of partial and full DM) was used as the basis to estimate forage biomass yield on individual subplot and reported in t DM/ha. The Kjeldahl method (ID 954.01) was used in crude protein (CP) analysis while Van Soest et al. (1991) techniques were employed during neutral detergent fibre (NDF) and acid detergent fibre (ADF) analyses. *In-vitro* dry matter digestibility (IVDMD) was determined following the Tilley and Terry (1963) two-stage procedure. Model 0.15(0.98*IVDMD-4.8) was used in estimating the metabolisable energy (ME) of sampled forages (Bwire et al., 2003).

The DM intake (DMI) and relative forage values (RFV) were calculated based on the NDF and IVDMD values of a respective forage sample using Equations 1 and 2 which were adopted from Mganga et al. (2021).

$$\textit{Dry matter intake} = \frac{120}{\textit{neutral detergent fibre}\ (\%)} \qquad (1)$$

$$\textit{Relative forage value} = \frac{\textit{dry matter digestibility x dry matter intake}}{1.29} \qquad (2)$$

The DMI was converted from calculated percentage bodyweight to kg DM/day by using Tropical Livestock Units, TLU (250 kg) as a standard with one cattle equivalent to 0.7 TLU ≈ 175kg live weight (Ruvuga et al. 2021). The DMI (kg DM/day) was used to estimate daily metabolisable energy intake (MEI) based on the ME value of the respective sampled forage. Mean grass cover was categorised as very poor (0%), poor (1 - 25%), fair (26 - 50%), good (51 - 75%), or excellent (76 - 100%) as described by Ruvuga et al. (2021).

Data analysis

The R statistical program version 4.0.1 was used to analyse herbage characteristics (above-ground forage biomass, plant height, leaf length and width, number of leaves per tiller, tiller density and inflorescence characteristics), grass cover, nutritional values, DMI, MEI and RFV of cultivated *C. ciliaris*. The ANOVA-type II model with interaction was used to analyse effects of seedbed type and manure level on the dependent variables. The model used was:

Y = seedbed type + manure level + seedbed type * manure level + residual error

Tukey's method was used to compare the treatment means at $P \leq 0.05$. Herbage characteristics were analysed for correlations using the Pearson correlation test.

Results

Herbage characteristics

The herbage characteristics and grass cover of established *C. ciliaris* are shown in Table 2. Seedbed type and manure level affected ($P \leq 0.01$) above-ground forage biomass and grass cover as expected but their interaction was not statistically different ($P > 0.05$). Forage biomass and grass cover were highest at TF in all manure levels while they were lowest at NT. Forage biomass and grass cover were highest in all seedbeds with manure at 10 and 15 t/ha, while they were lowest at 0 t/ha manure level. Mean grass cover was categorised as good in almost all treatment combinations except at TF 10 t/ha (76.0%) and TF 15 t/ha (78%) which were excellent.

Table 2: Mean herbage characteristics and grass cover of *Cenchrus ciliaris* established on different seedbed types (NT = not tilled; TF = tilled flat; SN = sunken) and manure levels

Seedbed type	Manure level (t/ha)			
	0	5	10	15
Biomass (t DM/ha)				
NT	$4.9^{a,B}$	$5.5^{a,AB}$	$7.4^{a,A}$	$7.6^{a,A}$
TF	$9.9^{b,B}$	$10.1^{b,AB}$	$12.4^{b,A}$	$12.6^{b,A}$
SN	$7.0^{c,B}$	$7.7^{c,AB}$	$9.5^{c,A}$	$9.8^{c,A}$
SEM (±)	0.7	0.6	0.8	0.6
Plant height (cm)				
NT	$99.2^{a,B}$	$103.3^{a,AB}$	$108.3^{a,A}$	$109.8^{a,A}$
TF	$113.2^{b,B}$	$117.2^{b,AB}$	$122.2^{b,A}$	$124.7^{b,A}$
SN	$105.0^{a,B}$	$109.1^{a,AB}$	$115.1^{a,A}$	$115.6^{a,A}$
SEM (±)	1.8	2.6	2.4	3.7
Tiller density/m²				
NT	487^{a}	537^{a}	565^{a}	617^{a}
TF	$453^{a,b}$	$502^{a,b}$	$530^{a,b}$	$582^{a,b}$
SN	356^{b}	406^{b}	434^{b}	486^{b}
SEM (±)	42.6	34.7	50.5	50.6
Number leaves/tiller				
NT	$9.8^{a,B}$	$10.2^{a,AB}$	$10.4^{a,A}$	$10.3^{a,AB}$
TF	$10.3^{b,B}$	$10.7^{b,AB}$	$10.9^{b,A}$	$10.7^{b,AB}$
SN	$10.1^{a,b,B}$	$10.5^{a,b,AB}$	$10.7^{a,b,A}$	$10.5^{a,b,AB}$
SEM (±)	0.1	0.1	0.1	0.1
Leaf length (cm)				
NT	$28.8^{a,B}$	$29.7^{a,AB}$	$31.1^{a,A}$	$31.4^{a,A}$
TF	$30.8^{b,B}$	$31.7^{b,B}$	$33.1^{b,A}$	$33.5^{b,A}$
SN	$29.4^{a,B}$	$30.3^{a,AB}$	$31.7^{a,A}$	$32.1^{a,A}$
SEM (±)	0.4	0.5	0.4	0.8
Leaf width (cm)				
NT	$0.96^{a,A}$	$1.01^{a,B}$	$1.03^{a,BC}$	$1.06^{a,C}$
TF	$1.00^{b,A}$	$1.05^{b,B}$	$1.06^{b,BC}$	$1.10^{b,C}$
SN	$1.01^{a,b,A}$	$1.06^{a,b,B}$	$1.08^{a,b,BC}$	$1.11^{a,b,C}$
SEM (±)	0.01	0.01	0.01	0.01
Grass cover (%)				
NT	$56.7^{a,A}$	$62.2^{a,AB}$	$67.0^{a,BC}$	$69.2^{a,C}$
TF	$65.7^{b,A}$	$71.2^{b,AB}$	$76.0^{b,BC}$	$78.2^{b,C}$
SN	$57.8^{a,A}$	$63.3^{a,AB}$	$68.1^{a,BC}$	$70.3^{a,C}$
SEM (±)	2.7	1.9	1.5	1.8

SEM = Standard error of the mean

Seedbed types with different small letter in the same column and manure levels with different capital letters in the same row are statistically different

Tiller density was significantly affected by seedbed type ($P = 0.045$) but not manure levels ($P = 0.211$). It was 487 - 617 tillers/m² at NT which was higher than SN (356 - 486 tillers/m²) while TF (453 - 582 tillers/m²) was intermediate. The number of leaves per tiller, plant height, leaf length and width were all significantly affected ($P \leq 0.01$) by both seedbed type and manure level. Plant height and leaf length were highest in TF compared to other seedbeds; leaves per tiller and leaf width were higher in TF and SN than in NT. Plant height, leaf length and width were higher at manure 10 and 15 t/ha compared to 0 t/ha in all seedbeds. The number of leaves per tiller was higher at 10 t/ha than at 0 t/ha manure level in all seedbeds, while others (5 and 15 t/ha) were intermediate. Overall, seedbed-manure interaction had no effects ($P > 0.05$) on tiller density, number of leaves per tiller, plant height, leaf length and width.

Table 3: Correlations among *Cenchrus ciliaris* herbage characteristics established on different seedbed types and manure levels

	Biomass	Plant height	Tiller density	Leaves/tiller	Leaf length	Leaf width
Plant height	0.99*					
Tiller density	0.18	0.27				
Leaves/tiller	0.86*	0.90*	0.08			
Leaf length	0.92*	0.96*	0.46	0.85*		
Leaf width	0.68*	0.75*	0.22	0.77*	0.82*	
Grass cover	0.90*	0.95*	0.56	0.82*	0.99*	0.77*

* *Indicates correlation among compared variables* ($P \leq 0.05$).

There was a positive correlation among all herbage characteristics ($P \leq 0.05$) except for tiller density ($P > 0.05$, Table 3). Inflorescence characteristics of the established *C. ciliaris* are shown in Table 4. Seedbed, manure levels and seedbed-manure interaction had no effects ($P > 0.05$) on inflorescence density which ranged between 46 - 87 per m^2. There were seedbeds ($P \leq 0.01$) and manure level ($P = 0.02$) effects, but, not seedbed-manure interaction on inflorescence length which was lower in NT 0 t/ha (10.9 cm) and NT15 t/ha (11.1 cm) compared to SN at 0, 10 and 15 t/ha and TF at 15 t/ha (all 12.1 cm). Seedbed and seedbed-manure interaction had no significant effect ($P > 0.05$) on inflorescence diameter, but manure levels affected it significantly ($P = 0.01$); NT 10 t/ha and SN 10 t/ha had higher inflorescence diameter (2.2 cm) compared to NT 15 t/ha (1.9cm). Inflorescence width within TF and SN seedbeds did not vary significantly at different manure levels.

Table 4: Inflorescence characteristics of *Cenchrus ciliaris* established on different seedbed types (NT = not tilled; TF = tilled flat; SN = sunken) and manure levels

Seedbed type	Manure level (t/ha)			
	0	5	10	15
Inflorescence density/m^2				
NT	59.3	66.3	69.5	81.2
TF	64.6	71.7	74.8	86.6
SN	46.0	53.0	56.2	67.9
SEM (±)	15.0	11.8	16.3	15.8
Inflorescence length (cm)				
NT	10.9^{a}	11.2	12.0	11.1^{a}
TF	11.7^{ab}	11.8	12.5	12.1^{b}
SN	12.1^{b}	11.5	12.1	12.1^{ab}
SEM (±)	0.2	0.2	0.2	0.2
Inflorescence diameter (cm)				
NT	2.0^{B}	2.0^{AB}	2.2^{A}	1.9^{B}
TF	2.0	2.0	2.0	2.1
SN	2.0	2.1	2.2	2.0
SEM (±)	0.03	0.03	0.04	0.02

SEM = Standard error of the mean

Seedbed types with different small letter in the same column and manure levels with different capital letters in the same row are statistically different

Nutritional values and intakes

Manure levels and seedbed-manure interaction did not affect ($P > 0.05$) DM, ash, CP, NDF and ADF among established *C. ciliaris* forages (Table 5). Also, seedbed type did not significantly affect nutritional parameters except for DM ($P = 0.03$) which was highest in NT (516 - 519 g/kg). The *C. ciliaris* had CP values ranging between 104 - 132 g/kg DM, NDF and ADF values were 685 - 710 g/kg DM and 392 - 430 g/kg DM, respectively. There were no variations among seedbed type and seedbed-manure interaction ($P > 0.05$) on IVDMD and ME, but the difference among manure levels was significant ($P \leq 0.05$). The 10 t/ha had the highest ME (4.9 MJ/kg DM) and IVDMD (38.4%) within TF seedbeds at different manure levels. There were no variations in IVDMD and ME within NT and SN seedbeds at different manure levels.

Table 5: Nutritional values of *Cenchrus ciliaris* established on different seedbed types (NT = not tilled; TF = tilled flat; SN = sunken) and manure levels

Seedbed type	Manure level (t/ha)			
	0	5	10	15
DM (g/kg)				
NT	519^{a}	517^{a}	518^{a}	516^{a}
TF	510^{b}	508^{b}	509^{b}	507^{b}
SN	514^{ab}	513^{ab}	513^{ab}	511^{ab}
SEM (±)	12.0	17.0	23.2	14.3
Ash (g/kg DM)				
NT	71.2	57.8	50.5	45.4
TF	67.0	56.3	53.2	45.6
SN	54.9	45.9	51.5	46.6
SEM (±)	5.3	5.1	3.6	4.7
CP (g/kg DM)				
NT	106	126	123	132
TF	104	121	118	125
SN	111	120	132	117
SEM (±)	4.4	3.1	4.9	4.4
NDF (g/kg DM)				
NT	690	695	710	706
TF	704	691	697	693
SN	696	707	685	698
SEM (±)	6.8	3.4	7.6	4.3
ADF (g/kg DM)				
NT	393	392	422	398
TF	425	407	405	408
SN	407	430	403	413
SEM (±)	8.5	7.5	6.5	8.3
IVDMD (%)				
NT	40.9	32.2	30.8	28.1
TF	21.2^{B}	25.2^{AB}	38.4^{A}	22.4^{B}
SN	33.1	27.6	36.7	24.6
SEM (±)	3.3	2.3	3.1	1.4
ME (MJ/kg DM)				
NT	5.3	4.0	3.8	3.4
TF	2.4^{A}	3.0^{A}	4.9^{B}	2.6^{A}
SN	4.2	3.3	4.7	2.9
SEM (±)	0.5	0.3	0.4	0.2

SEM = Standard error of the mean; DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = *invitro* dry matter digestibility; ME = metabolisable energy

Seedbed types with different small letter in the same column and manure levels with different capital letters in the same row are statistically different

The seedbed and seedbed-manure interaction did not affect ($P > 0.05$) RFV, DMI and MEI significantly. Manure level did not differ significantly in RFV and DMI, but it varied significantly ($P \leq 0.05$) for MEI; MEI was highest for manure at 10 t/ha for all seedbed types.

Table 6: Relative forage value (RFV), dry matter intake (DMI) and metabolisable energy intake (MEI) among different seedbed types (NT = not tilled; TF = tilled flat; SN = sunken) and manure levels

Seedbed type	Manure level (t/ha)			
	0	5	10	15
RFV				
NT	46.3	41.4	51.0	37.0
TF	38.2	33.3	42.8	28.9
SN	43.3	38.4	48.0	34.0
SEM (±)	4.9	3.0	4.3	1.8
DMI (kg DM/day)				
NT	2.99	2.98	2.98	2.98
TF	3.02	3.01	3.01	3.01
SN	3.02	3.01	3.01	3.01
SEM (±)	0.03	0.02	0.04	0.02
MEI (MJ/day)				
NT	13.2^{b}	11.6^{ab}	14.8^{a}	10.1^{b}
TF	10.5^{ab}	8.9^{ab}	12.0^{a}	7.4^{b}
SN	12.2^{b}	10.6^{ab}	13.7^{a}	9.1^{b}
SEM (±)	1.5	1.0	1.4	0.6

SEM = Standard error of the mean

Manure levels with different letters in the same row are statistically different

Discussion

Herbage characteristics

The above-ground biomass reported in this study is within 1.9 - 12.6 t DM/ha range reported in *C. ciliaris* by Kizima et al. (2014) and by Patidar and Mathur (2017). Biomass was affected by manure levels as was also reported by McRoberts et al. (2018). This emphasises importance of manure use for optimum forage yields and improved livestock production in semi-arid areas. The higher biomass yields reported at 10 and 15 t/ha manure level in all seedbeds meant that these two levels were best in optimising forage biomass as was also reported by Maleko et al. (2015) hence we accept the hypothesis that lower levels of manure will result in poor herbage characteristics. Manure application above the levels tested might result in even higher forage yields, however, it would also risk nitrogen leaching and contaminate water bodies.

Higher biomass yields in TF than in NT seedbeds was due to the tilling effect which improves root penetration, soil aeration and water percolation rate (Liu et al. 2021). Tilling is important in facilitating plant growth, especially on compacted soil which is the case in most degraded grazing lands (Abdalla et al. 2018). The biomass in SN seedbeds was also higher than NT (which might change in the long term due to improved soil bulk density), but was lower than TF contrary to findings by Nyambati et al. (2011) who reported higher *P. purpureum* biomass in SN than TF. The SN deviation from norms in this study is due to the flooding of the seedbed as a result of water logging. The SN seedbed flooded in weeks 2-3 of cultivation because of heavy rainfall (Figure 2), which slowed *C. ciliaris* growth due to its inability to tolerate water-logged soil (Koech et al. 2016). Therefore, positive growth results obtained by Nyambati et al. (2011) in SN were attributed to *P. purpureum* ability to tolerate water-logged soil. Furthermore, water logging and/or retention in SN was attributed to the binding together of soil particles due to high organic matter content in the applied manure (Lekasi et al. 2003). The TF had higher biomass than NT and SN which makes it appropriate for *C. ciliaris* establishment in semi-arid areas.

Plant height, number of leaves, leaf length and width contributed to variations in biomass among seedbeds and manure levels as they were found to positively correlate with each other. The *C. ciliaris* height, number of leaves and leaf width in NT were within 88 - 154 cm, 5.8 - 12.9 and 0.6 – 1.0 cm ranges reported in other studies for plant height, number of leaves and leaf width, respectively (Bhatt et al. 2007; Kizima et al. 2014; Mishra et al. 2010; Mseddi et al. 2009). Otherwise, TF and SN had plant height, number of leaves and leaf width on the upper limit or even exceeding the above-mentioned ranges. Furthermore, NT had lower values of fore-mentioned vegetative characteristics than TF and SN in this study which indicates NT inability to support optimum *C. ciliaris* growth and produce high biomass needed for sustainable livestock production. Poor NT vegetative characteristics than TF and SN is likely due to limited plant development caused by poor soil aeration and water infiltration (Opiyo et al. 2011). Leaf length in all seedbeds was lower than 36.5 - 44.8 cm but higher than 5.5 - 10.1 cm for *C. ciliaris* as was reported by Bhatt et al. (2007) and Mseddi et al. (2009), respectively. The variations between these two studies were attributed to differences in *C. ciliaris* growth stage and management.

Tiller density was higher than 116 - 155 tillers/m^2 (Bhatt et al., 2007) due to differences in methods used to determine tiller numbers. Aerial tillers were counted separately in this study instead of counting only those originating from tussock/basal tillers. Tillers were affected by seedbed type with higher values seen in NT but manure levels had no effects contrary to Tian et al. (2017) observations in rice. Lack of manure effects was attributed to tiller types whereby NT had a lot of aerial rather than basal tillers as seen in TF and SN due to NT inability to colonise inter-plant space probably due to soil compaction. This may also be the reason why there were no positive correlations between tiller density and either biomass or grass cover contrary to reports by Bhatt et al. (2007) and Kizima et al. (2014) on *C. ciliaris*. Furthermore, basal tillers have high weight as they obtain nutrients directly from the ground (Kizima et al. 2014) which explained the lower biomass seen in NT compared to TF and SN. Manure effects on ground cover within seedbeds were due to the increase of herbage parameters with the increase in fertiliser levels in this study which supports the findings of Tian et al. (2017). Grass cover was excellent in TF at 10 and 15 t/ha manure which indicated the ability of *C. ciliaris* to reduce ground exposure to erosion agents (Dunne et al. 2011). The TF at 10 t/ha manure is recommended as the best method to establish *C. ciliaris* for better grass cover as it would be more economic and did not differ with TF at 15 t/ha.

There were no seedbed or manure effects on *C. ciliaris* inflorescence density which was higher than 10.7 - 33.9 (Bruno et al. 2017) but contrary to Kumar et al. (2005), who reported higher inflorescence density in *C. ciliaris* with high nitrogen fertiliser. These variations are attributed to differences in *C. ciliaris* varieties (Bruno et al. 2017) and days in flowering (Kumar et al. 2005). The *C. ciliaris* inflorescence length was within the 8.4 - 13.0 cm range, but its diameter was higher than 1.1 - 1.4 cm (Bruno et al. 2017; Kizima et al. 2014; Kumar et al. 2005). The higher inflorescence length of TF at 15 t/ha manure compared to NT at 15 t/ha could be due to morphological differences as the result of surface runoffs in NT, which limited water and plant nutrients availability. Kumar et al. (2005) established that there is a positive relationship between inflorescence size and seed quality and/or quantity in *C. ciliaris*. Therefore, TF seedbeds at 15 t/ha manure had the potential to produce more seeds compared to NT seedbeds at 15 t/ha manure due to their differences in inflorescence length. Since, there were no variations in inflorescence length or width within TF seedbeds, TF at 10 t/ha manure is recommended for seed production as it also performed well in biomass and grass cover. Further studies are required to investigate the effect of seedbed types on seed quality and yields since these were not assessed in this study.

Nutritional value and intakes

The DM values observed were lower than 896 - 916 g/kg (Avilés-Nieto et al. 2013; Kizima et al. 2014) with observed variations caused by growth stage differences. NT had higher DM than TF because of differences in leaves per tiller, leaf length and width. These herbage characteristics were higher in TF than NT which indicated that NT plants had a relatively large stem proportion. Lack of seedbed and manure effects in CP, NDF and ADF indicated that *C. ciliaris* in this study were at the same growth stage. The CP values reported were higher than 39.0 - 109.3 g/kg DM (Kizima et al. 2014; Mishra et al. 2010) with the variations attributed to differences in growth stage, harvesting method, and analysed plant part. CP values were enough to meet the nutritional requirements of growing ruminants as estimated by Salah et al. (2014). The high CP in *C. ciliaris* could improve livestock production while reducing production costs, especially during dry periods (Ruvuga et al. 2022).

The NDF and ADF were lower than 771 - 898 g/kg DM for NDF and 509 - 593 g/kg DM for ADF (Avilés-Nieto et al. 2013; Kizima et al. 2014). The variations are attributed to the analysed plant parts and harvesting stage. The IVDMD varied statistically within TF manure levels despite a lack of significant differences in NDF, which was also observed by Trujillo et al. (2010), due to the sensitivity of the evaluation methods used. Also, it was because ADF declined with an increase in manure levels within TF despite not showing statistical differences in this study. Nonetheless, IVDMD was lower than 49 - 68% (Avilés-Nieto et al. 2013; Ruvuga et al. 2022). The IVDMD variations between current and former studies are due to the stage of growth, *C. ciliaris* inclusion level in the diet, and methods used to estimate digestibility.

The ME was higher than 0.6 - 0.7 MJ/kg DM (Kizima et al. 2014) but lower than 7.6 - 9.2 MJ/kg DM (Bwire et al. 2003; Ruvuga et al. 2022). The variations are attributed to the same factors which affected IVDMD since it was used directly to estimate ME in this study. Sampled forages had MEI lower than 24.4 - 86.4 MJ/day for Zebu cattle to gain 224 - 952 g/day live weight, but DMI was within 1.2 - 3.9 kg DM/day for forage (Asimwe et al. 2015; Mushi, 2020). The MEI variations between current and former studies, despite similar forage intakes, was attributed to the differences in structural carbohydrates *i.e.* NDF and ADF. High NDF reduces digestibility and intake (feed and nutrients) as was the case in this study since it increases animal feed retention and satiety (Salfer et al. 2018). Lower MEI indicated that none of the seedbed types or manure levels in this study was sufficient enough to meet energy requirements of cattle. Therefore, *C. ciliaris* should be supplemented with other energy-source feedstuffs, as was the case in the studies by Asimwe et al. (2015) and Mushi (2020), preferably leguminous fodder shrubs which are abundant in semi-arid areas (Magita and Sangeda 2017).

Nonetheless, MEI variations among manure levels were due to differences in sampled forage IVDMD and DMI used to determine MEI. The variations however indicated that manure at 10 t/ha was better than manure at 15 t/ha and had high energy intake in all seedbeds. Relative forage value (RFV) in this study was lower than 55 - 81 for *C. ciliaris* and other native forages in African semi-arid rangelands (Mganga et al. 2021). The variations could be due to differences in forage maturity stage between the two studies, and in the previous study leaves and stem were analysed separately unlike the current study. Otherwise, any of the seedbed types and manure levels could be promoted for *C. ciliaris* cultivation due to similar RFV. However, TF is the best seedbed since it had higher biomass and grass cover despite not showing differences in CP, IVDMD, DMI, ME and MEI with other seedbeds (NT and SN).

Conclusion

The stated hypothesis was accepted since manure levels 10 and 15 t/ha resulted in higher biomass in all seedbed types but TF seedbed had higher biomass compared to NT and SN. The variations were attributable to soil compaction and waterlogging which affected NT and SN, respectively. The TF at 10 and 15 t/ha manure had excellent grass cover which is useful in protecting the soil against erosion. The CP and ME did not vary among seedbeds, however, MEI varied among manure levels and was lower in manure at 15 t/ha than at 10 t/ha. MEI was insufficient for optimum livestock performance in all treatments which necessitates energy supplementation. There were positive correlations between biomass and other herbage characteristics; however, plant height, leaf numbers, leaf length and width were lower in NT than TF while SN was intermediate. Inflorescence density was not affected by seedbeds or manure levels, but TF at 15 t/ha manure had a higher potential to produce more seeds due to longer inflorescence. It was concluded that TF at 10 t/ha manure was the best seedbed and manure combination to establish *C. ciliaris* in semi-arid areas for higher biomass yield, grass cover, MEI and potential to produce many seeds.

Acknowledgement

The authors are grateful to the Government of Tanzania through the Ministry of Livestock and Fisheries - Department of Grazing Land and Animal Feeds Resources Development, and the NGO Sustainable Agriculture Tanzania (SAT), whose funds led to the completion of this study. We are also indebted to the Mela village council and livestock keepers who provided the experimental plot on which this study was conducted. Additionally, we are grateful to Ms. Mariam Issa Shabani for conducting the forage chemical analysis and Dr. Peter Rogers Ruvuga for reviewing this work and his valuable input during the study design.

Declaration of interest

The authors declare no conflict of interest.

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CHAPTER FOUR

4.0 General Discussion

4.1 *Cenchrus ciliaris* Cultivation

Cenchrus ciliaris was cultivated successfully in all land preparation methods and manure levels in the studied semi-arid area (Paper I & II). The successful result was contrary to the previous on-site failure due to insufficient rains and the use of poor-quality seeds (personal communication). The *C. ciliaris* seeds have low germination rate of 0.3 - 8.3% and 0 - 48% for untreated seeds, as reported by Kizima *et al*. (2013) and Venter and Rethman (1992), respectively. The low seed germination rates are attributed by poor soil fertility status, insufficient rainfall, and germination inhibitory structure in the seed caryopsis of some *C. ciliaris* varieties. Similarly, SSA has poor production and pasture seed regulations, which could be another reason for the broader circulation of sub-standard *C. ciliaris* seeds (Kizima *et al.*, 2014; Mekonnen *et al.,* 2022). This study has shown that vegetative propagation, e.g., splits with roots can be used instead of seeds to establish *C. ciliaris* in semi-arid areas, as were cuts used to establish *Pennisetum puerperium* in sub-humid climate (Maleko *et al.,* 2019). However, using vegetative propagations could be limited by planting material availability, as was the case with pasture seeds. It is, therefore, vital to introduce small *C. ciliaris* forage grass fields at the intended village, which would act as the demonstration plot and source of planting materials.

Furthermore, *C. ciliaris* splits had higher establishment rates (87% - 97%, Paper I) than 65 - 89% reported in transplanted seedlings in arid environments (Yáñez-Chávez *et al.,* 2023). The variations in establishment rate between the two studies were due to the environmental differences and planting materials used since seedlings are more fragile and require extra care during planting. Splits with roots had a superior establishment rate in this study than seeds or seedlings in the former studies, which meant that splits are better planting material for *C. ciliaris* establishment in semi-arid areas. The establishment rate variations between not-tilled (NT) and tilled (TF) land preparation methods were expected due to differences in water infiltration, surface runoffs, and below-ground biomass development (Opiyo *et al.,* 2011). The NT and TF did not vary in this study because of planting materials used (splits), soil physio-chemical conditions during cultivation, and irrigation coupled with rainfall during establishment (Paper I & II). The SN had the lowest establishment rate (87%) despite its loose soil particles for easy water infiltration, enhanced below-ground biomass development, and reduced surface runoffs because of soil tillage and raised soil bunds (Nyambati *et al.,* 2011; Maleko *et al.*, 2019). The lower SN establishment rate in Paper I was because experimental plots flooded during weeks 2 - 4, whereby *C. ciliaris* cannot tolerate water-logged soil, unlike *P. puerperium* (Koech *et al.,* 2016).

The establishment rate did not vary among manure levels in Paper I because of the short duration (week 3) from planting to evaluation with cattle manures release nutrients more slowly than other types of organic fertilisers (Bloukounon-Goubalan *et al.,* 2019; Piash *et al.,* 2021). Otherwise, manure levels significantly varied in above-ground biomass yield and grass cover by weeks 10 and 12 (Paper I & II) due to the essential nutrients released to the soil as the cultivation period progressed. The higher biomass and grass cover with increased manure levels in all land preparation methods was expected due to increased nitrogen, phosphorus, and potassium concentration (Kumar *et al.,* 2005; Maleko *et al.,* 2015). These results showed the importance of manure for forage grass cultivation in semi-arid areas. The lack of variations in biomass yields and grass covers between manure level 10 t/ha and 15 t/ha in all land preparation methods showed that either of the manure levels can be used with acceptable results. However, a 10 t/ha manure level is recommended since higher uses did not result in higher biomass yields or grass cover, suggesting optimum manure used due to diminishing returns (Jahan & Amiri, 2018). Higher manure levels would be labour-demanding and time-consuming while risking nutrient leaching and surface runoff into water bodies, leading to algae blooming that affect the aquatic ecosystem (Kimambo *et al.,* 2022).

The reported above-ground biomass (4.9 - 12.6 t DM/ha) and grass cover (56.7 - 78.2%) by week 12 in this study were slightly higher than 2.5 - 9.1 t DM/ha for biomass yield and 30 - 59% for grass cover in *C.ciliaris* cultivated in semi-arid areas (Mganga *et al.,* 2015; Koech *et al.,* 2016; Mganga, Kaindi *et al.,* 2021; Mganga, Ndathi *et al.,* 2021). The variations in biomass yields and grass cover between current and former studies could be due to the differences in the *C. ciliaris* variety used, cultivation period, and growth stage. Similarly, current biomass yields and grass covers were higher than 2 - 7 t DM/ha and 6 - 25%, respectively, among native forage grasses within the forage reserves in semi-arid areas (Tefera *et al.,* 2007; Verdoodt *et al.,* 2010; Ondier *et al.,* 2019). The variations between cultivated *C. ciliaris* and native forage grass species, were due to season, and management differences, but it emphasizes that improved grass species, such as *C. ciliaris,* can outperform native grasses in forage reserves. Therefore, *C. ciliaris* is recommended for sustainable livestock production due to its high biomass, while its high grass cover can ensure that soil is protected against erosion agents like running water and wind. The land preparation method influenced biomass yields and grass covers as they were higher in TF (9.9 – 12.6 t/ha) and (65.7 – 78.2%) respectively and were lowest in NT (4.9 – 7.6 t/ha) and (56.7% – 69.2%) while SN was in between in all manure levels (7.0 – 9.8 t/ha) and (57.8% – 70.3%) (Paper II), in contrast to the establishment rate observed in Paper I. Despite its lower establishment rate, the SN had higher biomass yields and grass covers than the NT because SN underwent compensatory growth after the water-logging period (week 2 - 4).

The SN water-logged soil and lower establishment rate were the reasons for its lower biomass yield and grass cover than TF since

TF did not suffer similar setbacks (Paper I & II). Otherwise, NT lowest biomass and grass cover was because of its inability to utilise inter-plant space compared to other preparation methods as the result of soil compaction, which led to limited root penetration due to a lack of soil tillage (Ji *et al.,* 2013; Liu *et al.,* 2021). This was the same reason that led to variations in agronomic parameters and their correlation with biomass yield (Paper II) among land preparation methods. Also, NT inability to utilise inter-plant space would leave open patches for weed invasions that reduce forage grass quantity and quality (Mganga *et al.,* 2021). Interestingly, tiller density was higher in NT (487 – 617) than SN (356 – 486) despite NT having lower biomass and grass cover. This was due to differences in tiller types, as NT had more aerial than basal tillers compared to other land preparation methods. This indicates that due to soil compaction, NT was adapting by making more aerial tillers than basal tillers. Aerial tillers have lower weight because they must take nutrients through the stem and compete with other plant parts, while basal tillers absorb nutrients directly from the ground (Kizima *et al.,* 2014). Generally, the TF preparation method was suitable and recommended for *C. ciliaris* cultivation in semi-arid areas with the same soil characteristics to the study site due to its higher biomass yields and grass cover. Furthermore, TF could utilise inter-plant space quickly, unlike NT and SN, limiting weed invasion and not suffering water-logging.

The interviewed farmer field school (FFS) members who participated in the *C. ciliaris* cultivation preferred the TF preparation method over NT and SN (Paper I). The deliberation showed the relevance of FFS in facilitating learning through practicing and helping farmers acquire new skills and technologies (van den Berg *et al.,* 2021). Therefore, FFS should be established and employed elsewhere in semi-arid areas to help pastoralists acquire other animal husbandry skills, such as haymaking. The FFS members rejected SN, which had a lower biomass yield and was labour intensive than TF (Paper I). The lower SN preference is understandable because it is commonly used to cultivate high-value horticultural products like tomatoes and forage grass seed production (Maleko *et al.,* 2015). Nonetheless, the TF preparation method included land tillage using hand-hoe as was done in Paper I and II, which was tedious and would be a potential reason for pastoralists to regress into NT with lower biomass. The introduction of draught power is recommended to reduce workload and facilitate effective land tillage in semi-arid areas (Ramaswamy, 1998; Abdul Rahman & Reed, 2014). The draught power use would be possible due to the cattle ownership in every household; however, FFS would be required to provide draught animal training and design the necessary implements.

Another strong motivation for draught power use would be women's empowerment in the Maasai pastoral households. The Maasai pastoralists have a division of labour based on gender, with a high likelihood that women will be responsible for forage cultivation (Mccabe *et al.,* 2010; Zampaligré *et al.*, 2014; Truebswasser & Flintan, 2018; Sala *et al*., 2020). The Maasai women would have to cultivate forage while managing other household responsibilities. This would reduce efficiency and participation in forage cultivation; hence, draught power would be essential to ensure a large area is cultivated. The ample forage cultivated area would be a basis for improved livestock performance and an additional source of income in case of forage surplus, which can be sold to other pastoralists (Sala *et al.,* 2020). Furthermore, pastoralists need to conserve forage as hay to reduce the risk of biomass losses during dry periods due to other users trespassing or unprescribed fire (Oluwole *et al.,* 2008; Ruvuga *et al.,* 2021). Finally, there is a need for further studies on the performance of *C. ciliaris* in the mixed sward with other forage grass species. The mixed sward would act as an insurance against *C. ciliaris* dominance despite its decreaser status, but an expansion of existing- and/or emergence of new pest or forage diseases like buffel grass dieback and fungal leaf spot as the result of climate change could lead to a complete loss of available forage resources (Makiela & Harrower, 2008; Mlay *et al.*, 2022).

Also, mixed sward tends to have higher nutritional values than pure stand (Agreil *et al.,* 2005; Hilario *et al.,* 2017).

4.2 Nutritional Values of *Cenchrus ciliaris*

The crude protein (CP), neutral- (NDF) and acid detergent fibre (ADF) did not vary (Paper II) among land preparation-manure treatments which meant that cultivated *C. ciliaris* were in the same growth stage. They were in the same growth stage because CP tends to decrease while NDF and ADF increase with an increase in growth (Patidar & Mathur, 2017). The CP, NDF, and ADF observed among treatments in the current study were slightly higher than 47 - 109 g/kg DM for CP, lower than 702 - 7l94 g/kg DM for NDF and within 365 - 566 g/kg DM for ADF as were reported in *C. ciliaris* (Bwire *et al.,* 2003; Mishra *et al.,* 2010; Mganga *et al.,* 2021). The CP and NDF variations between the two studies could be due to differences in analysed morphological parts, growth stage, and cultivated variety. Otherwise, reported CP values can be enough to meet the estimated digestible crude protein of 3.5g and 0.2 - 0.4g (per kilogram of metabolic live weight) for livestock maintenance and gain, respectively, of ruminants species in the tropical environment (Salah *et al.,* 2014). Further feeding studies are required to validate the CP requirements for local livestock breeds kept by pastoralists in semi-arid areas. Similarly, the feeding trial would provide information on *C. ciliaris* rationing for sustainable feeding during dry periods.

Metabolisable energy (ME) and dry-matter digestibility (IVDMD) in Paper II were lower than 5.5 - 8.1 MJ/kg DM and within 32 - 68%, respectively, reported in *C. ciliaris*-based diets with the variations in ME attributed to the stage of growth and diet inclusion levels (Bwire *et al.,* 2003; Kilyenyi *et al.*, 2023). The ME did not vary among land preparation methods because the IVDMD used for its estimation did not differ (Paper II). The IVDMD is affected by structural carbohydrates, namely NDF (Kilyenyi *et al.,* 2023), which was lower than the measured values in other studies, as described above. Similarly, ME and IVDMD did not vary with an increase in manure level except for TF, which was at the highest in manure at 10 t/ha. The deviation was also noted by Trujillo *et al*. (2010) and can be attributed to the water bath's temperature fluctuation, which skewed the IVDMD evaluation. The DM was lower than 855 - 952 g/kg (Kilyenyi *et al.,* 2023; Mganga *et al.*, 2021) due to the differences in growth stage between the two studies. Furthermore, the DM varied among land preparation methods because of their differences in agronomic parameters such as number of leaves per tiller, leaf-length, and width (Paper II). Despite observed DM variations in land preparation methods, all treatments had no differences in DM intake (DMI). The lack of DMI variation was attributed to similar NDF and ADF values that could influence feed intake by filling the gastrointestinal track quickly while causing a slow out-flow of digesta and leading to overall satiety (Mutimura *et al.,* 2018; Salfer *et al.,* 2018).

The DMI influenced ME intake (MEI), which was highest in manure level 10 t/ha in all land treatments. This meant that the manure level was better for producing energy-dense and nutritious *C. ciliaris*. Nonetheless, MEI in all treatments was lower than 57 - 86 MJ/day required by finished local cattle (*Bos indicus*) to attain 599 - 952 g/day (Asimwe *et al.,* 2015; Asimwe *et al.,* 2015; Kilyenyi *et al.,* 2023; Mushi, 2020). However, MEI in manure 10 t/ha (14 - 15 MJ/day, Paper II) was slightly closer to 24 MJ/day and 22 - 29 MJ/day required by finished and growing Zebu to attain 223 g/day and 179 - 219 g/day, respectively (Mushi, 2020; Nantongo *et al.,* 2021). Also, manure 10 t/ha had the potential of supplying MEI within 3 - 7 MJ/day required by local growing small ruminants (goats and sheep) to gain 23 - 74 g/day (Mushi *et al.,* 2009; Safari *et al.,* 2009; Safari *et al.,* 2011). These results showed that manure 10 t/ha had sufficient MEI required to support the optimum growth of small ruminants. It also indicated that *C. ciliaris* did not have enough MEI to meet the optimum performance of cattle. This meant that *C. ciliaris* could support cattle maintenance requirements and a relatively low weight gain, which is better than weight loss that could occur during a dry period due to feed shortage (Selemani *et al.,* 2013b). However, low weight gain would lead to underutilisation of available animal resources, cause food insecurity and increase methane emission that contributes to climate change (Hawkins *et al.,* 2021; Ripkey *et al.,* 2021). Therefore, it is recommended that *C. ciliaris* should be supplemented with the least cost and easily available energy source feeds, such as treated crop residues, to ensure optimum performance during dry periods.

4.3 Grazing Land and Feed Management

Grazing land refers to the site where livestock are foraging, while grazing management involves all activities related to site selection, duration, and frequency of livestock foraging (Godde *et al.*, 2018). The grazing land condition, meaning its capacity to support livestock production, was perceived as low by responding FFS members and non-members (Paper I). The poor condition was because they spent a long time in search of pasture with their animal, which is well-founded since animals tend to spend a long time foraging in grazing lands with poor grass covers (Jung *et al*., 2002; Selemani *et al.,* 2013b). Also, long livestock foraging reduces the time for other activities such as ruminating, resting, and mating, increasing energy expenditure for walking, compromising animal well-being, and minimizing reproduction efficiency (Jung *et al.*, 2002). Ecologically, excessive livestock grazing in poor grazing lands causes wildlife displacement and land trampling, facilitating erosion and converting previously grazed lands into deserts (Dunne *et al.,* 2011; Odadi *et al.*, 2009, 2017). The desertification would reduce the size of the available grazing lands in the country and put more pressure on the remaining resources. These consequences affect the overall national economy and food security, which can reverse positive measures taken to achieve different sustainable development goals.

Limited rangeland improvement practices and unclear land tenure systems were reported in Paper I and thought to be the drivers behind poor grazing land conditions because pastoralists collectively own forage resources (Mccabe *et al.,* 2021). This collective ownership and reluctance to improve rangeland can lead to a “tragedy of the common”. The tragedy of commons occurs when individuals do not manage communal property properly because of the existing legislature or by-laws and fear unfair utilisation by other users (Kilawe *et al.,* 2018; Solomon *et al.,* 2007). These challenges would require intensive management of livestock production among pastoralists. Traditional institutions can be an example of a collective approach to increase livestock intensification through deferred grazing among Maasai pastoralists renowned for their division of labour, using different age groups to facilitate grazing activities (Sangeda & Maleko, 2018). However, there is a need for the coherence of individuals into groups, adherence to social agreement, and even sharing of the expected benefits for traditional institutions to succeed (Glowacki, 2020). If these aspects are not realised due to cultural differences, free-riders, and corruption or nepotism, the traditional institutions will fail to achieve their goals.

Other intensification approaches could be made individually, such as feeding alternative feed resources like crop residues during the dry periods as practiced by some pastoralists in the study area (Paper I). Crop residues are poor-quality feedstuffs, barely enough to meet livestock maintenance requirements (Mushi, 2020; Nazli *et al.,* 2018; Njie & Reed, 1995). The crop residues are ideal for dry-season feeding despite their poor quality because of their easy availability; they keep livestock alive and reduce potential weight loss. However, pastoralists must optimize livestock performance to capture the demand for animal-source food and address food insecurity in SSA (FAO *et al.,* 2022; OECD/FAO, 2022). Therefore, crop residues can be treated with a strong alkali, urea, or fermented as silage to ensure break down of the indigestible carbohydrate, which would ultimately improve their digestibility and nutrients utilisation (Driehuis *et al.,* 2018; Kilyenyi *et al.,* 2023; Wanapat *et al.,* 2009). Further studies are needed to assess the feasibility of these treatment methods in semi-arid areas under pastoral systems. Since high temperatures could limit silage-making, their inaccessibility and high price can hinder urea and alkali use (Bernardes *et al.,* 2018).

Moreover, treated crop residues can be fed as a basal diet and *C. ciliaris* as the supplementary diet to ensure optimum cattle performance. The *C. ciliaris* can be cultivated in the private forage reserves (enclosures) established by the individual pastoralists in the grazing land since native forage resources have poor biomass and nutritional quality (Ruvuga *et al.,* 2021). However, fewer members (25%) and non-members (46%) owned forage reserves whose size was lower than 2.2 - 54.9ha (Safari *et al.,* 2019; Selemani *et al.,* 2012). The differences in forage reserve size between the current and former studies were attributed to the existing land tenure system, emigration of other livestock keepers due to allocated grazing land, and large herd size owned, as the respondents in Paper I mentioned. The village and national authorities must restrict livestock emigration into other villages, guarantee the grazing rights of the residents, and enforce private land ownership in the grazing land. These measures can be taken within the existing Tanzanian legal framework, such as the Grazing-land and Animal Feed Resources Act, Land Use Planning Act, and Village Land Act (Land Use Planning Act, 2007; Grazing-Land and Animal Feed Resources, 2010; Massay, 2016). These measures are anticipated to promote a sedentary pastoral system and intensive livestock production through forage cultivation and treatment of crop residues, improving performance and reducing conflicts among land users.

It should, however, be noted that the privatisation of grazing land through the formalisation of private forage reserves will not be without its challenges. The direct challenge would be the fragmentation of the grazing land due to private forage reserves, limiting livestock mobility to the watering points even within the respective village (Galvin *et al.,* 2008; Said *et al.*, 2016). The limited livestock mobility would result in regular conflicts among different pastoral households in the village and might lead to the degradation of grazing hotspots due to limited resting between grazing periods (Benjaminsen *et al.,* 2006; Egeru *et al.*, 2015). Perhaps the major challenge is the “paradox of pastoral land tenure” in semi-arid areas. The paradox of the pastoral land tenure phenomenon occurs when pastoralists want a land tenure that can protect their grazing rights against emigrating livestock keepers, but it should be flexible enough to allow them to migrate to other areas during stress periods such as prolonged droughts (Turner e*t al.,* 2016). Therefore, grazing land fragmentation would go against flexible livestock mobility, especially with the increase in drought frequency and intensity in semi-arid areas and a risk that *C. ciliaris* cultivation can be challenged by emergency and spread of new forage pests and diseases (Makiela & Harrower, 2008; Mlay *et al.,* 2022).

It would, therefore, be ideal to combine secured private forage reserves and flexible livestock mobility, as in Botswana (Basupi *et al.,* 2017). This can be done by allowing smaller private forage reserves and using the existing legislature to allocate grazing land in every village in Tanzania (Land Use Planning Act, 2007; Grazing-Land And Animal Feed Resources, 2010). The allocated grazing land from different villages or districts can be located closer to each other and connected to form a larger grazing area, which would allow migration similar to those available for wildlife where pastoralists can migrate during stressful conditions (May *et al.,* 2019; Omondi *et al.,* 2021). However, the larger grazing area would raise the managerial question as to who will own and manage these areas located in different villages since the current legislature identifies village authority as the sole custodian of customary land (Land Use Planning Act, 2007; Grazing-Land And Animal Feed Resources, 2010). The village authorities might not have sufficient skills or resources to monitor the grazing land, and they may decide to reallocate grazing land for other uses, which can be counterproductive (Basupi *et al.,* 2017; Nindi *et al.,* 2014). Therefore, the central government could intervene and manage the more extensive network of these grazing lands by guaranteeing legal grazing access and monitoring available resources to avoid grazing land degradation. This intervention would create a favourable environment for the transformation of pastoralism to a sedentary system followed by a more intensive small-scale ranch system.

4.4 Livestock Production

Pastoralists keep ruminants' livestock, such as cattle, goats, and sheep (Paper I), to convert human-inedible materials like grass into quality animal-source food products such as meat and milk. These livestock species have different foraging behaviours, meaning they can be grazed in the same area without competing with each other for the same feedstuffs. This is because cattle are bulk feeders capable of digesting low-quality fodder, sheep are selective grazers feeding on young forage, and goats are mainly feeding on shrubs (Hilario *et al.,* 2017; Mohammed *et al.,* 2020; Schroeder *et al.,* 2019). The local cattle, goats, and sheep breeds kept by pastoralists have a high resilience to pests, diseases, long drought, and hot conditions in semi-arid areas (Ngugi & Conant, 2008; Yaro *et al.,* 2016). Moreover, local livestock breeds have relatively small body sizes compared to their exotic counterparts and are early maturing due to the low amount of protein and energy required for their body maintenance and growth (Nogueira, 2004; Wei *et al.,* 2018; Worku & Alemayehu, 2020). Overall, this livestock facilitates a circular bioeconomy and the achievement of different sustainable development goals in return. Furthermore, livestock promotes a pastoral lifestyle through ceremonies and rituals with cultural significance, as mentioned by Mccabe *et al.* (2014) and Nyariki and Amwata (2019).

Paper I established that cattle are the most crucial animal and could be synonymous with livestock among pastoralists due to their relatively large number in the household herd's structure. Cattle are essential because of their large size, popularity, the high price fetched from the sale than other livestock, and preference for their products, namely meat and milk, unlike sheep and goats, respectively (Kibona *et al.,* 2022; Kidoido & Korir, 2015; Wang *et al.,* 2022). Alternatively, goats were the second most popular livestock species among respondents since they could be sold fast to address food, school, and medical needs while fetching an acceptable price because of the preference for goat meat than sheep (Komarek *et al.*, 2021; Kosgey *et al.,* 2008). Also, goats can control bush encroachments (Mohammed *et al.,* 2020; Rosa García *et al.,* 2012), especially in poor-conditioned grazing lands, as in the studied area. Therefore, it can be argued that cattle and goats are the most important livestock species in African semi-arid regions. Measures aiming to improve livestock production under the pastoral system must prioritize the nutrition and management of these two species.

Furthermore, respondents had above 20 TLU (Tropical Livestock Unit) per household, which can be categorised as wealthy based on the description by Kipuri and Sørensen (2008). The wealthy status meant that pastoral households in eastern Tanzania were better socially than their counterparts in northern Tanzania (Nkedianye *et al.,* 2019; Woodhouse & Mccabe, 2018). It is also worth noting that although the respondents were wealthy by pastoral standards, there is a risk of sliding into abject poverty. This is because their household herd sizes were much smaller than 105 - 600 for cattle, 53 - 108 for goats, and 50 - 106 for sheep among pastoralists (de Glanville *et al.,* 2020; Kimaro *et al.,* 2018b). The herd size variations can be due to the method of data collection, season of the year, and disease outbreaks. Similarly, there were higher herd sizes and number of individual livestock species in FFS non-members than members. The herd variations between the two groups were due to the potential differences in wealth or social status, livestock emigration during the dry period (when the study was conducted), and polygamy with pastoralists distributing livestock to different households in various villages (Woodhouse & Mccabe, 2018). Alternatively, the herd variations could be because FFS members underreported their herd size, hoping to receive assistance from the

Farmers and Pastoralists Collaboration (FPC) project or fearing the destocking campaigns.

Based on FPC membership and smaller forage reserve ownership, it was deduced that FFS members had smaller herd sizes because they were relatively resource-poor and more likely to be coerced into the social group (Paper I). Large herd size can be negated by high production performance per animal, but this is not usually the case among local livestock breeds or pastoral systems (Mwacharo *et al.,* 2006; Mwacharo & Rege, 2002; Ripkey *et al.,* 2021). The daily milk yield per cow reported in Paper I did not vary between the two groups and was lower than 0.7 - 3.2 l/day in the local cattle breeds under the pastoral system (Mwacharo & Rege, 2002; Ruvuga *et al.*, 2020). The daily milk yield variations between the current and former studies could be due to the differences in lactation stage, season, and calf suckling, either partial or unlimited. The lower daily milk yield resulted in a small proportion of milk sold, reducing potential household income and food security. It was clear that milk yield fluctuated between the rainy and dry season. These fluctuations are the reason for the reported lack of market access among pastoralists in the studied area. This is because of unreliable milk production, which would discourage investment in milk collection facilities (Twine *et al.,* 2017). Unreliable milk market can also lead to post-harvest milk losses due to spoilage during rainy season when the market is saturated (Ruvuga *et al.,* 2020). The post-harvest loss is bad for the environment and farm economy since all the resources put into food production are wasted.

Two simultaneous measures can be taken to ensure continuous milk production in pastoral households. Pastoralists should improve dry-season feeding through *C. ciliaris* cultivation, which can be successfully established in semi-arid areas (Paper I & II). The *C. ciliaris* forage can be fed with treated crop residues to meet cow nutritional requirements (see section 4.2). The continuous milk supply throughout the year due to improved dry-season feeding would attract investment in collection facilities, facilitating milk transportation to processing plants. However, rural roads, as was the case in the studied area, are not passable all year around due to poor infrastructure developments, which would require another strategy, such as a cooperative or innovation platform through the existing FPC organisation, to gain access to the formal dairy value chain (Kilelu *et al.,* 2017; Pham *et al.,* 2015). The innovation platform would unite actors with different backgrounds and roles in the livestock sector to serve a common goal. These actors include milk processors, government agencies, feed processors, and farm inputs traders (Cadilhon *et al.,* 2016). The milk processors would provide education to promote conformation to the proper milk handling and facilitate milk transportation to collection centers if needed.

The government agencies and farm input traders in the innovation platform would assist in animal health management due to the high prevalence of infectious livestock diseases, e.g., Contagious Bovine Pleuropneumonia (CBPP) and East Coast Fever (ECF) mentioned by the respondents (Paper I). The two actors would provide pastoralists access to vaccines and means to control livestock disease, e.g., acaricide for tick control. The innovation platforms would also support accurate prescription of veterinary medicines since livestock extension services are poorly developed in some semi-arid areas in SSA (Gustafson *et al.,* 2011; Mangesho *et al.*, 2021). Perhaps biosecurity measures would be the most effective disease control practice among pastoralists in the collectively grazed semi-arid areas. Biosecurity measures can be taken at the village level, whereby care should be taken to ensure that individual animals are appropriately vaccinated, and there is limited contact with herds from other villages (Kimaro *et al.,* 2017; Omondi *et al.,* 2021). The biosecurity measure and disease control combined would reduce livestock diseases as the major challenge among pastoralists, while *C. ciliaris* cultivation using the TF land preparation method and manure level 10 t/ha would address forage seasonal variability as discussed in section 4.1.

Generally, it is deduced that the presence of many livestock in the studied area, milk yield fluctuation, private forage reserves, and seasonal forage variability would provide strong reasons to pastoralists for *C. ciliaris* cultivation. Similarly, most respondents reported not utilizing manure for other economic activities (Paper I), which can be used as fertiliser for forage cultivation. However, this work did not establish how manure for forage production can be collected since livestock were extensively grazed. Also, there would be a higher demand for manure as it would need to be applied regularly after *C. ciliaris* harvesting to facilitate regrowth. If the required manure was to be collected from overnight livestock holding facilities as was in this study (Paper I & II) or directly from grazed areas, the existing trade-offs are not clearly understood. This is because the holding facilities provide nutrient hotspots for forage regeneration, and livestock defecation in the grazed areas recycles nutrients from the soil via forage (Mayengo *et al.,* 2020; Porensky & Veblen, 2015). It is expected that infertile soil due to manure off-take and regular grazing during the rainy season would be incapable of supporting plant growth, leading to desertification. Therefore, manure collection and existing trade-offs warrant further investigation to ensure effective and sustainable forage production.

CHAPTER FIVE

5.0 General Conclusions and Recommendations

5.1 General Conclusions

i. The participating pastoralists and cultivation study showed that the TF and manure 10 t/ha were the ideal land preparation method and manure level for *C. ciliaris* cultivation because of their high establishment rate, biomass yields, and grass covers. Furthermore, these treatments had an acceptable amount of CP, ME, and MEI required by the ruminants daily. However, the MEI values in TF and manure 10 t/ha were only sufficient to meet maintenance requirements and a weight gain for matured cattle compared to the optimum performance in the small ruminants. The *C. ciliaris* cultivated using TF and manure 10 t/ha might need to be supplemented with crop residues such as maize stover and bean haulm treated with molasses or urea to provide sufficient nutrients for optimum cattle performance.

ii. The respondents in the studied area perceived their grazing land ability to support livestock production as poor. This was because livestock spent a long time and walking distance searching for pasture, and there were limited grazing land improvement practices. The limited grazing land management practices were because of communal land use, disrespect for private property, and emigration of other pastoralists during the dry periods. The pastoralists were resolving into migration and feeding livestock crop residues mainly dry maize stover and beans haulms to alleviate the dry-season feed shortage in the semi-arid area. However, few respondents engaged in grazing land improvement practices and were doing so by establishing forage reserves. These forage reserves can be used for *C. ciliaris* cultivation to facilitate sustainable dry-season livestock feeding in the studied semi-arid area.

iii. Generally, pastoralists kept local breeds of cattle (Tanzania Short Horned Zebu), goats, and sheep, essential food sources, income, and other cultural values. The FFS members had an evarage of fewer livestock numbers than non-members this was attributed to their awareness on safe livestock carrying capacity. There was a high prevalence of livestock diseases such as East Coast Fever (ECF) and Contagious Bovine Pleuropneumonia (CBPP). Daily milk yield was low and varied seasonally due to forage fluctuation, leading to an unreliable dairy market and reduced farm income. The lack of grazing land improvement practices, low milk yield, and seasonal forage variations provide strong reasons for pastoral adoption and introduction of *C. ciliaris* in the studied area.

5.2 General Recommendations

i. More pastoralists should establish private forage reserves in the semi-arid rangelands to cultivate *C. ciliaris* using the TF land preparation method with a 10 t/ha manure application rate in the studied area and other areas with the same climatic condition and soil characteristics. National and village authorities must promote forage cultivation by protecting private property ownership through the existing legal framework to intensify livestock production in semi-arid areas.

ii. The FFS needs to be introduced and promoted in other semi-arid areas to facilitate knowledge and technology transfer to the pastoralists. Furthermore, FFS can address other animal husbandry challenges, such as forage conservation and ration formulation, milk marketing, and disease control.

iii. Scientifically, it is imperative to investigate the long-term performance (over one year) of *C. ciliaris* cultivated in different land preparation methods and involving multiple semi-arid areas. Studies are also needed on the growth performance of mixed swards containing *C. ciliaris* and other forage species including legumes. Overall, it would be crucial to investigate the effects of cutting or grazing frequencies in the *C. ciliaris* regeneration to formulate a sustainable management plan.

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APPENDICES

Appendix 1: A questionnaire on farm field school members and non-members on grazing lands and livestock management

1. Name of respondent……………………………… Phone number ………………... Household No……….
2. Gender : (a) Male
   (b) Female
3. Age (years)……………………………
4. Place/Village ……………………………
5. Education level (a) Primary school
   (b) Secondary school
   (c) University
   (d) Didn't attend to school
6. Marital status
   a) Single
   b) Engaged
   c) Married
   d) Divorced
   e) Separated
   f) Widowed
7. Household size – how many people live in your home?

Years	Females	Males
1-14		
14-17		
18-35		
36-45		
46-60		
Above 60		

8. What kind of work do you do? (a) Livestock keeping
   (b) Farmer
   (c) Business
   (d) Others

9. If you are livestock keeper, name the type of livestock you are keeping
   (a) Cattle ☐
   (b) oat ☐
   (c) Sheep ☐
   (d) Cattle and goat ☐
   (e) Cattle and sheep ☐
   (f) Sheep and goat ☐
   (g) Cattle, sheep and goat ☐
10. Are you a member of Farmer Pastoralist Collaboration (FPC)?
   (a) Yes

   (b) No

11. Indicate the numbers of cattle owned

		Breed	Number	Use (e.g. breeding, transport, ploughing, milking, etc)	Source (e.g. bought, inherited, pass on, project
Bulls					
Cows					
Heifers					
Steers					
Oxen					
Calves	female				
	male				

12. Other livestock owned beside cattle

Species	**Number**
Local goats	

Dairy goats	
Sheep	
Pig	
Poultry - chicken	
Others (specify)	
Others (specify)	

Land ownership

13. Do you own land? Yes
    No
14. If no, why?
    ....
    ....
15. If yes, how many acres? …………………
16. If you graze your animals, how much land have set aside solely for this purpose? .... Acres
17. Do you grow pasture? Yes
    No
18. If Yes, how many acres? ....
19. Why you grow pasture?
    …………………………………………………………………………
    ………………
20. Which species do you grow? ....
21. If not, why?.....................................

Production

22. Milk yields

S/N	Season	Liters/cow//day (a)	No. of cattle milked per day (b)	Value (Tshs)/liter (c)	Sold to (d)	Number of liters sold per day (e)
	Wet season					
	Dry season					

Sold to (d)
0. Did not sell,
1. Neighbors,
2. Secondary market (e.g. In nearby town),
3. Processing industry,
4. Trader(s) at farm,
5. Other outlets (specify) _______________
6. Large scale farm,
7. Local market,

Sell of animals

23. How many cows do you sell per annum? ....
24. Market price; Bull..........................., Cow……………….
25. Distance to Pasture**;** Dry season………. km Wet season………….km
26. Grazing time; Dry Season………. hrs, Wet season………... hrs
27. Distance to water (to and from); Dry season……. Km, Wet season……… km
28. What do you normally do when you face pasture shortage in your grazing areas?
    Purchase feeds [ ] Sale some animals [ ] Move them to somewhere else [ ] Do nothing [ ]

Others: Specify..

29. What do you normally do when you face pasture surplus in your grazing

areas?..

30. How do you access crop residues? (Interactions with farmers)
………………………………………………………………………………………………
31. In which form do you feed them? In-situ [ ], ex-situ [ ]
32. How do you access pasture in reserved areas? (Private and public – interaction with land users e.g., conservators WMA)
………………………………………………………………………………………
33. What initiatives do you take to improve grazing areas?...
34. What challenges do you face in improving grazing areas?...
35. Can you allocate time and resources for pasture establishment? (a) Yes ☐
(b) No ☐

Manure management Practices

36. Do you collect manure from cow shed? (a) Yes ☐
(b) No ☐
37. If no, how do you dispose manure…………………………………………………………………
38. If yes, how do you handle the collected manure? E.g Krall heaps, heaping, composting.............................
39. What do you do with the collected/handled manure?
(a) Apply on crop farms
(b) Apply on pasture/grazing land
(c) Selling
(d) Giving to other people for free
40. If you sell, give the cost (Tshs) at specific amount of manure...

41. What challenges you are facing in livestock production?

Challenge	**Remarks**
Diseases	Which diseases?
Market prices	e.g., milk? Which price do you think will suffice??
Market access	Auction? Location, middlemen, Laws and Regulations
Land ownership	What ownership?
Pasture	Availability?
Water	Availability? Distance to water soureces
Herding labor	Presence of Labor? labor cost
Conflicts with other land users	Farmers? WMA etc
Breeds	Low production?

Appendix 2: A questionnaire on preference of pasture establishment methods for farm field school members

1. ame of respondent……………………………… Phone number ………………... Household No……….
2. Gender : (a) Male ☐
   (b) Female ☐
3. Age (years)……………………………
4. Village ……………………………
5. Education level (a) Primary school ☐
   (b) Secondary school ☐
   (c) University ☐
   (d) Didn't attend to school ☐
6. Marital status
   g) Single ☐
   h) Engaged ☐
   i) Married ☐
   j) Divorced ☐
   k) Separated ☐
   l) Widowed ☐
7. Household size – how many people live in your home?

Years	Females	Males
1-14		
14-17		
18-35		
36-45		
46-60		
Above 60		

8. What kind of work do you do? (a) Livestock keeping
   (b) Farmer ☐
   (c) Business ☐
   (d) Others ☐

9. If you are livestock keeper, name the type of livestock you are keeping
   (h) Cattle ☐
   (i) Goat ☐
   (j) Sheep ☐
   (k) Cattle and goat ☐
   (l) Cattle and sheep ☐
   (m) Sheep and goat ☐
   (n) Cattle, sheep and goat
10. Can you allocate time and resources for pasture establishment? (a) Yes ☐
    (b) No ☐
11. Which method of pasture establishment you prefer among these?
    (a) Tilling and planting ☐
    (b) Planting without tilling ☐
    (c) Preparing sunken beds ☐
12. Give the reasons of choosing the method from the question above
    ……………………………………………………………………………
    ……………………
13. What are the reasons for not selecting ………… in pasture establishment?
    ……………………………………………………………………………
    …………………
14. What are the reasons for not selecting …………………… in pasture establishment?..

Appendix 3: Consent form

This study is about grazing land and livestock management in Mela village, Mvomero district. You are invited to participate in this interview. The study consists of over 40 questions and will take approximately 30 minutes to complete. Please answer the questions to reflect your opinions and experiences to the best of your knowledge. If you would like clarification on any of the questions, please do not hesitate to ask the interviewer. If you wish not to answer any particular question(s), please say so and the interviewer should be able to proceed to the next question. If you choose to participate the interviewer will record your name, and note your responses in the questionnaire. The interviewer should be able to inform you when the interview questions are complete. Although the respondents will be identified individually, collected information will only be used for report writing with anonymity and will not be shared to the individuals outside of the research team. Your participation is highly encouraged and appreciated.

Swahili translation

Huu ni mradi wa utafiti kuhusiana na hali ya malisho na mifugo katika kijiji cha Mela wilayani Mvomero. Unakaribishwa kushiriki katika dodoso. Dodoso litahusisha maswali zaidi ya 40 na itachukua takribani dakika 30. Tafadhali jibu maswali kulingana na maoni na uzoefu wako kwa kadiri ya uelewa wako. Endapo utataka ufafanuzi kwenye swali lolote lile tafadhali usisite kumuuliza mtafiti. Na pia kama hautapenda kujibu swali lolote lile mjulishe mtafiti naye atahamia kwenye swali linalofata. Endapo utachagua kushiriki mtafiti ataandika jina lako, na kuandika majibu yako katika karatasi. Ingawa taarifa zako binafsi zitakusanywa, taarifa hizi zitatumika kuandaa ripoti na tunakuahidi usiri/faragha, pia taarifa hizi hazitaonyweshwa kwa mtu yeyote isipokuwa kwa timu ya utafiti huu tu. Ushiriki wako ni muhimu na tunatanguliza Shukrani zetu kwako.

Appendix 4: Composting of cattle manure

Appendix 5: *Cenchrus ciliaris* planting in the experimental plots

Appendix 6: Measuring of cultivated *Cenchrus ciliaris* for growth and biomass in Mela village

Appendix 7: Interviewing a pastoralist on grazing lands and livestock management