Sokoine University of Agriculture

PhD Thesis

Characterization of Ecotypes of *Cenchrus ciliaris* (African Foxtail) from Selected Areas in Tanzania

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Characterization of Ecotypes of C*enchrus Ciliaris* (African Foxtail) from Selected Areas in Tanzania

Thesis Submitted in Fulfilment of the Requirements for the Award of the Degree of Doctor of Philosophy of Sokoine University of Agriculture, Morogoro.

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EXTENDED ABSTRACT

Ruminant animals in developing countries, such as Tanzania, heavily rely on natural pastures found in communal grazing lands. Unfortunately, these lands are facing rapid deterioration in various aspects. The pastures in these areas are generally of poor quality and insufficient in quantity, leading to challenges in sustaining animal production. Additionally, these grazing lands often experience extended dry periods, further exacerbating the problem of inadequate forage and negatively impacting ruminant nutrition and productivity. To address these issues, it is crucial to enhance these grazing lands to make them productive year-round, even during challenging seasons. However, these lands are often overgrazed, face high environmental temperatures, and suffer from poor soil quality, all of which hinder pasture growth. Therefore, conducting assessments of these pastures is essential to determine their potential to thrive under such environmental conditions. Furthermore, it is crucial to identify, select, and breed suitable pasture species for these areas.

This study focused on characterizing *Cenchrus ciliaris*, also known as African foxtail, in selected regions of Tanzania. African foxtail has shown tolerance and better yield potential as a pasture crop in challenging environments, making it a promising candidate for improving communal grazing lands in Tanzania. The research employed an integrative approach, including literature review, field surveys, and experimentation, to achieve four specific objectives:

Objective 1: Literature Review

The first objective involved conducting a systematic review of existing literature. The review gathered data on plant characterization, forage production, and environmental stresses from published and unpublished reports, journal articles, conference papers, government reports, book chapters, and theses published between 2002 and 2020. A total of 97 publications were considered, with 51 articles deemed relevant for the study.

Objective 2: Habitat and Morphological Assessment

For the second objective, a cross-sectional study was conducted in three Tanzanian districts: Kilolo, Kiteto, and Mpwapwa. Two villages were selected from each district, and potential sites within these villages were identified. Ecotypes of African foxtail were identified and named based on names provided by local residents. The ecotypes were Iramata malolo (*Ir*) and Iramata mtandika (*Im*) from Kilolo District, *Ologoraing'ok namelock* (*On*) and *Ologoraing'ok twanga* (*Ot*) from Kiteto District, as well as *Nzingangata* (*Nz*) and *Orupilipili* (*Op*) from Mpwapwa District. Various morphological characteristics, including plant height, tiller number per tussock, leaf number, leaf length, and inflorescence length, were assessed in ten randomly selected tussocks from each plot. Habitat characterization included data collection on landscape, climate, soil, and associated plant species. Soil samples were also collected for laboratory analysis.

Objective 3: Growth and Productivity Assessment. To achieve the third objective, an experiment was conducted at Magadu Dairy Farm using a completely randomized design. This experiment aimed to assess the growth and productivity of African foxtail ecotypes under common, stress-free environmental conditions. Five of the six ecotypes assessed in the second objective were included in this experiment. Sprigs of these ecotypes were planted in plots, and standard management procedures were applied. Forage growth, dry matter yield, and nutritional characteristics were assessed.

Objective 4: Response to Defoliation

The fourth objective involved an experiment in which the response of selected ecotypes to defoliation was assessed. Defoliation stress was measured through harvesting intervals of 21 days, 28 days, and 35 days. Five ecotypes from the third objective were used in this experiment, and various growth and nutritional parameters were measured to evaluate their response to defoliation.

Key Findings

Plant characterization is crucial for sustainable forage production in challenging environments. Different approaches, including agronomical, morphological, histological, biochemical, physiological, and molecular methods, can be used for this purpose. In Tanzania, agronomical and morphological approaches are commonly employed due to resources and technological constraints.

There is significant habitat and morphological variation among African foxtail ecotypes in their natural environments. This variation is permanent and persists when these ecotypes are grown under common environmental conditions. The assessed African foxtail ecotypes exhibit differences in several characteristics, including plant height, leaf area, tiller number, yield, and nutritional attributes. These differences make some ecotypes more suitable for specific purposes.

Harvesting interval significantly affects forage growth, yield, and nutritional quality of the ecotypes. Ecotype Olupilipili "Op" outperformed other ecotypes based on growth and yield characteristics, and ecotype *Ologoraing'ok namelock* "*On*" was the best on nutritional characteristics. Optimal productivity is achieved with a 28-day harvesting interval.

Conclusions and Recommendations

In conclusion, this study highlights the importance of characterizing forage species for sustainable livestock production in challenging environments. African foxtail ecotypes in Tanzania exhibit morphological variations and respond differently to environmental conditions and defoliation. Selecting suitable ecotypes and optimizing management practices can enhance the productivity of communal grazing lands, ultimately benefiting the livestock sector in the country. More research and the adoption of advanced characterization techniques are encouraged to improve forage production in Tanzania.

Based on their growth, yield and nutritional characteristics as reviled in this study "Op" and "On" ecotypes can be selected by farmers and for breeding programs. Harvesting interval of 28-day may be adopted for optimum productivity.

Additional studies on cost-benefit analyses for ecotype production under different management plans, as well as assessments of ecotypes under drought and salinity stresses, which are prevalent in the region are suggested. Molecular characterization of the studied ecotypes is also recommended as an advanced approach to plant characterization. This can help identify and utilize adaptive traits for stressful environments.

DECLARATION

I, Dorice Leonard Lutatenekwa**,** declare to the senate of Sokoine University of Agriculture that this PhD Thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

______________________ ______________________
Dorice Leonard Lutatenekwa Date
(PhD Candidate)

The above declaration is confirmed by;

______________________ ______________________
Prof Ephraim Joseph Mtengeti Date
(Supervisor)

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Dr George Mutani Msalya Date
(Supervisor)

LIST OF PUBLISHED PAPERS AND MANUSCRIPT

Paper One: Lutatenekwa DL, Mtengeti EJ and Msalya GM. (2020) A review of plant characterization: First step towards sustainable forage production in challenging environments

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Paper three: Lutatenekwa DL, Mtengeti EJ, and Msalya GM (2021) Forage growth, yield and nutritional characteristics of five African foxtail ecotypes grown at Magadu dairy farm in Morogoro, Tanzania.

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DEDICATION

To my lovely children Nyinondi and Nandi, whose presence beautifully coloured my life, let this thesis inspire you to aim higher in life. I love you.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
Cm	Centimeters
CP	Crude protein
DM	Dry matter
DNA	Deoxyribonucleic acid
EC	Electrical conductivity
ID	Index of dominancy
Im	Iramata Mtandika
Ir	Iramata Malolo
MDF	Magadu Diary Farm
NDF	Neutral detergent fiber
Nz	Nzingangata
On	Ologoraing'ok namelock
Op	Orupilipili
Ot	Ologoraing'ok twanga
PCR	Polymerase chain reaction
SD	Standard deviation
SEM	Standard error mean
SSA	Sub-Saharan Africa

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

In developing countries like Tanzania, ruminant production depends mainly on raising the livestock species such as cattle, sheep, and goats in natural pastures and water obtained in communal rangelands (Steinfeld *et al.,* 2006; Gelayenew *et al.,* 2016). In this regard, pasture is an essential component for ruminants' production if profitability is to be maximized. However, in tropical livestock farming conditions, feed shortage triggers smallholder farmers to feed their animals on any available forage, often with unknown nutritional value (Shem *et al.,* 2003). The problem of feed shortage is accelerated by challenges of environmental stresses, which encompasses defoliation, drought, and soil salinity stresses (Araujo *et al*., 2015; Blanco *et al.,* 2014; Lestienne *et al.,* 2006, Mansoor *et al.,* 2002). Defoliation becomes stressful when vegetation is clipped or grazed continuously and escalates by grazing a large number of animals on size-constrained rangelands with poor vegetation (Altesor *et al*., 2005; Rey *et al.,* 2017). In addition to defoliation, drought and soil salinity are stressors that directly reduce forage growth and productivity (Ali *et al*., 2017; Shrivastava & Kumar, 2015; Singh *et al.,* 2015). Plants frequently arouse a multifaceted cellular and molecular mechanism as a response of adaptation to stresses (Chaves *et al.,* 2003; Fahad *et al*., 2015). Eventually, these stresses contribute to morphological, physiological, biochemical, and molecular changes and directly affect forage growth and productivity (Singh *et al*., 2011; Singh *et al.,* 2015). The United Nations Food and Agricultural Organisation (FAO, 2007) agrees that the distribution of plant species, the shifts in range, and continuing biological changes are connected with responses to environmental stresses.

Response of plants to stress differs within and among species depending on stress intensity, stage of plant growth, and duration of exposure to stress (Clauw *et al.,* 2015). Morphological, physiological, biochemical, and molecular changes can become genetically fixed and may favour the adaptation of that population. Consequently, some species have developed ecotypes with variable morphological structures due to adaptation to environmental stresses (Chen *et al.,* 2018; Hoffmann & Willi, 2008). African Foxtail (*Cenchrus ciliaris*) is among the species with a good number of ecotypes harbouring variable stress-tolerant attributes (Kannan and Priyal, 2015). Variation is considered an advantage for adaptation, and African foxtail has been reported to adapt and produce well in various environmental conditions (Scott, 2014). Despite the multitude of ecotypes of African foxtail species, its qualities are documented at the species level; however, each ecotype has specific attributes. According to Nawaz *et al*. (2014), attributes of an individual ecotype evolve when adaptation pressure becomes permanent. The continual differentiation within ecotypes may lead to new varieties or species formation (Lowry *et al.,* 2014; Lowry, 2012).

On the other hand, contemporary biotechnological methods have enhanced the transfer of desirable attributes like productivity, tolerance, and adaptability from an ecotype or specie to a less advantaged species/ecotype (Ghose *et al.,* 2022). Subsequently, plant breeders' transfer of desirable attributes is aided by information generated from plant characterization. Therefore, the characterization of African foxtail ecotypes is important to ascertain their attributes and develop valuable information for farmers and breeders for selection and breeding based on trait preference. Therefore, this study was designed to perform agro-morphological characterization of African foxtail ecotypes and assess their response to defoliation from selected areas of Tanzania.

1.1.1 African foxtail (*Cenchrus ciliaris*)

Cenchrus (*C*.) *ciliaris,* also known as African foxtail, is one of the native grass species of tropical Africa and Asian countries (Scott, 2014). It is adapted relatively to heavy grazing and grows well in a wide range of soil types and altitudes (from sea level to 2000 m); in different ecological zones, from semi-arid to sub-humid climates (Marshall *et al.,* 2012). The qualities of *C. ciliaris* are numerous, and it has become a famous grass species in arid and semi-arid areas. This is due to its drought tolerance and potential to improve pasture, stabilize soil, and control erosion as it provides surface cover by its heavy stand (Grigg *et al*., 2000). The plant has been reported to tolerate drought and fire (Butler and Fairfax, 2003; Mansoor *et al.,* 2019). Also, it establishes easily in new areas and can compete successfully against other species in arid and semi-arid areas (Jackson, 2005). It provides comparatively high-value herbage with yields between 2 and 18 t DM/ha without using fertilizer and up to 24t DM/ha with the addition of fertilizers (Kumar *et al*., 2005).

Moreover, it makes reasonable quality hay when cut in the early flowering stage, yielding up to 2.5t/ha (Osman *et al*., 2008). In Tanzania, the grass grows in natural grazing lands and is widely planted by farmers in different areas during wet seasons (Kizima, 2015). According to Kizima *et al.* (2013), African foxtail is rarely made into silage because of its low moisture content. African foxtail species is recommended to be harvested at the interval of 6 to 8 weeks at the height of 7 to 8 cm for maximum dry matter production (Cook *et al*., 2005). This recommendation disregards the variation of populations within the species which have developed as result of adaptation to environmental variables. These populations referred to as ecotypes harbour variable morphological traits (Kannan and Priyal, 2015). Variability in traits are likely to influence the way the respond to cutting intervals and cutting height, thus a need for ecotype specific management approaches. Characterization of African foxtail grass was done to ascertain morphological and productivity variation among ecotypes and recommend ecotype specific management approach. The more frequently the grass can be harvested, grow back, and give desirable yield, the better. A harvesting interval of 3 to 5 was selected for this study to see if these ecotypes have the ability to withstand defoliation more than the recommended 6 to 8 weeks frequencies for the specie.

1.1.2 Ecotypic differentiation

The geographical distribution of individuals and environmental variability affect a population as species with a broad distribution rarely has the same genetic structure over its entire range (Konnert and Bergmann, 1995). According to Eckert *et al*. (2008), if individuals of the same species are separated over a wide range, the likelihood of genetic mixing is limited, and different forces acting on the species may become more pronounced, resulting in genetic differentiation. Genetic differentiation is caused by within-species niche divergence as species evade competition or as an adaptation technique to their geographical range (Kannan and Priyal, 2015). Genetic differentiation contributes to the emergence of groups normally treated as subspecies or varieties and more often recognized as ecotypes or ecological races (Lowry, 2012). Ecotypes are defined as collections of populations renowned by a compound variation in many traits due to adaptation to environmental variables that differ in different locations (Lowry, 2012). Ecotypic differences can become irreversible or genetically fixed. Accordingly, within-species variation is often considered an advantage, as it increases the chances of a species adapting to different environmental conditions (Rao and Hodgkin, 2002). Ecotypes evolve specific structural and functional characteristics and may differ in their edaphic, biotic, and microclimate requirements (Chevin, 2010; Mansoor *et al*., 2015). The ecotypic variation affects individuals' traits, such as productivity and chemical composition. Individual traits of African foxtail ecotypes, especially of Tanzania, have not been characterized.

1.1.3 Species characterization

Despite the variation of definitions of species characterization among scholars, some denote it as a description for heritable attributes varying from morphological to molecular markers (Hassen *et al.,* 2006; El-Esawi, 2019). A process that involves gathering and recording data on the important characteristics which distinguish one species from the other and accessions or varieties within species to enable easy and quick discrimination among phenotypes (Bioversity

International, 2007). There is a consensus among scholars that species characterization reveals desirable attributes for farmers and breeders (El-Esawi, 2019; Laurentin, 2009). Desirable attributes include environmental stress adaptive and/or insects and disease resistant, high yield, and good nutritional quality (Laurentin, 2009, Shem *et al.*, 2003). Plant characterization can be achieved through agronomic, morphological, biochemical, physiological, and molecular markers (Lutatenekwa *et al*., 2020). This study used morphological and agronomical approaches to characterize African foxtail ecotypes.

1.2 Statement of the Problem and Justification of the Study

Most communal grazing lands on which livestock producers in developing countries depend have lost the ability to provide enough pasture. The number of animals is increasing, forced by the high demand for animal-sourced food (ASF) products to feed the growing human population (Weber & Windsch, 2017). Challengingly, the size of grazing land to provide forage is constantly reduced by agricultural investments for food crop production and other development activities (Tamou *et al*., 2018). Thus, the remaining grazing land has been overwhelmed by grazing pressure due to the large number of animals concentrating on small areas, leading to overgrazing and land degradation (Kavana *et al.,* 2021). The problem of animal feed shortage is worsened by environmentally caused stresses, including extended drought periods, unanticipated floods, and increase of soil salinity (Harris, 2010). Forage species that fail to adapt to environmental stresses are lost (Bell & Collins, 2008). The livelihood of livestock keepers is frequently weakened by low productivity and loss of animals because of forage shortage which worsen in dry season (Abebe *et al*., 2012; Maleko & Koipapi, 2015). FAO (2016) reported the loss of thousands of cattle in Sub-Saharan Africa (SSA) during drought resulting in financial and food insecurity. Prolonged drought in arid and semi-arid regions increases water and soil salinity, resulting in limited access to fresh water resources (Abdelsattar *et al*., 2020). Animals grazing in areas with high salinity take in excessive salt from feed, drinking water, and soil which can lead to a reduced animal growth rate (Ru *et al*., 2005). On these grounds, the world is in a never-ending need to increase forage productivity and develop new varieties more adapted to evolving environmental defies (Shantharaja *et al.*, 2015). Bioversity International (2007) warned breeders and farmers about the underutilization of forage species due to a lack of essential information on their attributes. The common species are over-utilized because their attributes are known. If more species are characterized and their attributes made known, then the room for selection to fit a given environmental condition increases.

Adaptive varieties can be used in grazing land restoration and pasture farms establishment on farmers' private land. This will ensure sustainable access to quantity and quality forages and reduce stress on communal grazing lands. Previous researches indicate that African foxtail has high productivity and adapts well to various environments (Jackson, 2005; Mansoor *et al*., 2015; Marshall *et al.*, 2012; Scott, 2014). However, the variation in growth and productivity among ecotypes, especially in Tanzania, has not been studied. The general management procedure of African foxtail has been recommended, but an ecotype-specific management plan may be required. This study, therefore, characterized African foxtail ecotypes by assessing their morphological variations, growth, and productivity under common environmental conditions and when subjected to defoliation. The information generated from this study is important for selecting and breeding the best-performing ecotype. Consequently, ecotypes with good growth, yield, and nutritional characteristics will contribute to the sustainable production of livestock feeds, eventually improving livestock productivity and the livelihood of livestock farmers.

1.3 Objectives and Hypotheses

1.3.1 Overall objective

To characterize selected ecotypes of African foxtail and assess their response to environmental stress.

1.3.2 Specific objectives

i. To assess the importance of plant characterization in challenging environments;
ii. To assess habitat and morphological characteristics of selected African foxtail ecotypes in their natural environments;
iii. To assess the growth and productivity of African foxtail ecotypes grown under common environmental conditions; and
iv. To assess the response of African foxtail ecotypes to various defoliation regimes.

1.3.3 Research hypotheses

Ho: There are no differences in habitat and morphological characteristics among African foxtail ecotypes found in selected areas of Tanzania

Ho: Forage growth and productivity do not differ among African foxtail ecotypes when grown under common environmental conditions; and

Ho: African foxtail ecotypes have different responses to the effects of different defoliation regimes

1.4 Conceptual Framework

This study considers forage species characterization as a step toward achieving sustainable pasture production in an era of numerous environmental stresses. Environmental stresses are of two kinds, abiotic and biotic stresses. Abiotic stress includes temperature, soil salinity, drought, and flooding. Biotic stresses comprise pest and disease infestations, defoliation, and anthropogenic activities. Animal husbandry and land cultivation for cash and food crops are among the anthropogenic activities influencing pasture sustainability in various grazing lands. Indefinite expansion of cultivated land to feed the increasing human population squeeze grazing lands into small patches and reduce the forage resource base for grazing animals. On the other hand, most livestock producers depend on communal grazing lands to graze their animals. These animals are continually increasing due to the increasing demand for animal-based products. Grazing a large number of animals causes trampling of the soil, resulting in compaction and reduced soil aeration. Compacted soil also reduces an area's capacity to capture, store, and safely release water from rainfall and thus enhances accelerated soil erosion and frequent floods.

Removal of forage species from grazing lands due to a large number of grazing animals and other environmental stresses reduces the vegetation cover and sometimes results in bare land. The combination of bare land with poor water infiltration causes surface water runoff during the rainy season that erodes soil. Soil erosion removes top fertile soil, resulting in low infertility, and supporting limited forage species. Therefore, forage species characterization comes in as a way to identify the best species which can adapt to environmental stresses and produce quantity and quality herbage to feed the ever-growing number of ruminant animals.

African foxtail has been reported to have good adaptive and productive qualities. On the other hand, this species has a good number of ecotypes which may vary in terms of productivity and their ability to adapt to environmental stresses. This study, therefore, characterized African foxtail ecotypes to ascertain their variation and productivity, which will contribute to increased yield and secure grazing lands in challenging situations. Furthermore, the study recommends the best-performing ecotype for livestock farmers and forage breeders. The main target of this work is to contribute to sustainable livestock productivity and improved community livelihood as a result of access to sustainable forage for ruminant animals. A schematic diagram below (Fig. 1) represents this conceptual framework.

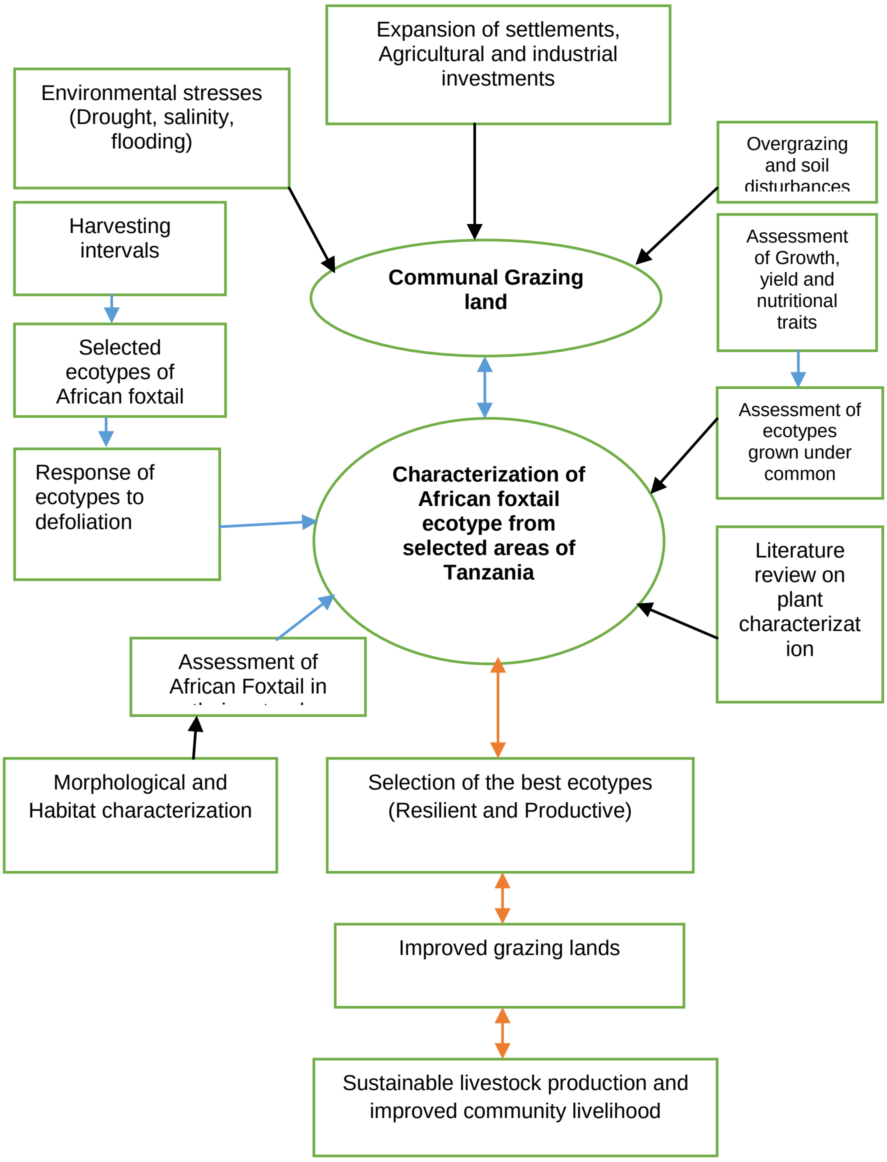

Figure 1: Conceptual framework of characterization of Cenchrus ciliaris ecotypes for sustainable forage production

(The direction of arrows indicate direction of pressure and causal effect relationship).

Source: Author, 2019.

1.5 Literature Review

This section reviews important aspects of the study and establishes the gap in the pool of knowledge. It is a brief review since profound scrutiny of the literature was done and published as paper one in this thesis.

1.5.1 Rangeland productivity and environmental stresses

Rangeland is an extensive area covering almost 50% of the earth's land area, occupied by herbaceous or shrubby vegetation grazed by wildlife and livestock (Xie *et al.,* 2019). The introduction of large numbers of grazing animals in this land of natural plant community brings intense effects on the soil and vegetation composition. The worldwide challenge of managing rangelands for sustainable productivity has always been raised from overgrazing (Menke & Bradford, 1992). According to Fynn (2012), the effects of livestock on grazing lands can be minimized by adopting malleable management practices which allow adaptation to be spatial and temporal variability in forage quantity and quality. Although grazing decreases above ground biomass, organic carbon, and nutrient concentrations in soil, well-managed grazing increases species diversity (Niu *et al*., 2016).

In addition to the effects of grazing animals on the rangelands, abiotic stresses directly affect the vegetation and the soils, which support the growth and development of forage resources (Archer & Stokes, 2000). Abiotic stresses have several forms, but the predominant ones are those with common effects on plant water status, including drought, extreme temperatures, and high salt concentration (Verslues, 2006). The effect of these stresses includes a reduction in the growth and productivity of plants (Burnett *et al.,* 2005). Unlike animals, plants are fated to places; hence they have to adapt and acquire attributes that enable tolerance to multiple stresses (Schulze *et al*., 2005). Therefore, abiotic stresses are among the influential factors determining plant species distribution in environments. Failure of plant species to adapt to environmental changes has resulted in a biodiversity crisis (Kristensen *et al.,* 2020).

However, there are forage species such as African foxtail which have been reported to adapt well and produce good quantity and quality herbage in stressed environments (Jackson, 2005; Mansoor *et al*., 2015; Marshall *et al.*, 2012; Scott, 2014). The trait of adaptability to a wide range of environmental conditions has led this species to develop a number of ecotypes with varying capabilities. This study, for that reason, selected and characterized the African foxtail forage species because of its variability and the potential for adaptability and productivity.

1.5.2 Description of African foxtail

African Foxtail grass is a perennial species from open bushlands and the grassland of Africa and has been established widely as an exotic pasture species in tropical and sub-tropical Australia (Jorge *et al*., 2008; Scott, 2014). It is found in open bushes, woodland, grasslands, and environments with light, sandy, rocky and shallow soil along the road or dry-river beds (Quattrocchi, 2006). Marshall *et al.* (2012) describes the history of this species' intercontinental dispersal and that its introduction to a wide area of the world intended to improve pastoral industries.

1.5.2.1 Morphological characteristics

African foxtail is a low- to tall-growing (about 0.3–2m), erect to sprawling, perennial tuft grass, depending on variety and growing conditions (Jorge *et al*., 2008). Seed heads are erect to nodding, straw, light green to purple at flowering, and grey or purple coloured foxtail at maturity 2–15 cm long and 1–2.5 cm wide, with seed units (fascicles) carried along a zig-zag axis (Kyle, 2006; Shantharaja *et al.,* 2015). The grass has a deep, strong, fibrous root system of up to >2.0 m (Jackson, 2005). These characteristics enable this species to play an important role in livestock grazing in the dry season and soil conservation (Kizima, 2015; Scott, 2014). According to Nawazish *et al.* (2006), this grass grows, perseveres, and remains green even in areas of extreme drought. Specific adaptation attributes of African foxtail pointed out by Nawazish *et al.* (2006) include; increased succulence, cuticle deposition, highly developed bulliform tissue, and reduced stomata size to prevent water loss. However, Arshad *et al*. (2007) recommend further evaluation of its ecotypes to determine if there are variations in its ability to adapt to changing environments.

1.5.2.2 Response of African foxtail to defoliation

It is important to understand plant response to defoliation which varies among species and even among varieties of the same species, to maintain feed availability. Resistance to grazing of a given pasture species increases with the ability to replace its clipped or grazed leaves (Briske, 1996). Favourable leaf replacement would result from setting up time and height of defoliation that will promote new tillers and avoid the development of leafless stalks (culms). Generally, studies have indicated that African foxtail is slow to establish; thus, grazing need to be delayed for 4 – 6 months after sowing, depending on establishment conditions (Mannetje and Jones, 1990). Since quality drops rapidly with age, studies recommend cutting or grazing African foxtail at least every eight weeks, depending on soil moisture and fertility. Harvesting this species at about 7 to 8 cm has also been recommended because leafiness is maintained at this height (Mannetje and Jones, 1990). This management plan is general for African foxtail specie. Knowing that this species is rich with ecotypes, it was conceptualized that different ecotypes might have different responses to the plan hence the need for a different management plan. This discernment led to the importance of characterizing selected ecotypes by subjecting them to different harvesting intervals. The aim was to contribute to the pool of knowledge regarding their characteristics and to determine the best harvesting interval for a given ecotype.

1.5.3 Forage species characterization

Forage species characterization is the first step toward selecting and breeding forage species with desirable attributes. Forage is defined as edible parts of plants, other than separated grain, that can provide feed for grazing animals or be harvested for feeding (Allen *et al*., 2011). Forage species characterization identifies attributes of interest to humans, such as productivity and adaptability, which can then be transferred in large collections to generate improved cultivars through breeding (Lutatenekwa *et al*., 2020). Plant breeding is a multidisciplinary science that engrosses and exploits innovative logical discoveries and technical approaches to recreate itself. It is a multidisciplinary science because plant breeding requires integrated knowledge of the basic biology of plants, principles of quantitative genetics, selection theory, principles and practices of genomics, skills of intellectual rights, applied statistics, and experimental design (Gepts & Hancock, 2006). Several approaches are used in forage characterization, including agro-morphological characterization, physiological characterization, Anatomical, histological and cytological characterization, and genetic or molecular characterization (Lutatenekwa *et al.,* 2020)**.** Scholars have characterized forage species for defoliation (Su *et al.,* 2013; Timpong-Jones *et al.,* 2015; Sanchês *et al.,* 2021), salinity (Al Dakheel & Hussain, 2016; Chen *et al.,* 2016; Dashtebani *et al*., 2014; Roy *et al.,* 2014) and drought (Clauw *et al*., 2015; Mansoor *et al*. 2002; Nawazish *et al*., 2006; Rauf *et al.,* 2014) by using one or a combination of two or three of the approaches as mentioned earlier. Forage species range from grass (Poaceae or Gramineae family) to leguminous plants; the scope of this thesis is on forage grasses and specifically focusing on African foxtail.

1.6 Material and Methods

1.6.1 Description of the study sites

Several sites were needed for this study. Firstly, the experimental ecotypes were morphologically assessed, and sprig samples were collected from three districts of Tanzania, namely Kilolo in Iringa Region (Southern Highlands), Kiteto in Manyara Region (Northern Tanzania), and Mpwapwa in Dodoma Region (Central Tanzania). These districts were selected purposively based on climatic, soil, and landscape variations as well as the availability of target grass species in the natural habitats. Iringa Region is located in the cool southern highlands of Tanzania and is characterized by temperate dry winter and warm summer climate, classified as a sub-tropical highland climate. The average annual temperature in Iringa is

19.1°C. The climate of Manyara Region is tropical savannah with average annual temperature and rainfall of 21.8°C and 678 mm, respectively. On the other hand, Dodoma Region depicts features of a semi-arid climate with relatively low rainfall and a high frequency of droughts. Experiments for agro-morphological characterization of selected ecotypes were set at Magadu Dairy Farm (MDF), a property of Sokoine University of Agriculture (SUA) found in Morogoro, Eastern Tanzania. The farm is located at 6 ° 50' 59'' S and 37 ° 39' 10'' E and 537 meters above sea level (masl) with sandy clay and reddish-moderately acidic soil. The area is characterized by a bimodal rainfall pattern of short and long rains. Short rains start from November to December, long rains start from March to May, and sometimes extend to June. The average annual rainfall ranges from 600 up to 900 mm, with mean annual temperature ranging from 25 ° C to 30 ° C. Laboratory analyses were carried out in the Animal Nutrition Laboratories at the Department of Animal, Aquaculture, and Range Sciences (DAARS) and in the Soil laboratory at the department of Soil and Geological Science at SUA.

1.6.2 Study design

This study was based on four specific objectives using integrative methodological approaches, including a literature review, survey, field experiments, and laboratory analyses.

A systematic literature review (SLR) of scientific documentations on plant characterization for sustainable forage production in challenging environments was conducted for the first specific objective. In order to establish a body of knowledge on the subject, various data sources, including published and unpublished documents, were used. Published online databases were accessed using numerous search engines with pre-determined keywords to filter for relevant literature (Pullin and Stewart, 2006). This review considered peer-reviewed journal articles, government reports, papers presented in conferences, book chapters, and theses published from 2002 to 2020. Information obtained was analysed to determine the situation regarding forage species characterization (Paper 1).

In the second objective (Paper 2), a cross-sectional study was conducted in three districts of Tanzania, namely Kilolo, Kiteto, and Mpwapwa, to assess the morphological characteristics of selected ecotypes in their natural environments. The selection of districts was purposeful grounded on information obtained beforehand concerning place accessibility and African foxtail availability. Moreover, the districts had variations in ecological, topographical, climatic conditions, and anthropogenic activities. Two villages were selected from every district, and potential sites were identified in each village where three plots (10 m diameter each) were made. Site or location data were collected, including geographic coordinates, temperature, rainfall, topography, soils at 0–20 and 20-40 cm depth, land utilization, associated plant species, and vegetation type. Ten tussocks of the desired (target) ecotypes were randomly selected from each plot and their morphological characteristics, which included plant height (PH), tiller number (TN), leaf number (LN), leaf length (LL), and inflorescence length (IL) were assessed and recorded. Ecotypes assessed were known based on the local names given by the native (citizens) of the corresponding village. When similar names from different villages were given, a village name was added for identification. Ecotypes from Kilolo were Iramata malolo (*Ir*) and Iramata mtandika (*Im*), from Kiteto were Ologoraing'ok namelock (*On*), and Ologoraing'ok twanga (*Ot*), and ecotypes from Mpwapwa were Nzingangata (*Nz*) and Orupilipili (*Op*).

At this point, the importance of conducting another study to assess the growth and productivity of these ecotypes in a common (same) environmental condition was realized (Specific objective 3). The experiment was set at MDF in Morogoro in a completely randomised design (CRD) with three replications. Forage growth and productivity of the ecotypes were evaluated. Planting materials were from the six ecotypes (*Ot*, *On*, *Nz*, *Op*, and *Im*. The *Ir* ecotype in this experiment failed to give enough experimental materials in the multiplication plots and, therefore, was left out (leaving only five ecotypes). Each of the five ecotypes was planted in a plot of 12 m^2. Standard management procedures were followed and applied equally to all ecotypes. The agronomic procedures involved were; fertilizer application, weeding, and need-based irrigation. The intention was to minimize the effects of other factors like moisture and nutrient stress on the plants.

In another experiment (fourth objective), the response of the five selected ecotypes to defoliation stress was assessed. Defoliation was represented by harvesting intervals. The study looked at the effects of harvesting intervals on forage growth, yield, and nutritional value of the five ecotypes and was conducted at MDF. A factorial design (5*3) with three replications was used. Ecotypes were *On, Ot*, *Nz, Op,* and *Im*, and the three harvesting intervals were 21 days (T1), 28 days (T2), and 35 days (T3). The literature recommends a general 6 to 8 weeks harvesting interval for the species without considering ecotype variation. Therefore, a harvesting interval of 3 (21 days), 4 (28 days) and 5(35 days) was selected for this study to see if these ecotypes have the ability to withstand defoliation more than the recommended frequencies and provide the desired yield.

1.6.3 Data collection

1.6.3.1 Literature study

The main data source was an Internet search, from which articles and reports on plant characterization approaches, forage, and environmental stresses were collected. Documents were screened by reading titles and abstract, when found relevant a full document was synthesized to extract facts, evidence, and key messages.

1.6.3.2 Vegetation sampling

Plant species in a 10 m diameter plot were counted and recorded for the determination dominance of African foxtail grass. Morphological assessment of African foxtail grass was done by recording plant height (PH), tiller numbers (TNT), inflorescence length (IL), and leaf area (LA) of ten randomly selected tussocks per plot. Fresh samples for analysis of forage dry matter yield and chemical composition characteristics were harvested from two quadrats of 1 m^2 per plot and sent to the laboratory for oven drying.

The collection of sprigs for propagation was done by purposeful sampling and uprooting five healthy sprigs per plot from eighteen plots of the six study sites. Sprigs collected were packed in plastic bottles filled with soil, which were well arranged in trays and transported to MDF at SUA, Morogoro. In multiplication plots, sprigs from the same site were planted in the same row, 2 m between rows and 50 cm between sprigs. After multiplication, sprigs were available to conduct agronomical experiments.

1.6.3.3 Soil sampling

The soil was sampled from three randomly selected points of each 10m diameter plot at 0 – 20 and 20 – 40 cm depth. The three samples from the same plot of a similar collection depth were mixed to form a homogenous soil. Soil samples weighing 500g were packed in a labelled polyethylene bag and sent to the laboratory for physical and chemical analysis.

1.6.4 Laboratory analyses

Laboratory analyses of vegetation samples were conducted at DAARS and that of the soil samples at the Department of Soil and Geological Sciences at SUA. Nutritional value analyses were conducted using the Kjeldah method - AN_ 300; Tecator Kjeltec System procedure for block digestion and steam distillation; fibre fractions in the detergent system according to Van Soest *et al.* (1991) and *in vitro* digestion according to Tilley and Terry (1963). Soil samples were analysed to determine soil colour, texture, pH, and salinity according to standard procedures (Okalebo *et al*., 2002).

1.6.5 Data analysis

Data on habitat and morphological characteristics of African foxtail ecotypes from selected areas of Tanzania were sorted and arranged in Microsoft Excel 2013 spread sheet. Data were then analysed by descriptive and inferential statistics. Plants associated with and the dominance of African foxtail in the sites studied were analysed by using Simpson's index formula (Whittaker, 1972) as shown below:

$$ID = 1 - (\sum \frac{n(n-1)}{N(N-1)}) \qquad (1)$$

Whereas, ID represent the dominance Index, n is the number of individuals of ecotypes in the sample, N is the total number (all species) of individuals in the sample, and $\sum$ is the summation sign.

Experimental data were subjected to analysis of variance analysed using a general linear model of the Statistical analyses System (SAS) software. Means were separated using least square means and Duncan mean comparison at the probability of five percent ($p < 0.05$).

Two statistical models were used.

$$Y_{ij} = \mu + E_i + \varepsilon_{ij} \qquad (2)$$

$$Y_{ijk} = \mu + E_i + H_j + EH_{ij} + \varepsilon_{ijk} \qquad (3)$$

Where: Y = Response, μ = General mean, Ei = ecotype effect, Hj = Harvesting interval effects, EHij= interaction effect of ecotype and harvesting interval and Ɛijk = error term

1.7 Scope and Limitations of the Study

The scope of this study was limited to three regions: the first from the northern part of Tanzania, the second from central Tanzania, and the third from the southern highlands of Tanzania. One district from each region was selected, and from each district, only two villages were included in the study. The selection of these villages was purposeful based on accessibility logistics and time limitations. Financial constraints limited the study from covering more districts and villages in the country; and access to sophisticated characterization approaches. The expeditions for habitat and morphological assessment required to be conducted during and soon after the rainy season when most of the grasses were at the blooming stage of growth and enabled species identification using inflorescences. In this period, it was also easy to take soil samples.

1.8 Layout of the Thesis

The present report is divided into five sections: extended abstract, the general introduction, a paper-based chapters, a general discussion, and conclusions and recommendations sections. The **Extended Abstract** gives a summary of the subject and obtained results. Chapter one (**General Introduction**) presents background information about the study, the statement of the problem and justification of the study, research objectives and hypothesis, a review of literature, methodology, limitations of the study, and a description of the organization of the thesis. This is followed by four **paper-based chapters,** including two original published papers (Chapters two and three), one accepted paper for publication (chapter four), and one manuscript submitted to the journals for publication (Chapters five). The papers are designed to complement each other towards accomplishing the study objectives. **The general discussion** (Chapter 6) focuses on general study findings based on the research hypotheses of this study. Finally, the **Conclusions and Recommendations section** summarises, concludes, and provides recommendations for the study based on the findings, discussion, and interpretation. The section further proposes the areas for further study.

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CHAPTER TWO

2.0 PAPER ONE

A review of plant characterization: First step towards sustainable forage production in challenging environments[1]

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Abstract
This review paper attempts to give an account of how a plant characterization assists the availability of information on desirable plant traits to enhance selective breeding for environmental stresses and thus attain sustainable forage production. Plant characterization is referred to as an account for heritable characters varying from agronomical, and morphological to molecular markers. It simplifies the grouping of accessions, development of core collections, identification of gaps, and retrieval of valuable germplasm for breeding programmes resulting in better insight into the composition of the collection and its genetic diversity. Plant characterization by morphological, physiological, and agronomic traits has long been used in selective breeding. However, the advancement of characterization to use molecular markers speeds up the process and permits optimal utilization of the adaptive traits harboured in all

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breeds for stressful environments. In countries like Tanzania, where agro-climatic conditions are challenging, technological progress is slow, and market institutions are poorly developed, selecting highly adaptive local varieties is important. Knowledge from the characterization of local varieties could be used to breed adaptive and resilient varieties. This will help the farmers to produce enough forages in fast-changing and stressful environmental conditions.

Key words: C*haracterization, Cenchrus ciliaris, drought, salinity, traits*

2.1 Introduction

Livestock producers in developing countries depend on rangelands' forage to feed their stocks (Msalya *et al.,* 2017). However, the forages from these rangelands are seasonally low in quality and quantity and, therefore, negatively influence livestock productivity (Waterman *et al.,* 2007). Butchart (2010) observed that valuable local species are becoming rare, some disappearing or on the brink of extinction. Loss of diversity has consequences beyond just the extinction of species. Once local populations are wiped out, the genetic diversity contained in each species to adjust to environmental stresses is weakened; in turn, the livestock production systems are also affected.

Like most other developing countries, livestock production systems in Tanzania are facing losses in response to several drivers (Thornton *et al.,* 2009). Environmental stresses are among the drivers that affect plant and animal productivity (Singh *et al.*, 2011). The effects of these stresses on plants have been documented (Naqvi *et al.,* 2015; Forni *et al.,* 2017; Dzavo *et al.,* 2019). The prevalent ones are those affecting plant water status (Claeys *et al.,* 2014). According to Verslues *et al.* (2006), not having enough water potential for a plant to perform its biological roles can be caused by drought, extreme temperatures, and salinity. Plants usually stimulate a complex cellular and molecular mechanism to adapt to stress (Fahad *et al*., 2015). The United Nation Food and Agricultural

Organisation (FAO, 2007) corroborates the distribution of wild plants, species' range shifts and gradual biological changes associated with environmental stress responses. Response of plants to stress differs within and among species depending on stress intensity, stage of plant growth, and duration of exposure to stress (Claeys *et al.,* 2014). The availability of varieties and ecotypes of species with different levels of tolerance to environmental stresses is an opportunity for selection and breeding for stress tolerance. Selection and breeding of grasses with stress tolerance traits are inevitable across the globe amid escalating environmental stresses. This paper examines available literature on plant characterization focusing on sustainable forage production in drought and salinity environments. Several forage species have been characterized, but this paper focuses on the agro-morphological, physiological, and molecular characterization of *Cenchrus ciliaris*. The species is selected because it grows well in a wide range of soil types and climatic conditions, and farmers have adopted it in different regions of Tanzania for pasture establishment. *Cenchrus ciliaris* is a perennial deep-rooted, tufted, and rhizomatous grass, traits which make it fairly adapted to heavy grazing and tolerant to drought (Jackson, 2005; Burson *et al*., 2012). The grass is a wealth of natural ecotypes with morphological diversity, which can be visually distinguished and rapidly screened (Burson *et al*., 2012). Morphological diversity of ecotypes signifies variability of response to environmental stresses hence the need to be characterized.

2.2 Methodology

The information gathering process employed PRISMA approach, a four stage method for literature review. The stages included Identification, Screening, Eligibility and inclusion. Identification of required information was done using Google scholar, an internet search engine that makes it easy to access online databases. Some databases accessed include African Journals Online, Directory of Open Access Journals, Emerald, JSTOR, Research4Life, Science Direct, and Web of Science. Furthermore, publications from FAO and International Livestock Research Institute were searched and reviewed. Peer-reviewed journal articles, conference papers, government reports, book chapters, and theses published from the year 2002 to 2020 were considered for this review. Key words or search terms used were: ‘characterization’, ‘plant characterization’, *‘Cenchrus ciliaris’*, ‘forage’, ‘pasture’, ‘fodder’, ‘environmental stress’, ‘drought stress’,’ water stress’, ‘salt stress’, ‘salinity stress’, ‘molecular characterization’, ‘physiological characterization’, ‘agronomical characterization’ and ‘morphological characterization’. Screening of the papers was done by reading the titles followed by the abstracts, and where relevant, a full document was read to extract facts, evidence, and key messages. A total of 97 publications were recovered, of which 19 were reports and book chapters, and 78 were journal articles and conference papers. A total of 46 publications were removed, of which 10 were abstracts, and their full paper could not be accessed, 6 were duplicates, and 28 were not relevant, the remaining 51 publications were used in this paper.

2.3 Findings and discussion

The review findings show the description of plant characterization by scholars, approaches of plant characterization, characterization for drought tolerance, characterization for salinity tolerance, plant characterization endeavours in Tanzania, and the novelty of plant characterization.

2.3.1 Plant characterization as concept

There are several definitions or descriptions of plant characterizations given by scholars. However, many scholars refer to it as an account of heritable characters varying from morphological to molecular markers (Hassen *et al.,* 2006; El-Esawi, 2019). It is a process that involves recording and compilation of data on important characteristics which distinguish one species from the other and accessions or varieties within species to enable easy and quick discrimination among phenotypes (Bioversity International, 2007). Plant characterization reveals desirable traits for farmers and breeders (Mwenda, 2019; Bucheyeki *et al*., 2010; Laurentin, 2009). The ability to adapt to environmental stresses and varieties with better quality and high yield are among the desirable plant traits (Laurentin, 2009; Mwenda, 2019).

2.3.2 Approaches of plant characterization

The review reveals that there are several approaches to plant characterization. Substantial works could be sorted into the main approaches, which are agronomic, morphological, biochemical, physiological, and molecular characterization.

2.3.2.1 Agronomic, morphological, biochemical, and physiological characterization

Past reviewed works pointed out that visual assessment of growth forms and structure of plants in different types of soils and using the variable amount of required nutrients is agronomical and morphological characterization (Jorge *et al*., 2008; Lima *et al.,* 2018; Wassie *et al.,* 2018). Agro-morphological traits include plant height, tiller number, tiller type, leaf size and number, internode distance; flower type, size, and colour; root type, and length. Agro-morphological traits are non-destructive parameters (Fuzy *et al.,* 2019) and describe plant morphologies efficiently (Blazakis *et al*., 2017). There are limitations to using agro-morphological traits for plant characterization, such as a limited number of traits to characterize, heritable traits showing insignificant variations, and trait expression is influenced by environmental conditions, age, and cultivation systems (Blazakis *et al*., 2017; Laurentin, 2009). Despite the limitations, morphological or visible descriptors remain important for identifying landraces to enhance selection and utilization. These descriptors will continue to be used especially in developing countries, until sophisticated methods like molecular markers are easily accessible and affordable. Biochemical characterization refers to characterization based on the types of phytochemicals present in a plant in a given environmental condition, root electrical capacitance, membrane stability index in roots and leave, the amount of methane (CH_4) produced, dry matter and nutrient composition (Kannan and Priya, 2020; Fuzy *et al*., 2019).

On the other hand, the characterization of plants based on their functions, such as their photosynthesis process, respiration gases produced, and nutrient circulation, is referred to as physiological characterization (Saini *et al.,* 2007). Furthermore, transpiration and CO2 assimilation rates are some physiological descriptors (Fuzy *et al.,* 2019; Mansoor *et al*., 2015). The limitation of biochemical and physiological descriptors is that they use destructive measurement techniques (Fuzy *et al.*, 2019). Saini *et al.* (2007) conducted a morpho-physiological characterization study with four *Cenchrus ciliaris,* two Cenchrus setigerus, and one genotype of *Panicum maximum* grass in an arid ecosystem. In their experiment, seven morphological characteristics and nutritional values were used for characterization. *Cenchrus ciliaris* cv. CAZRI 75 had higher total green fodder yield, DM, and nutritional value. Based on their results *Cenchrus ciliaris* cv. CAZRI 75 was found to be of high potential among the studied grasses to be used in the arid regions of southwest Haryana, India.

On the other hand, Kannan and Priya (2020) characterized ecotypes of *Cenchrus ciliaris* on biochemical compounds found in different components. The ecotypes were grouped based on inflorescence colour variation (white, green, and black). According to Kannan and Priya (2020), all ecotypes had the phytochemicals screened regardless of the part containing the compound, except for glycosides, which were absent in white and black variants (Table 1).

Table 1. Phytochemical screening of extracts from different parts of the three ecotypes of Cenchrus ciliaris (▲indicates the presence and ◊ indicates the absence of the substances)

Bioactive groups	White			Green			Black		
	Stem	**Leaf**	**Florets**	**Stem**	**Leaf**	**Florets**	**Stem**	**Leaf**	**Florets**
Phenol	▲	▲	▲	▲	▲	▲	▲	▲	▲
Flavanoins	▲	▲	▲	▲	▲	▲	▲	▲	▲
Saponins	▲	◊	▲	▲	▲	▲	▲	▲	▲
Glycosides	◊	◊	◊	▲	▲	▲	◊	◊	◊
Steroids	▲	▲	▲	▲	▲	◊	◊	▲	◊
Alkaloids	▲	▲	▲	▲	▲	▲	▲	▲	▲

Source: Kannan and Priya (2020)

Phytochemical composition is very much affected by environmental stresses; the absence or presence of these compounds can be used as a measure of the effects of stresses (Daniels *et al*., 2015).

2.3.2.2 Molecular characterization

Reviewed studies referred to characterization of organisms using DNA-based markers as molecular characterization (Laurentin, 2009; Kumar and Saxena, 2016). The process of molecular characterization used by Ouédraogo *et al.* (2019) involved DNA extraction and quantification, purifying of the PCR products, sequencing followed by editing of the raw sequences, and finally, assembly of the readings to check their identity. Molecular markers are prominently used for evolutionary studies, evaluating interrelationships among accessions and geographical groups. They are also potential for estimating genetic diversity and identifying duplicates (Laurentin, 2009). It allows simple grouping of accessions, development of core collections, identification of gaps, and retrieval of valuable germplasm for breeding programmes, resulting in better insight into the composition of the collection and its genetic diversity (Bioversity International, 2007).

Diversity is important if forage species are to adapt to different environmental conditions and provides room for selection and breeding. Kumar and Saxena (2016) characterized eight species of the genus *Cenchrus* (Table 2) based on their mode of reproduction. In addition, there was further characterization using Sequence Characterized Amplified Regions (SCAR) markers within the apomictic group to establish their diversity. It was observed that *Cenchrus glaucus* had more genetic diversity than the other three species, as shown in figure 1.

Table 2. Characterization of Cenchrus species based on mode of reproduction and ploidy status

***Cenchrus* species**	**Accession number**	**Habit**	**Ploidy status**	**Mode of reproduction**
C. biflorus	IG-03308	Annual	Diploid (2n = 2x = 34)	Sexual
C. ciliaris	G-693108	Perennial	Tetraploid (2n = 4x = 36)	Apomictic
C. echinatus	IG-96377	Annual	Tetraploid (2n = 4x = 68)	Sexual
C. glaucus	IG-96649	Perennial	Tetraploid (2n = 4x = 36)	Apomictic
C. myosuroides	IG-96380	Perennial	Heptaploid (2n = 7x = 70)	Sexual
C. pennisetiformis	IG-96707	Perennial	Hexaploid (2n = 6x = 54)	Apomictic
C. prieurii	IG-97473	Annual	Diploid (2n = 2x = 34)	Sexual
C. setigerus	IG-01346	Perennial	Diploid (2n = 2x = 36)	Apomictic

Source: Kumar and Saxena (2016)

Based on their research findings, they concluded that identified markers would be useful for comparative studies and marker-assisted breeding of *Cenchrus* (Kumar and Saxena, 2016).

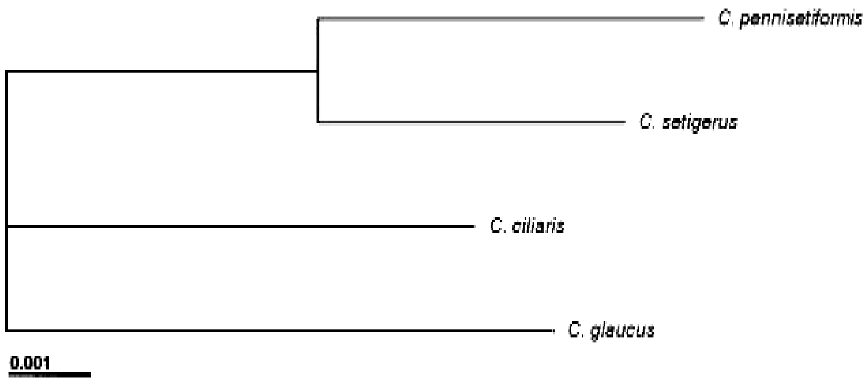

Figure 1. A dendrogram showing sequence diversity among the four apomictic Cenchrus species
(Kumar and Saxena, 2016).

2.3.3 Characterization for drought tolerance

Drought or soil moisture stress is characterized by periods of below-average precipitation, which are poorly distributed and have become a more frequent and enormous problem worldwide (Dzavo *et al.*, 2019; Forni *et al.,* 2017). Drought negatively impacts species diversity, quantity, quality, and reliability of forage as well as rangeland vegetation patterns (Giridhar and Samireddypalle, 2015; Nardone *et al.,* 2010). For plants to colonize and survive drought-affected areas, they need to adapt. Morphological adaptations like the development of thick leaves and epidermal layers, waxy cuticles, complex root systems, and diverse molecular mechanisms allow plants to live in extreme conditions (Clauw *et al.,* 2015; Nawazish *et al.,* 2006). According to Acuña *et al.* (2012), a systematic study of morphological, physiological, and biochemical characteristics that provide the ability to tolerate stress can lead to understanding the response of plants to water dearth.

Furthermore, Acuña *et al.* (2012) pointed out traits that can be used in selection for drought tolerance, including plant water status, stomata conductance and canopy temperature, spectral vegetation indices, chlorophyll fluorescence, and water use efficiency. Understanding desirable traits for high output and drought tolerance is a step toward plant improvement through selective breeding. A study by Mansoor *et al*. (2002) on 16 biotypes of *Cenchrus ciliaris* from the germplasm in Pakistan was conducted to examine the effect of drought on agro-botanical and morpho-genetical characters. Although certain biotypes expressed good individual scores regarding various characters, one excelled in plant height, number of leaves, root number and length, and fresh and dry weight. Based on their research findings, Mansoor *et al.* (2002) concluded that a high-volume root system is a good index to judge the level of drought tolerance. In another study (Mansoor *et al.,* 2015) on root morpho-anatomical adaptation for drought tolerance in *Cenchrus ciliaris, an* increase in root number, development of epidermis, endodermis, and cortical parenchyma for drought-tolerant ecotypes were reported. Drought-sensitive ecotypes expressed a decrease in all morphological and anatomical root characteristics (Mansoor *et al*., 2015).

On the other hand, Nawazish *et al*. (2006) characterized two ecotypes of *Cenchrus ciliaris* based on their response to drought by treating them with 100%, 75%, and 50% field capacity of soil moisture levels. Ecotypes were collected from the salt range of Punjab and irrigated soils of Faisalabad in Pakistan. Their results showed that the ecotype from the salt range adapted better to moderate and high drought levels. The drought adaptive ecotype had increased leaf thickness, cuticle deposition, and epidermal layer thickness but had reduced metaxylem area for efficient water transportation in adverse conditions. Nawazish *et al.* (2006) concluded that highly developed bulliform tissue (responsible for leaf culling) and reduced stomata size on the upper surface of the leaf to prevent water loss are important leaf anatomical traits for adaptation to drought. Koech *et al.* (2014) characterized six range grasses (*Chloris roxburghiana, Eragrostis superba, Enteropogon macrostachyus, Chloris gayana, Soghum sudanense and Cenchrus ciliaris*) from the rangelands of Kenya. The aim was to evaluate the effect of different moisture content levels (80%, 50%, 30%, and rain-fed) on seed yield of the six species. Among all species characterized, *Cenchrus ciliaris* expressed potential for seed production even under moisture deficit by having no significant difference with the watered treatments (Koech *et al*., 2014). A good number of ruminants are lost in Sub-Saharan Africa during drought, causing financial loss and food insecurity (Dzavo *et al.,* 2019). Nardone *et al.* (2010) pointed out that drought affects production in terms of growth, yield, and quality of forage produced. The negative effect of drought on forage poses a significant financial burden to livestock producers through decreased milk component and milk production, meat production, reproductive efficiency, and animal health (Naqvi *et al.,* 2015).

2.3.4 Characterization for Salinity Tolerance

Studies revealed that accumulated salt in soils is a major constraint in agricultural production as it decreases the osmotic potential of the soil with resultant effects on plant water uptake (Roy *et al.,* 2014; Verslues, 2006). More than 20% of cultivated land and about 62 million ha of the world’s irrigated soils have been affected by salt (Gupta and Huang, 2014; Fahad *et al.,* 2015). In arid and semi-arid lands, soil salinity is caused by evapotranspiration, lack of leaching water, and poor-quality irrigation water (Jouyban, 2012). The resultant effect of soil salinity is visible in seed germination, survival percentage, growth, yield, and quality of plants. A report by Verslues (2006) showed that salinity affects the metabolism of carbon and nitrogen, assists the accumulation of toxic ions, and alters the uptake of ions, especially K^+ and Ca^{2+}, which are important nutrients for plant growth and development. Thus, the effects of salinity on plants can be summarized to include water deficit due to high pressure on the root zone, ion toxicity, and nutrient imbalance (Ronen, 2016). Plants develop physiological and biochemical mechanisms in order to survive in salt-affected areas (Gupta and Huang, 2014). Some plant species have moderate salt tolerance and are capable of providing 5–10 tonnes of edible dry matter (DM) year^{-1}, at the lower levels of salinity (<15 dS m^{-1}) particularly when the availability of water is high (Masters *et al.,* 2007). Production levels drop, and the plant options decrease significantly at high salt concentrations (>25 dS m^{-1}). Al-Dakheel and Hussain (2016) conducted a study in Dubai on genotypic variation for salinity tolerance on 160 accessions of *Cenchrus ciliaris.* The salinity levels used were 10, 15, and 20 dS m^{-1} and 0 for control, and the trait tested for salinity tolerance was biomass yield. Their results revealed that a number of accessions could be grouped in one cluster due to their similar response to salinity levels. Out of 160 accessions characterized, only 12 were stable, salt tolerant, and produced a good dry biomass yield, suggesting their potential to contribute to the improvement of grass crops through genetic mechanisms in saline areas (Al-Dakheel and Hussain, 2016).

There have been developments in this area with the purpose of producing stress-tolerant species. A study by Lopez *et al.* (2011) targeting to obtain a new *Cenchrus ciliaris* germplasm that would tolerate salinity and drought were conducted through induced physical and chemical mutation and invitro selection. Five hundred mature seeds of *Cenchrus ciliaris* were subjected to treatment with x-ray (400 Gy) or Ethyl methane sulfonate water solution (EMS) 5.5mM for 24 hr. After seven days, germinated seeds were subjected to NaCl and Mannitol to simulate salinity and drought, respectively. 20 Seedlings grown from seeds treated with x-ray tolerated up to 200 mM NaCl, and 8 tolerated up to 100mM mannitol. 21 Seedlings grown from seeds treated with EMS tolerated up to 200 mM NaCl, and 5 tolerated up to 100 mM mannitol. Hence, a total of 54 tolerant plants were obtained from induced mutation. According to Lopez *et al*. (2011), ten plants out of 54 tolerant plants obtained indicated polymorphism with respect to the control cv Biloela using RAPD technique. Only five among the polymorphic plants exhibited morphological modification under *ex vitro* conditions.

2.3.5 Studies on Forage species Characterization in Tanzania

Several studies on plant characterization have been conducted in Tanzania, but these studies have been biased toward food crops.

Gramineae family (a family where forage grasses belong) selected as examples of characterized food crops in the country are Mangosongo *et al*. (2019), Dolo (2018), Fisher *et al*. (2015), and Bucheyeki *et al*. (2010). Mangosongo *et al*. (2019) characterized four wild rice populations based on their agro-morphological traits. Their result indicated a wide range of variation for all traits studied among and within populations. The variation in agro-morphological traits presents an opportunity for selection and breeding. A study by Dolo (2018) evaluated the response of 8 rice genotypes to salinity at levels of 0, 50, and 100 mM NaCl. Reduction in physiological traits, ion accumulation, and dry matter content of rice were used to distinguish salinity tolerant and susceptible genotypes. The study used a marker-assisted selection technique to identify salinity-associated traits in order to increase selection efficiency and accelerate the breeding process. One of the eight studied genotypes was tolerant to salinity and was used as a donor parent to improve salinity-susceptible genotypes. According to Dolo (2018), improved genotypes were more tolerant to salinity than the parent genotypes. Another study by Bucheyeki *et al*. (2010) characterized 40 sorghum landraces from Tanzania and two from Zambia. The aim was to determine genetic relationships among landraces and assess important agronomic traits. Their study observes 78.6% total variability among the races. Bucheyeki *et al*. (2010) concluded, based on their research findings, that molecular markers undoubtedly separated landraces within and between groups more than morphological markers.

On the other hand, a report by Fisher *et al*. (2015) showed that 25% of maize crop cultivating areas in Africa suffer frequent droughts with losses of up to half the harvest. Drought-tolerant maize developed after the screening, selection, and breeding enhanced by information on desirable traits and disseminated to 13 African countries, including Tanzania. However, there was limited adoption of drought-tolerant maize seeds by farmers, which varied considerably between countries. Among the factors that hindered farmers' fast adoption of drought-tolerant maize seeds was limited knowledge of beneficial traits harboured in those new ones (Fisher *et al*., 2015). Farmers and breeders need reliable information to make informed decisions for selecting and breeding forage plants. As pointed out earlier, when desirable traits of species, varieties, or ecotypes are properly understood, it makes a good step toward selecting and breeding for environmental stresses. Conversely, there is limited work on range grass characterization for environmental stresses in Tanzania; thus, researchers' deliberate efforts are required to attain sustainable forage production amid environmental challenges.

2.3.6 The Novel of Plant Characterization

With the advancement of agricultural and allied science and technology, the ability to feed the increasing number of humans and livestock in the next twenty years is still uncertain, particularly because of the challenging environmental conditions. The demand for good quality soils to produce food crops and fruits has escalated, pushing the production of forage crops to marginal lands with a multitude of environmental challenges (Acuña *et al*., 2012). In this perspective, the ability of forage plants to tolerate environmental stresses is indispensable. Various strategies have been proposed to optimize reliability and resource use for increased forage demand (Busby *et al.,* 2017). Plant Characterization is one of the priority areas expected to ensure adaptive and productive characteristics are identified and appropriately utilized to enhance plant productivity. Plant breeders will easily access and utilize this information to develop new productive plants with improved environmental stress tolerance (El-Esawi, 2019). Govindaraj *et al*. (2015) suggested that the application of plant characterization would lead to long-lasting increased productivity and benefit the environment. It is explicit that plant characterization can lead to capturing plant genetic diversity; store it in the form of plant genetic resources like the gene bank and DNA library for a long period. The conserved plant genetic resource is readily available materials to be utilized for crop improvement in order to meet future global challenges in relation to food and nutritional security. However, the use of genetic resources is limited by inadequate essential information on phenotypic and genotypic characters (Shantharaja *et al.,* 2015).

Since plant breeding research and cultivar development are integral components of improving food production; therefore, the availability of and access to information on diverse genetic and phenotypic sources will ensure that the global food production network becomes more sustainable (Govindaraj *et al.,* 2015). It was denoted by Hoffman (2010) that most tropical-adapted varieties are essentially uncharacterized. The characterized plants ended at the species level documenting a specie's response to different levels and types of stress. On the other hand, there are variations of characters within species important for the development of stress-resistant cultivars and varieties (Jorge *et al*., 2008; Acuña *et al.,* 2012). Therefore, understanding adaptation in stressful environments and optimal utilization of the adaptation traits harboured in all breeds need to be strengthened for sustainable livestock forage production.

2.4 Conclusion

Evidence of a substantial decline in livestock feeds quality and quantity due to environmental stresses calls for appropriate strategies to optimize the reliability of forage production with scarce resources. Drought and salinity threaten the sustainability of forage production by negatively impacting plant growth and productivity. A good knowledge of response variation among and within forage species to stress is required to facilitate the identification of an effective tolerance mechanism. It is worth taking advantage of available tools and technologies like plant characterization to improve plant selection and breeding, targeting adaptable traits to environmental stresses. Agro-morphological, physiological, biochemical, and molecular characterization are among the approaches used to generate information on desirable plant traits. *Cenchrus ciliaris,* a forage species focused on in this review, revealed its ability to adapt to drought and salinity, which affect the water potential for a plant to perform its biological roles. Its adaptation was enhanced by a complex root system, reduced stomata size on the upper side of the leaf, increased leaf thickness, cuticle deposition, epidermal layer thickness, and reduced metaxylem area for efficient water transportation. Through this process, plant characterization fast-tracks systematic information generation to assist plant breeders in efficiently selecting adapted plants to specific environmental stresses. The limited literature on forage species characterization in Tanzania calls for deliberate efforts from researchers in this area.

2.5 Disclosure of conflict of interest

This review paper is a part of a PhD research work in Animal Science at Sokoine University of Agriculture.

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CHAPTER THREE

3.0 PAPER TWO

Morphological Characterization of Selected Ecotypes of African Foxtail Grass (*Cenchrus ciliaris*) from Selected Areas of Tanzania[2]

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Abstract

This study assessed the morphological variation of African foxtail grass (*Cenchrus ciliaris*) ecotypes in natural habitats from three selected districts, namely, Kilolo, Kiteto, and Mpwapwa in Tanzania. In each district, two villages were selected, and morphological traits were assessed at one site for each village. Three plots 10 m in diameter and 40 m apart were made at each site. Ten tussocks of African foxtail grass were randomly selected from each plot to assess height, tiller number, leaf number, leaf length, and inflorescence length. Environmental characteristics like altitude, vegetation, and soil types were also assessed because they affect the morphological traits of African foxtail grass. The lowest altitude was in Kilolo (Malolo village) at 528 masl, and the highest was at 1613 masl in Kiteto (Twanga village). The soil texture was primarily sandy clay, with p^H ranging from moderate acidic of 5.6 to moderate alkaline of 8.3. The recorded average annual rainfall and temperature ranged from 643 – 1157 mm and 19.4 to 24^{o}C,

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respectively, in the study areas. The vegetation was influenced by anthropogenic activities, mainly grazing and farming. The study found a significant variation for all morphological traits assessed across the selected ecotypes. Ecotypes from Kilolo and Mpwapwa districts had relatively higher mean values for all traits assessed except tiller numbers, while ecotypes from Kiteto District had low mean values for all traits except tiller numbers. The study concludes that African foxtail grass is morphologically variant among and within ecotypes. Further assessment of these ecotypes when grown under common environmental conditions is recommended to reaffirm the morphological variation.

Keywords: *Ecotype variation,* Environmental condition, *Habitat, morphological traits.*

3.1 Introduction

Tanzania depends mainly on natural pastures in communal rangelands to feed ruminant species such as cattle, sheep, and goats. On the other hand, low pasture biomass production and fodder scarcity are major challenges affecting livestock production (Maleko *et al.,* 2019). In addition, negative effects of climatic variability, including unpredictable floods, prolonged drought periods, and salt accumulation in the soils of arid and semi-arid lands, threaten productive rangelands (Scott, 2014). To disentangle these challenges, it has been recommended to select and breed pasture species with high productivity and the potential to withstand different stresses or at least have the capacity to adjust to certain ecological and environmental situations (Arshad *et al*., 2007). Successful selection, breeding, commercialization, and easy adoption of species by farmers depend on available information about desirable traits generated through species characterization (Govindaraj *et al.,* 2015; Lutatenekwa *et al.,* 2020). Therefore, plant Characterization is a priority area expected to contribute to ensuring adaptive and productive traits are identified and appropriately utilized to enhance plant productivity (Lutatenekwa *et al.,* 2020).

Nevertheless, forage species' characterization has been a neglected area of study in Tanzania. Before this study, there was limited information on the extent of morphological variation among and within African foxtail ecotypes in the country. Ecotypes are groups of populations distinguished by a complex variation in many traits due to adaptation to the environmental variables that differ in different geographical locations (Lowry, 2012). This study, therefore, characterized the habitat and morphological traits of African foxtail ecotypes in the selected three districts of Tanzania. Specifically, the study assessed the dominance of African foxtail grass in selected areas, the morphological traits, and the characteristics of the habitats that support the species under study. Districts were selected based on differences in climatic and ecological conditions and geographical distances between them with expectations of population differentiation. Population differentiation led to the trait diversity of a given species (Zhou *et al*., 2003). According to Jorge *et al*. (2008), among 68 accessions of African foxtail grass maintained in field gene banks and seed stores of the International Livestock Research Institute (ILRI) in Ethiopia, 33 accessions were collected from Africa and were never evaluated before. Furthermore, the underutilization of forage species results from inadequate characterization and evaluation data (Shantharaja *et al.,* 2015). On the other hand, the characterization results are important to make desirable traits of species known so that they can be promoted for production and utilization among livestock farmers in the country.

African foxtail grass is a widely established forage grass in various parts of the tropics because of its desirable traits. The grass is deep-rooted and has tufted-rhizomatous characteristics, which make the grass fairly adaptive to heavy grazing pressure and tolerant to drought conditions (Jackson, 2005; Burson *et al*., 2012). Furthermore, it grows well in a wide range of soil types and altitudes from sea level to 2000 m above sea level (masl) in different ecological zones from semi-arid to sub-humid climatic areas (Marshall *et al*., 2012). The adaptability of African foxtail grass to tropical climates, including that of Tanzania, has resulted in a wealth of natural ecotypes which are morphologically diverse (Burson *et al*., 2012; Marshall *et al*., 2012). Ecotypic diversity is a potential characteristic for productivity and tolerance to environmental challenges. Therefore, African foxtail grass is a potential species to bring economic benefits to pastoral communities where pasture production is widely practiced.

3.2 Materials and Methods

3.2.1 Description of Study Areas

The study was conducted in three districts of Tanzania, namely Kilolo, Kiteto, and Mpwapwa, which are located in three administrative regions of the country, Manyara (northern Tanzania), Dodoma (central Tanzania), and Iringa (Southern Highlands) respectively. The three districts were purposely selected based on prior information with respect to the availability of African foxtail grass and easy accessibility. Moreover, the districts show variation in ecological, topographical, climatic conditions, and anthropogenic activities, which in different ways can contribute to the morphological diversity of the grasses. Therefore, two villages (smallest administrative units) were selected in each district, making a total of six study sites. In each site, sampling of African foxtail grass for morphological traits assessment was carried out around grid points and altitude, as shown in Table 1.

Table 1: Location and altitude of study sites

District	Village	Geo-Position		Altitude (masl)
	Twanga	5° 24' 15" S	36° 30' 37" E	1608 – 1613
Kiteto	Namelock	5° 24' 40 S	36° 29' 51" E	1555 – 1557
	Ipera	7° 7' 58" S	36° 29' 28" E	1226 – 1248
Mpwapwa	Mazae	6° 21' 21" S	36° 27' 20" E	982 – 984
	Mtandika	7° 32' 46" S	36° 25' 30" E	585 – 588
Kilolo	Malolo	7° 28' 11" S	36° 30' 39" E	528

Source: Field data, 2020

The climate of studied areas ranged from semi-arid to sub-humid with average annual rainfall ranging from 643 – 1157 mm, and the temperature ranges from 19.4 to 24 ^{o}C. Studied areas had different land uses, including grazing and farming. Table 2 presents each studied site's average annual temperature, rainfall and land use.

Table 2: Climatic and land use (anthropogenic activities) of the study site

Parameter	Namelock	Twanga	Ipera	Mazae	Mtandika	Malolo
Average Annual Precipitation (mm)	643	643	758	644	1137	1157
Average Annual Temperature ^{o}C	19.4	19.4	20.1	23	23.9	24
Anthropogenic Activities	Grazing	Grazing	Farming	Farming	Fallow land	Reserved pasture land

Source: Field Data, 2020

3.3.2 Sampling procedure and data collection

A Cross–sectional study on Morphological characterization of African foxtail ecotypes involved the assessment of this selected species from six sites in the study areas. In each site, three plots of 10 m diameter 40 m apart were made on transect. Ten grass tussocks were randomly selected for morphological traits assessment in every plot. A total of 180 randomly selected tussocks of African foxtail grass from the six sites were assessed. Quantitative traits assessed included tussock height, tiller number, leaf number, penultimate leaf length, and flower length. All heights and lengths were measured in centimetres (cm) by using a tape measure. Tussock height was measured from the base of the tussock to the base of the inflorescence. Tillers and leaves of every selected tussock were counted and recorded in the data sheet immediately. The penultimate Leaf length was measured from the ligule to the tip of the leaf blade, and the flower length was measured from its base to the tip. Each leaf and flower length data were recorded as an average of three measurements. All tussocks of African foxtail grass and associated plant species in each plot were counted in order to establish the African foxtail grass index of dominance (ID). ID is a measure of the distribution of individuals among other species in the community. The value of ID ranges between 0 and 1; the greater the value of ID, the lower the species diversity in the community, implying the higher dominance of the species under study and vice versa. This index was calculated using Simpson's Index formula as described by Whittaker (1972).

$$ID = 1 - \left(\sum \frac{n(n-1)}{N(N-1)}\right) \quad (1)$$

Where ID is the Index of dominance;

n is the number of individuals of African foxtail grass in the sample;

N is the total number of individuals (all species) in the sample and

$\sum$ is the summation sign

Soil samples were collected using a soil auger from each study site at a depth of 0 - 40 cm. A homogeneous soil sample of 500 g was made by mixing soils from randomly selected three points in each plot. The samples were then packed in plastic bags and carried to the soil laboratory at the Soil and Geological Science Department of Sokoine University of Agriculture for analysis. Physical properties assessed include silt, sandy, and clay ratio. Soil chemical properties assessed were p^H and Electrical conductivity (EC), a numerical expression of total salt concentration in an aqueous soil solution (Kashenge-Killenga *et al*., 2016). EC and p^H were measured using digital p^H and EC metre in the supernatant suspension in water at the ratio of 1:2 and 1:2.5, respectively (Kashenge-Killenga *et al*., 2016).

3.2.3 Data analysis

Data were summarized in excel and exported to Statistical Analysis System (SAS) for One-way Analysis of Variance (ANOVA) to determine if there were significant differences in mean values. The Duncan's Multiple Range test (DMRT) was used to measure specific differences between pairs of means. In order to determine the interrelatedness among the assessed traits, a correlation analysis was performed.

The statistical model used was a general linear model:

$Y = \mu + E_i + \varepsilon_{ij}$ ………………………………………………………… (2)

Where: Y = Trait response, μ = General mean, Ei = ecotype effect, Ɛij = Experimental error.

3.3 Results and Discussion

Six ecotypes of African foxtail grass were assessed in selected study sites of the three districts. Since the ecotypes have not been studied before, their names were derived from local names used by the people within that area. In the case of similar local names, a village name was added at the end of the local name. Ecotypes from Kilolo Districts were *Iramata malolo* (Ir) from Malolo village and *Iramata Mtandika (Im)* from Mtandika village, from Kiteto District were *Ologoraing'ok namelock (On)* of Namelock village *and Ologoraing'ok twanga (Ot)* of Twanga village; and in Mpwapwa District, ecotypes were *Nzingangata (Nz)* from Ipera village, and *Orupilipili (Op)* from Mazae village.

The first ecotype assessed was *Ologoraing'ok (On)* found in Namelock village in Kiteto District. The landscape of the studied area was a water-logging valley with scattered yellow acacia trees (*Acacia xanthophloea*), a few forbs, and sedges. The index of the dominance of *On* was 0.52; this was contrary to Friedel *et al. (*2006), who reported that the African foxtail grass does not tolerate water logging. *On* expressed high tiller population despite the establishment of greyish cracking clay soils of moderately alkaline pH and grazing pressure, as the site was close to the watering point (Table 4). The observation was contrary to Cox *et al*. (1988), who reported that African foxtail grass loses vigour and eventually dies when established on cracking clay soil. The findings of this study collaborate with Marshall *et al.* (2012) that African foxtail grass adapts well to a wide range of soil types. The tussock height of this ecotype ranged from 38 to 59 cm, with a number of leafless tillers due to grazing. The leaves of this ecotype were short grey-green with a maximum leaf length of 13 cm and a minimum of 5 cm. The observation concurs with Sbrissia *et al*. (2010) that the severity of defoliation determines leaf length. The grass had relatively short inflorescences.

Ologoraing'ok' (*Ot*) is the second ecotype that was found in Twanga village, Kiteto District. The site where *Ot* was sighted is a gently sloping area along the hill, dominated by woodland with scattered short acacia trees and few forbs and shrubs, reserved grazing land for young animals in the dry season. The Tussock heights of *Ot* were relatively short, ranging from 39 to 65 cm, with a relatively high number of aerial tillers. The leaves of this ecotype were glabrous, short grey-green with a maximum leaf length of 16 cm and a minimum of 7 cm. The inflorescences were relatively short green, ranging from 1 to 2.5 cm. Although the area had a high diversity of grasses and forbs, the ID of '*Ologoraing'ok twanga'* was found to be 0.33. Less dominancy of *Ot* was influenced by the landscape of the area, as it has been pointed out earlier that African foxtail grass is less common in gentle slope areas and other slopes (Van Devender and Dimmitt, 2006).

The third ecotype, *Nzingangata (Nz),* was found and assessed in the sloppy- hilly landscape of Ipera Village located in Mpwapwa District. The site is close to Ipera primary school, and the native suspect that African foxtail grass was brought to this site by pupils from different areas as it was not seen in other places except around the school. The light and fluffy nature of the seeds increases their ability to spread and occupy new areas (Friedel *et al.,* 2006). The soil of this area was reddish-brown sandy clay with moderately alkaline pH, which supported the establishment of Nz ecotype. The place was surrounded by trees with scattered shrubs and forbs. The landscape and vegetation type of Ipera limited the dominance of Nz as it was found with an ID of 0.27(Table 3). African foxtail grass grows in abundance in open and plain areas (Marshall *et al*., 2012). The height of *Nz* ranged from 59 to 92 cm with moderately robust tussock of mainly basal tillers, which ranged from 32 to 97. The lower the index of dominance, the lower the dominance of a species under study.

Orupilipili (Op) is the fourth ecotype discovered at Mazae village in Mpwapwa District. *Op* was traced in a plain area with an altitude ranging from 982 to 984 masl. The place is used for crop production and has red sandy clay with a pH ranging from neutral to moderately acidic (Table 4). Closer to the sampled area was a big gully indicating massive soil erosion by water. Soil erosion may be a possible cause of acidic soil. As water passes through soils leaches basic nutrients like magnesium, phosphorus, and calcium are replaced by acidic elements like aluminium, iron, and boron (USDA-NRCS, 2014). Despite the soils being moderately acidic (5.58), African foxtail grass established well and dominated the place (ID = 0.64) more than other species of grasses and forbs (Table 3). This indicates that African foxtail grass grows well in a wide range of soil types with varying chemical compositions. In addition, like any other C_4 grasses, African foxtail grass grows and dominates open plain areas compared to sloping landscapes and closed systems (Marshall *et al.*, 2012). Two growing habits of the grass were observed at Mazae. The first was erect and robust, with a maximum tussock height of 114 cm. The other was semi-erect or decumbent, with a maximum height of 36 cm. Both the erect-robust and decumbent grass had purple inflorescence.

Iramata (*Im)* ecotype was discovered at Mtandika villages in Kilolo District. The *Im* was sighted in the plain open area with reddish-brown sandy clay loam soils, which were moderately alkaline. *Im* ecotype is robust green grass with plant height ranging from 51 to 98 cm, dominated by basal tillers with few branching. The ecotype had purple closed inflorescence. *Im* fairly dominated other species (ID = 0.52) as an open and plain landscape supported it (Marshall *et al.,* 2012; Van Devender and Dimmitt, 2006). Learning from the local community members, the place was fallow land for one year, previously used for horticultural crop cultivation. The condition minimizes anthropogenic disturbances on African foxtail grass establishment.

Iramata Malolo (Ir) is the sixth ecotype sighted and assessed at Malolo village in Kilolo District. *Ir* was found in few clumps (ID = 0.16) under the shade of trees and thorny shrubs in a sloped area near the Lukosi River. The soils of this area were moderately alkaline blackish-brown sandy clay loam. Low EC was recorded despite the common phenomenon that lowlands have high EC due to the accumulation of salts (USDA-NRCS, 2014). The low amount of EC recorded perhaps is due to the high average annual rainfall of 1157 mm received in the area per year. There were no signs of the place being grazed perhaps due to the sloping landscape of the area and closed shrubs and trees. Instead, the ecotype recorded the highest tussock height. The cause of stem elongation, in addition to the absence of grazing, is to place leaves in upper strata to increase the range of leaf area index traversed for the light interception. According to Da Silveira Pontes *et al*. (2015), this kind of elongation goes at the expense of tillers. Da Silveira Pontes *et al.* (2015) concurs with what was observed in Malolo where the ecotype recorded a low number of tillers with dispersed leaves.

3.3.1 Landforms, vegetation, and dominance of African foxtail grass in studied area

The studied areas had a range of vegetation types on varying landforms, as presented in Table 3. These are among the environmental factors that influence the adaptability and dominance of African foxtail grass in the area. The findings suggest that African foxtail grass is less common in sloping areas and hardly dominates closed woodlands. This condition was observed on Ir ecotype in the slopes of Malolo near the Lukosi river area and Nz ecotype in the hills of Ipera. In the two villages, trees and shrubs dominated the area. Thus, African foxtail grass was sighted in a few clumps with an ID of 0.16 for Ir, and 0.27 for Nz Ot ecotype, which was in the hills of

Twanga and also had a lower index of dominancy (ID = 33) next to Ir and Nz (*See* Table 3). The findings corroborate Van Devender and Dimmitt's (2006) observation that African Foxtail is less common in slopes and usually scatter in patches when found. Conversely, *Im* and *Op,* found in open plain grassland areas, flourished well and dominated other species. The observation agrees with Marshall *et al*. (2012) that, like any other C4 grasses, African foxtail grass flourishes in open areas with ample light.

Table 3: Landforms, vegetation and level of dominance of African foxtail ecotypes

District	Village	Ecotype	Landform	Vegetation	ID
Kiteto	Namelock	On	Valley	woodland	0.52
	Twanga	Ot	Hill	woodland	0.33
Mpwapwa	Mazae	Op	Plain	grassland	0.64
	Ipera	Nz	Hill	woodland	0.27
Kilolo	Malolo	Ir	Slope	woodland	0.16
	Mtandika	Im	Plain	grassland	0.52

3.3.2 Soil characteristics of studied sites

Soil is an important habitat component that directly dictates what kind of vegetation will successfully establish. According to Mangosongo *et al*. (2019), soil's physical and chemical properties are among the environmental factors that influence plant growth. The ability of a plant to access water and other nutrients depends on the soil texture (physical characteristics). The findings presented in Table 4 indicate that the soil texture of the studied sites was primarily sandy clay, and African foxtail grass adapted well in these soils.

Table 4: Selected soil characteristics of the studied areas (USDA-NRCS system)

District	Village	Depth (cm)	Texture	P^H	*P^H Class	EC (dS/m)
Kiteto	Namelock	0 – 40	Clay	8.07-8.34	Moderately alkaline	3.15-4.79
	Twanga	0 - 40	Sandy clay	6.62-7.07	Slightly acid to neutral	1.42-1.56
Mpwapwa	Ipera	0 – 40	Sandy clay	8.12-8.31	Moderately alkaline	2.31-2.49
	Mazae	0 - 40	Sandy clay loam	5.58-6.74	Moderately acid to Neutral	0.83-1.31
Kilolo	Mtandika	0 - 40	Sandy clay loam	8.17-8.26	Moderately alkaline	2.34-2.41
	Malolo	0 – 40	Sandy clay loam	8.06-8.30	Moderately alkaline	1.53-2.52

**pH classification as per the United States Department of Agriculture Natural Resources Conservation Services (USDA- NRCS 2014) classification system*

The soil pH (chemical characteristic) in these areas ranged from moderate acidic at 5.6 to moderate alkaline at 8.3. The optimum soil pH for most plants ranges from 5.5 to 7.5, but African foxtail grass, among other grasses, has adapted to thrive beyond the optimum range. Principally soil pH affects the availability of nutrients to plants by controlling their chemical forms and influencing their chemical reactions (Kabata-Pendias, 2004). Table 4 also shows the other soil chemical characteristic considered in this study was soil electrical conductivity (EC) or soil salinity. It is a measure of the amount of salt in the soil and is likely to contribute to the morphological variation of the ecotypes. EC affects plant nutrient availability and activities of soil microorganisms, affecting plant growth characteristics (Physical and morphological). Excess salts (more than 4 dS/m of the saturation extract in the root zone) restrict plant growth by affecting soil-water balance (Shrivastava and Kumar, 2015; Kashenge-Killenga *et al.,* 2016). ECs of the soils in the studied sites were in the normal range except for Namelock, which was saline with an EC of 4.79 dS/m. Despite the higher EC in Namelock, *On* established well with the higher number of tussocks in the area (ID = 0.52) comprised of strong short tillers showing its ability to adapt to high salinity levels. These findings agree with Castelli *et al.* (2010) that African foxtail grass is tolerant to salinity.

3.3.3 Morphological traits of the studied African foxtail ecotypes

The findings reveal that the morphological traits of the six ecotypes assessed had a significant variation (p-value <0.0001). Trait variations, for example, tussock heights ranged from 36 – 160 cm. The wide range variation of African foxtail tussock height was also observed by Marshall *et al*. (2012), who reported a height range of 20 to 150 cm. Other traits, such as tiller numbers ranged from 11 – 122 cm, leaf numbers ranged from 13 – 153, leaf length ranged from 12 – 56 cm, and flower length from 1 –12 cm. *Ir, Im, Nz,* and *Op* ecotypes had relatively high mean values for all traits assessed except tiller numbers, while *On* and *Ot* ecotypes had low mean values for all traits except tiller numbers (Table 5). The observed variations were not by chance, as high SD and F-values presented in Table 5 affirm. The high SD (standard deviation) and F-values suggest that the six assessed African foxtail ecotypes contained distinct outliers implying more natural variation within ecotypes (Jorge *et al.,* 2008). According to Da Silveira Pontes *et al*. (2015), trait variation signifies a high level of plasticity, allowing species to adapt to a wide range of environments. This phenomenon was also reported by Crispo (2008), that the effects of phenotypic plasticity on interactions allow species differentiation; the context that African foxtail grass can still be explained.

Table 5: Morphological traits of African foxtail Ecotypes (LS Mean ± SD) n = 180

District	Eco types	Traits: Tussock height (cm)	Tiller number	Leaf number	Leaf length (cm)	Mean f. l* (cm)
Kiteto	*On*	$47.8^{c} \pm 7.1$	$93.8^{a} \pm 20.8$	$22^{e} \pm 8.4$	$9.6^{d} \pm 6.9$	$1.4^{d} \pm 0.5$
	Ot	$54.8^{c} \pm 5.1$	$67.2^{b} \pm 20.5$	$75^{d} \pm 17.6$	$11.8^{d} \pm 5.5$	$1.83^{d} \pm 0.7$
Mpwapwa	*Op*	$76.5^{b} \pm 12.9$	$66\ ^{b} \pm 17.3$	$125^{a} \pm 15.5$	$45^{a} \pm 6.2$	$9.8^{ab} \pm 1.7$
	Nz	$75.1^{b} \pm 32.4$	$65.6^{b} \pm 20.8$	$86.5^{c} \pm 11.2$	$41.7^{b} \pm 3$	$10.1^{a} \pm 0.9$
Kilolo	*Im*	$84.8^{b} \pm 14.5$	$53^{c} \pm 13$	$107^{b} \pm 17.1$	$35.7^{c} \pm 5.2$	$9.3^{c} \pm 0.7$
	Ir	$132.8^{a} \pm 20.7$	$35.4^{d} \pm 15.8$	$78.1^{d} \pm 5.7$	$35.8^{c} \pm 8$	$9.4^{bc} \pm 1.2$
	SEM	3.56	3.30	2.58	0.86	0.18
	PV	< .0001	< .0001	< .0001	< .0001	< .0001
	FV	71.01	33.70	185.15	107.05	523.38

Note:(i) f. l* = flower length (ii) different letters indicate that means along the columns differ significantly while those with similar letters have no significant difference, FV = F-value and PV=P-value at 0.05 confidence level

In order to understand how the studied variables are linearly related to each other, a correlation analysis was performed, and the correlation coefficient results are presented in Table 6. A correlation coefficient greater than zero indicates a positive relationship, while a value less than zero shows a negative relationship. The results showed that tussock height for all ecotypes expressed a strong negative correlation (r = - 0.910) with tiller numbers (Table 6). The observation implies that the taller the grass grows, the fewer tillers it will make. *Ir* ecotype, which recorded the highest tussock height of all ecotypes, had the lowest tiller numbers, while the *On* ecotype, which recorded the shortest height, had the higher tiller numbers of all.

Table 6: Correlations of morphological traits of African foxtail ecotypes from six study sites

Morphological traits	Tussock height (cm)	Tiller number	Leaf number	Leaf length (cm)	Flower length (cm)
Tussock height (cm)	1				
Tiller number	-0.910	1			
Leaf number	0.352	-0.558	1		
Leaf length (cm)	0.582	-0.575	0.807	1	
Flower length (cm)	0.677	-0.668	0.761	0.983	1

The findings of this study concur with Sbrissia *et al.* (2010) observations that tiller numbers were affected by sward height. In their study, the sward maintained at 10 cm had higher tiller density (1,044 tillers m^{-2}), while low tiller density (665 tillers m^{-2}) was recorded on those maintained at 40 cm. Furthermore, the study observed negative correlations of tiller numbers with all other traits studied. Expectedly, while other parts of the grass are reduced by grazing, stems are less grazed due to their hard culm, which is tough for the animals to digest, a reason for the high numbers of leafless tillers in frequently grazed areas. According to Sbrissia *et al*. (2001), the restoration of sward area after severe grazing or cutting occurs by recruiting new tillers from the plant base as a compensation mechanism. However, tillering rate depends on soil nutrient availability and climatic conditions (Caminha *et al*., 2010).

Moreover, there was a considerable variation in leaf length; the ecotype *On* recorded fewer and the shortest, while the longest leaves were of the *Op* ecotype. Few and short leaves of *On* were an adaptation to grazing pressure because the study site was close to the watering point, thus frequently grazed. Fewer leaves affect canopy light interception, resulting in low herbage production.

The variation of morphological traits observed in this study is not surprising, given the difference in growing conditions. Additionally, long geographical distances between the study sites are likely to favour morphological variability. According to Zhou *et al*. (2003), differentiation between populations increases with the increase in geographical distances, implying that isolation by distance increases morphological differentiation.

3.4 Conclusion and Recommendations

The study ascertains the presence of six ecotypes of African foxtail grass in the study area. The findings on the dominance of species in the area lead to the conclusion that the physiognomy of the landscape influences African foxtail grass colonization of the area. The study revealed that six ecotypes of African foxtail grass in studied areas exhibit a wide range of morphological variation among the ecotypes. It was observed that African foxtail grass could successfully adapt to different habitats in the rangelands of Tanzania, therefore, a potential species for pasture and rangeland improvement.

The morphological variation observed among the six ecotypes will likely influence growth and productivity. This calls for a study on ecotypes' performance in terms of growth characteristics and productivity when grown under common environmental conditions. Another molecular characterization study is recommended on these ecotypes to determine if the observed morphological difference will be expressed genetically. Furthermore, this study recommends further study on the characterization of the six ecotypes on growth and productivity when subjected to stresses like defoliation, drought, and salinity. The results will aid farmers and breeders in selecting the best productive ecotype for a given environmental condition.

3.5 Acknowledgement

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CHAPTER FOUR

4.0 PAPER THREE

Forage growth, yield, and nutritional characteristics of five African foxtail ecotypes grown at Magadu dairy farm in Morogoro Tanzania[3]

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Abstract

This study was conducted to assess the growth, forage yield, and nutritional characteristics of five ecotypes of African foxtail (*Cenchrus ciliaris*) grown under the common environmental condition at Magadu Dairy Farm (MDF), of the Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. The ecotypes were collected from semi-arid areas of three districts, namely Kiteto (*Ologoraing'ok namelock* and *Ologoraing'ok twanga* ecotypes), Mpwapwa *(Nzingangata* and *Orupilipili* ecotypes), and Kilolo *(Iramata mtandika ecotype).* Each ecotype was planted in a 12 m^2 plot with plants interspacing of 0.5 m and 1.5 m space between plots and three replications. A total of 30 tussocks were randomly sampled per ecotype, and plant height, tiller number, inflorescence length, leaf length, and leaf mid-width were recorded. The dry matter yield and nutritional characteristics were analysed from the

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harvested above-ground biomass in two quadrats of one square meter per plot at the age of six weeks of regrowth. The results indicated significant (p-value<0.05) variation among ecotypes on the studied characteristics. *Orupilipili* ecotype indicated higher mean values of plant height (93.8 cm), leaf area (25.8 $cm^{2)}$, inflorescence length (10.1 cm), and dry matter yield (10.35 $tDMha^{-1}$). *Ologoraing'ok namelock* had the lowest growth and yield characteristics except mean tiller numbers (197.3). The lowest-yielding ecotype indicated the highest percentage of Crude Protein (21.15), Acid Detergent Fibre (31.35) and ash content (16.91) but with lowest Neutral Detergent fibre (55.89). Correlations were significant for all pairs of traits assessed. Discriminant tests suggested close relationship between *Ologoraing'ok namelock* and *Ologoraing'ok twanga, Nzingangata* and *Iramata mtandika* but each ecotype indicated significant number (>46%) of unique individuals. This study recommends further study on the ecotypes when subjected to stresses such as defoliation, salinity and drought.

Key words: Characterization; *Cenchrus ciliaris*; Dry matter; Morphological variation; Productivity

4.1 Introduction

African foxtail (*Cenchrus ciliaris* L.) is a widely distributed tropical grass. Morphologically the grass is short to tall (20-200 cm), erect to sprawling, tussock forming, short rhizomatous with deep, course, fibrous root system of up to >2 m (Jackson, 2005; Lutatenekwa *et al.*, 2021). The seed heads are erect to nodding, straw, grey or purple coloured like foxtail (hence the name African foxtail), 2-15 cm long and 1.0-2.5 cm wide, with seed units (fascicles) carried along a zig-zag axis (Cook & Clem, 2000). Furthermore, African foxtail is distributed well in different ecological zones from semi-arid to sub-humid areas (Marshall, 2012). It is adapted to a wide range of elevation from sea level to 2000 metres above sea level (masl). The grass can be found on different soil types but perform best on a welldrained fertile and lighter-textured soils (Cook & Clem, 2000). African foxtail is one of the most important pasture species which responds more rapidly to rain than other species (Jackson, 2005; Brunao *et al.,* 2017). The ability of this grass to adapt to a range of environmental conditions triggers the formation of several ecotypes (Kannan and Priyal, 2015; Kirwa *et al*., 2018). Ecotypes are groups of populations which are distinguished by multifaceted differences in many traits as a result of adaptation to the environmental variables that diverge in different geographical locations (Lowry, 2012).

Tanzania has about seven (7) agro-ecological zones which support a number of ecotypes of African foxtail, however, there is limited information about these ecotypes. *Lutatenekwa et al*. (2021). characterized six ecotypes based on their morphological characteristics, in natural areas of three Agro-ecological zones of Tanzania. These ecotypes were never characterized before, their naming based on local names. From each ecological zone, one district was selected and in each district two ecotypes were assessed. The districts were Kilolo, Kiteto, and Mpwapwa. Ecotypes from Kilolo were *Iramata malolo* and *Iramata Mtandika* Kiteto were *Ologoraing'ok namelock* and *Ologoraing'ok twanga,* and from Mpwapwa were *Nzingangata* and *Orupilipili* (Lutatenekwa *et al.*, 2021). Their study (Lutatenekwa *et al.,* 2021) indicated high variability in terms of plant height, tiller numbers, leaf and flower size when they were assessed in their natural areas. Conversely, there is limited information on growth characteristics, forage yield and nutritional characteristics among these ecotypes when grown under similar environmental conditions. This study was designed to assess if there would be any variability among the ecotypes of African foxtail which were collected from three districts of Tanzania (Kilolo, Kiteto, and Mpwapwa). In the current study, five ecotypes of African foxtail were grown under common stress-free environmental conditions with common management practices. In particular, the study paid attention to growth, forage yield and nutritional characteristics. Information gathered becomes an important tool which can be used to support selection and breeding for desirable traits.

4.2 Materials and Methods

4.2.1 Description of study area

The experiment was set in a totally unshaded area at Magadu Dairy Farm (MDF), a property of Sokoine University of Agriculture (SUA) found in Morogoro, Tanzania. The area is found at 6^{o} 50' 59'' S and 37^{o} 39' 10'' E (GPS coordinates), 537 metres above sea level (masl), on sandy clay, reddish-moderately acidic soil. The area is characterized by a bimodal rainfall pattern of short and long rains. Short rains start from November to December and long rains starts in March to May and sometimes extends to June. The average annual rainfall ranges from 600 up to 900 mm with mean annual temperature of 25^{o} C to 30^{o} C.

4.2.2 Experimental design and treatments

The experiment was set in a completely randomised design (CRD) with three replications of five ecotypes. The five ecotypes were *Ologoraing'ok namelock (On), Ologoraing'ok twanga (Ot)*, *Nzingangata (Nz), Orupilipili (Op)* and *Iramata mtandika (Im*).

4.2.3 Source of experimental materials

African foxtail ecotypes used in this study were collected from three districts of Tanzania namely Kilolo (southern highlands, Iringa region), Kiteto (northern Tanzania, Manyara region), and Mpwapwa (central Tanzania, Dodoma region). Initially the study planned and collected two (2) ecotypes from each district. Ecotypes from Kiteto were *On and Ot*, from Mpwapwa were *Nz* and *Op* and ecotypes from Kilolo were Iramata malolo (*Ir)* and *Im*. In this experiment the Ir ecotype which was collected from the slopes of Lukosi River was left out. This ecotype failed to give enough experimental materials in the multiplication plots thus the experiment remained with five ecotypes. Collection of the ecotypes considered variation of collection sites in terms of topographic and climatic conditions, soil types and anthropogenic factors (Lutatenekwa *at el.,* manuscript submitted for publication).

4.2.4 Land preparation and establishment of grasses

Prior to planting of African foxtail ecotypes sprigs, the land was cleared and tilled to ensure even seedbed ready for plots setting. Fifteen plots each measuring 3 m × 4 m (plot area of 12 m^2) were established and 35 sprigs per plot were planted with interspacing of 0.5 m to allow manual weeding. The distance between plots were 1.5 m to evade inter-ecotypic competition.

Diammonium Phosphate (DAP) was applied at the rate of 145 kg ha^{-1} during planting. Need-based irrigation was applied to ensure growth and establishment. Standardization cut was done after two months from planting at the height of 8 cm above the ground level. A top-dressing fertilizer N-P-K (15-9-20 %) was applied at the rate of 145 kg/ha after standardization cut. The application of fertilizer and irrigation was to make sure a stress-free environment is provided for the ecotypes to perform to their best.

4.2.5 Data collection

Parameters measured were plant height (PH), tiller number per tussock (TNT), inflorescence length (IL), leaf length (LL) and leaf mid-width (LW) and above ground fresh weight (FW).

4.2.5.1 Sampling frame and procedure used

Growth characteristics were recorded on mature plants at the age of 6 weeks from standardization cut for all ecotypes. Measurements were done on 10 randomly selected tussocks per plot, from the middle of the plot to avoid edge effects. Every single data entry for LL, LW and IL recorded was an average of three individual measurements per tussock. PH was measured from the ground surface to the tip of inflorescence and TNT were counted per tussock. LL was measured from ligule to the leaf apex, both LL and LW were measured from the leaf just below the flag leaf (penultimate leaf). PH, LL and LW were measured by using a tape measure. Leaf area (LA) was obtained by the formula below:

$$LA = LL \times LW \qquad (1)$$

FW was obtained by harvesting and weighing above-ground biomass at 8 cm height from ground level in two quadrats of 1 m^2 per plot. Weighed samples from the five ecotypes were packed in bags for laboratory analysis.

4.2.6 Data Analysis

4.2.6.1 Laboratory Sample analysis

Packed samples of harvested African foxtail ecotypes were taken to the laboratory, oven-dried at 70°C for 72 hours, dry weights were recorded for further calculations of DM and $tDMha^{-1}$ per ecotype. DM and $tDMha^{-1}$ were calculated as follows:

DM % = (Wt3 -Wt1/Wt2-Wt1) × 100……………………………. (2)

Where by: Wt1 = Weight of a container, Wt2 = Weight of a container and fresh sample, Wt3 = Weight of a container and dry sample (USDA NIFA, 2019)

($tDMha^{-1}$) = [FW/ harvested area (m^2)] × DM×10……………. (3)

In order to perform proximate analysis, the dry samples were milled to pass through 2 mm sieve. The content of Crude Protein (CP), Acid Detergent Fibre (ADF) and Neutral Detergent fibre (NDF) were calculated on the basis of chemical analyses. CP was analysed by Kjeldah method using AN_ 300; Tecator Kjeltec System procedure for block digestion and steam distillation. ADF and NDF were analysed by using Ankom technology. Ash contents was obtained by igniting the Crucibles containing the dried samples in the Muffle furnace at 550°C for three hours.

4.2.6.2 Statistical analysis

Data conception was done in excel followed by One-way analysis of variance (ANOVA) which was performed using General Linear Model (GLM) procedure of Statistical Analysis System (SAS) 2014, Duncan's Multiple Range test and Least square Means were used to separate the means.

The statistical model was: $Y_{ij} = \mu + E_i + \varepsilon_{ij}$…………………………. (4)

Where: Yij = Trait response, µ = General mean, Ei = ecotype effect, Ɛij = Experimental error

Correlations between traits were computed using CORR procedure of SAS to determine the interrelatedness and the strength of the relationship between assessed traits.

Discriminant analysis was performed using DISCRIM procedure of SAS to assess the variation between ecotypes. This analysis procedure calculate Mahalanobis squared distance (MSD) and the percentage of individual observations assigned to their respective ecotypes (Assignment test).

4.3 Results

4.3.1 Variation in growth characteristics of the five ecotypes of African foxtail

It was observed that all five ecotypes started sprouting on the 3rd day after standardization cut. There were variations in number of days to first flowering, for instance, *Im* and *Nz* started flowering in the 2nd week and reached 50% flowering in the 5th week. Conversely, *Op, On* and *Ot* started flowering in the third week and reached 50 % flowering in the 6th week.

Generally, there was a considerable variability among the ecotypes with regard to all growth traits assessed as presented in Table 1. It was observed that *Op* ecotype outperformed all other ecotypes with the highest mean PH, mean LA and mean IL but had the lowest TNT. The second well-performing ecotype was *Nz* followed by *Im* then *Ot*. Then again, *On* ecotype had the lowest PH and LA but presented the highest TNT compared to other ecotypes.

Table 1. Least square means of growth characteristics (n per ecotype = 30 individuals).

Ecotypes	PH	TNT	LA	IL
On	82.4[c]	197.3[a]	3.4[c]	2.8[c]
Ot	83.1[bc]	187.0[a]	3.7[c]	2.8[c]
Op	93.8[a]	80.8[c]	25.8[a]	10.1[a]
Nz	89.3[ab]	110.1[b]	13.8[b]	9.9[ab]
Im	87.7[abc]	104.0[b]	12.6[b]	9.7[b]
SEM	2.191	7.693	0.873	0.146
P-value	0.0016	<.0001	<.0001	<.0001

4.3.2 Forage yield and nutritional characteristics of the five *African foxtail ecotypes*

The results showed a significant variability ($p < 0.05$) among the ecotypes on their DM, tDMha^{-1} and nutritional characteristics which included ADF, NDF, CP and Ash. *Op* was the highest yielder and the lowest yielder was *On* followed by *Ot* while *Nz* and *Im* had comparable forage yield results. Although On had the lowest yield, the ecotype presented highest values of ADF, CP and Ash.

Table 2. Least square means for DM, tDMha-1, ADF, NDF, CP and Ash.

Ecotype	DM%	tDM ha^{-1}	ADF %	NDF %	CP %	Ash
On	18.34[b]	5.94[c]	31.35[a]	55.89[bc]	21.15[a]	16.91[a]
Ot	18.80[b]	6.92[bc]	31.15[a]	56.53[b]	21.10[a]	16.01[ab]
Op	26.32[a]	10.35[a]	29.94[ab]	59.79[a]	19.07[b]	15.39[b]
Nz	21.11[ab]	8.24 [ab]	29.11[b]	57.82[b]	18.46[bc]	15.39[b]
Im	21.72[ab]	8.60 [ab]	28.66[b]	57.48[b]	17.20[d]	13.86[c]
SEM	1.435	0.799	0.564	0.839	0.322	0.390
P-value	0.005	0.008	0.0244	0.0015	<.0001	0.0036

Note: Variable means followed by same letters along the column are not statistically significant ($p > 0.05$). SEM= standard error of the mean, tDMha-1 = tons of dry matter per hectare

4.3.3 Correlations among growth traits and biomass yield

The correlation growth traits and yield were assessed and results are presented in Table 3. Generally, all pairs of traits assessed indicated significant positive and negative correlation coefficients. TNT had an inverse relationship (strong negative correlation coefficients) with all other traits. The highest correlation coefficient was indicated between PH and LA.

Table 3. Correlation coefficients (r) showing relationships between pairs of studied parameters.

	PH (cm)	TNT	LA (cm^2)	IL (cm)	DM%	tDM ha^{-1}
PH (cm)	1.000					
TNT	-0.949	1.000				
LA (cm^2)	0.990	-0.920	1.000			
IL (cm)	0.894	-0.981	0.845	1.000		
DM%	0.962	-0.888	0.989	0.790	1.000	
tDM ha^{-1}	0.969	-0.948	0.969	0.869	0.971	1.000

4.3.4 Relationships between ecotypes

4.3.4.1 Comparison of ecotypes by using MSD

Growth characteristics of the ecotypes were compared by using the MSD technique of the discriminant procedure and the results are presented in Table 4. *On* paired with *Ot* had MSD less than one but showed large MSD when the two were paired with the rest of the ecotypes. Again, a pair of *Im* with *Nz* showed MSD of less than one.

Table 4. MSD between pairs of African foxtail ecotypes.

From Treatment	*On*	*Ot*	*Op*	*Nz*	*Im*
On	0.00				
Ot	0.08	0.00			
Op	120.69	117.46	0.00		
Nz	110.96	107.75	9.85	0.00	
Im	107.95	104.74	7.72	0.17	0.00

4.3.4.2 Comparison of the ecotypes by using Assignment test results

Altogether, 60 percent of 150 assessed individuals were correctly assigned to their ecotypes while 40 percent were shared into closely related ecotypes. The highest percentage of individuals correctly assigned belonged to *Op* followed by *On,* then *Nz* and *Ot, Im* had the lowest number of individuals unique to its ecotype, majority of its individuals (43.33) shared with *Nz* ecotype*.* The results of an assignment test with number of individuals and their percentages for each group are presented in Table 5.

Table 5. The number of individuals and percentages (in brackets) as fitted by assignment test into their corresponding groups.

From Treatment	Correctly assign	Misassigned to other Ecotypes				
		On	***Ot***	***Op***	***Nz***	***Im***
On	19 (63.33)	-	11 (37.67)	0	0	0
Ot	16 (53.33)	14(46.67)	-	0	0	0
Op	23 (76.67)	0	0	-	2 (6.67)	5(16.67)
Nz	18 (60)	0	0	0	-	12 (40)
Im	14 (46.67)	0	0	3 (10)	13 (43.33)	-
Total	90 (60)	14 (9.3)	11 (7.3)	3 (2)	15 (10)	17 (11.3)

4.4 Discussion

The variation of PH, TNT, LA, and IL observed among the ecotypes when grown under similar environmental conditions, imply that there was no reduction of variability compared to the original ecotypes when they were assessed in their natural areas (Lutatenekwa *et al*., 2021). Other studies have reported a wide range of variation within this species (Bruno *et al*., 2017; Jorge *et al*., 2008). Higher growing ecotypes was on expense of TNT while short ecotypes had highest numbers of small tillers. These results are in line with Sibrissia *et al*.

(2010) who reported that tiller population density is affected by sward height.

Grasses are the main source of animal feeds cheaply obtainable for livestock production. To attain and maintain desirable animal productivity, higher quantity and quality of the grass matters. With regard to quantity, this study observed that taller ecotypes produced the highest DM and tDMha^{-1} while shorter ecotypes produced the lowest DM and tDMha^{-1}. Similar results were reported by Meena and Nagar (2019) that low plant height resulted to low fodder yield. The findings are contrary to Doyo *et al*. (2018) who reported high dry matter yield (2.8 ton ha^{-1}) from short-height African foxtail genotypes and low dry matter yield (1.33 ton ha^{-1}) from medium-height genotypes. PH as a result of stem elongation in addition to LA, enhance light penetration to support photosynthesis resulting to higher productivity.

A specie producing higher quantity fodder is valued if its quality is satisfactory as well. Forage quality is mainly determined by CP, fibre (ADF and NDF) and ash content (Al-Dakheel *et al*., 2015). According to Arshadullah *et al*. (2011), the production of meat, milk and associated livestock products depend on feed quality by 75% while the rest (25%) is dependent of heredity factors. The lowest yielding ecotype depicted the highest values of nutritional characteristics of ADF, CP and Ash content while indicating the lowest NDF contrary to higher-yielding ecotypes. Higher CP as an indication of high-quality forage is important for meat, milk and animal body maintenance (Al-Dakheel *et al*., 2015). NDF, a predictor of voluntary intake, echoes the bulkiness of forage. Low NDF (<60%) is preferred since there is a limit of bulkiness the animal can accommodate in the rumen (Belyea *et al*., 1993; Van Saun, 2013). Furthermore, ADF values are inversely related to digestibility and higher values (>35%) in a feed suggest lower-quality feed (Belyea *et al*., 1993; Van Saun, 2013). The findings of this study are with an implication that low yielding ecotypes are of good quality compared to higher-yielding ecotypes. Comparable results were reported by Al-Dakheel *et al*.

(2015). Regardless the variation in the nutritional characteristics observed among the ecotypes, all values for CP%, ADF%, and NDF% were in acceptable ranges. The five ecotypes studied therefore, can be considered forage of good quality (Arshadullah *et al.*, 2011; Van Saun, 2013).

Concerning correlations, it was important to know the relationships among various growth characteristics because they are the potential for ecotype selection and improvement. This study observed a significant negative correlation between TNT and all other studied traits. This observation can be explained by the concept that, short forage grasses compensate the height by adopting to high bulk of small tillers with narrow and short leaves (Sbrissia *et al.*, 2010; Meena & Nagar, 2019). On the other hand, taller forage grasses adopt low bulk of bigger tillers with broader leaves as an approach to make best use of canopy light access (Assuero & Tognetti, 2010; Sbrissia *et al.*, 2010). Op with lowest TNT recorded the highest PH and LA. *On* which has the highest TNT recorded the lowest PH and LA.

From MSD and the assignment test it was indicated that *On* and *Ot* are closely related. MSD less than one is considered an indication that these ecotypes are closely related while higher values show that the ecotypes have no relation. On the other hand, individuals with similar traits are assigned into similar groups when the assignment test is used. Therefore, the closer the ecotypes are, the more individuals will be shared among them. Contrary to On and Ot, the ecotypes from Kiteto, the ecotypes from Mpwapwa district namely *Op* and *Nz* indicated a distinct differentiation (MSD =9.85) and the fact that there were no individuals shared between them. The differentiation between *Op* and *Nz* may have been influenced by elevation, temperature and soil type of their place of origin which varied significantly and the change have become permanent. Conversely, *Nz* and *Im* (from different districts) were surprisingly less differentiated despite the difference in environmental conditions of their place of origin.

On the other hand, higher MSDs which were shown when *Op* was paired with the rest the ecotypes have the implication that this ecotype is far more differentiated from all other ecotypes. The phenomenon of differentiation of *Op* was further supported by the highest percentage (76.67%) of individuals correctly assigned to its group.

4.5 Conclusion

This study concluded that morphological variations were expressed among ecotypes when subjected to similar environmental conditions. The morphological variation observed among these ecotypes allow for initiation of breeding programs to improve important characteristics which positively affect dry matter yield. There are possibilities that the observed morphological variations could be phenotypic and less genetical. This study therefore, recommends further studies on the genetic characterization of the ecotypes. The study also recommends characterization of the ecotypes when subjected to stresses to find out if the ecotypes have variability in their response to stresses such as defoliation, drought and salinity. The results will be useful to farmers and breeders in selecting the best performing ecotype for a given environmental condition.

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CHAPTER FIVE

5.0 PAPER FOUR

Effects of harvesting interval on forage growth, productivity and nutrition of selected African foxtail ecotypes[4]

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Abstract

A factorial experiment (5*3) with three replications was conducted to assess the effects of three harvesting intervals on growth, productivity and nutrition of five *Cenchrus ciliaris* ecotypes. Ecotypes *Ologoraing'ok namelock (On), Ologoraing'ok twanga (Ot), Nzingangata (Nz), Orupilipili (Op)* and *Iramata mtandika (Im*) were harvested at 21 (T1), 28 (T2), and 35 (T3) days. Plant height (PH), tiller number (TNT), and leaf area (LA) measured forage growth; herbage was oven dried to determine productivity. *In vitro* two-stage method was applied to determine dry matter digestibility (IVDMD), Ankom technology to analyse neutral detergent fibre (NDF) and acid detergent fibre (ADF). A combined analysis of variance revealed a significant effect ($p<0.05$) of harvesting interval on forage growth, productivity, and nutritional attributes. Long harvesting interval reduced nutritional quality but increased PH and LA. Harvesting at T2 had highest productivity. Ecotype with highest PH, LA, and

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productivity was Op, highest nutritional attributes were recorded on ecotype *On.* Cumulative productivity ranged from 8251 kgDMha^{-1} (T1) to 18149 kgDMha^{-1} (T2). Therefore, it is concluded that long harvesting intervals reduce nutrition but increase growth and productivity attributes of the five ecotypes. From the results, ecotypes Op and *On* are recommended in areas with similar environmental conditions to Magadu.

Keywords**:** *Cenchrus ciliaris,* digestibility, fibre content, management, Tanzania.

5.1 Introduction

African foxtail (*Cenchrus ciliaris*) is a forage grass preferred by farmers for its ability to adapt to a wide range of environmental conditions. It has been reported to adapt well to drought and respond well to defoliation (Beltrán *et al.,* 2021; Cook and Clem 2000; Kirwa *et al*., 2018; Jackson, 2005). Adaptation to defoliation stress is attained through mechanisms that ensure grass longevity and photosynthetic efficiency (Beltrán *et al.,* 2021). Defoliation affects the plant's physiological processes with visible outcomes on the morphology and sward structure (Beltrán *et al.,* 2021). The effects include a reduction of leaf area index with an implication on canopy light interception, resulting in low herbage production (Lutatenekwa *et al.,* 2021). Appropriate harvesting practices, referring to timely and right harvesting height and removal of forage from the field as green -chop, hay, or ensilage, is critical to minimize the effects of defoliation stress. According to the American natural resource conservation service (NRCS, 2010), good forage harvest management practices guarantee the optimization of forage quality and yield and promote vigorous re-growth. Furthermore, studies have reported delayed harvesting as among the factors that negatively influence the quality of forage (Cahill *et al.,* 2014; Yigzaw, 2019; Timpong-Jones, 2015). Other factors include forage variety or ecotype, soil fertility, and climatic condition of the area.

The plant growth stage at which to harvest and frequency of harvesting (harvesting interval) varies considerably with every forage species. Each forage specie has its suitable harvesting interval. Variation of response to harvesting interval within a specie (i.e., among varieties or ecotypes) is conceivable. According to Beltran *et al.* (2021), sward response to harvesting patterns varies with the variation in grass morphology. Studies on harvesting interval have been done elsewhere (Ansa and Garjila, 2019; Timpong-Jones, 2015; Yigzaw, 2019), and their findings vary with species and geographical areas. Information on the growth, yield, and quality of African foxtail ecotypes is lacking in Tanzania. The experiment intended to assess the effects of harvesting interval on forage growth, herbage yield, and feed quality of five African foxtail ecotypes. The five ecotypes were collected from three districts, namely Kilolo, Kiteto, and Mpwapwa, in Tanzania (Lutatenekwa *et al.*, 2021). The experiment results contribute to the planning of effective management practices for the selected five ecotypes in Tanzania.

5.2 Materials and methods

5.2.1 Description of study area

This study was conducted at Magadu Dairy Farm (MDF) of Sokoine University of Agriculture (SUA) in Morogoro Municipality, Tanzania, about 537 masl, along the Western foot of Uluguru mountain ranges at 6^{o} 50' 59" S and 37^{o} 39' 10" E. The area has sandy clay reddish soil, which is slightly acidic with a p^H of 5.8. The area receives total annual rainfall ranging between 570 to 1050 mm and a temperature range of 25^{o}C to 30^{o}C (Kizima *et al.,* 2014; Mkonda, 2015).

5.2.2 Experimental design and treatments

This experiment was set in a factorial design, and the factors were harvesting intervals with three levels and ecotypes with five levels. The levels of harvesting were 21 days (T1), 28 days (T2), and 35 days (T3). Ecotypes of African foxtail used were *Ologoraing'ok namelock (On), Ologoraing'ok twanga (Ot)*, *Nzingangata (Nz), Orupilipili (Op),* and *Iramata mtandika (Im*). The plot size was 8 m^2, and each treatment had three replications making a total of forty-five (45) plots.

5.2.3 Source of experimental materials

Ecotypes used in this study were those collected from three districts: Kilolo, Kiteto, and Mpwapwa (Lutatenekwa *et al*., 2021). The selection of areas for ecotypes collection considered the presence of variation in geographical locations and topographic and climatic conditions. Then, sprigs of ecotypes collected were planted in multiplication plots; after acquiring enough planting materials, experimental plots were set.

5.2.4 Establishment and management of grasses

Experimental plots, each measuring $8m^{2,}$ were prepared prior to planting sprigs of African foxtail ecotypes. Before planting, diammonium phosphate (DAP) fertilizer with the composition of 18% nitrogen and 46% phosphate was applied at the rate of 145 kg/ha. Sprigs from multiplication plots were cut at a similar height of 12 cm. The distance between plots was 1.5 m, and the distance between plants was 0.5 m. Spaces between plots were kept clear to serve as paths and avoid shades to the treatments. Need-based irrigation was applied equally to all experimental plots during the dry spell. Weeding was frequently done whenever the weeds were spotted to avoid light and nutrient competition. Harvesting of the ecotypes sward was done after 60 days from planting for standardization before application of treatments. Using a sickle, the sward was cut uniformly at a height of 8 cm above the ground. The height used for the standardization cut was selected to ensure that cells capable of division and growth in the shoots were not destroyed. Timpong-Jones *et al.* (2015) subscribe that shoot revitalization uses sugars stored in the bottom of the tillers around 4 cm in height. Top-dressing fertilizer N-P-K (15-9-20 %) was applied at the rate of 145 kg/ha after the standardization cut. The uniform application of fertilizer and irrigation to all plots was opted to control nutrient and moisture stress factors.

5.2.5 Data collection

In order to study the effects of harvesting interval on forage growth of the ecotypes, plant height (PH) measured in centimetres (cm), and leaf area (LA) in cm^2 (calculated from leaf length and leaf width) were measured using a tape measure, and tiller number per tussock (TNT) were counted. These growth traits were recorded on ten randomly selected tussocks per plot in each of the three replicates. T1 had four (4) harvests, T2 had three (3) harvests, and T3 had two harvests throughout the experimental period. Pooled data from all cuts of each harvesting interval were analysed. Fresh weight (FW) used to estimate yield per hectare was obtained by harvesting and weighing above-ground biomass at 8 cm height from ground level in two quadrats of 1 m^2 per plot. Subsamples of 500g from each treatment were packed in labelled envelopes and taken to the laboratory for oven drying.

5.2.6 Data Analysis

5.2.6.1 Laboratory Sample analysis

In the laboratory, 500 g samples were oven dried at 60 ^{0}C for 72 hours to determine DM used to calculate dry matter yield per hectare (DMkgha^{-1}). Forage dry matter yield was calculated following standard procedures (Insua *et al*., 2019). The samples were milled to pass through a 2 mm sieve (Enoh *et al*., 2005), then further dried at 105 ^{0}C for 48 hours, and *in vitro* two-stage method of Tilley and Terry (1963) was used to determine dry matter digestibility (IVDMD). Acid detergent fiber (ADF) and neutral detergent fibre (NDF) were analysed by using Ankom technology following the procedure as explained by Van Soest *et al.* (1991).

5.2.6.2 Data processing and statistical analysis

Data conception was done in excel, followed by a combined analysis of the pooled data. Pooled data were obtained from four, three, and two harvesting frequencies for T1, T2, and T3, respectively. A factorial analysis of variance was performed using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS 2008). The means were compared between the ecotypes, harvesting interval, and their interaction using least square means (LSmeans) and Duncan's multiple range test at $p < 0.05$ level of significance.

Correlations between traits were computed using the CORR procedure of SAS to determine the interrelatedness and the strength of the relationship between assessed traits.

5.3 Results

5.3.1 Effects of harvesting interval and ecotype on forage growth, yield, and nutritional quality

The results of the effects of harvesting intervals on forage growth, yield, and nutritional quality of African foxtail ecotypes are shown in Table 1.

Growth characteristics were significantly ($p < 0.05$) influenced by harvesting interval and ecotypes. The plant height (PH) and leaf area (LA) increased with an increase in harvesting interval, but long harvesting interval reduced tiller numbers per tussock (TNT). The variation of PH and LA among ecotypes was in the order of ecotype Op > Nz > Im > Ot > On, and TNT was in the order of ecotype On > Ot > Im > Nz > Op. Maximum forage yield was recorded at 28 days harvesting interval of T2. Yield declined at 35 days cutting interval, and the lowest yield was recorded at 21 days cutting interval. The yield from harvesting at T2 exceeded that of T3 by 5.78%. Similarly, the yield of T2 exceeded that of T1 by 54.54%, and the average yield per hectare for all cutting intervals was 1352.27 DMkgha^{-1}. Additionally, there was yield variability among ecotypes with the trend of Op > Nz > Im > Ot > On.

Short harvesting interval produced herbage with the highest IVDMD; as the harvesting interval increased, IVDMD decreased (Table 1). The opposite trend was shown by NDF and ADF contents, where short harvesting intervals had low ADF and NDF, but these traits increased as the harvesting interval increased. There was also the variability of IVDMD, ADF, and NDF among ecotypes, as presented in Table 1. There was also an interaction between the factors with all traits except ADF and NDF. Therefore, further analysis was conducted on traits with the interaction of the factors' effects.

Table 1. Least square means of growth, yield and quality attributes; effects of harvesting interval and ecotype

Treatment	Least square means for assessed traits						
	PH	LA	TNT	Yield	IVDMD	NDF	ADF
Effect of harvesting interval (HI)							
T1	55.54^{c}	9.02^{b}	183.29^{a}	8251de	56.76^{a}	56.33^{b}	29.73^{b}
T2	65.51^{b}	9.42^{ba}	160.57^{b}	18149.^{a}	53.44^{ba}	57.89^{b}	33.97^{a}
T3	76.89^{a}	9.84^{a}	152.41^{c}	17101^{b}	49.85^{c}	60.56^{a}	34.32^{a}
Mean	65.98	9.43	165.42	14500	53.78	58.26	33.13
SEM	1.672	0.551	11.403	2.7600	3.339	1.371	2.058
P-value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0031	0.0101
Effect of Ecotypes							
On	55.64^{d}	3.27^{c}	235.90^{a}	9282^{b}	58.84^{a}	56.84^{a}	33.97^{a}
Ot	61.26^{c}	3.69^{c}	227.32^{a}	13963^{a}	55.14^{a}	57.43^{a}	32.81^{a}
Op	70.44^{a}	20.89^{a}	120.72^{b}	14860^{a}	56.79^{b}	59.76^{a}	32.49^{a}
Nz	65.69^{b}	10.47^{b}	137.13^{b}	14116^{a}	52.59^{b}	58.70^{a}	32.52^{a}
Im	64.72^{cb}	9.52^{b}	137.64^{b}	14072^{a}	50.13^{c}	58.58^{a}	31.58^{ba}
Mean	63.55	9.57	171.74	13258	54.09	58.26	32.67
SEM	1.5416	0.4305	11.3000	2.0472	0.0058	0.0261	0.4037
P-value	0.0003	0.0006	<.0001	0.0061	0.0017	0.2531	0.1550
(HI*E)	<.0001	<.0001	<.0001	<.0001	<.0001	0.2937	0.056

On = Ologoraing'ok namelock, Ot = Ologoraing'ok twanga, Nz = Nzingangata Op = Orupilipili and Im = Iramata mtandika, Means presented are the average of each parameter per treatment; SEM = standard error of the mean, HI*E = the probability value at 5% for the interaction of ecotypes effects and harvesting intervals effects. Similar letters along the column = means are not statistically different

5.3.2 The simple effect of harvesting interval and ecotype on forage growth, yield, and digestibility

The significant (P< 0.05) interaction between harvesting interval and ecotype led to the simple effect test. The test involved further analysis of the means of forage growth, yield, and digestibility attributes at each level of the factors. The results on the five studied attributes, PH and LA, TNT and yield, and digestibility are presented in Tables 2, 3, and 4, respectively.

5.3.2.1 The simple effects of harvesting interval and ecotype on plant height and leaf area

The simple effect of harvesting interval and ecotype was significant ($p < 0.05$) on the PH and LA (Table 2). The results reveal that PH and LA varied considerably for each ecotype and across harvesting intervals. The results also indicate that the combined effect of the two factors led to a significant variation of the means of PH and LA between ecotypes and harvesting intervals. The PH and LA were significantly ($P < 0.05$) higher (87.20 cm and 22.92 $cm^{2,}$ respectively) on the interaction effect of ecotype Op with T3. The lowest PH and LA were shown by On interaction at T1 (46.40 cm and 3.27 cm^2), respectively.

Table 2. The simple effects of harvesting interval and ecotype on plant height and leaf area

Ecotypes	**Plant Height (cm)**				**Leaf area (cm^2)**			
	Harvesting interval				**Harvesting interval**			
	T1	**T2**	**T3**	**Mean**	**T1**	**T2**	**T3**	**Mean**
On	46.40^{e+}	60.29^{cb}	67.15^{b}	57.95^{BC++}	3.27^{d+}	3.44^{d}	3.46^{d}	3.39^{C++}
Ot	52.90^{d}	62.14^{cb}	76.15^{ba}	63.73^{B}	3.56^{d}	3.72^{d}	3.72^{d}	3.67^{C}
Op	62.25^{cb}	70.17^{ba}	87.20^{a}	73.21^{A}	20.48^{a}	21.54^{a}	22.92^{a}	21.65^{A}
Nz	58.45^{c}	68.63^{b}	77.10^{ba}	68.06^{BA}	8.99^{c}	10.27^{b}	13.06^{b}	10.77^{B}
Im	57.68^{c}	66.33^{b}	76.38^{ba}	66.80^{BA}	8.82^{c}	9.18^{cb}	11.62^{b}	9.87^{B}
Mean	55.54^{C+*}	65.51^{B}	76.79^{A}		9.02^{B+*}	9.63^{BA}	10.96^{A}	
3HI mean	65.95				9.87			
SEM	1.861	2.0778	2.8046		0.6515	0.48	0.7816	
P-value	**	**	**		**	**	**	

On = Ologoraing'ok namelock, Ot = Ologoraing'ok twanga, Nz = Nzingangata Op = Orupilipili and Im = Iramata mtandika, ** Significant at 0.05, 3HI mean = general mean for the three harvestings; + Values with different small letters are significantly different at 0.05 confidence level; +* Means with different capital letters (row mean) are significantly different; ++ Means with different capital letters (column mean) are significantly different at 0.05 confidence level. SEM = standard error of the mean.

5.3.2.2 The simple effect of harvesting interval and ecotype on tiller number and yield

The results in Table 3 indicate the simple effect of harvesting interval and ecotype factors on tiller numbers and yield attributes. This effect was significant ($p < 0.05$) on the two attributes. The TNT and yield varied considerably for each ecotype across harvesting intervals. The combined effects of the two factors led to a significant ($P < 0.05$) variation in TNT and yield between ecotypes and harvesting intervals. The TNT was the highest (239.9) on the interaction of ecotype On with T1, while the yield was the highest (20420DMKgha^{-1}) on the interaction of ecotype Op and T2. The lowest TNT (76.9) was obtained from the interaction of ecotype Op and T3, while the lowest yield (6443 DMKgha^{-1}) was from the interaction of ecotype On and T1.

Table 3. The simple effects of harvesting interval and ecotype on tillers and yield

Ecotypes	**Tiller number**				**Yield (DMKgha^{-1})**			
	Harvesting interval				**Harvesting interval**			
	T1	**T2**	**T3**	**Mean**	**T1**	**T2**	**T3**	**Mean**
On	239.9^{a+}	223.2^{a}	215.4^{ba}	226.2^{A++}	6443^{c+}	13506^{b}	12650^{b}	10866^{C++}
Ot	229.7^{a}	207.5^{a}	198.9^{b}	212.1^{A}	6546^{c}	18681^{a}	17081^{a}	14102^{CB}
Op	139.2^{c}	95.13^{d}	76.9^{e}	103.7^{CD}	10361^{b}	20420^{a}	19813^{a}	16865^{A}
Nz	157.5^{b}	108.8^{cd}	102.1^{cd}	122.9^{C}	9153^{c}	19385^{a}	18963^{a}	15834^{B}
Im	150.1^{b}	98.37^{d}	98.1^{d}	115.5^{C}	8781^{c}	18777^{a}	18532^{a}	15363^{B}
Mean	183.3^{A+*}	146.6^{B}	138.3^{C}		8256^{DE+*}	18154^{A}	17408^{B}	
3HI mean	159.06				14606			
SEM	11.101	10.533	10.932		79.906	97.821	36.419	
P-value	**	**	**		**	**	**	

*On = Ologoraing'ok namelock, Ot = Ologoraing'ok twanga, Nz = Nzingangata Op = Orupilipili and Im = Iramata mtandika, ** Significant* at 0.05, 3HI mean = general mean for the three harvestings. + Values with different small letters are significantly different at 0.05 confidence level, +* Means with different capital letters (row mean) are significantly different. ++ Means with different capital letters (column mean) are significantly different at 0.05 confidence level. SEM = standard error of the mean.

5.3.2.3 The simple effect of harvesting interval and ecotype on digestibility

There was a significant (P < 0.05) effect of harvesting interval and ecotype on digestibility (Table 4). It was revealed that digestibility varied considerably for each ecotype across harvesting intervals. The results also indicate that the combined effect of the two factors led to a significant (P <0.05) variation in the means of digestibility between ecotypes (column mean) and harvesting intervals (row mean). The IVDMD was the highest (59.35%) on the interaction effect of ecotype On with T1 and the lowest on the interaction of ecotype *Im* and T3.

Table 4. The simple effects of harvesting interval and ecotype on digestibility

Ecotypes	Digestibility (IVDMD %)			
	Harvesting interval			
	T1	T2	T3	Mean
On	58.39^{a+}	52.49^{a}	43.25^{b}	55.38^{A++}
Ot	54.56^{a}	50.93^{a}	42.58^{b}	54.36^{A}
Op	56.49^{a}	51.93^{a}	42.79^{b}	54.70^{A}
Nz	53.88^{b}	46.89^{b}	42.83^{b}	52.87^{BA}
Im	53.45^{a}	45.95^{b}	40.32^{b}	50.57^{BA}
Mean	55.35^{A+*}	49.64^{B}	42.35^{CB}	
3HI mean	49.12			
SEM	2.211	1.620	0.708	
P-value	**	**	**	

** Significant at 0.05, 3HI mean = general mean for the three harvesting

+ Values with different small letters are significantly different at 0.05 confidence level

+* Means with different capital letters (row mean) are significantly different. ++ Means with different capital letters (column mean) are significantly different at 0.05 confidence level. SEM = standard error of the mean.

5.3.3 Correlations among forage growth, yield, and quality attributes of the ecotypes

A correlation analysis was conducted among forage growth, yield, and quality attributes. The results in Table 5 reveal that plant height and leaf area contributed positively to yield due to their positive correlation coefficient. On the other hand, plant height, leaf area, and yield were negatively correlated to tiller numbers and digestibility.

Table 5. Correlation coefficients among growth, yield, and digestibility attributes

	PH	***TN***	***LA***	***DMkgha-1***	***IVDMD %***
PH	1.000				
TN	-0.222	1.000			
LA	0.435	-0.760	1.000		
DMkgha-1	0.793	-0.424	0.272	1.000	
IVDMD %	-0.723	0.329	-0.233	-0.651	1.000

5.4 Discussion

Adaptation to defoliation is a potential attribute of a good forage species in the era of livestock feed constraints. The findings of this experiment revealed that harvesting intervals affected forage growth, yield, and quality of African foxtail ecotypes. It was observed that long harvesting interval increases plant height, leaf area, and forage yield. According to Sbrissia *et al.* (2010), plant height and leaf area (a function of leaf length) depend on the severity of defoliation; thus, frequently harvested sward will be short with a small leaf area. Srisook *et al.* (2015) associate frequent harvesting with the shortage of carbohydrates, which changes the plant's physiological processes. The findings of this study agree with observations reported by Yigzaw (2019) that longer harvesting intervals increase the growth characteristics of African foxtail. Comparable observations of short harvesting intervals resulting from decreasing in plant height were reported by Ansa and Garjila (2019) on elephant grass (Pennisetum purpureum).

Conversely, this study reported an increase in TN with short harvesting intervals. Tiller production is influenced by light intensity (Wherley et al. 2005). Short harvesting intervals allow higher light intensity towards the tussock crown than long cutting intervals. Silveira *et al.* (2010) linked the increase of tillers to the trait of tolerance to defoliation. Tiller number per tussock increases as a compensation mechanism to increase the area for light interception

(Assuero and Tognetti 2010). The inference is made because tiller number per tussock is among the three important sward characteristics which contribute to leaf area index (LAI), the other two being leaf size and number of leaves per tiller (Sbrissia *et al.,* 2010). According to Guitian and Bardgett (2000), tillering induced by frequent harvesting results from priority allocation of assimilates and reserves to support more rapid regrowth of above-ground tissue following defoliation stress.

On the other hand, the optimum yield was observed by harvesting at the interval of 28 days; beyond this interval, the yield was reduced. Reduced yield can be associated with leaf death and seed shedding, which was observed in the 5^{th} week. This finding agrees with a study conducted by Cahill *et al*. (2014) on the cost and benefits analysis of switch grass harvest time and their effect on nutrient use and yield. In their study, Cahill *et al.* (2014) observed that delaying harvest dates past maximum yield resulted in lower biomass yield and less nutrient removal from the soil.

Moreover, this study revealed that there was a variation in response to the harvesting interval among the ecotypes of African foxtail. The observed variation among the five ecotypes was depicted in a trend such that an ecotype with the highest growth, yield, and quality attributes to T1 was similarly the highest with T2 and T3. Considering the height of the plant, leaf area, and forage yield, ecotype Op gave the highest values to the three harvesting regimes. The ecotype Op from plain grassland of sandy-clay-loam soil with moderate acidity had the highest dominance in nature (Lutatenekwa *et al*., 2021). The continual expression of the highest growth and productivity in the experimentation area, attributed to dominance in nature, verifies the perpetuity of these traits. Correspondingly, when these ecotypes were grown under the common stress-free environment of Magadu (Lutatenekwa *et al.*, In press), ecotype Op was the best performing in terms of growth and yield traits.

Livestock performance, in most cases, reflects the quality of the feed they are consuming (Newman *et al.,* 2009; Zhai *et al.,* 2018). The contribution of feed quality to livestock productivity signifies that farmers need to know the nutritional composition of forage species (Lazzarini *et al*., 2009; Woolley *et al*., 2011). This experiment determined forage quality by ADF and NDF content and in-vitro digestibility. Low ADF and NDF and high digestibility percentages signify good quality forage. The plant cell content is the basic determining factor of forage digestibility. Hemicellulose, cellulose, and Lignin concentrations (composition of NDF and ADF) increase with age, resulting in reduced digestibility (Särkijärvi *et al*., 2012).

On the other hand, soluble carbohydrates and proteins are completely digestible (Yigzaw, 2019). Therefore, sufficient nutrients are acquired from highly digestible feed than what could be expected from feed with low digestibility. Harvesting the grass sward on short harvesting interval (T1) was observed to have the highest forage digestibility and lowest ADF and NDF percentages. Increased forage quality resulted from retrogression in plant development, back to a stage characterized by high absorption of nutrients (Timpong-Jones *et al.,* 2015). Freitas *et al*. (2012) and Virkajärvi *et al*. (2012) agree that plants undergo quality growth in the early stage by accumulating nutrients drawn from the soil; at senescence, nutrients are moved back to the soil. Atis *et al.* (2012) reported divergent results that ADF and NDF content in forage sorghum decreased with advanced plant maturity.

A significant ($P < 0.05$) variation in forage quality was observed in this experiment among ecotypes ($p = 0.003$). The ecotype On depicted the highest forage quality compared to the other ecotypes.
Furthermore, positive correlation coefficients observed between plant height, leaf area, and yield imply that plants of higher height and broad leaves are expected to produce the highest yield. Conversely, negative correlation coefficients of these traits with forage quality suggest that the forage quality will decrease as growth and yield attributes increase. Consequently, the best harvesting time

is required to strike between maximum yield and quality for the best livestock productivity. From these observations, the experiment considers ecotypes Op and On to be the best choices for breeding programs as their attributes of forage growth, yield and quality complement each other.

5.5 Conclusion and recommendations

The knowledge of forage growth, yield, and quality at a given harvesting interval is important for farmers to decide a good management plan that maximizes productivity. Harvesting interval significantly affected forage growth, yield, and quality of African foxtail ecotypes. Forage growth and yield increased while forage quality decreased with the increase in harvesting interval. The highest yield was recorded on T2. There was a variation in response to harvesting intervals among ecotypes which followed a similar trend among the three harvesting intervals. Ecotype Op recorded the highest forage yield, and ecotype On recorded the highest feed quality; hence these two ecotypes are recommended for breeding programs since their attributes complement each other.

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CHAPTER SIX

6.0 GENERAL DISCUSSION

6.1 Introduction

The idea of African foxtail ecotypes characterization was conceived and executed after a thorough literature survey. It was established that despite its importance, the characterization of forage species in Tanzania had received little or no attention. However, the increasing impacts of environmental stresses on forage species and the livestock sector necessitate selecting and breeding varieties more adapted to changing environmental conditions (Shantharaja *et al.*, 2015). Successful selection and breeding depend on the availability of information on forage species which results from forage characterization (Lutatenekwa *et al.,* 2020). This thesis is designated to contribute to a pool of knowledge on the scope and importance of plant characterization, morphological variation of African foxtail ecotypes in natural environments, growth and productivity of African foxtail ecotypes under common stress-free environments, and their response to defoliation.

6.2 Scope and importance of plant characterization toward sustainable forage production in challenging environment

The review of literature observed that researchers had conducted plant characterization in Tanzania; however, most of these studies were biased toward food crops, neglecting forage crops (Bucheyeki *et al*., 2010; Dolo, 2018; Fisher *et al*., 2015; Mangosongo *et al*., 2019 and Muthoni, 2010). Elsewhere, forage species have been characterized (Jorge *et al*., 2008; Kannan and Priya, 2020; Lima, 2018; Saini *et al.,* 2007), and different approaches have been used. The approaches of forage characterization reviewed included morphological, agronomical, biochemical, physiological, and the use of molecular markers. Assessment of visible characteristics and structure of plants; study of quantity and quality produced in different types of soils, response to variable amounts of fertilizers were in the scope of agro-morphological characterization (Jorge *et al*., 2008, Lima *et al.,* 2018; Muthoni, 2010 and Wassie *et al.,* 2018). Caramori *et al*. (2004) and Kannan and Priya (2020) refer to biochemical characterization as characterization based on the types of biological active compounds present in a plant. On the other hand, physiological characterization is based on plant functions such as photosynthesis, respiration gases produced, and nutrient circulation (Saini *et al.,* 2007). Molecular characterization is the characterization of organisms using DNA-based markers, also called molecular markers (Laurentin, 2009; Kumar and Saxena, 2016). Molecular markers are important in evaluating interrelationships among accessions and geographical groups to estimate genetic diversity and identify genes associated with a given attribute (Laurentin, 2009). Molecular characterization is a more advanced and sophisticated approach to forage characterization than agro-morphological characterization.

It was observed that characterization approaches could be used singly (Caramori *et al.,* 2004; or in a combination of two (Lima *et al.,* 2018; Photita *et al.,* 2005; Stevenson-Paulik *et al.,* 2002; Virga *et al*., 2020) or more (Gupta and Huang, 2014) approaches. Lima *et al*. (2018), for example, used a combination of morphological and physiological approaches to characterize *Megathyrsus maximus, Urochloa decumbens,* and *Urochloa brizantha* in Brazil. In their study, it was revealed that nutritive value and CH4 production could be employed as parameters for grass species selection when aiming at forage production sustainability.

Furthermore, it was noted that in developing countries, agro-morphological approaches for characterization are more commonly used than advanced and sophisticated approaches such as the use of molecular markers. The reason for the inadequate use of sophisticated characterization approaches includes limited access and affordability. Despite the realised weaknesses of morphological and agronomical characterization, it was concluded that developing countries continue using this approach because they are cheap and easily accessible.

Literature indicated that the characterization of forage species focuses on productivity and adaptability to stress attributes (Al -Dakheel & Hussain, 2016; Al -Dakheel *et al*., 2015; Ansa and Garjila, 2019; Doyo *et al.,* 2018; Jorge *et al.,* 2008; Lima *et al*., 2018; Meena & Nagar, 2019; Silveira *et al.,* 2010; Timpong-Jones *et al.,* 2015; Yigzaw, 2019). Regarding characterization for adaptation to stresses, literature indicated that researchers focus on characterization for adaptation to drought (Acuña *et al*., 2012; Li *et al.,* 2015), salinity (Fahad *et al.,* 2015; Forni *et al.,* 2017), and defoliation (Timpong-Jones *et al.*, 2015).

African foxtail is among the forage species most studied elsewhere (Jackson, 2005; Mansoor *et al*., 2015; Scott, 2014; Marshall *et al.,* 2012), and it has been revealed that this species possesses adaptability and productivity attributes worthy of exploring. Together with this valuable information, literature has revealed that due to the adaptability of different environmental stresses, African foxtail could have many ecotypes with variable attributes (Kannan and Priya, 2015; Marshall *et al*., 2012), which may develop sustainable pasture production. Conversely, there was limited information on the ecotypes of this grass species, especially in Tanzania. The study at hand, therefore, used morphological approaches to characterize African foxtail ecotypes.

6.3 Habitat and morphological characteristics of African foxtail ecotypes

This study assessed six ecotypes of African foxtail grass in three districts of Tanzania. The districts are Kilolo Kiteto, and Mpwapwa. Ecotypes assessed in this study have not been studied before. Therefore, this study used native nomenclature as used by the people around the study areas. Lest similar local names a village name was used together with the local name for distinction. Ecotypes studied from Kilolo, were *Iramata malolo* (Ir) from Malolo village and *Iramata Mtandika (Im)* from Mtandika village. The ecotypes *Ologoraing'ok namelock* of Namelock village (*On*) and *Ologoraing'ok twanga* (*Ot*) of Twanga village were from Kiteto

District. The third District was Mpwapwa and ecotypes studied were *Nzingangata (Nz)* from Ipera village, and *Orupilipili* (*Op*) from Mazae village. First, the habitat supporting the existence of African foxtail grass was assessed. Habitat assessment included altitude and topography of the area, temperature, rainfall, anthropogenic activities, soil characteristics, and plant species associated with African foxtail. Morphological characterization of the ecotypes followed after habitat characterization.

6.3.1 Habitat characteristics

A study conducted on habitat and morphological characterization of African foxtail ecotypes in their natural environments revealed that African foxtail grass inhabits places with variable characteristics. The physiognomy and environmental condition of the places where these ecotypes inhabited ranged from grass plains to hills with scattered woodlands at the altitude of 528 to 1613 meters above sea level (masl). These findings concur with Scott (2014) that African foxtail has adapted well to varied environments from semi-arid to arid climates with altitudes up to 2000 masl. The anthropogenic activities of the studied areas were grazing, farming, fallow land, and reserved area of the river banks. In frequently grazed areas, African foxtail were short with higher number of tillers. Grazing is especially important because it disturbs natural processes, influences species persistence and changes the composition and structure of grass communities (Romme *et al.,* 2009; Papanikolaou *et al.,* 2011). African foxtail of farming and fallowed land for agriculture expressed higher dominance since these places were plain and open without shadows of tall trees and shrubs. In reserved areas of the river bank the grass was located in few stands due to the presence of shadows from many trees and shrubs around. These observations concur with Marshall *et al*. (2012) that African foxtail grass flourishes in areas with less shade and enough light, like any other C4 grasses.

African foxtail was found to be associated with scattered woody legumes such as *Leucaena leucocephala and Acacia xanthophloea.* The findings concur with Tix (2000) that African foxtail is intolerant to shade. Grasses that were found in association with African foxtail include *Setaria verticillata*, *Urochloa maxima*, *Cyperus esculentus, Chloris species, and* Hyparrhenia species. The dominance of African foxtail ecotypes varied considerably following the type of the landform Ecotypes on areas with steep slopes like those of Malolo and on hills like Ipera and Twanga villages had a low index of dominance. Ecotypes found on valleys and plains, dominance was over 50%, an index of more than 0.5. This implies that African foxtail is uncommon and infrequently dominates hills and steep slopes, similar to Van Devender and Dimmitt's (2006) findings.

The soil is an important media of life sustenance through the provision of ecosystem goods and services like carbon storage, water regulation, and plant nutrients with direct effects on human welfare (FAO, 2015). The soil characteristics where these ecotypes were found were observed to have great variability, from red sandy loam to black cracking clay. These findings contradicted Cox *et al*. (1988) report that African foxtail will strive and finally die when grown on black cracking soils.

Furthermore, soil pH greatly influences soil biogeochemical processes in the ecosystem (Neina, 2019). In the studied areas, soil pH varied from slightly acidic to slightly alkaline, with electrical conductivity (EC) ranging from 0.8 to 4.8 (dS/m) (Lutatenekwa *et al.,* 2021). The ability of African foxtail grass to grow well in such a wide range of soil pH and EC confirms its adaptability attribute. In addition to the soil variability, this study observed the annual rainfall and temperature variation from 643 to 1157 mm and 19.4 to 24 ^{0}C, respectively. African foxtail has been reported to withstand drought but is less tolerant to extended flooding (Kharrat-Souissi *et al*., 2012). African foxtail grass can withstand low rainfall of up to 250 mm (Tix, 2000) and higher rainfall of about 1200 mm (Cox *et al*., 1988). On the other hand, according to Barrera and Castellanos (2007), African foxtail grass has a low tolerance to freezing temperatures but can tolerate very high temperatures of about 45°C.

6.3.2 Morphological characteristics

The findings described in this thesis reveal morphological attributes' variation for the six ecotypes of African foxtail. Assessing and documenting species' morphological attributes is important to aid farmers and breeders in selecting their attribute preferences (Schlautman *et al.,* 2018). Morphological attributes assessed in the current study include plant height, leaf number, leaf length, tiller number per tussock, and inflorescence length. These attributes revealed a great range of variation among studied ecotypes. The plant height of studied ecotypes ranged from 36 – 160 cm. This study's observation on plant height agrees with Marshall *et al*. (2012) that the height of African foxtail range from 20 to 150 cm. Ecotypes assessed from the grazing areas of Kiteto were relatively short compared to the ecotypes of Kilolo and Mpwapwa. The ecotype Iramata Malolo was the tallest and was assessed from the area of reserved river banks under trees and shrubs with no grazing disturbances. In addition to the area having no human and animal disturbances, the height may be due to shade, implying that stem elongation increased in search of light. According to (Nagashima & Hikosaka, 2012), the stem elongates to place the plant on higher strata in search of light to enhance quality photosynthesis. Ecotype *Im* was also on the undisturbed fallow land, which may justify the height observed. The height of ecotypes *Op* followed by *Nz* from the agricultural area was fairly higher than the ecotypes from the grazing area of Kiteto. These findings are in agreement with Carnevalli *et al*. (2006) and Mandle and Ticktin (2012) that frequent harvesting reduces growth by suppressing plant height. The other traits were the tiller number per tussock, which ranged from 11 – 122, and the highest tiller number per tussock was observed from grazed areas of Kiteto. The leaf number ranged from 13 – 153, and the leaf length ranged from 12 – 56 cm. The Shortest and few numbers of leaves were again observed from grazed areas of Kiteto, of ecotypes *On* and *Ot*. The findings on leaf size agree with Cruz *et al*. (2010) that continuous grazing hinders grass leaves from reaching their normal size.

Furthermore, the inflorescence length of the selected ecotypes ranged from 1 –12 cm, the highest produced by *Op* ecotype and the lowest by *On* ecotype. Variation of characteristics within and among ecotypes suggests increased level of adaptability, thus a species is able to colonize extensive environments (Da Silveira Pontes *et al*., 2015). Similarly, Crispo (2008), reported the effects of plasticity of observable characteristics that they allow species differentiation for adaptation; in a similar context, African foxtail grass can still be explained.

It was conceptualized that morphological variation observed among the six ecotypes is prospective to affect growth and forage production. Additionally, the need to ascertain if variations observed among ecotypes in their natural environment were permanent led to an experiment on ecotypes' performance when grown on a common environment.

6.4 Growth and productivity of African foxtail ecotypes under common environmental conditions

Considering the variation among ecotypes observed in selected natural areas, an experiment was conducted to assess the growth and productivity of these ecotypes grown under common environmental conditions. Five ecotypes, *On, Ot, Nz, Op,* and *Im,* were used in this experiment as the sixth ecotype *Ir,* from Malolo village of Kilolo District, failed to produce enough experimental materials in the multiplication plots.

This experiment revealed a variation among ecotypes of African foxtail on growth attributes, including plant height, tiller number per tussock, inflorescence length, and leaf area. Variations followed a comparable trend to what was observed when ecotypes were assessed in the natural environments (Lutatenekwa *et al.,* 2021), implying that there was no variability reduction. Diversity within species has been reported by other scholars (Bruno *et al*., 2017; Jorge *et al*., 2008). The direction of variation of plant height, inflorescence length, and leaf area was such that *Op* > *Nz* > *Im* > *Ot*

>*On* while tiller number per tussock followed the opposite direction where *On* > *Ot* > *Im* > *Nz* > *Op*. From this observation, the experiment inferred that plants grow higher in height with broadened leaves at the expense of size and number of tillers. The inference is supported by Sibrissia *et al*. (2010) that the height of the sward is influenced by tiller population density.

Forage grasses are the main component of cheap livestock feeds from communal grazing lands. In order to attain desirable animal productivity, sustainable access to the quantity and quality of the forage grass matters. With regard to quantity, this study observed that ecotypes with higher plant height and leaf area (*Op*) produced the highest yield, while ecotypes with the lowest plant height and leaf area (*On*) gave the lowest yield. This observation indicated a positive correlation between plant height, leaf area, and forage yield, but these three attributes were negatively correlated to the tiller number per tussock. The findings of this study concur with the results reported by Anwar *et al.* (2012) and Meena and Nagar (2019) that low plant height resulted in low fodder yield. Furthermore, stem elongation, in addition to leaf area, enhance the position of the plant to higher strata for easy light penetration to support photosynthesis resulting in higher productivity (Paradiso and Proietti, 2021). On the other hand, short forage grasses adopt a high bulk of small tillers with narrow and short leaves to compensate for the height (Meena and Nagar, 2019; Sbrissia *et al.,* 2010).

Forage species with high productivity will be preferred by farmers and breeders when their nutritional value (forage quality) is also satisfactory. According to Arshadullah *et al*. (2011), the production of meat, milk, and associated livestock products depends on feed quality 75%, while the rest (25%) depends on heredity factors. It was from this perspective that the experiment at hand analysed the nutritional value of the studied ecotypes. Forage quality in this experiment was determined by crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF), and ash content. According to Al-Dakheel *et al*. (2015), forage with higher CP indicates high-quality importance for meat, milk, and animal body maintenance. On the other hand, low NDF and ADF (below 60% and 35%, respectively) are preferred in a feed as they suggest high digestibility of the herbage (Belyea *et al*., 1993; Van Saun, 2013).

There was a variation in forage quality among ecotypes, and the ecotype with the lowest yield (*On*) was found to have a higher nutritional value than the rest of the ecotypes. However, regardless of the variation in the nutritional value observed among the ecotypes, all values for CP%, ADF%, and NDF% were in the acceptable range (Belyea *et al*., 1993; Van Saun, 2013). This observation indicated that the five ecotypes studied, therefore, can be considered forage of good quality.

It was, therefore, evident that agro-morphological variations continue to be expressed among ecotypes when subjected to common environmental conditions. The agro- morphological variability is likely to influence the response of ecotypes to stresses. The need for stress-tolerant variants led to the idea of characterizing the ecotypes when subjected to defoliation stress.

6.5 Response of African foxtail ecotypes to defoliation

Adaptation to defoliation is a potential attribute for a good forage species in the era of livestock feed constraints. The response of African foxtail ecotypes to defoliation stress was determined by assessing the effects of harvesting interval on forage growth, yield, and nutritional value of ecotypes *On, Ot, Nz, Op,* and *Im.* The regimes of harvesting were 21 (T1), 28 (T2), and 35 (T3) days using a factorial design with three replications. Harvesting intervals affected the five ecotypes' forage growth, yield, and nutritional value. It was observed that long harvesting intervals increase the plants' height, leaf area, and forage yield. The findings of this experiment agree with observations reported by Yigzaw (2019) that growth characteristics of African foxtail grass increased with longer harvesting intervals. Similar observations were reported by Ansa and Garjila (2019) on the decrease in the growth height of elephant grass as a result of short harvesting intervals. Contrariwise, the optimum yield was observed by harvesting at 28 days; beyond this interval, yield was reduced. The yield reduction is likely caused by leaf death and seed shedding, which was noted in the fifth week of plant growth. This finding agrees with a study conducted by Cahill *et al*. (2014) on the cost and benefits analysis of switch grass harvest time and their effect on nutrient use and yield. In their experiment, Cahill *et al.* (2014) observed that delaying harvest dates past maximum yield resulted in lower biomass yield and less nutrient removal from the soil.

The experiment revealed that there was a variation in response to defoliation among ecotypes of African foxtail. The observed variation among the five ecotypes was depicted in a trend such that an ecotype with the highest growth, yield, and nutritional attributes to T1 was similarly the highest with T2 and T3. Considering the height of the plants, leaf area, and forage yield, ecotype *Op* gave the highest values to the three harvesting regimes. The ecotype *Op* from plain grassland of sandy-clay-loam soil with moderate acidity had the highest natural dominance. The continual expression of the highest growth and productivity, attributed to dominance in nature, in the experimentation area verifies the perpetuity of these traits.

Nutritional value of the forage plays an essential role in the nutrition and performance of grazing animals (Zhai *et al.,* 2018). According to Lazzarini *et al*., 2009; Woolley *et al*., 2011), it is in the livestock farmers' best interest to know the forage quality because animals' performance depends on the quality of forage consumed.

Good nutritional attributes in this study were observed by harvesting the sward on short harvesting intervals. Plants undergo quality growth in the early stage by accumulating nutrients drawn from the soil; as the plant senescence, a plant starts translocation of its nutrients and giving back to the soil (Freitas *et al*., 2012; Virkajärvi *et al*., 2012). Despite its low yield (9282kgha^{-1}), ecotype *On* depicted the highest nutritional values, as described by relatively higher invitro dry matter digestibility (56.76%) and relatively lower neutral detergent fibre (56.33%). The nutritional value of ecotype *On* was also reported to be higher than the other four ecotypes (Lutatenekwa *et al.*, submitted for publication), where it recorded crude protein of 21.15% and Neutral detergent fibre of 55.89%. From these observations, the experiment considers ecotypes *Orupilipili (Op)* and *Ologoraing'ok namelock (On),* to be the best selection for breeding as their attributes complement each other. Therefore, it was concluded that harvesting intervals affect forage growth, yield, and nutritional value of the selected African foxtail ecotypes.

6.5.1 Implications of the findings

The response of African foxtail ecotypes to harvesting intervals experiment provide valuable insights and messages to farmers. The information obtained will help farmers make informed decisions about their grazing management strategies. Harvesting intervals significantly impacted forage quality. These were simulation experiments to grazing and demonstrated that shorter harvesting intervals can lead to higher-quality forage, which can result in better livestock performance. Farmers can be encouraged to adjust their grazing management to include rotational grazing to provide higher-quality forage to their animals.

On the other hand, longer harvesting intervals may allow for greater forage quantity to accumulate. Harvesting interval experiment shows that there is a trade-off between forage quality and quantity. Farmers can learn that adjusting harvesting intervals can help them strike a balance between these two factors based on their specific goals and the needs of their livestock. Harvesting intervals experiments highlight to farmers the importance of maintaining land and pasture health. Continuous grazing in contrast, without adequate rest periods can lead to overgrazing and pasture degradation. Recommended harvesting intervals can help farmers to learn that implementing rotation grazing maintain pasture health, reduces soil erosion, and promotes biodiversity.

The findings of this study on the effect of harvesting intervals informs on environmental sustainability. Similarly, grazing management has environmental implications. The findings emphasize that responsible management, such as rotational grazing or shorter harvesting intervals, can reduce environmental impact, such as soil erosion and nutrient runoff. Farmers can be encouraged to adopt practices that align with sustainability goals.

Another message to farmers is that there is no one-size-fits-all approach. Farmers should consider local climate, soil types, and available resources when determining the best harvesting intervals or grazing strategies. Information generated from this study can help them understand how these factors interact with management choices. Farmers should plan for the long term outcomes since short-term gains from continuous grazing may lead to long-term declines in pasture productivity and livestock performance. It is important that farmers think about the long-term sustainability of their operations by making informed decisions that align with their specific goals and the well-being of their livestock and land.

6.6 Key findings of the study

The findings of this study uncover a number of issues that are important for the general knowledge among livestock farmers, researchers and professionals as well as policymakers. Firstly, reviewed research reports showed that characterization efforts are biased toward food crops and less toward forage crops. It should be noted that characterization is a key step toward providing the required information on forage species. The information is of great significance in ruminants' production by aiding forage species selection and breeding. The process ascertains the presence or absence of desired attributes of productivity and adaptability in species. Also, it has become evident that African foxtail specie grow on soils with a variable range of physical and chemical compositions. This study ascertained that the species is rich with ecotypes of variable agro-morphological traits, which enhance selection for breeding programs. The study also revealed that ecotypes variability continues expressing even when grown on a common environmental condition. The ecotypes growth, yield and nutritional attributes variations were observed in response to defoliation regimes. The findings lead to the selection of two ecotypes, *Orupilipili* (*Op*) and *Ologoraing'ok namelock* (*On*), as the best for farmers and breeders due to their complementing attributes i.e productivity and nutritional attributes. Ecotype *Op* is the best in productivity (yield), whereas *On* presents good nutritional composition and digestibility.

CHAPTER SEVEN

7.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

Several conclusions can be made based on the findings and interpretations made in this study. First, forage species characterization can fast-track the process of generating information on desirable traits. It is worth taking advantage of accessible technologies to advance the assortment and breeding of species. The aim is to select species with high production and environmental stresses adaptable traits. If this is successfully done, systematic information can be generated and will assist breeders in efficiently selecting species adapted to specific environmental stresses. Such a strategy can increase the sustainability of forage production and thus improve livestock productivity.

Secondly, the abundance of ecotypes in this study seems to be influenced by the vegetation physiognomy and the landscape of the habitat. Therefore, African foxtail is less common and occurs in scattered patches in sloping areas and around trees and bushes of closed canopy. Nevertheless, it grows well and colonizes open plains in Tanzania’s most grazing lands. It is, therefore, a prospective species to be used for improvement of pasture and grazing land.

The ecotypes exhibited a wide range of morphological variations even when subjected to common environmental conditions. No doubt that morphological variations influenced the ecotypes' growth, productivity, and nutritional value. Variations among the ecotypes allow for the initiation of breeding programs to improve important characteristics which can positively affect forage quality and dry matter yield.

With regard to the ability to respond to defoliation pressure, ecotypes behaved differently, leading to variation in forage growth, yield, and nutritional value. However, their response followed a similar trend in all cutting intervals. The ecotype with the highest productivity with T1 was the same with T2 and T3. Generally, short harvesting intervals are good for the highest nutritional value of forage. Conversely, short harvesting interval (21) will give the lowest forage yield, while the highest yield is produced by harvesting at 28 days (medium period). Yield decreased with a harvesting interval of 35 days (long interval). The results are important to farmers for the arrangement of management plans specific to a given ecotype. The findings of this study suggest *Op* and *On* as the best ecotypes because of their complementing attributes of growth, productivity, nutritional value, and adaptability to defoliation pressure.

7.2 Recommendations

1. Deliberate efforts need to be made in the country to characterize our forage resources to accumulate information on their attributes important for developing our forage industry. This will enhance the selection of forage species with desirable attributes for breeders and farmers.
2. A call is also made for universities and research institutions to upgrade their laboratories to enable availability and easy access to advanced equipment and technologies for forage characterization.
3. These government and development partners urged in financing research and the capacity needed to invest in forage characterization, selection, and breeding to improve forage production.

7.3 Areas for Further Research

1. Although only small land in Tanzania was covered in this study, more ecotypes of African foxtail can be traced in other ecological zones that need to be characterized to establish comprehensive conclusions and recommendations.
2. With funding and capacity building, molecular-based evaluations are necessary to confirm whether the variations in the ecotypes are either genetically or environmentally influenced.

3. Furthermore, subjecting the ecotypes to more common stresses, such as drought and salinity, which were not covered in the present study, is recommended.
4. This study dealt with African foxtail grass only but there is a need to characterise other forage species of which Tanzania is endowed with (such as *Panicum maximum*) to increase the room of selection for resilience and productivity.

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Kuhusu Tasnifu Hii

Kusudi kuu la kufanya utafiti huu lilikuwa ni kubaini aina ya nyasi za *Cenchrus ciliaris* (African foxtail), zinazoweza kustahimili changamoto za kimazingira ili kuhakikisha upatikanaji endelevu wa malisho katika machunga. Utafiti huu ulijikita kubainisha tabia muhimu zinazoweza kuathiri uzalishaji na ustahimilivu wa nyasi hizi katika mazingira yenye changamoto. Utafiti huu ulifanyika kwa kutumia vipando vya nyasi vilivyokusanywa kutoka mikoa mitatu nchini Tanzania. Kutoka mikoa hiyo wilaya tatu ambazo ni Kilolo, Kiteto na Mpwapwa zilichaguliwa. Katika kila wilaya vijiji viwili vilichaguliwa, ambavyo ni Malolo na Mtandika kutoka Kilolo; Namelock na Twanga kutoka Kiteto; na Ipera na Mazae kutoka Mpwapwa. Taarifa muhimu juu ya nyasi hizi na mazingira yanayoruhusu ukuaji wake zilikusanywa katika maeneo yake ya asili, kisha nyasi hizi zikapandwa Magadu, SUA- Morogoro kwa utafuti zaidi. Lengo la kupanda nyasi hizi Magadu lilikuwa ni kudhibitisha kama tabia bainishi za nyasi hizi toka maeneo tofauti ya Tanzania zitaendelea kujidhihirisha. Nyasi hizi zilikatwa kila baada ya kila baada ya siku 21, siku 28, siku 35 ili kubaini mwitikio wake katika ukuaji, uzalishaji na lishe.

Matokeo ya utafiti huu yalibainisha kwamba nyasi za *Cenchrus ciliaris* zinatofautiana kimwonekano kulingana na mazingira ya maeneo zinakopatitana. Tofauti hizi ziliendelea kujidhihilisha hata nyasi hizi zilipolimwa katika maeneo mapya ya pamoja ya Magadu. Tabia bainishi za nyasi za *Cenchrus ciliaris* ziliathiriwa na ukataji. Ukataji wa mara kwa mara (siku 21) uliongeza lishe na kupunguza uzalishaji. Nyasi kutoka Mazae Mpwapwa zilionesha ustahimilivu mkubwa kwa athari ya kukatwa kwa kukua na kuzalisha kiwango kikubwa zaidi ya nyasi kutoka maeneo mengine. Ilibainishwa kuwa pamoja na uzalishaji mdogo wa nyasi kutoka Namelock-Kiteto, nyasi hizo zilikuwa na lishe nzuri zaidi. Pamoja na utofauti huo, nyazi kutoka wilaya zote tatu zilionekana kuwa na uzalishaji mzuri zikikatwa kila baada ya siku 28. Utafiti huu unapendekeza kwa wafugaji na wakulima wa malisho, nyasi kutoka Mazae zilimwe kwa mchanganyiko na nyasi kutoka Namelock, na kukatwa kila baada ya siku 28 ili kupata faida za uzalishaji mkubwa na lishe bora kwa ajili ya mifugo.