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Water Stress Tolerance of Six Rangeland Grasses in the Kenyan Semi-arid Rangelands

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Abstract: This study evaluated six grass species in terms of water stress responses by visual quality and living ground cover attributes and the recovery responses post water stress grown at 80, 50, 30% field capacity soil moisture contents. The grass species evaluated were *Chloris roxburghiana, Eragrostis superba, Enteropogon macrostachyus, Cenchrus ciliaris, Chloris gayana,* and *Sorghum sudanense.* The grasses demonstrated varied levels of water stress tolerance as evaluated by quality ratings based on colour (greenness) and uniformity of colour, leaf firing, living matter and wilting signs. All species declined in visual quality rating with prolonged water stress treatment with exception of *Sorghum sudanense* and *Cenchrus ciliaris* that had better quality ratings of six after 42 days water stress period. *Sorghum sudanense, Chloris gayana* and *Cenchrus ciliaris* had accelerated recovery in quality, attaining a visual rating of eight at 21 days of water stress period. The three soil moisture content treatments had higher quality ratings than rainfed conditions which represented water deficit. *Sorghum sudanense* and *Chloris gayana* had higher quality ratings and water use efficiency under rainfed compared to the other species. All the grasses showed higher living ground cover greater than 40% at recovery period of 28 days, when irrigation was resumed at the prescribed level, and attained living cover of over 60% by day 42. *Sorghum sudanense, Chloris gayana* and *Cenchrus ciliaris* were able to withstand water stress longer and had also a quick recovery among the six grasses. These three species are recommended for pasture establishment in semi-arid lands where water supply uncertainties exist, owing to their high tolerance to water stress.

Keywords: Drought Tolerance, Water Stress Tolerance, Range Grasses, Pasture Irrigation, Kenya

1. Introduction

Plants survival in the arid and semi arid lands (ASALs) is determined by their adaptive capacities to the prevailing unpredictable and highly variable climatic conditions (Kimani & Pickard, 1998; Doss *et al.,* 2008). Range grasses have evolved in these uncertainties and developed their inherent resistance or tolerance levels to the frequent dry seasons and droughts (Kabubo-Mariara, 2008).Understanding water stress tolerance of grasses is crucial in pasture management when it comes to water supply and choice of adapted species depending on climatic conditions. Different grass species have inherent genetic composition that enhances their varied adaptation to water stress during droughts. Some of the adaptation mechanisms are related to; rooting depth, pattern and distribution; seed germination rates, leaf characteristics, and stem:leaf ratios among others (Rünk *et al.* 2014). During the dry seasons and droughts, pastures are exposed to water stress and they respond by among others; reducing transpiration rates to minimize losses, leaf rolling, growing leaf hairs etc. However, this may reduce pasture yields, but enhance survival which is more critical in the arid environments. This process is different among grass species depending on plant root and leaf characteristics (Hanson, 1988; Gibbens & Lenz, 2001; Vicente-Serrano *et al.,* 2010). For example, *Cynodon dactylon (Bermuda* grass) and *Medicago sativa* (Alfafa) have deep roots that enhance utilization of water in the lower soil profile (Schenk & Jackson, 2002a; Schenk & Jackson, 2002b). Water stress tolerance of grasses is one of the considerations in selecting drought tolerant species suitable for drylands in the face of climate variability and change. This gives opportunities for dryland pasture establishment and reseeding with the most adapted species as a result of the increasing unreliable rainfall in the recent past. Tworkoski & Glenn (2001) also observed variability in grass species tolerance to droughts which influence their individual survival rates and tolerance to water stress. Droughts have negative impacts on plant's performance and productivity, but the intensity depends on their adaptation mechanisms and responses (Passioura, 2007; Farooq *et al.,* 2009).

Grass species have a wide range of overlapping adaptive strategies to water stress (Ludlow, 1980). This includes; escape mechanism where annual grasses set seeds early to avoid dry seasons, storage organs like rhizomes, dormant buds and resurrection leaves that can become active with availability of precipitation. Other strategies are adjustments by plants to reduce leaf area through leaf firing, dropping of leaves and leaf rolling, adjusting the water uptake from roots e.g. root elongation and branching, maintaining turgor pressure, reduced growth during drought (dormancy) and rapid growth when water stress is reduced. Some species maintain maximum number of plants tillers and/or leaves during dry season as documented by Ludlow, (1980). Grass plants have also been observed to have physiological responses to droughts that have sustained them in the natural environment under conditions of uncertainties (Larcher, 2003).

Pasture productivity is of great concern for livestock producers in the ASAL environments and there is need to promote proper pasture management and choice of species that are adapted to frequent water deficits that ensures reliable supply of good quantity and quality forage in the face of climate change and variability. This study evaluated the water stress tolerance and determined the living basal ground cover during recovery of the grass species. The species evaluated were *Chloris roxburghiana, Eragrostis superba, Enteropogon macrostachyus, Cenchrus ciliaris, Chloris gayana, Sorghum sudanense*. The evaluation aimed at determining the species response to water stress to aid in species selection for pasture establishment in drylands of Kenya as well as help in planning the management of the same species with regards to water supply.

2. Materials and Methods

2.1. Study Area

The study was carried out is in Tana River County (figure 1), within coordinates 1°30′S, 40°0′E, 1.5°S 40°E. The climate of the area is hot and dry with daily temperatures ranging between 20 and 38^{o}C. Rainfall is bimodal in distribution with long rains occurring in April-June and short rains in November-December. Long-term average rainfall ranges from 220 to 500 mm and is erratic in distribution. Temperatures are highest between February and April and September to October. The County is divided into three livelihood zones; namely, pastoral, agro-pastoral (mixed farming) and marginal mixed farming.

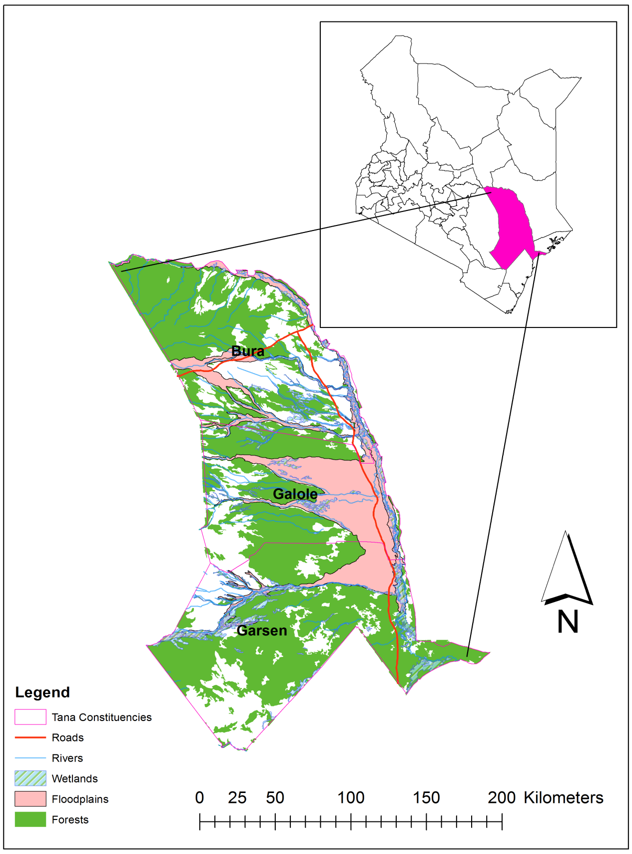

Figure 1. *Study Country - Kenya (top right) in relation to study area- Tana River County.*

The soil types are vertisols and vertic fluvisols associated with swelling and forming ponds during wet seasons with low infiltration rates from the sealing by high clay content. During dry seasons, the soil dry out and develop cracks. At the hinterlands are shallow and have undergone seasons of trampling by livestock, thus are easily eroded during rainy seasons. Pastoralism and agropastoralism are the main economic activities in the study area, with two established National irrigation schemes, Hola and Bura, with the latter being the experimental study site.

2.2. Experimental Layout and Design

One-acre parcel of land that had not been cultivated during the last season was identified within Bura irrigation scheme, National Irrigation Board (NIB) research site. The land was cleared of all bushes, ploughed and harrowed to a fine tilth. The area was then divided into 4 main plots of 39 m x 11 m size each. The plots within the one acre were demarcated to be 5 metres apart to minimize lateral seepage among the main plots. Each main plot was then sub-divided into 30 sub-plots measuring 3 m x 3 m with 1 m boundary.

The experimental design was factorial experiment in a completely randomised design comprising two factors, grass species and soil moisture content at 6 and 4 levels, respectively. Main plots demarcated were each randomly assigned a watering schedule as first treatment where treatment one (T1) was 80% FC, treatment two (T2) was 50% FC, treatment three (T3) was 30% FC and treatment four (T4) was the control (rain fed). The second treatment level was grass species randomly assigned to the 30 sub-plots within each of the 4 main plots. The grass species treatments were; *Chloris roxburghiana* - CR, *Eragrostis superba*- ES, *Enteropogon macrostachyus* -EM, *Cenchrus ciliaris* -CC, *Chloris gayana* -CG, *Sorghum sudanense* -SB. The species were randomly allocated to the sub-plots.

2.3. Experimental Materials, Sowing and Irrigation

Gypsum blocks (GBs) were used to determine different soil moisture content levels and monitoring soil moisture changes. The method was also used in determining soil moisture recharge times to maintain prescribed moisture contents of 80, 50 and 30% Field capacity (FC). GBs were installed at the centre of each sub plot, at two depths, 15 and 30 cm in separate holes which were dug using a 50 mm soil auger. Prior to installation they were soaked overnight as recommended. Before installation, moisture readings corresponding to 80%, 50%, and 30% FC soil moisture content was calibrated for all the GBs using moisture meter which aided in determining prescribed soil moisture content for the main blocks. After installation, wire ends originating from the installed blocks were carefully supported by vertical sticks for ease of taking readings and identification of installation points.

The source of grass seeds was Kenya Agricultural Research Institute (KARI), Kiboko Range Research Station. Before planting, the seeds were tested for germination percentage using the standard seed test by germination method as described by ISTA (1976) before planting. The germination rates obtained were used to determine the mixing and sowing rates of the species. Sowing was done manually in the finely prepared seedbeds. Phosphate fertilizer was applied to all the treatments at the recommended rate of 200 kg ha-1 to enhance establishment. Thereafter, no fertilizer application was done for the whole data collection period. All other routine pasture husbandry practices such as weeding were done for all the treatments. For each treatment, soil moisture was maintained at the prescribed level through irrigation at the prescribed soil moisture content by means of the Delmhorst Soil Moisture Meter Gypsum Blocks (GBs) installed within each sub-plots.

2.4. Data Collection on Grass Responses to Water Stress

At week 16, when the grasses were fully established, water stress condition was applied for 49 days. This was done by suspending irrigation for all the three soil moisture content until the grasses showed signs of water stress (wilting symptoms, colour change, colour uniformity and leaf firing). The grass species were rated by looking at the colour of leaves by visual quality in terms of greenness estimated on a 1-9 scale, with 1 being brown dead grass, six being minimally acceptable and nine being optimal green colour and uniformity following the procedure described by Morris & Shearman, (2006) and Tarawali *et al.,* (1995). This was done at 14th, 21st, 28th, 35th, 42nd and 49th days from the day of water deprivation. After the 49 days water stress treatment, a recovery period was evaluated by resumption of irrigation for the three respective levels of 80, 50, 30% FC and the ratings done at the same days from resumption. The rates of each species took to return to normal vegetative state (recovery of leaves and re-growth, uniformity and green colour) was recorded. The grass species living basal cover determination during water stress recovery phase was estimated by point frame method as described by Evans & Love (1957).

3. Results

3.1. Grass Responses to Water Stress

Table 1. *Grass visual quality ratings (1-9) based on green colour, leaf firing and uniformity from water stress responses for 49 days at 80, 50 and 30% FC soil moisture content and rainfed.*

%Soil moisture content	**Days of drought tolerance test application**					
80% FC	**14**	**21**	**28**	**35**	**42**	**49**
C R	9.0^{a}	8.2^{a}	6.1^{ab}	4.1^{b}	3.2^{c}	2.0^{c}
E S	9.0^{a}	9.0^{a}	7.0^{ab}	7.0^{ab}	4.0^{b}	3.2^{c}
EM	9.0^{a}	9.0^{a}	6.2^{ab}	6.1^{ab}	5.2^{ab}	4.0^{b}
CC	9.0^{a}	9.0^{a}	9.0^{a}	8.2^{a}	6.0^{ab}	4.0^{b}
CG	8.0^{a}	8.2^{a}	5.0^{ab}	4.2^{b}	3.1^{c}	3.2^{c}
SB	9.0^{a}	9.0^{a}	9.0^{a}	8.0^{a}	6.3^{ab}	6.0^{ab}
50% FC						
C R	8.0^{a}	8.0^{a}	6.4^{ab}	4.3^{b}	3.1^{c}	3.5^{c}
E S	9.0^{a}	9.0^{a}	7.0^{ab}	7.2^{ab}	4.2^{b}	3.4^{c}
EM	8.0^{a}	9.0^{a}	6.3^{ab}	6.0^{ab}	5.4^{ab}	3.2^{c}
CC	9.0^{a}	9.0^{a}	9.0^{a}	8.0^{a}	6.1^{ab}	4.3^{b}
CG	8.1^{a}	6.0^{a}	5.3^{ab}	4.0^{b}	3.0^{c}	3.2^{c}
SB	9.0^{a}	8.2^{a}	9.0^{a}	8.1^{a}	6.0^{ab}	6.0^{ab}
30 % FC						
C R	8.2^{a}	8.2^{a}	5.1^{ab}	4.2^{b}	3.0^{c}	2.0^{c}
E S	9.0^{a}	9.0^{a}	8.2^{a}	6.0^{ab}	4.2^{b}	2.2^{c}
EM	8.1^{a}	9.0^{a}	6.1^{ab}	6.0^{ab}	5.0^{ab}	3.0^{c}
CC	9.0^{a}	9.0^{a}	8.4^{a}	6.2^{ab}	6.2^{ab}	3.0^{c}
CG	8.2^{a}	5.1^{ab}	5.0^{ab}	3.2^{c}	3.0^{c}	3.0^{c}
SB	9.0^{a}	8.2^{a}	8.0^{a}	7.0^{b}	6.2^{b}	5.0^{ab}
Rainfed						
C R	6.2^{ab}	5.0	4.0^{b}	3.0^{c}	3.1^{c}	2.0^{c}
E S	6.4^{ab}	5.4^{b}	4.0^{b}	3.2^{c}	3.3^{c}	2.2^{c}
EM	6.0^{ab}	5.4^{b}	4.1^{b}	3.1^{c}	3.0^{c}	2.0^{c}
CC	6.0^{ab}	6.2^{ab}	4.2^{b}	3.2^{c}	3.2^{c}	2.1^{c}
CG	5.3^{ab}	4.0^{b}	4.0^{b}	3.2^{c}	3.0^{c}	2.0^{c}
SB	6.0^{ab}	6.1^{b}	5.2^{ab}	3.1^{c}	3.0^{c}	3.2^{c}

Means within the same columns with different superscripts are significantly different at $p<0.05$.

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense. Visual quality ratings 1 to 9 was used as visual rating scale with 1 being complete wilting, 100% leaf firing, complete dormancy or no plant recovery; and 9 being no wilting, no leaf firing, 100% Green

The visual quality ratings of grasses grown at 80, 50, and 30% FC soil moisture content and rainfed treatments are presented in Table 1. At 14th day of water stress the irrigated grasses treatments showed higher visual quality ratings 0f 8.0 - 9.0 compared to rainfed treatment with quality rating of 5.3-6.4. At 28th day, *C. ciliaris* and *S. Sudanense* had quality rating of over eight with all the species being below seven. At the same time, rainfed grass species showed lower quality ratings than the irrigated at ratings of 4.0 - 4.2 except *S. sudanense* which had a rating of 5.2. *C. ciliaris* and *S. sudanense* had visual quality rating of six after 42 days, with over half of the specie showing green colour. *C. roxburghiana* and *C. gayana* had the lowest rating of three at the same period. After 49 days of water stress, *S. sudanense* had the highest tolerance to water stress with a quality rating of six at 80 and 50% FC soil moisture content and rating of five at 30% FC soil moisture content. At the same period rainfed treatment showed lower quality ratings for all the grass species compared to the irrigated treatments, however, *S. sudanense* still had higher quality rating of three with the rest having two.

Table 2. *Grass visual quality ratings (1-9) based on green colour, leaf firing and uniformity during recovery period following 49 days water stress treatment at varying soil moisture contents.*

%Soil moisture content	Days of drought tolerance recovery					
80% FC	**14**	**21**	**28**	**35**	**42**	**49**
C R	5.2^{b}	6.4^{ab}	7.2^{ab}	8.2^{d}	8.2^{d}	9.0^{d}
E S	5.4^{b}	5.0^{b}	9.0^{b}	9.0^{d}	9.0^{d}	9.0^{d}
EM	4.5^{b}	5.0^{b}	6.0^{ab}	6.2^{ab}	8.0^{d}	9.0^{d}
CC	5.1^{b}	8.4^{d}	9.0^{d}	9.0^{d}	9.0^{d}	9.0^{d}
CG	4.3^{b}	5.3^{ab}	8.3^{d}	8.2^{d}	9.0^{d}	9.0^{d}
SB	6.2^{ab}	8.0^{d}	8.4^{d}	9.0^{d}	9.0^{d}	9.0^{d}
50% FC						
C R	5.1^{ab}	6.2^{ab}	7.1^{ab}	8.2^{d}	9.0^{d}	9.0^{d}
E S	6.3^{ab}	5.0^{b}	8.2^{d}	9.0^{d}	9.0^{d}	9.0^{d}
EM	4.2^{b}	5.2^{b}	6.4^{ab}	8.0^{d}	8.0^{d}	9.0^{d}
CC	5.3^{ab}	8.0^{d}	9.3^{d}	9.0^{d}	9.0^{d}	9.0^{d}
CG	5.1^{ab}	6.0^{ab}	8.1^{d}	9.0^{d}	9.0^{d}	9.0^{d}
SB	6.3a^{b}	8.4^{d}	8.2^{d}	9.0^{d}	9.0^{d}	9.0^{d}
30 % FC						
C R	4.4^{b}	6.0^{ab}	6.5^{ab}	6.2^{ab}	9.0^{d}	9.0^{d}
E S	4.3^{b}	5.0^{b}	8.4^{d}	8.1^{d}	9.0^{d}	9.0^{d}
EM	4.0^{b}	5.4^{b}	6.1^{ab}	8.3^{d}	8.2^{d}	9.0^{d}
CC	5.2^{ab}	8.4^{d}	9.0^{d}	8.4^{d}	9.0^{d}	9.0^{d}
CG	3.1^{c}	5.1^{b}	6.3^{ab}	8.2^{d}	8.1^{d}	9.0^{d}
SB	5.0^{b}	8.2^{d}	8.3^{d}	9.0^{d}	9.0^{d}	9.0^{d}
Rainfed						
C R	2.3^{c}	2.4^{c}	2.0^{c}	2.1^{c}	3.2^{bc}	4.3^{b}
E S	2.4^{c}	2.2^{c}	2.1^{c}	2.3^{c}	3.4^{bc}	4.1^{b}
EM	2.0^{c}	2.3^{c}	2.2^{c}	2.3^{c}	3.0^{bc}	4.3^{b}
CC	2.1^{c}	2.2^{c}	2.1^{c}	2.2^{c}	3.0^{bc}	4.2^{b}
CG	2.4^{c}	2.0^{c}	2.0^{c}	2.0^{c}	3.2^{bc}	5.1^{b}
SB	3.5^{c}	3.2^{bc}	2.3^{c}	2.3^{c}	4.1	5.0^{b}

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM = Enteropogon macrostachyus, CC = Cenchrus ciliaris, CG = Chloris gayana, SB= Sorghum sudanense. Visual quality ratings 1 to 9 was used as visual rating scale with 1 being complete wilting, 100% leaf firing, complete dormancy or no plant recovery; and 9 being no wilting, no leaf firing, 100% Green-no dormancy, or 100% recovery.

The quality ratings for recovery of the grasses for the 49 days after water stress tolerance are presented in Table 2. At 14 days after irrigation resumption for the respective soil moisture contents of 80, 50 and 30% FC, all the grasses recovered having quality rating of between 4.0 and 5.5 except for *C. gayana* at 30% FC that had rating of 3.1. All the grass species under irrigation attained visual quality ratings greater than six after 28 days of recovery and a rating of nine at 49th day. *C. ciliaris* and *S. sudanense* had accelerated recovery by day 21, having quality rating of over eight at all the soil moisture treatments. Grass species under rainfed did not have any recovery up to day 35 due to lack of rainfall. However, at day 42 and 49 recovery period, the six grass species showed recovery after receiving rains amounting to 107mm allowing *S. sudanense* and *C. gayana* attain quality rating of five at 49 days while the other species rated four.

3.2. Grass Basal Ground Cover During Water Stress Recovery

The percentage living basal ground cover of the selected grass species during recovery period after water stress tolerance treatment, are presented in Table 3. There was an increase in the living basal cover with recovery periods at the irrigated treatments. Basal cover for 80 and 50% soil moisture content was >75% and significantly ($p \leq 0.05$) higher than 30% FC (<75%) and rainfed treatment at the end of 49 days recovery period. Rainfed treatment had significantly ($p \leq 0.05$) lower living basal cover compared to the irrigated treatments at the end of recovery period (<40%). There was no observed significant difference in basal cover among the individual grass species at specific soil moisture content treatments.

4. Discussions

4.1. Water Stress Tolerance

The findings of this study demonstrate that range grass species have varied adaptation capacities to water stress tolerance which mimic drought effects. The observed decline in grass species quality with prolonged water stress was from the increased evapotranspiration demands that are not met hence most grass physiological processes reduced. The grasses respond by adjusting their photosynthesis process to minimize excessive water loss through leaf firing and rolling as well as wilting which reduce vegetative growth which can be fatal if it is prolonged water stress to attain permanent wilting point (PWP) (Croser *et al.,* 2003). Dodd & Orr, (1995) assessed drought tolerance and recovery of 11 species of perennial legumes for 18 months and also observed *T. pratense* lines to be more susceptible to water stress than others (*T. semipilosum* lines, and *T. tumens*) which were highly tolerant and recovered well from simulated drought.

The higher tolerance of *S. sudanense* to water stress could be attributed to the higher tiller numbers and deep rooting observed in this study published (Koech *et al.,* 2014). The deeper rooting improves drought tolerance of perennial temperate C4 grasses (Kemp & Culvenor, 1994). These factors have been reported to have a contribution to water stress tolerance of grasses by having enough reservoir of water in tissues (Ludlow, 1980). Eneji *et al.* (2008) working on effects of silicon application on growth and water stress responses of *Festuca arundinacea*, *Phleum pretense*, *Chloris gayana*, and *Sorghum sudanense* reported *S. sudanense* to have been least affected by water stress compared to the three species which was attributed to its deep rooting system. Chen *et al.* (2008) also reported *S. sudanense* to have large root biomass that makes it competitive for water and nutrient absorption when grown in mixtures and hence increased drought tolerance. The findings of this study reveal that for established pastures in the semi-arid environments should consider the species' responses to water stress tolerance and droughts for improved productivity. This has also been reported to be important considerations for pasture breeding (Kemp & Culvenor, 1994).

Table 3. *Percentage of living basal ground cover ratings during recovery period after 49 days water stress treatment at varying soil moisture contents*

	Days of recovery					
80% FC	**14**	**21**	**28**	**35**	**42**	**49**
C R	24.3 ±3.3	31.3±7.8	44.8±7.5	55.5±14.5	77.5±9.5	77.5±9.5
E S	34.7±9.3	36.4±2.4	45.2±9.8	64.5±8.2	82.5±5.0	82.5±5.0
EM	20.0 ±4.1	28.0±6.2	33.5±4.7	58.0±12.1	77.0±23	98.0±23
CC	31.4±6.1	40.1±9.8	54.2±11.8	62.3±19.5	69.5±7.5	96.5±19.3
CG	15.0±6.2	33.3±8.9	48.4±7.9	66.0±12.4	71.0±22.0	92.4±24.1
SB	45.5±6.5	54.0±2.3	60.5±21.4	76±7.9	82.4±15.7	94±15.37
50% FC						
C R	20.4±6.1	31.2±9.4	45.4±11.2	57.5±6.4	68.2±19.1	81.5±19.5
E S	31.3±7.4	43.3±5.6	44.4±9.6	59±12.0	77±21.0	87.5±15.0
EM	17.7±6.2	28.4±3.1	38.9±7.9	53.0±5.2	68.7±15.1	97.0±31.3
CC	28.8±3.2	34.5±11.3	52.1±11.1	60.5±22.5	70.2±9.5	92.5±14.5
CG	11.0±3.2	24.3±14.2	26.2±4.8	45.5±11.1	97.5±5.0	90.1±32.2
SB	46.1±11.2	51.8±13.5	58.5±3.5	72.5±19.5	85.5±29.3	98.0±25.7
30% FC						
C R	14.2±4.6	17.3±6.3	22.0±6.2	37.3±9.4	55.5±11.1	67.5±9.5
E S	33.2±9.3	35.2±7.6	44.4±9.6	61.3±16.1	65.0±11.2	69.4±14.0
EM	12.8±2.9	19.4±7.0	38.9±7.9	49.0±15.0	56.7±9.8	69.8±5.0
CC	31.2±7.6	35.2±9.3	52.1±11.1	58.3±13.1	67.8±9.5	71.5±9.5
CG	8.6±1.5	16.5±8.2	26.2±4.8	40.5±9.1	67.9±9.8	74.5±5.0
SB	48.2±23.1	48.1±12.3	55.5±3.5	62.5±19.5	72.4±11.6	74.5±19.5
Rainfed						
C R	14.2±4.1	11.3±6.2	8.0±3.0	7.5±3.0	15.3±2.3	22.5±3.1
E S	13.2±2.4	11.5±4.2	10.4±9.6	7.5±2.4	16.5±4.2	28.0±3.2
EM	12.8±2.4	12.4±3.1	10.9±7.9	6.8±3.2	18.0±2.5	27.0±4.8
CC	11.2±4.1	10.5±3.3	10.1±11.1	7.5±3.5	19.5±3.2	38.8±3.5
CG	18.6±2.5	13.5±8.2	10.2±4.8	7.5±3.2	20.5±2.2	28.9±2.5
SB	28.2±3.3	24.0±2.4	10.5±3.1	8.5±3.0	18.0±2.4	29.5±3.5

Key: CR=Chloris roxburghiana, ES= Eragrostis superba, EM= Enteropogon macrostachyus, CC= Cenchrus ciliaris, CG= Chloris gayana, SB= Sorghum sudanense, ±Standard deviation

The observed higher water stress tolerance of *S. sudanense, E. macrostachyus* and *C. gayana* compared to *C. roxburghiana, C. ciliaris* and *E. superba* in this study further emphasizes the species inherent genetic constitution in adapting to water stress. This was also observed by Guenni *et al.* (2002) working with five Bracharia species (*B. brizantha* (CIAT 6780), *B. decumbens* (CIAT 606), *B. dictyoneura* (CIAT 6133), *B. humidicola* (CIAT 679) and *B. mutica*) under simulated drought reported wilting occurring after 14 days for *B. brizantha, B. decumbens* and *B. mutica* and after 28 days in *B. humidicola* and *B. dictyoneura*.

Despite *C. ciliaris* having lower water stress tolerance than *S. sudanense* and *E. macrostachyus* in this study, the species had better and quicker recovery than the rest. This finding therefore suggests that grass species may have low water stress tolerance but be adapted to accelerate recovery as a strategy; therefore, caution should be exercised in selecting species based on hardiness to water stress only. Nawazish *et al.* (2006) evaluated water stress tolerance of *C. ciliaris* from different ecotypes (drought hit habitat and irrigated soil) under three moisture regimes of 100% FC (control), 75% FC and 50% FC. They reported that ecotype from drought hit habitat was adapted to moderate and high moisture deficit. This species was also noted to depict adaptation against severe water deficits by having thick epidermal layer and cuticle that reduced evapotranspiration. The observed different adaptation of *C. ciliaris* to drought tolerance depending on ecotype is a consideration that was not factored in this study when evaluating water stress tolerance and should be considered in future studies.

Other study also reported drought tolerance of *C ciliaris* made it invasively the dominant grass species over *Heteropogon contortus* in Hawaii native grasslands (Daehler & Goergen 2005). This invasiveness was associated with its adaptability to droughts and grazing than most native species in the area. De la Barrera (2008) also reported *C. ciliaris* to be an invader in southern Sonoran Desert due to its drought tolerance. The results of this study similarly indicated that *C. ciliaris* was the most resilient species after droughts due to accelerated recovery, this could be the reason this studies found the species to be an invader as a result of quick recovery than the other plants. The drought tolerance of *C. ciliaris* has been documented by others (Lazarides *et al.,* 1997; Bhattarai *et al.,* 2008, Marshall *et al.,* 2012). The species has been identified as high value feed for livestock (Kumar *et al.,* 2004; Guevara *et al.,* 2009). *C. ciliaris* has also been reported as the most suitable for reseeding degraded arid saline soils (Lazarides *et al.,* 1997). However, Marshall *et al.* (2012) named it as one of the remarkable threats to biodiversity in drylands due to its invasive nature. Despite the varied views of *C. ciliaris* as a weed or invader in other parts of the world, it is ranked the best and most preferred livestock feed by pastoral communities in the Kenyan rangelands (Reed *et al.,* 2008; Ndathi *et al.,* 2011). For similar reasons, *C. ciliaris* is being promoted for reseeding denuded grazing lands in Kenya (Mnene, 2006; Kirwa *et al*., 2010; Mganga *et al.,* 2010; Verdoodt *et al.,* 2010; Mureithi *et al.,* 2014; Koech, *et al.,* 2014).

There is need for long-term investigations on the drought responses of the grasses evaluated in this study since it only represented short-term dry seasons of 49 days and responses under prolonged dry seasons may be different. The responses and mechanism observed in this study can be used as reference point for irrigated pastures management, where short-term water shortages and the expected effects on grass species performance can be used to make management decisions and for making choice of species to cultivate. The high temporal variability of rainfall was also reported by Ifejika *et al.* (2008) in Makindu, a semi-arid agro-pastoral area in Kenya, with limited pasture production. Rainfall variability has been identified as one of the determinants of livestock productivity in the Kenyan rangelands (Davis *et al.,* 2006; Orindi *et al.,* 2007; Theisen, 2012). This calls for innovative ways of improving water resource utilization for fodder production sustainability, for instance, integration of water harvesting and pasture production with pastoralism.

4.2. Living Basal Ground Cover

The observed higher basal cover for irrigated treatments compared to rainfed is attributed the fact that the species under this condition were not adversely affected by water stress and showed quick recovery. These findings highlight the benefits of water supply in increasing ground cover therefore enhancing soil conservation. Ground cover in the semi-arid environments determines the soil hydrological properties, soil moisture and also influences present and future productivity. The observed variations in percent ground cover among the species with *S. Sudanense* attaining higher cover at day 28 could be attributed to genetic variability. Hu *et al.* (2010) subjected two genotypes of Kentucky bluegrass (Poa pratensis L.), 'Midnight' (tolerant) and 'Brilliant' (sensitive) which differ in drought resistance to drought stress for 15 days. They then re-watered for 10 days and observed that single-leaf net photosynthetic rate, stomatal conductance and transpiration rate decrease during drought, with a less rapid decline in 'Midnight' than in 'Brilliant', which they attributed to genetic variations. These findings could explain the observed variability in cover for the different species in this study. Malinowski & Belesky, (2000) also reported drought tolerance in grasses to be influenced by both physiological and biochemical adaptations of species hence varying responses to water stress.

Study by Chai *et al.* (2010) looking at physiological traits of two C_3 perennial grass species, Poa pratensis and Lolium perenne, for drought survival after well watering before 20 days drought through withholding irrigation observed that seven days of re-watering, drought-damaged leaves were rehydrated and recovered fully in P. pratensis but could not fully recover in L. perenne. P. pratensis. The species also produced a greater number of new roots, while L. perenne had more rapid elongation of new roots after 16 days of re-watering. The observed low ground cover for rainfed at the end of recovery period indicate that natural grasslands productivity is limited by moisture supply and irrigation can be used to bridge the gap. All the species except *E. macrostachyus* attained living ground cover greater than 40% by day 28 and by 42 days the cover was over 70%, at the irrigated moisture content levels. This finding suggests ecological adaptability of the evaluated grasses to the highly variable environment which has perpetuated their survival under frequent droughts over the years. Mganga *et al.* (2013) also recommended *C. ciliaris*, *E. superba* and *E. macrostachyus* as suitable for range reseeding and rehabilitation due to their high drought tolerance. This study has showed *E. macrostachyus* to be slow in recovery among the six species, but interestingly, at the end of 49 days recovery phase, the species had almost similar percentage living ground cover to other species.

5. Conclusions

*C. ciliari*s and *S. sudanense* emerged to be best species adapted to water stress while *C. roxburghiana* and *C. gayana* had the lowest tolerance to water stress. Notably, still *S. sudanense, C. ciliaris* and *C. gayana* had higher recovery rates from water stress in that order which suggest better adaptation to droughts than *Chloris roxburghian.* Two species have shown greater candidates for drought tolerance in this study, namely; *C. ciliari*s and *S. sudanense*. These findings also indicate that relying on rainfall for pasture production is not reliable and yields are bound to be affected by rainfall variability and the unpredicted droughts which is common in the drylands. Therefore, irrigation can be considered as one way of improving pasture production for reliable fodder supply in the ASALs of Kenya.

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