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CLIMATE CHANGE AND VARIABILITY AFFECT RANGELAND QUALITY AND PRODUCTIVITY- HOW?

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ABSTRACT

Climate change is a principal threat to the sustainability of our planet which consists partly of the world's rangelands. According to numerous studies and reports, the trend at which the global climate is changing is a clear indication that the long term sustainability of global rangelands is uncertain. There is abundant evidence of climate change across the globe. The global average surface temperature is predicted to increase between 1.8°C and 4.0°C by 2100. This will no doubt have adverse and tremendous impact on the quality and productivity of rangelands, which in turn is expected to affect ruminant livestock production since about 70 % of forages fed on by animals are produced from these rangelands. The current climate change is basically as a result of anthropogenic activities leading to a build up of greenhouse gases in the atmosphere. These gases are trapped in the atmosphere and in return increase global surface temperature and alter known climatic patterns globally. This review, therefore, highlights the effect of climate change on rangeland quality and productivity considering how the drivers of climate change impact on the length of the growing period, plant species composition, nutritional value of forages, drought stress in plants, lignification, vegetation flammability and mortality/extinction of range plant and animal species. The review revealed that, climate change will result into the extinction of over one million terrestrial species in the next five decades. The elevation of CO_2 levels will increase non-structural carbohydrate content of grasses by 25 % and reduce their nitrogen content by about 8 %. It is also reported that, for every 1 % rise in temperature, there will be 0.4 % rise in Neutral Detergent Fibre decreasing forage intake and digestibility. Rising temperature also results in faster decomposition of soil organic matter. However, minerals will be lost through leaching and erosion if mineral uptake by rangeland plant species is slower than the rate of mineral release into the soil. It is clear that changing climate is having a toll on rangeland quality and productivity, the impact is mixed and difficult to quantify. It is recommended that, much research efforts be put into quantification of climate change impacts on rangelands through modelling and projections simplified for the comprehension of the resource poor livestock farmers particularly in developing countries. Vulnerable rural based livestock farmers should be assisted with adaptation strategies to remain in production.

Key words: Composition of plant species, drought stress, nutritional value, plant mortality

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INTRODUCTION

Climate change is presently regarded as a major and predominant threat to the sustainability of the planet Earth, which includes rangelands [1]. Naturally, the earth has experienced some alterations in its climate through changes in the orbital variation and also from volcanic eruptions, causing changes in the amount of solar radiations reaching the earth. However, human activities are substantially contributing to climate change [2, 3]. The agricultural sector is therefore vulnerable by the exposure and responsiveness to these climate conditions and the ability to adapt or cope with the changing climate [1]. There is therefore the need for farmers to have several strategies to employ to cope with the anticipated climate variability, which include adjusting their farming practices as required (that is applying adaptive range management and climate adaptation strategies). The total earth's terrestrial surface is covered by about 50 % of rangeland ecosystems [4]. Millions of people around the world depend on the grazing resources of rangelands as their source of livelihood.

Livestock contributes about 30 % of agricultural gross domestic product in developing countries, with a projected increase to about 40 % by the year 2030 [5] and is becoming the fastest growing sub-sector in agriculture. However, report indicates that there is an uncertainty in the long term sustainability of rangelands [6], since the effect of climate change will have a major impact on these rangelands as well as farmers. Economically developing countries and regions of the world are the ones whose rangeland resources are likely to suffer and are the most vulnerable since they are not capable of adapting to the unexpected change in climate and other extreme environmental conditions. Many of these economically developing countries are characterized by high population growth and as such are forced to use areas of very marginal productivity as grazing lands, and this tends to put stress on already stressed landscape due to climate change [7].

The agriculture sector is expected to be affected by climate change due to direct and indirect effect of climate change on crop and rangeland production. Rangelands provide about 70 % of the forage needs of ruminant livestock across the globe [4], thus, the livestock sub-sector will not be spared. Drivers of climate change will cause changes in rangeland ecosystems. The impact is expected to be severe in sub-Saharan Africa where a vast land area falls under the Arid and Semi-arid regions of the world and also because Agricultural activities in these regions is heavily dependent on climate [8]. Therefore, for a sustainable livestock production, there is the need to adequately understand the effect of climate change on

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rangelands. This will be helpful in the formulation of appropriate range management decisions to optimize forage production in a changing climate. Thus, this review highlights the impact of climate change on rangeland quality and productivity emphasizing how drivers of climate change affect the length of growing period, plant species composition, nutritional value of forages, drought stress in plants, vegetation flammability and mortality/extinction of valuable plant and animal species.

LITERATURE REVIEW

Climate Change

Climate is often described by the statistical interpretation of rainfall and temperature data recorded over a long period of time for a given region or location [2]. Climate is usually the weather conditions in a given location averaged over a 30-year time period. The Intergovernmental Panel on Climate Change Third Assessment Report (IPCC TAR) defined climate change as any alteration in the climate over a period of time, as a result of anthropogenic or natural factors [9]. It is also defined as a change of climate which is associated to human activity that modifies the composition of the atmosphere and also includes natural climate variability observed over a period of time. Climate variability on the other hand, is defined as “the variation in climate on all temporal and spatial scales beyond that of individual weather events”. The United Nations Framework on Climate Change [10] makes a contrast between ‘climate change’ which is caused by human activities on atmospheric composition of the world and ‘climate variability’ which is attributable to natural causes. Based on these definitions, it can therefore be implied that climate change can occur as a result of natural variability and human activity [11].

Greenhouse gases and climate change

The atmosphere is composed of a mixture of gases which are essential to life, and as such our lives depend on it [11]. Greenhouse gases (GHGs) which consist of the trace gases in the atmosphere tend to be increasing fast and contributing significantly to climate change. The GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Chlorofluorocarbons (CFCs), and tropospheric ozone (O_3). Carbon dioxide’s involvement in global warming is massively higher than the other GHGs because of its high emission into the atmosphere [12]. Other GHGs such as CH_4, CFCs and N_2O are also fairly increasing. In the past 200 years, CO_2 concentration in the atmosphere has increased by more than 30 %, CH_4 by more than 150 % and N_2O by 17 % [13]. Scientists are more than 95 % certain that global warming is caused mostly by increasing concentrations of these GHGs through anthropogenic activities [14]. Some of these activities include burning of fossil fuel, livestock production (during respiration, they release CO_2 and CH_4, their excreta releases N_2O and NH_3), felling of wood indiscriminately which affect the carbon balance, landfill systems and other forms of industrial air-pollution [11]. The aforementioned confirms that profound changes in the mechanisms of the atmosphere is due to human activities [12].

Evidence of climate change

The IPCC [15] provides clear evidence that climate change is a reality, as shown by the increase in global temperatures and changes in rainfall patterns experienced globally. Evidence shows that the relative changes in climate over the past century have already had significant impacts on a wide range of plant species in terms of their distribution, abundance, phenology and physiology. Many instances of alteration in species distributions toward the poles have been documented [16]. Reports from IPCC revealed that there will be more wet areas which will lead to severe floods as well as dry areas which will also lead to severe drought, all in the tropics with low latitudes [2, 14]. Additionally, temperatures are anticipated to rise further by 1 to 4 ^{0}C in some decades to come [17]. Report on the African continent indicates that, there has been a rise in the mean annual land surface temperature above the 0.7 °C recorded in the 20th century [18]. The above-mentioned evidence of climate change is the reality the entire earth is faced with today.

Rangelands and Climate Change

Rangelands can be defined as ecosystems which are capable of supporting grazing and browsing animals [19]. Globally, rangelands are estimated to occupy 50 % of the entire earth's terrestrial surface [19]. Their expanse makes rangelands very important to humans with their importance far outweighing their challenges [4]. The composition and productivity of rangelands are basically influenced by rainfall, fire, grazing, changes in temperature and the concentration of atmospheric CO_2 over longer time frames [20].

Climate change puts enormous pressure on rangelands [21] and as such, the phenomenon is now recognized as a dominant issue of concern for their sustainability. Species distribution in rangeland communities are likely to be altered in relation to changes in rainfall patterns and temperature levels. Some rangeland species are likely to migrate as temperature increases similarly to the reported occurrence in the early to mid-Holocene (10,500 to 5,000 years ago) [22]. Climate change is reported to be responsible for the extinction of many plant species, although, the extent and nature of this future occurrence is very difficult to predict.

In most plant species, there is an increase in the rate of photosynthesis when the concentration of atmospheric CO_2 increases and this leads to increase of plant growth, decreased water use and reduced tissue concentrations of protein and nitrogen [23]. The quality of forages on rangelands declines as the concentration of plant tissue nitrogen and protein decreases [24]. A rise in the atmospheric CO_2 also affects the primary productivity of rangelands [25]. In Africa, most grassy rangelands have been taken over by shrubs and trees which results in bush encroachment, a phenomenon that tends to increase plant biomass but limits the productivity of rangelands [26]. A study on 37 selected sites of the Mongolian rangelands to understand the impact of climate change on the productivity of these rangelands, showed that the Mongolian Steppe was already affected by climate change leading to marginal increase in the soil organic carbon level, and resulting in reduction of the productivity of forage plants [27].

Effect of climate change and variability on rangeland quality and productivity
Length of growing period (LGP)
Climate change has either lengthened or shortened the length of the growing season in various regions globally. In West Africa, areas around the west Guinean coast are reported to experience about 20 % decrease in the length of the growing period whereas regions around the east are expected to experience an increase of about 5-10 % [27]. The central and eastern Sahel areas of Africa are to experience over 30 % increase in the length of the growing seasons while the western Sahel regions will experience shorter growing seasons [28]. Most parts of the sub-Saharan Africa will experience a decrease in the length of growing period as a result of the combined impact of changes in temperature and rainfall, whereas the decrease will be severe in some cases [20].

The length of the growing season has an impact on the quality and quantity of forages as well as the duration and period when live forages are accessible [27]. The semi-arid rangelands of the Sahel have been affected by climate change (high temperatures and recurrent droughts) which has led to a higher ratio of actual to potential evapotranspiration. This has limited plant growth and reduced the length of the growing season [28]. A reduction in the length of the growing season translates into lower forage yields and shorter periods of availability of lush pasture for ruminant livestock.

In the temperate regions, increasing temperatures will affect the length of growing season through reduced cold stress and increased heat loads during summer [37]. It is projected that by 2050, most parts of the world will possibly have an increase

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in temperature during the growing season than currently experienced, and this temperature increase will eventually be associated with more rainfall variability [29].

Drought stress in plants

Rangeland quality and composition can be affected by the interactions existing among temperature, rainfall, atmospheric CO_2 concentration as well as land cover change and grazing. For example, drought stress in plants is increased when there is an increase in temperature [20]. Prolonged drought is associated with a comparable reduction in the net annual productivity of rangelands. The survival of long-lived perennial tree and pasture species is threatened by severe droughts. Browse species have high chance of survival than grasses during drought periods as a result of the effect of climate change and as such, farmers with large ruminants such as cattle are forced to shift from cattle production to the production of small ruminants such as goats and sheep since they require less feed and water [11]. Drought stress leads to physiological and morphological changes in forage plants. This is a natural response to avoid water deficit and heat stress. This response ultimately reduces the nutritional value and digestibility of the forage plants.

Changes in plant species composition

Global average surface temperature is predicted to increase between 1.8°C to 4.0°C by the year 2100 according to IPCC [2]. Approximately 20 to 30 % of some plant and animal species are reportedly at the risk of becoming extinct with an increase of 1.5°C to 2.5°C [30]. This will lead to severe outcomes for food security in developing countries. Plant species composition is influenced by climate change mainly by shifting the amount, seasonal pattern, and vertical placement of soil water which will turn out to affect the outcome of competition by plants [31]. A rise in CO_2 concentration contributes to changes in composition of species by lowering transpiration to prolong soil water availability within a growing season [32]. The current CO_2 level of 350ppm in the atmosphere is projected to rise to 700ppm by 2100 [30]. This projected rise may tend to favour C_3 shrubs and legumes over C_4 grasses, consequently leading to changes in plant species composition. A study on plant species diversity in South Africa revealed that 11 % of the species investigated were at risk of extinction [33]. It is also reported that, climate change will result in the extinction of over one million terrestrial species in the next five decades [34]. Loss in plant species biodiversity is said to result from increase in temperature and prolonged droughts creating the right conditions for intensive rangeland fires. These fires together with changes in hydrologic and life cycles are expected to alter the habitats that support vulnerable plant species, thus leading to loss of species or changes in species composition in favor of more resilient species [35].

Impact on plant nutritional value

Forage quality is affected by rise in CO_2 and temperature as well as variations in precipitation, which complicates the quality of forages [27]. Forage quality can be increased by concentrating nitrogen moderately into plant tissues especially during the dry conditions and delaying maturity [36]. An increase in CO_2 tends to increase total shoot nonstructural carbohydrates and this adds up to improve forage quality [37]. This is because increase in CO_2 increases the rate of photosynthesis which converts the CO_2 into sugars and therefore, elevated CO_2 will stimulate the production of nonstructural carbohydrates. However, in dry and nitrogen limited rangelands, a rise in CO_2 reduces forage quality by increasing the ratio of carbon to nitrogen, lowering crude protein content, and finally increasing the fiber content of forage which will eventually decrease digestibility [38]. Studies have shown that nonstructural carbohydrate content of grasses increased by 25 % under elevated CO_2 levels but under the same condition, nitrogen content decreased by 8 % [39]. This reduction in the concentration of plant tissue nitrogen and protein will undoubtedly lead to a decline in forage quality in pastures and rangelands [24]. However, CO_2 elevation in the atmosphere is also expected to increase the population of C_3 legume species in rangelands, thus, compensating for the reduction in the concentration of plant tissue nitrogen and protein in elevated CO_2 levels [40]. C_3 plants respond to elevated CO_2 levels by increasing photosynthesis and reducing conductance in the stomata. This makes it possible for legumes to increase N_2 fixation, thus, reducing the impact of drought on N_2 fixation [41]. Other studies also suggest that, the response of legumes to elevated CO_2 is only in managed systems and not in natural systems [41]. This is because nutrient deficiency can limit the response of legumes to elevated CO_2 [42]. Phosphorous limited the response of legumes to elevated CO_2 in a N-poor calcareous grassland which subsequently limited N transfer to non-leguminous species in the grassland ecosystem [43].

Ozone (O_3) acts as a shield to prevent harmful shortwave ultraviolet solar radiations from reaching the surface of the earth. However, the presence of O_3 on the earth's surface has added to the impact of GHGs to plants. Plants exposed to high concentrations of ground-level O_3 suffer from reduced photosynthetic activities, experience accelerated rate of senescence, reduced rate of plant growth and lower yields [44].

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Lack of adequate soil water coupled with high atmospheric temperatures increase evapotranspiration, which results in increased lignification of forage species thereby reducing intake and digestibility by livestock that feed on them [45]. It has been reported that increase in temperature does not only increase drought stress in plants but also increases lignification of their tissues which affects both digestibility of plants as well as their rate of decomposition [20]. Lignin and cell wall contents in plants also increase as a result of a rise in temperature and this lowers digestibility. Neutral Detergent Fibre (NDF) is also said to increase with rise in temperature. It is reported that, NDF increases by 0.4 +/- 0.06 % for every 1^0C rise in temperature [46], and the higher the NDF content, the lower the feed intake by ruminants. According to US Global Change Research Programme [24], temperatures are expected to increase by 2.0–3.08 °C by 2050 and 2.2– 5.58 °C by 2100. There is, therefore, no doubt that the grasses in rangelands are going to be less nutritious, so livestock that feed on them are going to gain less nutrients leading to their poor condition and a subsequent reduction in productivity.

Increase in vegetation flammability

Increased temperatures coupled with lowered rainfall increases vegetation flammability [20]. Some rangeland grasses promote fire and are also by themselves promoted by fire, whereas the woody plant populations are sensitive to fire in their seedling stage but may be competitively superior once established. This makes rangelands dominated with woody plants less prone to fire than grasslands [47]. An increase in fuel load is expected under high levels of CO_2 since plant growth would be high. Temperature increases driven by climate change will cause areas with low rainfall to experience an increase in fuel dryness and a reduction in relative humidity [48]. With high amounts of fuel load and warmer environments, rangelands can experience wildfires caused by natural means (lightning) or by anthropogenic activities (hunting, grazing and burning of croplands).

In northern Australia's open woodlands, it is perceived that woodland thickening is as a result of reduction of pasture burning [49]. Continuous fire of annual grasses can cause a shift from grassland to shrublands and woodlands, whereas on a large scale change from shrublands to homogenous grasslands can affect evapotranspiration, moisture transfer and rainfall. The net effect could be an increase in aridity of the region [22].

Wildfires (driven by climate change) in rangelands may lead to the loss of forage biomass essential for livestock feeding. However, these wildfires can also clear

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close woody canopies and enhance sunlight penetration into rangelands. This will enhance growth of herbaceous species and encourage plant diversity.

Mortality of plants

When rangelands are exposed long enough to high temperatures, they undergo stress which eventually leads to a large-scale mortality of species in these rangelands. Some climatic events can lead to the death of some specific rangeland species [50]. A severe and prolong drought can result in the mortality of perennial plants and cause a shift to an annual-dominated vegetation [51]. There has been considerable death of trees across the globe which is attributable to severe drought [52]. For example, in Africa there were tree mortalities of *Cedrus atlantica* in Belezma Park, Algeria and quiver tree (*Aloe dichotoma*) in Tirasberg mountains in Namibia [52]. Loss of species also affects the interactions with other species, thus, having an impact on the overall function of the ecosystem [35]. There is also the extinction of animal species like the checkerspot butterfly. This is as a result of an increase in the variability of precipitation leading to a reduction of temporal overlap between the larvae of the butterfly and its host, the dwarf plantain [53]. An increase in air temperature above the physiological limits has also led to the extinction of 48 lizards. The presence of all these organisms contribute to rangeland ecosystem function [54].

Effect of Climate Change on soil

With the advent of climate change and variability, CO_2 content in the atmosphere is reported to have increased by some 30 % in the last fifteen decades [55]. Atmospheric CO_2 concentration is projected to rise to 800ppm by the end of the 21st Century [56]. With respect to the Carbon pool in the soil, it is also reported that the soil alone contains 75 % of the total carbon pool in the ground [57]. The soil serves as a means where plants and some microorganisms directly or indirectly secure their food, thus serving as carbon sink. The rise in CO_2 level in the atmosphere coupled with fluctuations in temperature and precipitation lead to alterations in important soil processes. This exposes the soil to physio-chemical degradation, salinization, erosion, reduction in water availability and storage of soil nutrients [57].

Rise in temperatures caused by climate change induces rapid decomposition of organic matter in the soil. This leads to loss of CO_2 from the soil and a reduction in soil organic carbon stock [57]. Generally, a rise in temperature will result in faster rate of soil organic matter decomposition, faster rate of mineralization and nitrification of Nitrogen [58]. The high rate of soil organic matter decomposition will be due to the fact that warmer temperatures stimulate microbial activities. This high rate of decomposition will lead to loss of soil nutrients through leaching and erosion, thus reducing nutrient availability to forage plants [59]. A rise in temperature of about 0.3 to 6 ^{0}C increases the rate of Phosphorus mineralization in litter by 48 % [60]. Additionally, when the rate of mineralization is faster than rate of plant mineral uptake, the result is leaching. Extremely high temperatures and droughts result in evaporation of soil moisture, which in turn reduces the amount of dissolved nutrients for plants uptake from the soil [11].

Precipitation plays a vital role in the growth and development of plants. Precipitation which is expected to increase in some areas of the world by reason of climate change will make more soil moisture available to plants. Soil moisture will in turn make minerals available to plants. However, extreme precipitation depletes the nutrients in the soil through leaching and erosion through runoff water. It is estimated that an increase in precipitation by 1 % in a given area can lead to an increase in erosion by 1.5 – 2 % [56]. Soil moisture and fertility among others are the factors to consider during the production of rangelands. Therefore, any environmental alterations which affects the process by which soil water is attained will have a severe influence on the stability and productivity of forage plants [4].

Changes in the carbon to nitrogen ratio (C: N) of vegetation which comes as a result of climate change affect soil nutrients indirectly and causes changes in some characteristics of soil as well [61]. Response to these climate change drivers such as increasing CO_2, temperature and rainfall tend to vary with different locations because of the difference in soil characteristics such as the water-holding capacity [62]. In addition, structures and functions of some aspects of the ecosystem will be affected due to the overall effect of these climate change drivers on the availability of soil water [31]. However, rangelands can be managed to help alleviate anthropogenic causes of climate change through a process known as carbon sequestration. This is the storage of carbon from the atmosphere into the soil and vegetation through photosynthesis, humification and aggregation [4] and store the carbon in organic forms, including plant biomass and soil organic matter. The process enhances soil fertility due to the increasing amounts of soil organic matter.

CONCLUSION

Climate change no doubt has been and is still a topical issue across the globe. The Earth's climate has changed through natural events and now in an era where anthropogenic activities are immensely contributing to this phenomenon. Gases such as CO_2, N_2O, CH_4 and CFC's collectively known as GHGs are responsible for the change in climate. Climate change is adversely affecting rangeland's quality

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and productivity. High temperatures with little or no precipitation affect the length of growing periods of plants, nutritional value of forages, species composition, vegetation flammability, drought stress and mortality of range plant and animal species. Climate change also affects soil chemical and physical properties, leading to changes in the availability of soil water to plants. For sustainable livestock production, there is the need to fully understand the effect of climate change on rangelands. This will be helpful in the formulation of appropriate range management decisions to optimize forage production and utilization by livestock.

It is recommended that:

- Novel range management policies be enacted and implemented for sustainable rangeland use in the face of climate change.
- Scientists be properly resourced to effectively quantify the impact of climate change on rangeland resources and results communicated to the understanding of all including the resource poor livestock farmers.
- Vulnerable rural based livestock farmers should be assisted with adaptation strategies to remain in production.

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