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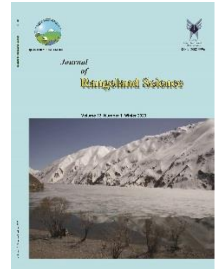

Research and Full Length Article:

Effects of Grazing Management on Greenhouse Gas Emissions in Southern Rangelands of Kenya

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Abstract. Rangelands ecosystems play a critical role in regulating the emission and uptake of the most important Greenhouse Gases (GHGs) such as CO_2, CH_4, and N_2O. However, the effects of grazing management on GHG fluxes in the semi-arid lands of East Africa remain unclear. The present study compared the effects of three grazing systems on cumulative CO_2, CH_4, and N_2O fluxes in the semi-arid grazing land ecosystem in Yohani ranch Makueni County, Kenya. The study followed a pseudo-replication design in which there were three treatments: 1) Continual grazed, 2) rotational grazed and 3) and ungrazed. Greenhouse gas samples were collected using the static chamber method for a period of three months covering the dry and wet season as well as a transition period. Cumulative soil CO_2 fluxes were highest in continual grazing system (2357±123.9 kg ha^{-1} 3 months), followed by rotational grazing (1285±123.9 kg ha^{-1} 3 months) and lowest in the ungrazed (1241±143 CO_2 kg ha^{-1} 3 months), respectively. The three month cumulative N_2O and CH_4 fluxes were also highest in continual grazing and lowest in ungrazed site 677.9±130.1, 208.6±127.3 and 162.2±150.3 (g ha^{-1} 3 months) and CH_4, 232.7±126.6, 173.1±126.6 and 80±46.2 (g ha^{-1} 3 months) respectively. The results suggest that the continual livestock grazing system increases emissions of GHGs compared to rotational grazing.

Keywords: Greenhouse gas fluxes, Grazing management systems, Rangelands

Introduction

Greenhouse gas (GHG) emissions were estimated globally to be 49×109 $MgCO_2$ eq. in 2010 (Change, 2014a, 2014b), with approximately 21.2–24% (10.3–12×109 $MgCO_2$ eq.) of emissions originating from soils in agricultural, forestry and other land use (Tubiello et al., 2015). Annual CO_2 and CH_4 emissions from agriculture were estimated to be 5.2–5.8×109 $MgCO_2$ eq.yr^{-1} in 2010 (FAO, 2014; Tubiello et al., 2013), with approximately 4.3–5.5×109 $MgCO_2$ eq.yr^{-1} attributable to landuse change (Change, 2014a). Greenhouse gas fluxes in Africa play a vital role in the global GHG budget Thompson *et al.*, 2014; Valentini et al., 2014). For instance, in sub-Saharan Africa, Nitrous oxide (NO_2) emissions have been estimated to contribute between 6 and 19% of the global total changes in soil fluxes in Sub Saharan Africa with high inter-annual variations in the tropical and subtropical environments (Thomas and Rosenstock, 2016).

Rangelands are important ecosystems not only because of the vast area they occupy and their contribution as major feed resource to livestock, but are also important ecosystems in the global budget of the greenhouse gases (GHGs); carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In Kenya, rangelands occupy more than three quarters of land and the primary users of these are pastoral communities who practice extensive grazing. However, there are some agro-pastoralists and commercial ranching farms. Livestock production in these areas has gained importance due to increased human population, resulting to increased food demand.

Consequently, this has led to increase in grazing pressure in most of the rangeland areas.

Rangelands have experienced soils and vegetation degradation due to overgrazing, climate change and plant invasions. Thus, management practices that will favour plant production for increased livestock productivity is desirable. This should have potential to restore or even increase grassland soil carbon storage and provide a potential positive feedback on the global carbon cycle (Smith *et al*., 2010).

The extent to which rangeland act as a net sink or a source for GHGs is determined particularly by their management (Conant *et al*., 2001). Rangeland degradation through inappropriate livestock grazing management can lead to a net release of GHGs, predominantly in the form of CO_2 that deplete soil organic carbon stocks (Lal, 2004). On the other hand, efficient grassland management and restoration of degraded sites, e.g. through planned grazing or exclusion, offer large GHG mitigation potential, mainly through the sequestration of atmospheric CO_2 (Conant *et al*., 2001; Lal, 2004; Smith, 2008). A complete understanding of agriculture's impact on radiative forcing and the accurate quantification of GHG mitigation potentials require field-level measurements of CO_2, CH_4, and N_2O (Robertson *et al*., 2000). Complete field-level GHG fluxes of agricultural systems have been extensively measured in intensive and semi-intensive European grasslands in the Midwest and Northeast United States on croplands and unmanaged sites (Robertson *et al.,* 2000) and on moderately and heavily grazed pastures of the temperate steppe in the United States (Liebig *et al*., 2010). However, we didn't find literature on the GHG balance of livestock farming in Kenyan rangelands. Furthermore, the influence of grazing management on the balance of GHGs is not yet well established, and further research is needed to quantify the effect of grazing management in GHGs emissions (Gill *et al*., 2010).

Although the effects of grazing impact on greenhouse gas emissions have been studied in a wide range of ecosystems worldwide, there is no existing literature on studies done to examine the linkage between greenhouse gas emissions and grazing systems in Kenyan rangelands (Pelster *et al*., 2015). Worthwhile, the effects of livestock grazing management systems on greenhouse the gas emission need to be understood in order to sustainably utilize grassland and determine "low emission development strategies" (LEDS). Therefore, we investigated the influence of two grazing systems (continual and rotational grazing systems) on GHG emissions and compared to an ungrazed area in the southeastern rangeland of Kenya.

Materials and Methods

Site description

The study was conducted in Yaoni ranch located in Makueni County, approximately 125 km southeast of Nairobi, Kenya (Fig. 1).

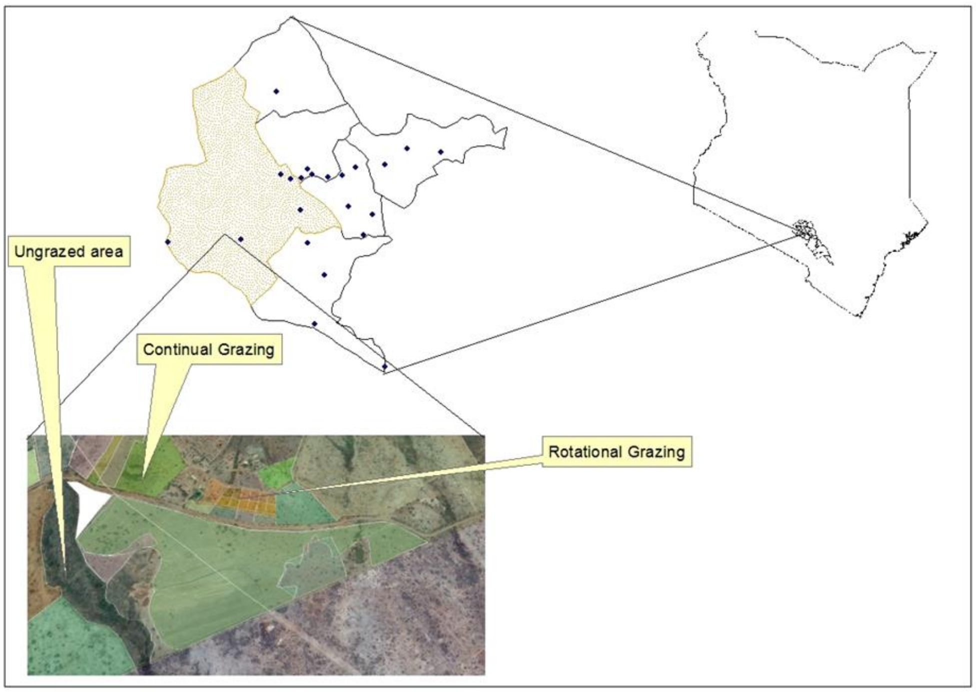

Fig. 1. Map of Kenya showing study

The county borders several counties which include Kajiado to the West, Taita Taveta to the South, Kitui to the East and Machakos to the North. It lies between Latitude 1º35´ and 30º00´ South and Longitude 37º10´ and 38º 30´East.

The area lies at an altitude of between 1200-1400 m above sea level and receives bimodal rainfall with long rains falling between the months of March to May and short rains in October to December. Total annual rainfall is between 400 and 600mm. In between the rainy seasons, the area experiences intervening dry spells in January/February as well as July to September.

The county is largely arid and semi-arid and usually prone to frequent droughts. The study site falls under agro-ecological zone IV and V In terms of agro-ecological potential.

The terrain is characterized by plains to the North, undulating hills to the South. The geology of the study area is characterized by relatively deep over-burden, with very few exposures of the underlying basement rock. The soils are highly varied, dominated by sandy soils punctuated with vertisols, acrisols, and cambisols. The natural vegetation of the study area consists of Themeda triandra, a tufted perennial grass species that is preferred by grazers, and Themeda –Balanites or Themeda- Acacia wooded grassland.

Experimental Design

The experimental design was a completely randomized design (CRD) involving two grazing systems and ungrazed area: continuous grazing, rotational grazing and ungrazed area grazing (control). This research site was on a commercial grazing ranch, which practices both rotational and continuous grazing systems. Within the same ranch, there was a section with similar geomorphology and soils as the rotationally grazed which was not converted and has been continuously grazed for over 30 years to represent the continuous grazing system. Under rotational grazing, a large herd of livestock is moved between paddocks for short periods of time. The ungrazed area consists of an abandon section of the ranch for more than 30 years due to a deep gully which was formed by gully erosion creating an isolated area inaccessible by livestock.

Flux measurements

The concentration of CO2, N2O and CH4 were measured using the static greenhouse gas chamber approach (Pelster et al., 2015). In each grazing system, four sampling points were randomly selected, and within each sampling point, four chambers were installed to form a 10 x10m square. The, chambers consisted of a collar (0.27m×0.372m×0.1m) and a lid (27×37.2×12.5cm) made of plastic. The collars were inserted up to 10cm into the ground. The lids were equipped with 50cm long (2.5cm diameter) vent tubes, thermometers to measure internal temperature, fan and a gas sampling ports.

During measurements, the lid was placed on the collar and both increments were tied with clamps with a gasket between the lid and the collar for airtight seal. Chamber bases were inserted at least one week prior to the first greenhouse gas concentration measurements and remained in place throughout the three months sampling period. During each sampling event, chambers were closed for 30 min and thereafter, four samples taken at 10 min intervals (0, 10, 20, and 30 min) from each individual chamber. A gas pooling technique was employed where 15 ml of gas was sampled in each of the four chambers within a sampling point. This was done using a 60ml propylene syringe with Luerlocks and immediately transferred into 20 ml glass vials fitted with crimp seals (Butterbach-Bahl et al., 2016). The first 30ml of the sample were used to flush the vial and the remaining 30ml filled the vial in order to pressurize it to reduce the likelihood of contamination with ambient air. Samples were analyzed within 36 hours after every sampling period.

Concentrations of CO2, N2O, and CH4 were analyzed using a gas chromatograph (model 8610C; SRI) equipped with two detectors; a flame ionization detector (FID) comprising of a Platinum catalyzed methanizer for catalytic conversion of CO2 to CH4 and for subsequent detection of CH4 and CO2 and an electron capture detector (ECD) to detect N2O. A mixture of CO2 and N2 pre-mixed in the ratio of 5:95, was used as the ECD Make-up gas to improve on the detector sensitivity.

The analytes were separated on (3m, 1/8″) chromatographic columns packed with Hayesep D stationary phase at an isocratic oven temperature program of 70°C. ECD and FID detectors temperatures were set at 350°C. 99.99%. White spot Nitrogen was used as carrier gas at flow rates of 25ml min-1 on both FID and ECD lines. Gas concentrations of samples were calculated based on the peak areas measured by the gas chromatograph relative to the peak areas measured from calibration gases run at two calibration levels. This was done four times each day.

Calibration gases ranges from (4.28-8.31 ppm) for CH4, (400-810.5 ppm) for CO2 and (0.36-0.76 ppp) for N2O. Concentrations were then converted to mass per volume using the Ideal Gas Law (pV = nRT) and measured chamber volume, internal chamber air temperature, and atmospheric pressure determined during sampling. GHG fluxes were calculated using linear regression of gas concentrations versus chamber closure time.

Statistical analysis

Gas flux data was subjected to analysis of variance (ANOVA) using GenStat Discovery 15th edition statistical software. Tukey's HSD post hoc was used to separate the treatment means.

Results and Discussions

Influence of grazing management on N2O fluxes

Significantly higher soil nitrous oxide fluxes ($p \leq 0.05$) were obtained in the continuously grazed site (677.9 ±130.1 g ha-1 3 months) compared to both rotationally grazed and ungrazed site (208.6±127.3 and 162.2±150.3 g ha-1 3 months), respectively, with the ungrazed area having the lowest nitrous oxide fluxes (Fig. 2).

The high N2O emission rates observed in grazed pastures than ungrazed area can be attributed to N and C from the deposition of animal excreta to the soil and anaerobic conditions as a consequence of soil compaction caused by animal treading. Trampling compacts the soil affecting the abiotic soil characteristics such as pore size, soil moisture and soil aeration. The low air filled pores as a result of soil compaction leads to a decreased oxygen concentration and more anaerobic conditions which can result in high denitrification, thus leading to a significant loss of inorganic N via gaseous emissions. Similar results were found by Douglas and Crawford (1993) who reported N20 emissions and denitrification rates were two times higher in compacted than in uncompacted grassland soils. The same results were also reported by Torbert and Wood (1992) who found an increase in bulk density resulting to increased total "N losses by a factor of 3.6 and attributed this to denitrification as a major cause of the observed N loss. Accordingly, moisture effects on soil nitrous oxide fluxes are a result of the limitations of oxygen diffusion into the soil and expansion of soil anaerobiosis, which in turn promotes reductive microbial processes such as denitrification under continual grazing system (Patra et al., 2005)

The observed high N2O fluxes in the continual grazing system can also be attributable to the low vegetation cover which may have led to high soil temperatures. Continuous grazing system reduces above ground vegetation cover compared to rotationally grazing management system due to high grazing pressure on continual basis throughout the year. The low vegetation cover leads to increased soil temperatures under continual grazing which increase N2O emissions. This can be explained by an expansion in the soils pores that are triggered by the accelerated soil respiration leading to increased denitrification rate, and the temperature sensitivity of the underlying enzymatic processes causing N2O release. Grazing livestock reduce aboveground herbaceous cover which increases evaporation at the soil surface, resulting in higher salinity and increase in denitrification rates Our observation of high fluxes from continual grazing agrees with other previous studies which have reported an increase in nitrous oxide fluxes with increase in soil temperature (Brumme, 1995; Dinsmore et al., 2009; Dobbie and Smith, 2003).

The high emissions from continual grazing can also be attributable to high grazing frequency because of the presence of active hot spots of urine and dung depositions, due to continuous grazing throughout the year. According to Nunez and others (2007) the nutrient cycle is influenced by grazing animals who can return as much as 80% of consumed N in the form of dung and urine. Other studies, for example, Wolf and others (2010), found higher N2O emissions with an increase in stocking rate (LU ha-1). Restricted grazing not only reduces N-input from urine, but also reduces hoof compaction of the soil. Similarly, (Nunez and others 2007) in their study of effects stocking rate on soil nitrogen, reported that, the application of the concept of carrying capacity (the number of animals that the pasture can support) can significantly reduce the N2O losses from soils.

Influence of grazing systems on soil CO_2 fluxes

The continually grazed site showed significantly higher CO2 fluxes ($P \leq 0.05$) than both rotational and ungrazed sites (Fig 3). Rotationally grazed site had slightly higher CO2 fluxes than the ungrazed site though were not statistically significant ($P \leq 0.05$). The three month cumulative emissions for continual, rotational grazing and ungrazed area were 2357±122.1, 1285±123.9 and 1241±143 CO2 (kg h-1 3 months), respectively (Fig. 3).

The observed high C02 fluxes in the continuous grazing system can be attributed to the effects of grazing livestock on soil temperature, soil moisture, plant litter and the amount of urine and dung deposition which influences the C02 fluxes. Urine and dung deposition acts as hot spot for the emissions of CO2. Soil temperature influences enzyme kinetics and metabolic turnover rates of nitrifiers and denitrifiers. Microbial activities and organic matter mineralization are higher at higher soil temperature, thereby resulting in higher CO2 emissions. The observed low soil CO2 fluxes under the rotational grazing and ungrazed land can be attributed to shedding effect that results from adequate herbaceous and woody vegetation cover, respectively, which tends to reduce the soil temperatures. The low herbaceous plant cover under the continual grazing system exposes soils to sun rays leading to increased soil temperatures and evapotranspiration rates hence increased decomposition of organic matter resulting to carbon loss from the soil.

Moreover, the high carbon dioxide emissions under continual grazing can likely be attributed to decrease in photosynthesis and carbon transportation to the roots occasioned by the low vegetation as a result of grazing pressure. The high CO2 emissions under the continual grazing can also be attributed to the grazing influence on topsoil carbon sequestration. Mechanism such as trampling induces soil compaction and deterioration of the soil structure. This is followed by mineralization of organic carbon that is released due to destruction of macro-aggregate structures.

Similar results were reported by Zhou et al. (2013) in a study where it was reported reported that, at constant temperature, wetter soils emitted more CO2 due to better conditions for microbial respiration. This observation is only true until the point of water saturation when CO2 fluxes tend to decrease, as those conditions favor the development of anaerobiosis, slowing down the decomposition of organic matter and reducing CO2 diffusion to the atmosphere (Knowles et al., 2015).

Grazing management influence on CH_4 fluxes

The three-months cumulative emission of CH4 was highest at continually grazed site and lowest at ungrazed area, i.e. the emissions for continual, rotational grazing and ungrazed area were, 232.7±126.6, 173.1±126.6 and 80±46.2 (g ha-1 3 months) respectively (Fig4).

The reduced production of CH4 in areas under rotational grazing and ungrazed sites can be attributed to low soil bulk density from grazing effects which is important for CH4 uptake since atmospheric CH4 is the only source for methanotrophs communities in the soils. When the diffusion rate of CH4 from the atmosphere to soil layers is affected by trampling, the oxidation rate of CH4 is also affected as a consequence. Thus, an improvement in the physical structure of the soil in the form of a lower bulk density is likely to be the main reason for the reduction of CH4 production in the rotationally and ungrazed sites. Our findings collaborates with those done by Shi (2017) on the effects of grazing on CO2, CH4, and N2O fluxes in three temperate steppe ecosystems reported an increase in CH4 emissions with increased bulk density due to trampling by livestock.

The high emission under continual grazing system could be due to high soil moisture caused by changes in soil bulk density. The low air filled porosity as a result of soil compaction leads to more anaerobic conditions which lowers the diffusion rate between the atmosphere and soil, as the only way for CH4 absorption by methanotrophs, hence leading to emission of CH4. Our findings collaborates a study done by Paz-Ferreiro (2012) who reported an increase in CH4 emissions with increasing grazing intensity in temperate grasslands.

The higher emissions under continually grazed area can be due to the fact that cattle are always present in the area hence continuously depositing dung and urine on daily basis thus increasing the emissions of CH4. Grazing animals on continuous basis reduces standing biomass and vegetation cover which ultimately increase soil evaporation hence an increased water stress, which could inhibit the activities of methanotrophs. The difference in CH4 emissions between the continual and rotational grazing systems can be attributed also to the populations of soil methanotrophs.

Greenhouse gas balance across grazing management systems

Based on the $C0_2$ equivalent calculations, the study revealed that the continual grazing management regime emits up to $87kgha^{-1}$ CO_2 equivalent of the greenhouse gases, while the rotational grazing system and ungrazed areas leads to carbon sequestration with a negative carbon balance of (-54.47kg ha-1 and -105.56 Kgha-1) respectively (Fig 5).

Our results clearly demonstrated the need for taking into account the fluxes of all three gases (CO2, N2O and CH4) when calculating the greenhouse gas balance of a grassland. As expected, reducing grazing pressure strongly reduced both GHG emissions. Hence, grassland management methods that reduce herbaceous vegetation cover, biomass production and increases soil bulk density, may not be appropriate as a mitigation option in semi-arid grasslands.

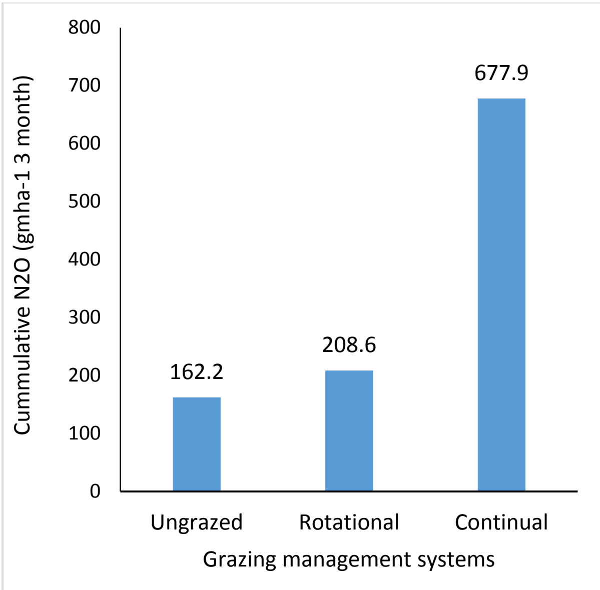

Fig. 2. Cumulative flux of N_2O across grazing management systems.

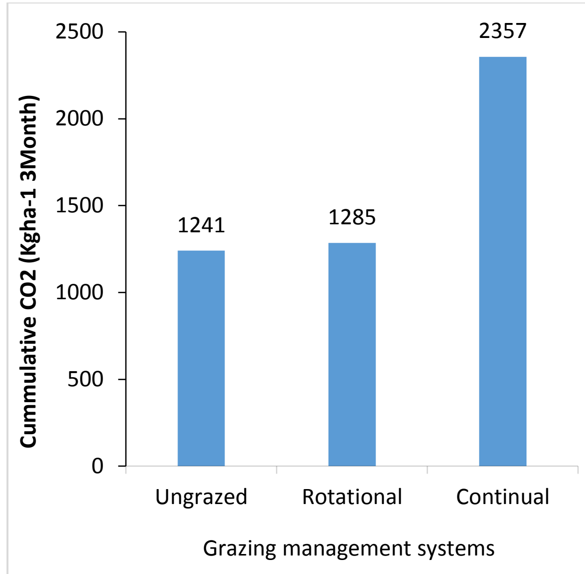

Fig. 3. Cumulative fluxes of CO_2 across grazing management systems.

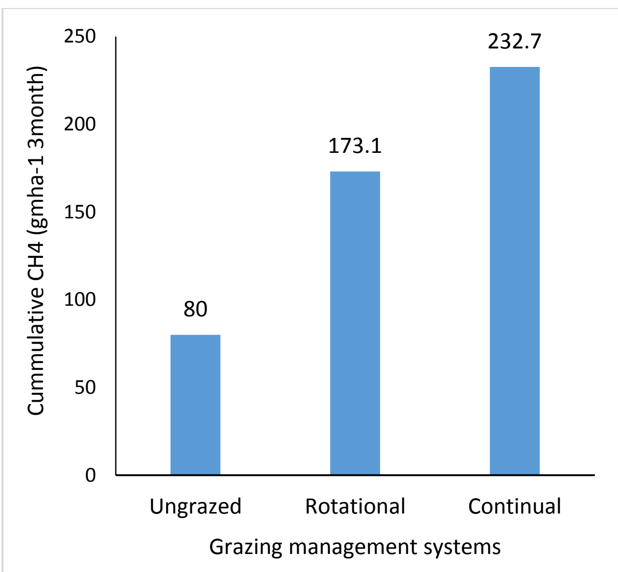

Fig. 4. Cumulative flux of CH4 across grazing management systems

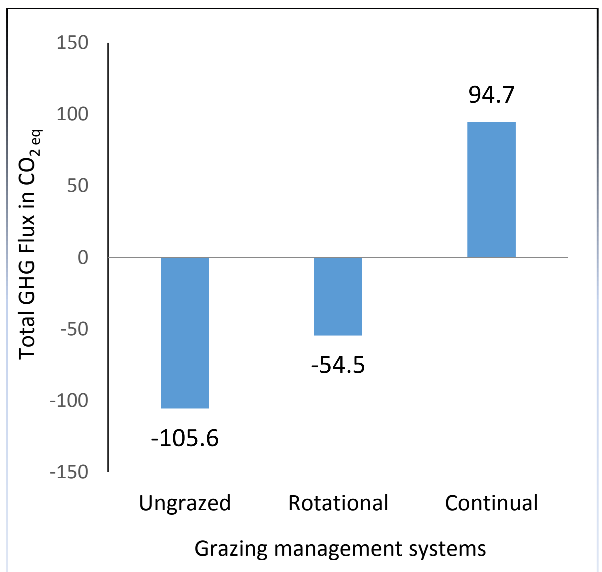

Fig. 5. Total GHG balances across grazing management systems

Conclusion

Despite the relatively short study period, the findings did indicate that continuous grazing system had the highest emissions of the three greenhouse gases followed by rotational grazing system while the ungrazed site had the lowest emissions. The results suggest that the continual livestock grazing system leads to high soil emissions of GHG compared to rotational grazing and that grazing exclusion holds large potential to restore the semi-arid soils to sequester atmospheric GHGs. The balance between grazing management system predominantly determines GHG balances of grass-based livestock farming in this region. Therefore, for reduced GHG balance of grazing lands, rotational management system needs to be adopted.

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