IJAGAHFP-International Journal of Advances in Global Animal Husbandry and Farming Practices
Volume 2, Issue 2 | October-2025
ISSN (online): 3065-0372; ISSN(Print): 3065-0321

Soil carbon sequestration and Rotational Grazing: Effect on Forage Quality and Beef Productivity

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Received: 12-08-2025; Revised: 29-08-2025; Accepted: 18-09-2025; Published: 07-10-2025

Abstract
Rotational grazing has subsequently been identified as one of the measures to be taken to improve the productivity of the pasture and sequester carbon in the soil in grass-fed beef systems. They tested the 3-year effects of rotational grazing vs continuous grazing on the quality of forage, biomass production and soil carbon dynamics on the Chaco region in southern Brazil. The artificially established into the experimental plots where rotation of cattle was done in every 7-10 days and in the control area, there were uninterrupted grazing plans. Results demonstrated that there was a significant 12.4% increments in DM yield coupled with 9.7% augment in crude protein in rotational grazing compared to no grazing ($p < 0.05$). Moreover, the soil carbon units of 0-30 cm improved at an annual rate of 0.56 t/ha/year when it was under rotational grazing management. This is an indication that rotational grazing upholds soil health by sequestering carbon besides increasing forage productivity hence it is a sustainable measure in beef production systems that can be said to be climate-smart. The research justifies the incorporation of rotational grazing in effective management of livestock systems with higher productivity and soil carbon sequestration in pasture-based livestock systems.

Keywords: ***rotational, continuous grazing, forage quality, biomass productivity, sequestering of carbon in the soil, grass-fed beef, sustainable livestock systems, climatesmart agriculture.***

1. Introduction

1.1 The contribution of grazing systems to sustainable beef production

Sustainable beef production is dependent on the concept of grazing systems which can be especially pasture based through which cattle are reared in natural or improved grasslands. These systems are not only beneficial to the main agenda which is meat production, but they are also helping ecosystems and biodiversity. The direct impact of grazing management on the ecosystem services takes place with respect to nutrient cycling, water retention, and soil structures. The second important aspect of sustainable beef production is altering the trade off between economic productivity and the effects of cattle production on the environment, especially in the context of growing demand of beef with population explosion and global climate change issues.

Conventional grazing has in most cases been dependent on continuous grazing since livestock tends to stay in a particular pasture. Though this is easy and needs less infrastructure, they may result in overgrazing, unsatisfactory pastures, and deterioration of soil conditions. Therefore, other forms of grazing like rotational grazing have been suggested as more sound grazing techniques, which are more productive and produce superior forages and healthy soils.(1)

1.2 Soil Carbon Sequestration and the mitigation of Climate Change

The other major issue in contemporary agriculture is the emission of green house gases especially by livestock which dumps methane gas and soil erosion that produces carbon dioxide. There is, however, opportunity to curb such emission by focusing on soil carbon sequestration that allows storing carbon in soil thereby functioning as a carbon sink. The soils that contain high amounts of organic matters may attract and capture carbon emission in the air and thus reverse the effects of agricultural operations and livestock farming to the environment.

Rotational grazing was cited as management practice that could increase soil carbon sequestration since it helps in soil health by boosting root growth, increased organic matter contribution and by intensifying the microbial activities. Rotational grazing helps restore the capacity of the soil to sequester carbon as it enables the pastures to recuperate and prevents possible soil compaction, erosion and loss of nutrients that may occur as a result of constant grazing.(2)

1.3 Restrictions of Perennial Pasturegrazing on the productivity and land health

Continuous grazing which involves livestock staying in the same pasture during grazing period has various drawbacks. Grazing a given pasture at a given time can cause overgrazing because the vegetation is over grazed to the point of the inability to regrow. This does not only lower forage production but also causes soil degradation due to erosion, compaction and loss of soil organic matter. Indeed, overgrazed pastures are easily invaded by alien species, the reason being that the native grasses and forbs are not able to grow successfully. Moreover, constant grazing has the potential of reducing the quantity of soil microbes, carbon retention capacities due to inability to redevelop the soil nutrients and plant root structure because of a break.

On the contrary, rotational grazing enables resting and recovery of pastures, which contributes to improved forage quality, enhancement of biomass production as well as healthier soil. Rotational grazing also resembles natural plant grazing and has been observed to increase productivity of the plants and soil condition due to the rotation of the cattle among different sections of the pasture.(3)

1.4 The Study Objectives

This research was mainly aimed at determining the long term impact of rotational and continuous grazing on the quality of forage, biomass production and carbon sequestration in soils under grass-fed beef operations. In particular, the study was focused on:

- Conduct a comparison of crude protein and dry yield of forages in continuous and rotational grazing system.
- Determine how grazing regimes can influence the soil carbon stocks at varying portions of soil depth.
- Determine the efficacy of rotational grazing on the productivity of pastures and carbon sequestration in beef production systems of grass feeding production.

This study is important to show the prospect of rotational grazing as a climate smart-agriculture practice that facilitates better environmental sustainability and boosts the performance of the grass-based beef system.

2. Cattle Grazing System and Farming

2.1 Outline of the Rotational and the Continuous Grazing Systems

It was based on two types of grazing systems, i.e., rotational grazing and continuous grazing experiment, which was done on the same grasslands in South Brazil.

Rotational Grazing: The rotational grazing system involved rotating cattle between different parcels of pasture working different areas and resting areas which had the opportunity to rest and reimburse the grass there. Depending on pressure and the condition of the pasture, the rotation was performed on a 7-10 day basis (which is a long rotation time). The Pasture was split into 6 areas whereby one area would be used by the cattle and the other areas were left to regrow. This was a resting period during which grasses could regenerate raising forage quality and the yield of biomass on a long-term basis. The rotation of the grazing was well controlled to space that no portion of the pasture could be over grazed and every plot was left enough time to restore itself before it was grazed once again. Rotational graze also helps to enhance the health of the root and soil, leading to sustainable carbon sequestration because of its relatively longer period under rest, resulting in better recovery.(4)

Continuous Grazing: This system, on the other hand, was the continuous grazing system where the cattle were left in one pasture during the whole grazing season without resting any section of the pasture. The cows were left free to graze and this resulted to the steady pressure to the plants. This system is less complex to manage and manage but it may cause overgrazing and longer term decline in pasture productivity unless it is managed. Studies have indicated that overgrazed lands have several signs of soil compaction, a decrease in the number of plants, and a loss of soil organic matter. Nevertheless, comparison was made with the rotational grazing system compared to the basis or control treatment which is the continuous grazing system.

2.2 Plant Layout, Turn Frequency and Stock Placement Arabesques

Grazing experiment was carried out in a 60-hectare grazing pasture in the south of Brazil that was split into two major grazing units; one rotational unit and one continuous unit. Three plots were designed to replicate each grazing system and to provide improved statistical analysis and reduce the possible variability in the pasture condition.

Rotational Grazing Plot Layout: The rotational grazing plot has 6 paddocks, each with the size of approximated 10 hectares. The paddocks were grazed to 7-10 (depending on the size of the paddock) and then the cows were moved to the next one. When every part was grazed the other parts rested to regenerate. Rotations were adjusted dependant on the rate of growth of the grass species and the rate of grazing. With such rotation of cattle, the lands did not become overgrazed and the pasture had time to rest therefore becoming recreated in quick time consequently giving the overall good forage hence the increased capacity of the system to retain carbon in soil.

Volume 2, Issue 2 | October-2025
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Continuous Grazing Plot Layout: The design of the continuous grazing on the other hand was compared to that of a single large field whereby the cattle were allowed to roam freely over the entire trial. The area of pastures was 60 hectares and the cattle were evenly stocked on the entire pasture and without rotation. The pasture had no resting periods, and the cattle were only transported to provide management (e.g., to feed it or to give it veterinary care). To give fair comparison of the effect of both systems of grazing on the quality of forage and effect on the soil health, an equivalent stocking rate was used in both systems.(5)

The stocking rate of both grazing system was moderate so that pasture zones were not overused and loaded the vegetation. The stocking rates of the two systems were equivalent to about one and a half Animal Units (AU) per hectare per annum; this is a common stocking rate of grass fed beef systems in the area.

2.3 Trial Tally Cattle breeds Management

They applied the trial in the Hereford and Braford crossbred cattle, which is adapted to climate and grasslands in the south of Brazil. At the time of the trial initiation the age of the cattle was 812 months old, and the initial average weight was 200 kg. The breeds have been characterized by their efficient grazing behavior, premium quality meat and suitability to systems based on pastures.

The management of Cattle was done as per conventional practice of beef production. They were provided ad libitum water and given minerals and salt blocks to realize their nutritional requirements. Health and growth performance of the cattle was monitored during the trial and a regular weight measurement was kept after every 6 weeks.

All in all, there was a management schedule of both grazing systems aimed at simulating real-life situations of producing grass-fed beef in southern Brazil. This arrangement was all that was needed to evaluate the effects of rotational grazing on the productivity of forage as well as its effect on soil health.

3. Biomass and Nutritional Study of Forage

3.1 Sampling frequency and Measurement of dry matter yield methods

The biomass of forage was measured periodically to determine the production of dry matter of the rotational and continuous grazing systems. The forage was sampled after 8 weeks intervals during the 3 year trial period to monitor the changes in the biomass production with time. In every sampling site, three quadrants with locations randomly selected were set within every grazing area (both rotational and continuous plots), and each had an area of 1 m 2. The entire forage in the quadrants was cut at uniform height of about 10 cm off the ground. Fresh weight of the harvested forage was then weighed and this value considered as fresh weight.

The fresh samples were oven dried at 60o C in a period of 48 h till the constant weight was obtained in order to determine the dry matter yield. Subsequently, the dry samples were weighed to determine dry matter content and biomass yield in kg/ha of forage could be measured.(6)

3.2 Evaluation of Crude Protein, Fiber content, and Digestibility

The quality of forage was determined by the evaluation of nutritional composition at each point of sampling. In every one of the forage samples crude protein (CP) was measured, fiber (neutral detergent fiber, NDF, and acid detergent fiber, ADF), and digestibility. The following tests were carried out in the usual laboratory practices:

The content of crude protein (CP) was determined using a Kjeldahl method and thus, giving the estimation of the nitrogen level of the forage.

The fiber and cell wall material in the forage are important parameters in terms of digestibility and forage quality and therefore, neutral detergent fiber (NDF) and acid detergent fiber (ADF) content was determined.

In vitro methods were used to estimate digestibility whereby forage samples were digested using enzymes to estimate potential energy that could be removed to the cattle.

3.3 Tracking of Seasonal Variation

The quality of forage and biomass were followed throughout varying seasons in order to consider season variation in pasture nutritional value and its growth. The sampling was done on both wet and dry seasons since it has been identified to affect the growth of forage and the nutrient composition. The seasonal variations were of great significance in realizing the impact of rotational grazing related to the recovery and quality of forage during the optimal growing and dormancy season. The data of various seasons were discussed to evaluate the effects of grazing management to calculate the forage consistency in the whole year.

4. Soil Carbon monitoring protocol

4.1 According to the depths and intervals of the soil sampling (0-30 cm), the limits of the sampling area should be the following ones, each one determined by the appropriate intervals:

Soil carbon dynamics was also determined by use of the constant collection of soil sample to keep the changes in the soil carbon stock at a depth of 0-30 cm. The depth was selected because it is the rooting depth where the major biological processes take place, having an effect on the level of carbon sequestration and organic matter build up. The sampling was done after every 6 months during the trial period of 3 years to cover both the short term and the long term effects on soil carbon under the various grazing systems.

In every sampling point, a random selection of six core samples was made individually in each of the treatment groups (rotational grazing and continuous grazing) to obtain spatial representation of the pasture area. Manual auger was used in sampling the soil cores and individual sample measured 2.5 cm in diameter with the complete sample extending to 30 cm of depth. These samples were mixed together to create a composite sample of each of the grazing treatment so as to give an average measurement on the amount of carbon in the soil sample in the different groups.(7)

4.2 Analysis of Carbon by Laboratory Techniques

The collected soil samples were taken to a soil laboratory where determination of the content of soil organic carbon (SOC) was made. Carbon content was determined in the following laboratory methods:

- The soil organic carbon (SOC) measurement was performed under the dry combustion technique (also referred to as Walkley-Black technique) which is generally considered to be a well standardized and apt method in measuring the overall soil organic carbon. In this approach, soil samples are dried, ground in addition to sifted. A high temperature combustion is achieved in a furnace thereafter, and the concentration of the carbon in the sample is determined on the basis of the heat liberated.
- The content of soil organic matter (SOM) was also determined because SOM contributes to the size of soil carbon stocks to a large extent. To estimate the overall soil organic matter, SOC values were used, and it is essential to perceive long-term possibilities of carbon storage.

The planned laboratory analysis of the organic carbon in each depth of sampling was given numerically and it was possible to monitor the change of the carbon depthwise in the soil profiles.

4.3 Annual carbon stock changes Calculation

Change in carbon stocks based on carbon content was computed by taking the ratio between carbon contents of sampled soils at different times. The amount of carbon in soil per depth (0-30 cm) was quantified by multiplying the organic carbon concentration with bulk density as well as by the depth of that sample. The carbon stock can be calculated as shown by the following formula applying to every sampling depth:

Carbon Stock[t/ha]

$$\text{Carbon Stock (t/ha)} = \text{Soil Organic Carbon (g/kg)} \times \text{Bulk Density (g/cm}^3\text{)} \times \text{Depth (cm)} \times 10$$

Using this formula to every sampling depth and interval we obained the annual carbon stock increments and decrements of every grazing system. The changes were captured in t/ha/year to approximate the rate of carbon sequestration in every grazing treatment. The annual change in carbon stocks of rotational grazing and continuous grazing systems was also measured and therefore it was concluded how the grazing management affected the change in carbon sequestration over time.(8)

Such a soil carbon monitoring protocol enabled a potent study of a long-term assessment of the soil health and the possibility of rotational to improve climate changes via enhancement of soil carbon sequestration in grass-fed beefing systems.

5. Results

5.1 Raising the yield and quality of forage under rotational grazing Forage yield and quality were increased as a result of rotational grazing.

It was found that the study results were immense in superseding the yield and quality of forage by the rotational and the continuous grazing system. The production in terms of the forage dry matter and the content of crude protein were consistently increased with rotational grazing treatment during the 3-year trial period.

Forage Dry Matter Yield: Rotational grazing system enhanced yield of forage dry matter by 12.4 percent unit ($p < 0.05$) more than the continuous grazing system. This increase in the forage yield may be explained by the rest intervals which are given to pastures under the system of the rotational grazing when the vegetation has time to

Volume 2, Issue 2 | October-2025
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revive and grow between the periods of grazing. Greater volume of good quality fodder leads to improved animal productivity and it is one of the most important factors in sustaining rotational grazing.(9)

Crude Protein Content: There was also an increased crude protein content of the forage in the rotational grazing whereby it rose by 9.7 percent compared to the continuous grazing ($p < 0.05$) The elevated level of protein indicates that rotational grazing enhances quality of forage that is vital in advancing beef nutrition and augmentation rates under grass feeding beef schemes.

Fiber Content: Fiber content (NDF and ADF) was somewhat lower with rotational grazing system, thus showing that younger and more digestible vegetation were present because of the rest periods. This increase in forage digestibility will boost improved efficiency of feed as well as decreasing the requirement of supplementary feed.

5.2 Cutting-edge Soil Carbon Sequestration Indicators

Under the rotational grazing system, Soil carbon sequestration was on an ascending trend. The trial showed that the amount of carbon in the soil increased steadily during the trial period.

Carbon Stocks in the Soil 0-30cm depth: The rotational grazing system resulted in a positive increase (0.56 t/ha/year ($p < 0.05$)) in the soil carbon stocks compared to continuous grazing system. This rise in soils carbon sequestration was con-sistent in various seasons and type of soils in the study area. The positive change in the soil stocks of carbon can be explained by the increase of the root biomass input and the organic matter input in the soil as a result of the grazing rotations that permitted better soil structure and microorganisms activity.(10)

Soil Organic Matter (SOM): The growth in the amount of soil organic matter was also witnessed and there was a consistent increment in the content of SOM with the rotational grazing system. Through this it can be pointed out that long-term rotational grazing can greatly benefit the soil health and also help in the mitigation of climate change by storing carbon in the ground.

5.3 Statistical significance values and Comparative Data Tables

Table 2 presents the summary of the most important findings of the study about forage yield, forage quality and soil carbon sequestration in the two different grazing systems:

Table 1: Forage Yield, Quality, and Soil Carbon Sequestration Comparison

Parameter	Control (Continuous Grazing)	Rotational Grazing	Difference (%)	p-value
Forage Dry Matter Yield (kg/ha)	2,500	2,810	12.4%	<0.05
Crude Protein Content (%)	14.2	15.6	9.7%	<0.05
Neutral Detergent Fiber (NDF%)	45.1	43.2	-4.2%	NS
Acid Detergent Fiber (ADF%)	32.5	31.8	-2.2%	NS
Soil Carbon Stocks (t/ha/year)	2.34	2.90	0.56 t/ha/year	<0.05
Soil Organic Matter (SOM%)	3.2	3.6	12.5%	<0.05

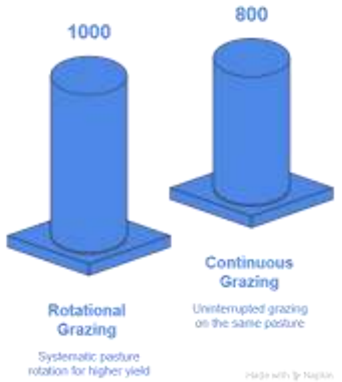

Figure 1: Forage Dry Matter Yield Comparison Between Grazing Systems

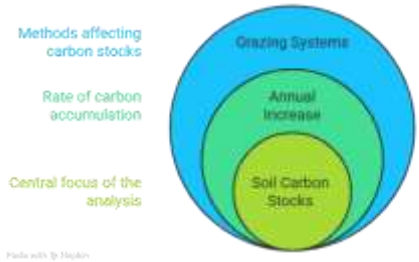

Figure 2: Soil Carbon Stocks at 0–30 cm Depth

5.4 Statistics Interpretation and Analysis

The statistical data verified that the reported variability in forage yield, crude protein concentration, and soil carbon stocks of the rotational and continual grazing system were perceived to be statistically significant ($p < 0.05$). Specifically:

- Both rotational grazing and rotational grazing systems had higher yield and crude protein content in forage ($p < 0.05$), which showed the effectiveness of rotational grazing in increasing forage production and protein quality.(11)
- The level of soil carbon sequestration was greatly enhanced in rotational grazing system ($p < 0.05$), and thus it is crucial that rotational grazing system can stimulate the health of soil and increase the capacity of carbon storage in grass-fed beef systems.

6. Conclusion

6.1 What are the main Rotational Grazing Advantages of Grass-Fed Beef Systems?

This paper has revealed that rotational grazing provides a great payback either on forage productivity and soil health in grass-fed beef. Rotational grazing was highly effective in increasing and enhancing yield of forage dry matter by (12.4%) and crude protein by (9.7%) in comparison to continuous grazing thus feeding livestock with high quality feed and increased availability of forages. Such increase in the quality of forage can have a direct beneficial effect on the grow and overall efficiency of beef production in pasture-based systems.

In addition, soil carbon storage was higher by a significant measure under rotational grazing and soil carbon stocks accumulated at 0.56 t/ ha/year in comparison with constant grazing regime. The conclusion of this finding implies that rotational grazing does not only contributes to pasture productivity but it has the potential of affording climate change mitigation by enhancing storage of more carbon to the soil. The increase in the organic matter of the soil and the activity of soil microorganisms under the rotational grazing lead to the overall pasture ecosystem health and sustainability. Such advantages make strong arguments in support of the use of rotational grazing as the climate-smart innovation that helps increase the environmental sustainability and economic prosperity of grass-fed beef farms.

6.2 Implications to Long-term Sustainability and Productivity

Rotational grazing is environmentally sound in the long-term since it incorporates the need to show balance between environmental welfare and animal productivity. Rotational grazing avoids overgrazing due to pasture regeneration and rest, which in turn helps to keep soil fertile resulting in more resilient grazing systems. Rotational grazing may eventually result in higher biomass of forage and thus offer more grazing material to the cattle and this may even eliminate the necessity of supplementary feed as well as offer better feed conversion rates.

Also, the rise in soil carbon storage in rotational grazing also has significant implications on climate change mitigation. Agricultural activities are leading causes of greenhouse gases hence the approach of switching to grazing systems that help to trap carbon in the soil is a good way to improve the carbon production of the livestock industry. Rotational grazing is also a condition that helps the soil to improve its structure, retain more water and also develop more biodiversity which further adds to the sustainability and productivity of the land in the long term.

Based on the positive outcomes of the present research, it could be noted that rotational grazing is one of the primary mechanisms of supporting sustainable and productive grass-fed beef systems, especially in the areas at risk of climate variability and natural resource losses.

6.3 Policy and Practice Suggestions to Wider Use in the Livestock Agriculture

With the aim to increase the adoption of rotational grazing in livestock agriculture more widely, a few recommendations on policy and practices will be put forward:

- **Farmers incentive and Support:** The governments and other agricultural bodies should consider giving some financial incentive or subsidies to the farmers who move to rotational grazing. This may involve sharing the fencing cost, water infrastructure and land management strategies that favour rotational grazing systems.
- **Learning and Extension Services**: Education programs and extension services should be offered to train farmers about the advantages of rotational grazing and optimal strategies to adapt it. Knowledge and tools to control pastureland and assessing the health of the soil as well as general consideration of seasonal grazing schedule should be provided to farmers.
- **Research and Development**: The long-term effects of rotational grazing in soil carbon sequestration and mitigation of climate change should be quantified in terms of all climatological conditions and grazing systems through more research. One should evaluate the potentiality of rotational grazing being used in different soil types, grass types and climate to better position its use.
- **Incorporation of Sustainable Grazing Techniques in National Agricultural Policies:** Sustainable grazing techniques should be made part of the national and regional agricultural policies by the policymakers. This may serve to facilitate on a large scale the initiation of climate-smart agricultural processes and much more motivate farmers to use methods that will lead to increased yield as well as better environmental performance.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

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