



Contribution of Selected Herbivores' Dung on the Soil Organic Carbon and Nitrogen in Serengeti National Park, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study was done to determine the contribution of selected herbivores' dung in the grazed ecosystem of Serengeti National Park, Tanzania. To achieve this Soil Organic Carbon and Nitrogen were determined in four distinct textural soils in three sites, namely Serena with clay and clay loam, Barafu with sandy loam, sandy clay loam, and Seronera with sand clay loam. Thereafter the decomposition of dung pats in terms of weight change and percentage of nutrients in dung pats of four herbivore species (buffalo, zebra, wildebeest and elephant) incorporated into the soil beneath the dung pats were determined. Fresh dung, soil cores beneath the dung pats and control soils 1 m adjacent to the pats were taken for laboratory analysis. Dung pats and soil samples were analysed for initial percentage OC, N, pH and soil particle size distribution. Weight changes of the dung pats after each three weeks period were monitored. Similarly, monthly rainfalls during the study period were recorded from the rain gauges near the sites. The results indicate that the surface soil (0-15 cm depth) pH ranged from 6.0 - 7.5, 7.4 -7.9 and 6.1 - 7.4 for Serena, Barafu and Seronera respectively. While the soil texture was highly significantly different in percentage OC added after 18 weeks, the treatments and texture were both not significant for percentage N increased in the soil after 18 weeks. There was a difference of 1% between the ruminants and non-ruminants in

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percentage N increase although they were fluctuating over time due to weather changes. The C/N ratios of the controls and the treatments were on average 11 and 15 respectively, being highly significantly different and indicating that, treatments had a potential contribution to the soil OC and N in the ecosystem.

Keywords: Serengeti; herbivores; dung pats; soils; nutrients.

1. INTRODUCTION

The Serengeti ecosystem is comprised of approximately 25,000 km², located northwest of Tanzania, but spanning the border into southern Kenya. It is one of the last remaining large natural grassland ecosystems in the world and home to about 3 million herds of over 25 species of herbivores. The grassland also homes a famous wildlife migration that is dominated by wildebeest herds traversing from south to north of the ecosystem and vice versa [1]. As the herbivores herds move, they fertilize their path through dropping up to approximately 420 tons of dung daily [2]. These animal droppings contribute, among other things, to the maintenance of the resilience and productivity of the grassland ecosystems through nutrient cycling McNaughton [2], cited by Frank [3].

Herbivores feed on plants that contain various levels of N and C in terms of quantities and qualities [4]. Normally, digestion of plant materials through the gastro-intestinal track is never complete, thus herbivores produce excreta that contain large quantities of unreleased minerals in the form of dung and urine [5]. Therefore, herbivore organic waste in the soil can be taken as one among important factors contributing to nutrients availability in grasslands that carry large numbers of grazing animals [6]. However, the incorporation of the nutrients to the soil differs from one soil textural class to another [7].

Carbon and nitrogen are some of the most important elements which are essential for the growth and maintenance of plants [8]. Ungulate digestive wastes are among the important driving mechanisms for grazers in stimulating N availability and plant nutrient uptake at the plant community level [5]. It has been documented that, grazers' feeding and defecating behaviour have an important role to play in ecosystem processes, since the animals act as a nutrient medium by transferring major quantities of nutrients from tall grass savannah under-stories to adjacent open grasslands due to their mobility [9]. The ingested N is poorly utilised by herbivores, with only small proportions of intake being incorporated into body tissues or products

which is due to the excretion pathway of nitrogen. Much is excreted into dung and urine deposited in localised distinct areas in grazing and browsing pastures. The amounts of N excreted depend very much on the N inputs to the system and the content in the diet; whereas excretion in dung remains relatively constant [10]. Consequently, the distribution between dung and urine has implications for turnover and losses from the soil such that, more N is lost when excretion outputs are diverted to the urinary pathway.

Grass eating ruminants digest their feed more efficiently with an increasing proportion of fibre in their diets than non-ruminants do [11]. This is due to the fact that, the ruminants chew their cud while the non-ruminants do not. This can lead to large particle sized excreta by the non-ruminants of which cannot easily undergo the microbial processes after being deposited on the soil surface compared to ruminant products [12]. In addition, large non-ruminants herbivores especially elephants can utilise lower quality diets due to their non-selective feeding habit [11].

Texture of soils determines the ability of soils to store nutrients, absorb and store water needed by plants. Sandy soils are known to have poor ability of storing nutrients and water retention. Ross et al. [13] revealed that, moderate to heavy herbivores grazing on sandy loam and loamy sand soils in Serengeti National Park typically increase the level of nutrients and lead to storage of carbon in the soil. This indicates that, their presence contributes to the soil nutrients, but the amount of nutrients contributed by their deposits on the soil is not clearly known. The soil texture also affects litter decomposition by altering soil water availability, pore size distribution, nutrient availability, and surface area. Soil texture as abiotic factor is important factors that influence distribution of minerals organic matter retention, microbial biomass and other soil properties [14]. Accordingly, pore space distribution and the small soil pores has a major impact on the abundance of bacteria and fungi, and the physico-chemical properties of the soils such as soil moisture (rainfall) together with pH of the soil might be responsible for higher rates of mineralization [15,16].

Few studies have been conducted on the effect of dung on the soil nutrients; most of them mainly focusing on agricultural ecosystems and pasture land for livestock. McRitchie and McSherry (2009) pointed out the effect of herbivores on grassland ecosystems as far as nitrogen fixation, wildlife and livestock grazer effects on soil carbon and fire are concerned. However, there is inadequate information to indicate the contribution of animal excreta i.e. dung and urine to the soil nutrients. Recent studies have shown that, grazing by wildlife has strong influence on maintaining the fertility, and thus on potential productivity of the areas in which they are conserved (David and McNaughton, 2006). These results suggest that conserving wildlife implies conserving the ecosystem that contains them.

The mechanisms for this are not well known, it seems that grazing ungulates deposit their dung in areas where it will be quickly recycled by localised dung beetles, earthworms and bacteria populations which later release their nutrients ready to be consumed by plants in the soil. Generally, the findings indicate that N returned to the soil in dung and urine is absolutely important through its long-term effect on N stocks in the soil and its short-term effect on small areas of the grassland. It has further been reported that the rate at which dung breaks down in the field is largely dependent on season and weather (i.e. rain and drought) [17, 18, 19, 20], so the seasonal and weather measurements can be difficult to compare quantitatively.

Therefore, there was a need to examine the contribution of herbivorous species' dung to soil nutrients, specifically to OC and N in the grazed grassland ecosystem in Serengeti National Park. The current study is specifically aimed at determining the percentage of OC and N in herbivores dung on the soil surface and that incorporated into the soil, assess the contribution of different herbivore species' dung to the soil carbon and nitrogen in Serengeti National Park and examine dung pat decomposition rate by monitoring weight changes. These herbivores are zebra (*Equus burchelli*), African elephant (*Loxodonta africana*), wildebeest (*Connochaetes taurinus*) and buffalo (*Syncerus caffer*). The study is also aimed at determining the rate of dung decomposition in function of soil types (on the basis of texture) in varying rainfall. The information generated can contribute to, among others, knowledge related to the effect of large herbivorous species on ecosystem, specifically

their dung deposits on the soil OC and N and their variation in different seasons of the year. The study is envisaged to generate crucial knowledge and exposure that is needed by ecologists in order to increase awareness of different stakeholders on issues related to conservation of the Serengeti National Park ecosystem and other natural ecosystems.

2. MATERIALS AND METHODS

2.1 The Study Area

2.1.1 Location

Serengeti National Park (1°30'-3°20'S, 34°00'-35°15'E) is a World Heritage Site located in Northern Tanzania, 200 kilometres (km) northwest of Arusha. The park covers 14,763 km² (5,700 square miles) of grassland plains and savannah as well as riverside forest and woodlands. The park bordered to the north by the Tanzania- Kenyan border, where it connects with the Maasai Mara National Reserve. To the southeast of the park is the Ngorongoro Conservation Area, to the southwest lies Maswa Game Reserve, and to the western borders are Ikorongo and Grumeti Game Reserves, while to the northeast lies Loliondo Game Control Area [21].

2.1.2 Climate

Serengeti National Park mean annual precipitation varies from 1150 mm in the northwest and 950 mm in the western corridor to less than 500 mm in the leese of the Ngorongoro Highlands in the east. It falls mainly between October and May with peaks in November (short rains) and from March to April (long rains). The annual drying up in May triggers wildlife migration to the north; the rains which start in October trigger the returning migration south. Generally the climate is warm and dry, coolest from June to October, with a mean annual temperature of 20.8 °C, which is often less than the diurnal variation [1]. The study was conducted during the short rains; so, the monthly rainfalls were useful in accounting for seasonal changes in the sites.

2.1.3 Vegetation

The Serengeti National Park vegetation is one of Africa's most complex and least disturbed ecosystems, alternating between dusty drought to green winter and spring lushness. Its centre is

savannah with scattered acacia trees; in the south there are wide open short grass plains; in the west and north there are thorn wood grasslands, along the rivers there are gallery forest and in the hilly western corridor extensive woods and black clay pans can be found [1]. Following the randomly chosen sites, the dung pat experiment was allocated into two vegetation types including short grass plains (Barafu-which was in west Serengeti) and wooded grassland (Seronea and Serena).

2.1.4 Soils

Soils of Serengeti have been distinguished into three distinct groups namely ridge soils, ridge slope soils and valley bottomed soils [22]. The ridge soils have shallow to moderate depth with very dark grey brown sandy soils also pale brown to deep brown sand soils. The ridge slope soils occur on the slopes between ridges and valley bottoms. They are clayey and usually covered with grass vegetation only. Some of these areas consist of loamy sand, whereas the topsoil of the termite mounds is sandy clay [22]. The valley bottom soils mainly consist of sandy soils with bare patches and highly compacted soils. In addition, Jager [22] proved that, there is a clear relationship between soils, vegetation and topography in underlying landscape and this makes herbivores to be selective in foraging areas depending on the availability of resources over time.

2.1.5 Site selection

Three sites were selected along a 100 km East-West transect in the Serengeti National Park, Tanzania. In each site, soil samples were collected for laboratory analysis. The sites were randomly chosen basing on soil types (on the basis of different texture), vegetation types and accessibility due to the resources available. This was done by selecting representative sites of which were previously used by researchers for animal ex-closer experiments and they are almost scattered all over Serengeti National Park. During the preliminary study, Global Positioning System (GPS) Garmin 32 eTrex vista was used to locate the selected points of the study area and their altitudes using UTM coordinate system, Arc 1960 Map Datum and True North reference. These were used to trace back the sites during the dung sample collection, dung weighing and soil sampling [23]. In addition, only the un-burnt areas were chosen following the history of the area to avoid conflicting results.

2.2 Methods

2.2.1 Collection of fresh dung

Fresh dung pats were collected on the soil surface around the study sites soon after the species had deposited them on the soil surface or a few hours later. This was done with the aid of a vehicle by following a group of species seen close/around the selected sites. To have a uniform effort on the dung pat experiment, only the adults' fresh dung was collected. A portion of the collected fresh dung samples (approximately 20g) was taken, stored in plastic bags and labelled using a permanent marker pen, then frozen to stop further microbial activities until it was sent to the laboratory for initial organic carbon and nitrogen analysis.

2.2.2 Experimental design

The experiment was established during the short rains of 2011/2012. Within the three sites selected, four treatments with three replicates (to increase the precision) were randomly placed on each site, which were allocated within 100 x 100 m² plots on each site. The treatments were buffalo, zebra, wildebeest and elephant dung pats together with a control 1 m apart from each treatment. The collected dung samples were placed on a confined wire mesh, weighed and used to create artificial dung pats on a cleared soil on the selected sites. Around each field site, dung samples were used artificially to create dung-pats (diameter of 30 cm and 2 kg initial wet weight) on 3 plots as replicates. The dung pats for each species were placed on a wire-mesh (3 cm opens) to allow easy dung-pat weighing, non-destructive sampling of soil under the dung pats and ensuring a free movement of fauna (earthworms and dung-beetles) between the soil and the dung pats [24].

2.2.3 Measuring of dung pats weight change

By using a weighing machine, dung pat decomposition in terms of wet weight (kg) as the initial weight and dry weight (kg) subsequent for the first three weeks was determined. Wire mesh was occasionally and carefully lifted up and placed on a weighing machine to measure the weight of the dung pats after every week. It was possible to do this initially in day 1, week 2 and week 3 only to avoid disturbance of the faunal activities and the dung pats in most sites started to disintegrate thus complicating measurement.

2.2.4 Soil sampling beneath the dung pats

By lifting up the dung pats confined in a wire mesh, the soils beneath the dung pats (15 cm deep and 3 cm diameter) and further four samples were taken 1 m adjacent from each of the dung pats as controls were sampled after every six weeks. The controls were the plots with no treatments which were used to monitor changes of nutrient status over time in the plots with treatments. These were stored in plastic bags and frozen to stop further microbial activities until they reached the laboratory for analysis processes [24,25]. The sampling process was repeated initially starting from day 1 and subsequently on days 42..., 126 after application on the selected four sites' plots each with three replicates for the four herbivore species selected. This was done by extending time for samples collection during the dry season starting from the short rains in November 2011 to March 2012.

To determine the percentage of OC and N of the dung pats applied on the soil surface and that incorporated after 18 weeks, the initial OC and N of the dung pats used for the experiment, were used to calculate the percentage organic carbon and nitrogen added in the soil after 18 weeks during the short rains from November 2011 to March 2012. This was done by comparing the initial percentage of OC and N with the recorded percentage OC and N increased after 18 weeks in the soil beneath the dung pats.

To assess the contribution of different herbivore species' dung pats on the soil carbon and nitrogen in different soil textures and between ruminants and non-ruminants, the soil cores 15 cm depth and 3 cm diameter beneath the dung pats were sampled and samples were taken into the laboratory for OC, N analysis and soil texture determination. Ruminants (buffalo and wildebeest) and non-ruminants (elephant and zebra) dung pats contribution were compared by looking at the means difference in percentage OC and N added to the soil for the period of five months. Monthly rainfall data for the sites obtained from the Serengeti Ecological department which were monthly recorded from the nearest rain gauges near the sites.

2.3 Soil Analysis

The samples obtained were air-dried and grinded to pass through a 2 mm sieve for OC and N analyses. Organic carbon was determined by the

Black and Walkley chromic acid wet oxidation method [26]. The procedures involved reduction of potassium dichromate by OC compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulphate of the potassium dichromate [27]. Total Nitrogen was determined by using micro-Kjeldahl digestion-distillation method [28]. The soil was digested in concentrated sulphuric acid (H_2SO_4) with a catalyst mixture to raise the boiling temperature and to promote the conversion from organic-N to ammonium-N. Ammonium-N from the digest was obtained by steam distillation, using excess NaOH to raise the pH. The distillate was collected in saturated Borate acid (H_3BO_3); and then titrated with dilute H_2SO_4 to pH 5.0. The C and N values obtained were the used to calculate the C/N ratio.

Soil texture was determined by hydrometer method as described by the National Soil Service [29] to estimate percentage of 0.05-2.0mm fraction (sand), 0.002-0.05 mm fraction (silt), and <0.002mm fraction (clay) and the textural classes were thereby determined by the USDA soil textural triangle [30]. Soil pH was measured by means of a digital pH meter (Metrohm E500) in a suspension of 10.0 g soil and 25.0 ml 0.01 mol L^{-1} $CaCl_2$ solution [23].

2.4 Statistical Analysis

Analysis of variance was done by using R i386 2.15.0 2012 software to determine the effects of treatments on soil parameters, OC and N in 18 weeks. These were used to determine the variation between treatments effect on the soil nutrients and in different soil textures. Statistical significances were determined and the means contribution of species dung pats were compared using a t-test two sample means contribution per individual species dung pat over time (weeks) in the three study sites by using Microsoft Excel software.

3. RESULTS

3.1 Physico-Chemical Properties of the Soils for the Experiment

3.1.1 Soil texture

Four main soil textural classes were identified in the sites namely; clay, clay loam, sandy loam and sand clay loam soil on which it was possible to set the dung pats experiment. The textures of the study sites are shown in Table 1.

Table 1. Soil textural classes of the study sites

Sites/Replicates	Particle size distribution			Textural class
	% Clay	% Silt	% Sand	
S1R1	55.8	19.3	25	Clay
S1R3	35.4	21.6	43	Clay Loam
S1R3	33.8	23.3	43	Clay Loam
S1R2	31.8	26.3	3.3	Clay Loam
S2R1	25.4	19.6	55	Sand Clay Loam
S2R2	19.8	19.3	61	Sandy loam
S2R3	27.4	17.6	55	Sand Clay Loam
S3R1	21.4	9.6	69	Sand Clay Loam
S3R2	31.8	5.3	63	Sand Clay Loam
S3R3	21.8	9.3	69	Sand Clay Loam

S= Site, S₁= Serena, S₂= Barafu, S₃ = Seronera and R₁ = Replicate one R₂=Replicate two, R₃ =Replicate three

3.1.2 Soil pH change and monthly rainfall of the study sites

Generally, the pH of the soil in the study sites ranged from 6.02 to 7.9 (Table 2). In site one, the soil pH ranged from 6.02 to 7.5 while in site two from 7.38 to 7.9, and in site three from 6.05 to 7.38. In all the three sites, the soil pH was tending to increase over time after application of the dung pats on the soil surface and after 12 weeks the pH started to fall. But again, the pH showed to increase again on the 18th week as shown in Table 2.

The highest rainfall recorded in Serena was 283 mm in November while the lowest was 10 mm in January 2012 (12th week after dung pat experiment was set). This month had the least rainfall recorded in all study sites. In November the three sites had a moderate monthly rainfall of 158, 153, and 119 in Serena, Barafu and Seronera respectively. But again, the rains started to increase in March as shown in Table 3.

3.1.3 Dung nutrient contents applied on the soil surface by the herbivores and the percentage incorporated into the soil

The results show that site one (Serena), with high clay soil, had the highest percent of N incorporated in the soil compared to the other sites for all treatments (dung pats); buffalo, zebra, wildebeest and elephant 40%, 39%, 39% and 19.2 respectively followed by that in site two (Barafu) and site three (Seronera) as shown in Table 4. For the case of OC incorporated in the soil over the period of 18 weeks was quite low. However, it was recorded high in Seronera followed by that in Barafu and Serena (Table 4). Buffalo and elephant dung pats collected in Barafu recorded to have the highest percent of OC (i.e. 61.9 % and 50.2 % respectively), but with lower percentage incorporated in the soil after 18 weeks was smaller compared to Buffalo and Elephant dung pats in other sites.

Table 2. Average soil pH change over time beneath the dung pats

Study site	Control's Soil pH (H ₂ O)	After soil weeks	After 12 weeks	Soil pH after 18 weeks
Serena- Buffalo	6.9	7.1	7.06	7.3
Serena -Zebra	6.08	6.2	6.02	6.3
Serena-Wildebeest	6.8	7.01	7.21	7.5
Serena-Elephant	7.01	7.2	7.1	7.4
Barafu- Buffalo	7.45	7.39	7.38	7.5
Barafu -Zebra	7.42	7.32	7.7	7.4
Barafu -Wildbeest	7.71	7.9	7.6	7.8
Barafu -Elephant	7.5	7.6	7.5	7.6
Seronera- Buffalo	7.16	7.38	7.24	7.2
Seronera -Zebra	7.17	7.19	7.09	7.2
Seronera -Wildbeest	6.72	6.8	6.5	6.1
Seronera -Elephant	6.51	6.6	6.07	6.3

Table 3. Monthly rainfall (mm) from November 2011-March 2012

Months	Site 1-Serena	Site 2-Barafu	Site 3-Seronera
November	283	75	116
December	158	153	119
January	37	30	10
February	70	49	29
March	50	38	82

3.1.4 Contribution of different herbivore species' dung pats to the soil organic carbon and nitrogen

The Percentage increase in soil organic carbon in Serena after 18 weeks was on average 1.8, 1.6, 1.7 and 2 times the initial amount of organic carbon beneath the buffalo, zebra, wildebeest, elephant, dung pats respectively. In Barafu, the percentage increase in soil organic carbon after 18 weeks was on average 1.4, 1.7, 2 and 2 times compared to the initial amount of organic carbon beneath the buffalo, zebra, wildebeest, elephant, dung pats respectively. Also, 6, 5, 6, and 6 times compared to the initial amount of organic carbon beneath the buffalo, zebra, wildebeest, elephant, dung pats respectively in Seronera as shown in Table 5.

Table 6 shows the level of significance in contribution of the treatments on the total organic carbon over time in weeks over the three study sites. Zebra and wildebeest dung pats showed to have a significant increase of percentage N at $\alpha = 0.05$, $df = 2$, ($t_{0.05, 2} = 2.9$), $P = 0.01$ soon after six weeks. But, in buffalo there was no significant increase up to the 18th week ($P = 0.07$). While elephant dung pats were highly significant $\alpha = 0.01$ on the 18th week. The significant differences of percentage OC was fluctuating over time as shown in Table 6.

The box plots in Fig. 2 and 3 show the mean difference between the percentage OC controls and the percentage OC added after 18 weeks with respect to sites, treatments, soil textures and the scattered plots for rainfall changes. Serena site which had a higher level of clay soil had a higher level of increase in OC compared to other sites with, sand clay loam and sandy loam soils over the period of study during the short rains.

There was no significant difference between the treatments and soil textures on percentage OC contribution over the three study sites $P = 0.18$ and 0.27 for soils and treatments respectively (Table 7) but, for treatment effect, comparing the

controls adjacent to the treatments, the box plots show a clear difference between the controls and the added OC after 18 weeks as shown in Fig 4. But again, the amount of percentage OC changes over the monthly rainfall, the percentage OC was ranging from approximately 2% - 4.2% on the average monthly rainfall of 50 mm in November compared to 1 % < OC < 3.5% on the 250 mm in March.

The average Nitrogen added beneath the dung pats after 18 weeks in the three study sites was substantially different as shown in Table 7. Comparing the sites and species, the results show that, the percentage nitrogen added after 18 weeks was 3.1 buffalo, 3.8 zebra, 5.25 wildebeest and 3.0 elephant, times the initial amount in site one (Serena). In Barafu, 2.8 buffalo, 3 zebra, 2.9 wildebeest, 3.0 elephant times the initial amount and 2.4 buffalo, 1.6 zebra, 2.8 wildebeest and 1.6 elephant times the initial amount in Seronera as shown in Table 7.

Based on t-test two sample means all the four treatments showed a significant increase in percentage N after 18 weeks at 5 % significance level, ($t_{0.05, 2} = 2.9$), $P = 0.02$, $P = 0.02$, $P = 0.01$ and $P = 0.009$ for zebra, elephant, wildebeest and buffalo dung pats respectively. The results showed that, buffalo and wildebeest effect were significant after 12 weeks compared to zebra and elephant although they were tending to fluctuate over time as shown in Table 8. There is also a positive trend on Nitrogen increase in the soil beneath the dung pats over time from week six to week 18 as shown in Fig 5. Table 7 summarises the recorded percentage increase in N with the maximum of 0.62 and 0.63 increased by the buffalo and wildebeest dung pats respectively after every six weeks up to 18 weeks. There was no difference in percentage N within the sites although Serena site seemed to have a slighter difference compared to the other sites as shown in Fig. 7 and 9. The box plots in Fig. 10 shows that there is no difference in the percentage N added after 18 weeks.

Table 4. Percentage OC and N incorporated in the soil after 18 weeks in the three sites

Properties	Treatments											
	Site 1-Serena				Site 2-Barafu				Site 3-Seronera			
	B	Z	W	E	B	Z	W	E	B	Z	W	E
Initial dung N (%)	1.05	0.93	1.30	1.72	1.12	0.95	1.5	1.19	1.23	1.77	1.75	1.07
Initial soil N (%)	0.2	0.13	0.12	0.16	0.14	0.14	0.15	0.14	0.22	0.22	0.20	0.23
Last N (%)recorded	0.62	0.5	0.63	0.49	0.40	0.41	0.43	0.37	0.54	0.37	0.56	0.38
(%) N Incorporated after 18 weeks	40	39	39.2	19.2	23.2	28.4	18.6	19.3	26	8.5	20.5	14
Initial dung OC (%)	42.2	47.7	39.67	43.55	61.9	48.17	39.97	50.2	39.17	48.93	41.33	47.23
Initial soil OC (%)	2.71	2.63	2.60	2.5	2.41	2.45	2.64	2.38	0.98	0.96	0.86	0.98
Last recorded soil OC (%)	4.38	4.34	4.66	6.62	3.44	4.38	5.40	5.0	5.97	5.96	5.4	5.95
(%) OC Incorporated after 18 weeks	3.96	3.58	5.19	9.46	1.66	4	6.91	5.22	12.74	10.21	10.98	10.52

Z= Zebra, B= Buffalo, W= wildebeest and E= Elephant

Table 5. P-values for t-test two sample means for percentage OC added in the soil by dung pats after every six weeks

Treatments	Six weeks	12 weeks	18 weeks
Zebra	0.01	0.04	0.03
Elephant	0.16	0.05	0.04
Wildebeest	0.01	0.01	0.02
Buffalo	0.06	0.06	0.07

Table 6. Percentage increase in soil OC after every six weeks beneath the dung pats

Sites	Controls				After 6 weeks				After 12 weeks				After 18 weeks			
	B	Z	W	E	B	Z	W	E	B	Z	W	E	B	Z	W	E
1	2.71	2.63	2.60	2.5	3.11	2.99	2.79	4.53	3.71	3.98	3.14	6.16	5	4.34	4.66	6.62
2	2.41	2.45	2.64	2.38	2.62	2.71	3	2.41	2.59	3.13	3.47	3.48	3.44	4.38	5.40	5
3	0.98	0.96	0.89	0.98	1.27	1.43	1.22	1.35	2.27	3.18	2.17	2.82	5.97	4.97	5.96	5.95

Sites: 1= Serena, 2: Barafu, 3: Seronera, Z= Zebra, B= Buffalo, W= Wildebeest and E= Elephant

Table 7. Increase in percentage nitrogen after every six weeks beneath the dung pats

Sites	controls nitrogen				After 6 weeks				After 12 weeks				After 18 weeks			
	B	Z	WB	E	B	Z	WB	E	B	Z	WB	E	B	Z	WB	E
1	0.20	0.13	0.12	0.16	0.26	0.2	0.21	0.25	0.42	0.36	0.45	0.36	0.62	0.5	0.63	0.49
2	0.14	0.14	0.15	0.14	0.19	0.19	0.22	0.21	0.31	0.27	0.31	0.27	0.40	0.41	0.43	0.37
3	0.22	0.22	0.20	0.23	0.25	0.25	0.27	0.22	0.38	0.32	0.36	0.29	0.54	0.37	0.56	0.38

Z= Zebra, B= Buffalo, WB= wildebeest and E= Elephant

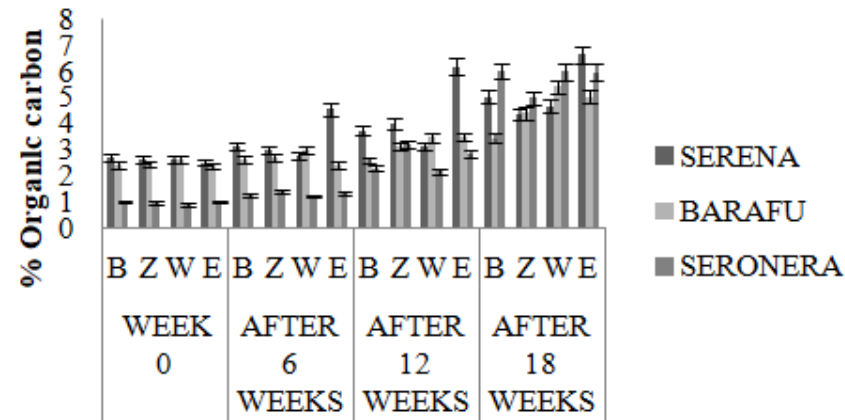


Fig. 1. Relationship between the percentage increase in OC for the individual treatments and the sites over time

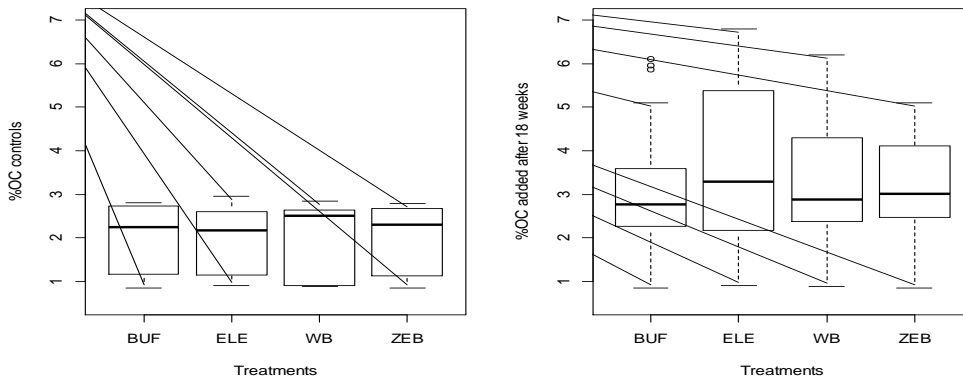


Fig. 2. Mean percentage OC controls (left) and added OC after 18 weeks (right) for the treatments
ZEB= zebra, BUF= buffalo, WB= wildebeest and ELE= Elephant

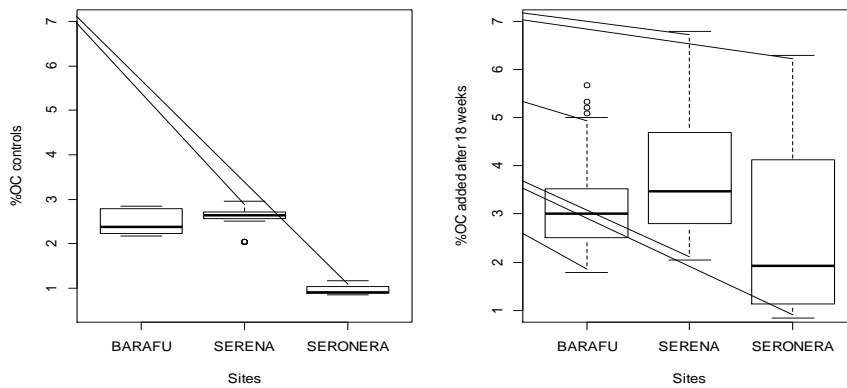


Fig. 3. Means difference between percentages OC controls (left) and OC added to the soil in the study sites after 18 weeks (right)

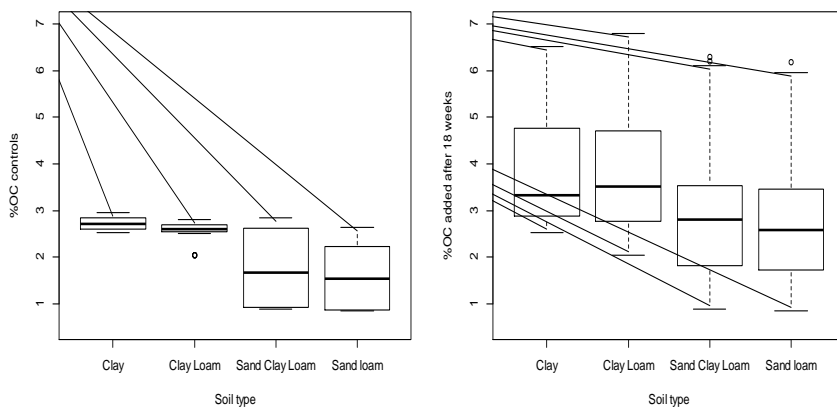


Fig. 4. Means OC controls (left) and OC added in soil by the treatments in different soil types after 18 weeks (right)

Table 8. P-values t-test paired two sample means (controls and added percentage N contributed in the soil by dung pats over the three study sites) after every six weeks

Treatments	Six weeks	12 weeks	18 weeks
Zebra	0.02	0.02	0.02
Elephant	0.12	0.04	0.02
Wildebeest	0.03	0.03	0.01
Buffalo	0.016	0.005	0.009

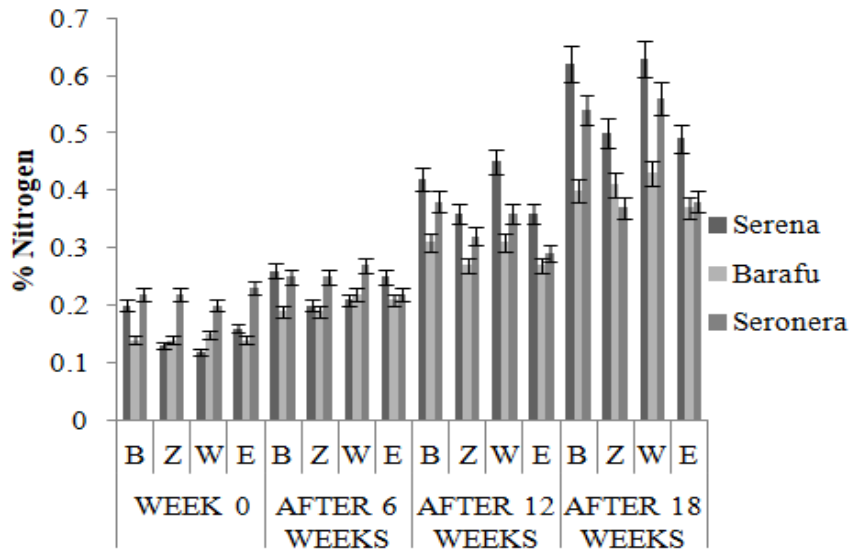


Fig. 5. Relationship between the percentage increase in N for the individual treatments and the sites with respect to the controls

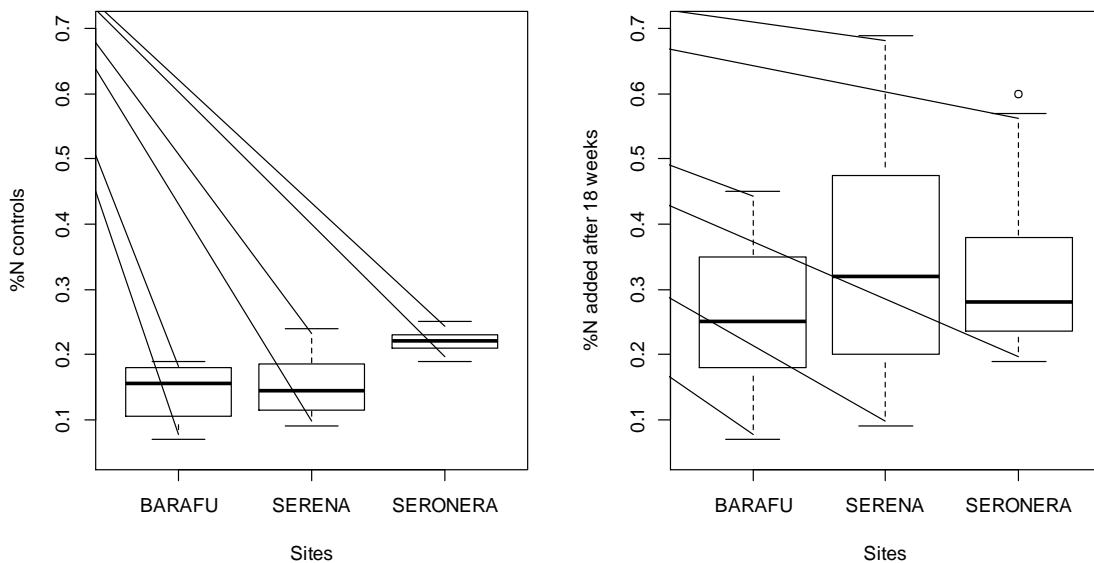


Fig. 6. The means percentage N controls (left) and added N (right) in the soil after 18 weeks in the study sites

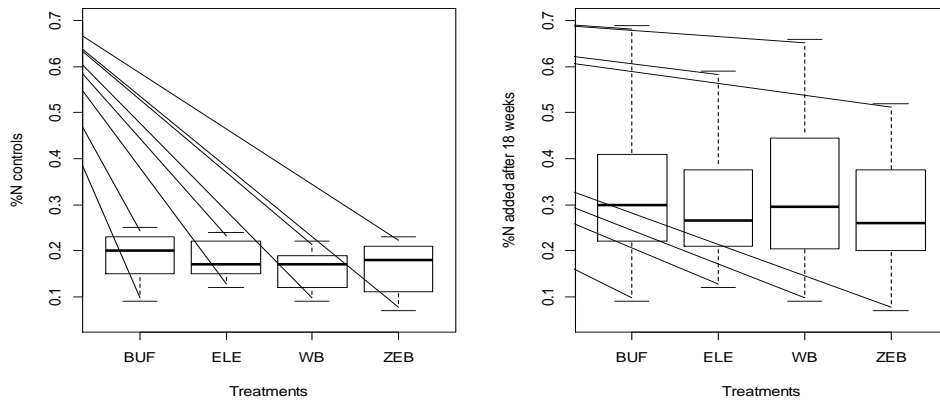


Fig. 7. The means percentage N controls (left) and added N after 18 weeks (right) by the treatments (species dung pats)

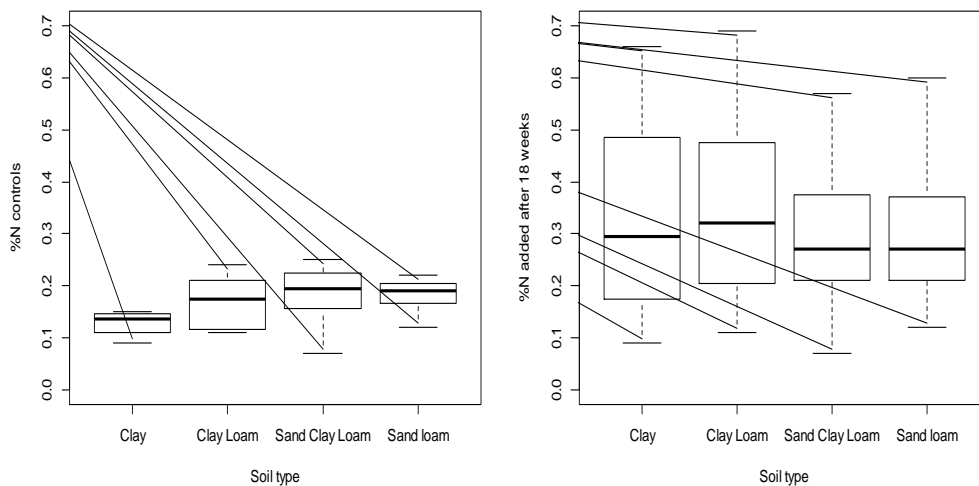


Fig. 8. The means percentage N controls (left) and added N to different soil types after 18 weeks (right)

Though there is a difference between the controls percentage N and the percentage added N after 18 weeks. There is a higher increase in percentage N in clay soil compared to the sand soils as shown in Fig 10 having a significant difference of $P= 0.007$ (Table 10). The percentage nitrogen was higher at 50 mm rainfall (0.25 to 0.5% N) in November compared to 250 mm rainfall (<0.01 to <0.25% N) in March as shown in Fig 10.

3.1.5 Ruminants and non-ruminants' OC and N contribution to the soil

Elephant and zebra dung pats had 0.3 % contributions which was lower than those of buffalo and wildebeest (Fig. 7). The percentage OC contribution was only higher in elephant dung

pat greater than 3% on average compared to other species as shown in Fig 3. Table 8 and 10 show the P values for the treatments (dung pats) percentage contribution in the soil OC and N over time in weeks being highly significant within the species dung pats over time. But, there was no significant difference between the two groups in percentage OC contributed after 18 weeks (P values were 0.03 zebra, 0.04 elephant (non-ruminants) and 0.02 wildebeest and 0.07 buffalo (ruminants)). The percentage N added after 18 weeks were also significant difference between the two groups as $P= 0.02$ for both zebra and elephant (non-ruminants) and 0.01 and 0.009 ($\alpha= 0.01$) for buffalo and wildebeest (ruminants) respectively which had a difference of 1% using a t-test two sample means (Table 9).

3.1.6 ANOVA tables for the effect of treatments on the soil organic carbon and nitrogen in the sites

Table 11 and 10 show the results of a two way analysis of variance between two factors, treatments and soil texture probability levels for N and OC percentage as a response increased over the 18 weeks.

The four treatments used were buffalo, zebra, wildebeest and elephant dung pats. The ratio of the treatment means square to residual means square follow the F-distribution. The calculated F = 1.3, tabulated $F_{0.05, 3, 136} = 2.68$ and $P= 0.27$ so, meaning that contribution of the treatments on the soil nitrogen were equal. The same effect was seen on the variation on the texture (soil type) showing that there is no significant difference in nitrogen contribution by the treatments on the soil nitrogen, as the calculated $F= 1.67$, tabulated $F_{0.05, 3, 136} = 2.68$ and $P=0.18$ as shown in Table 10, suggesting that contributions of percentage N were equal in different soil textures.

The same case was applied in determining the effect of the four treatments used buffalo, zebra, wildebeest and elephant dung pats on the soil OC. The ratio of the treatments means square to residual means square also follow the F-distribution. The tabulated $F_{0.05, 3, 137} = 2.68$, F calculated =1.5, $P= 0.19$ so, there was no enough evidence to reject the null hypothesis that the means for the treatments contribution on the soil OC were equal. For the case of soil texture, the variation was highly significant in OC contributed

by the treatments on the soil as the F calculated = 4.2 was greater than the F tabulated at $F_{0.01, 3, 137} = 1.81$, $P= 0.007$ and hence having enough evidence to reject the null hypothesis that the means contribution of percentage OC were equal in different soil textures.

3.2 Carbon to Nitrogen Ratio

The C-to-N ratio of the controls and the species dung pats (treatments) after 18 weeks were substantially different as shown in Table 11. The box plots show that the C-to-N ratio for the treatments were slightly higher, i.e. 16 compared with 12 (on average) for the controls species dung pats (Fig. 09).

The C-N ratio showed that the difference between the controls C-N ratio and the added C-N ratio after 18 weeks were highly significant as the F tabulated $F_{0.01, 35, 108} = 1.845$, F calculated = 2, $P= 0.00331$ as shown in Table 11.

3.2.1 Dung pat decomposition by monitoring weight changes

To examine dung pat decomposition by monitoring weight changes, the dung pats were weighed (kg) for the first three weeks after application on the study sites as shown in Table 12.

Initially, dung pat weight for the four species were 2kg for all the dung pats in all the three sites and the average changes were recorded as shown in Table 12.

Table 9. ANOVA table for percentage nitrogen increased in the soils by treatments

SoV	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Texture	3	0.0912	0.03039	1.670	0.18
Treatments	3	0.0721	0.02403	1.321	0.27
Residuals	136	2.4934	0.01820		

Table 10. ANOVA table for percentage OC increased in the soils by treatments

SoV	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Texture	3	26.72	8.907	4.2	0.007
Treatments	3	10.05	3.349	1.579	0.19
Residuals	137	290.55	2.121		

Table 11. ANOVA table C-N ratio controls and carbon nitrogen ratio added after 18 weeks

SoV	Df	Sum Sq	Mean square	F value	Pr(>F)
Carbon-nitrogen ratio controls	35	1929	55.12	2.013	0.00331
Residuals	108	2958	27.39		

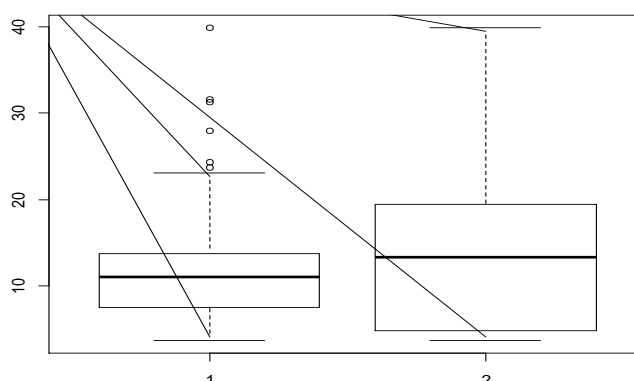


Fig. 9. Mean difference between the C-to-N ratio for the controls and treatments over time for the period of the experiment

1= Controls and 2=Treatments C-N ratios. Boxes indicate the inter-quartile range, the middle bar represents the median, and the 'whiskers' show the range of the data

Table 12. Average weight change of dung pats applied on the soil surface for experiment

Week	SERENA				BARAFU				SERONERA			
	Z	B	WB	E	Z	B	WB	E	Z	B	WB	E
1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2	1.5	1.5	1.5	1.6	1.3	1.1	1.3	1.5	1.5	1.3	1.4	1.5
3	1.1	1.1	1.2	1.2	0.9	0.8	0.9	1.2	1.0	1.4	1.0	1.1

Z=Zebra, B=Buffalo, WB= Wildebeest; E=Elephant

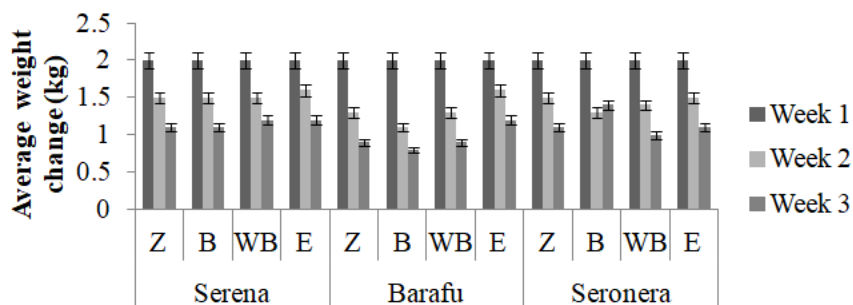


Fig. 10. Relationship between the dung pats weight (kg) change of the individual species in the study sites in three weeks after application

Z=Zebra, B=Buffalo, WB= Wildebeest; E=Elephant (Treatments)

For site one, after one week the decrease in weight was a bit slower starting with elephant; followed by wildebeest, zebra and buffalo. For the third week buffalo dung pat was faster in weight decrease compared to the other species. Fig. 11 indicates that site two had the fastest decrease in dung pats weight for the first three weeks compared to other sites.

The box plots show that there is no significant change in weight between the treatments. The plotting of the mean weight change for the recorded time per species in the study sites had a trend which indicates that elephant and wildebeest dung pats had a slower mean change in weight of 1.5 on average while buffalo and zebra showed an average fast change in weight in the recorded period of time.

The amount of percentage OC changes over the monthly rainfall is shown in Fig. 12. The percentage OC was ranging from approximately 2% - 4.2% on the average monthly rainfall of 50 mm in November compared to 1% < OC < 3.5% on the 250 mm in March.

4. DISCUSSION

4.1 Dung Nutrient Contents Applied on the Soil Surface by the Herbivores and the Percentage Incorporated into the Soil

Ward et al. [31] found that over 10 weeks cattle dung pats had lost approximately 60% of their total C and N but the extent to which these nutrients had entered the soil was uncertain. This shows that the low amount of nutrients incorporated into the soil was also caused by the loss of nutrients before they entered the nutrients pool and the lost amounts were greater than the gain i.e. not more than 40% and 12% beneath buffalo dung pats for both N and OC respectively incorporated for the period of 18 weeks. Dickinson and Craig [32] observed that loss of nutrients from dung was not matched by an equivalent gain in the underlying soil. They found that there was considerable downward and lateral movement of nutrients from cow dung due to a general stimulation of root growth. In this study it was found that, this was marked being associated with rainfall and the type of soil in the study sites. For example, the percentage of OC incorporated into the soil was quite low starting with Seronera followed by Barafu and Serena in the recorded period of 18 weeks as appeared in Table 5. This could be due to the monthly rainfall of the sites as Seronera had high mean monthly rainfall compared to Barafu and Serena. MacDiarmid and Watkin [33] measured lateral movement of dung N to 15 cm from the edge of cow dung pats and noted that even if most of the C and N that was lost from the dung had entered the soil, this would represent about only 6% of the total dung nutrients entering each week. The breakdown of dung pats and release of dung nutrients is, however, an extremely variable process. Other workers have reported wide ranging rates of dung breakdown: Dickinson and Craig [32] found a loss of 1% in dry matter from dung pats, Castle and MacDaid (1972) found that dung pats disappeared in about 16 weeks and Holter [34] reported that pats took 50-65 days to disappear in normal summers but in a dry summer only 35% of the dung had disappeared in 62 days. This can also justify the slow nutrient

incorporation into the soil as slower dung pats decomposition can lead to slower nutrients incorporation into the soil. In the case of the current study, in some sites e.g. Serena and Seronera, some species dung completely disappeared within 6 weeks but the elephant dung pats disappeared by less than approximately 50% after the period of 18 weeks (Appendix 1) in all the three sites. The elephant dung pats showed slow decomposition, and at the same time had smaller amounts of N incorporated into the soil due to the nature of the dung pat.

4.1.1 Contribution of different herbivore species' dung to the soil carbon and nitrogen

It was well established that the rate of breakdown and nutrient incorporation into the soil is mainly affected by climatic factors such as rainfall and humidity. It has been pointed out that if the dung remains moist, it is rapidly decomposed; but if it dries out then the decomposition is slow [35,36]. The current study has shown that there is a relationship between monthly rainfall changes as high rainfall easily washes away the nutrients in the soil from one place to another or leached to the depth greater than 15 cm in the soils which lower the stocks of N and OC in the soils. This shows that, although the rain can stimulate the microbes to perform their activity of decomposition of the pats due to the presence of moisture around the dung pats, it can also wash away the nutrients so that they become less available to the plants for uptake [37]. The same phenomenon was observed in this study that, during high rainfall the nutrients concentration was low since it may be washed away by rain water from one place to another or leached to more than 15 cm depth down the soil. Unstable effect was seen in a short term when comparing monthly rainfalls with soil N and OC but, it could have a stable effect when looking on a long term due to the soil nutrient stability over time. This can also be the reason as to why the significant difference was fluctuating over time. This has a general implication that the herbivores contribute to soil nutrients differently in different soil textures. Since Serena had a pure clay and clay loam, it showed to have higher level of increase mean > 3% in OC on average compared to the other sites with sand clay loam and sandy loam soils. Significant difference in percentage OC and N contribution in the soil between treatments for both nutrients exists. The same phenomenon was also observed that, the clay content or

"colloidal" fraction of soils has a pronounced effect on the nutrient holding capacity and water retention. Soils high in clay have a high water retention which can cause tillage delays during wet periods which can be done by the movements of grazers in the pasture land in the grazed ecosystem like Serengeti. Clay soils are not very friable as compared with soils which have a low clay content, namely the silt loams, loamy sands, etc [38].

4.1.2 Ruminants and non-ruminants nutrient contribution to the soil OC and N

Jarvis *et al.* [10] pointed out that the magnitude of returns of plant N to the soil in excreta is a function of animal body mass and of plant characteristics eaten, such as N content and tannin levels. But again, the ingested feeds are poorly utilised by their body, only small proportions of intake being incorporated into their body tissues. Many nutrients are excreted into dung and urine and are deposited in localised, discrete areas in grazing land and browsing pastures. So, generally the amount of nutrients in the excreta depends very much on the N inputs to the system and the content in the diet; whereas excretion in dung remains relatively constant. However, ruminants chew their cad and this facilitates the macro and microorganism to breakdown the dung pats which, for the case of non-ruminants, may take longer time in their dung decomposition [12]. This could be true for the case of N contribution as there was a significant difference between the two groups. For the case of OC, there was no considerable difference in percentage OC incorporation by the

treatments between the ruminant and non-ruminants. Similar observations were reported by Ahmad *et al.* [12] that the more complex the structure the more resistance there is to microbial breakdown which will slow the nutrients incorporation into the soil.

4.1.3 Carbon to nitrogen ratio

The higher N and OC content of the species dung for the dung pats experiment may have resulted from the fact that the herbivores were feeding on different food types together with the nature of the area in terms of the texture of the soil and climatic changes. OC contents also differed and the C-to-N ratio of the controls and the species dung pats (treatments) were substantially different. The C-to-N ratio for the treatments was higher, i.e. 16 compared with 12 (on average) for the controls species dung pats. This can also evidently justify that all the species dung pats had a positive effect on the soil nutrients in a short term period of 18 weeks. Consequently, it has a remarkable contribution to the soil nutrient pool and hence increase plants productivity for the animals feed.

4.1.4 Dung pat decomposition by monitoring weight changes

To examine dung pat decomposition by monitoring weight changes, the dung pats were weighed (kg) for the first three weeks after application on the study sites. It was assumed that there was a remarkable disturbance of the fauna on the dung pats breakdown and decomposition processes [39]. Also, other dung

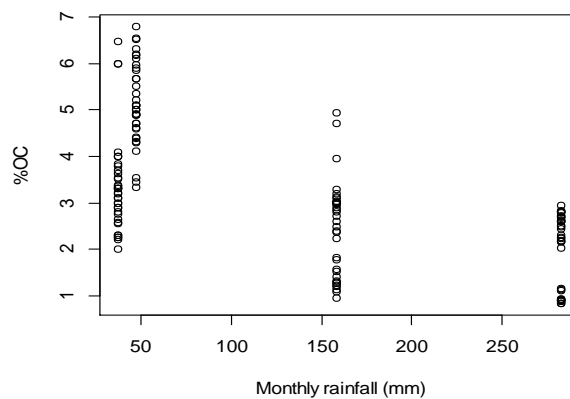


Fig. 11. Relationship between the percentage total OC for the overall experiments and the monthly rainfall over time

pats were almost started to decompose completely as what observed in site one and three i.e. Serena and Seronera. The weight changes were attributed by many factors especially the exposure to the sun, high wind blowing and nature of the area to which the experiment were set.

Lovell and Jarvis [39] noted that by using the cow dung, within a few days after starting the experiment a hard crust had formed over the dung pats and they dried rapidly, losing 50% of their fresh weight in the first week and 85% of their weight by the 6th week.

The breakdown of dung pats and release of dung nutrients is, however, an extremely variable process [24]. This can be due to the nature of the area including high exposure to the sun radiations, nature/shape of the dung pat and wind movement. In site two which is Barafu, the dung pats showed the fast decrease in weight. The elephant dung pats just dried up with slight decrease in weight and became late to disappear up to the last visit after five months. The area (Barafu) had short grasses vegetation type and high wind movements which blew from the lee side west of Serengeti National Park compared to other sites. In other sites including Serena and Seronera the dung pats showed slight decrease in weight over time and the other dung pats started to disappear during the first three weeks. In addition, the monthly rainfall contributed to the breakdown of the dung pats as during the 6th week there was high monthly rainfall which stimulated dung breakdown. The zebra, wildebeest and buffalo dung pats disappeared up to 85% after 8 weeks following the application in Serena and Seronera but the elephant dung disappeared to less than 50 % for the whole period of the experiment in all the three sites. For the other species, example in Serena, the dung pats for zebra, buffalo and wildebeest completely disappeared while grasses were found regrown over Seronera and Serena sites with the exception of Barafu site which had short grasses (Appendix 1. A wide ranging rates of animal dung breakdown: as pointed before, Dickinson and Craig [32] measured 1% loss of dry matter from dung pats, Castle and MacDaid (1972) found that dung pats disappeared in about 16 weeks and Holter [34] reported that pats took 50-65 days to disappear in normal summers but in a dry summer only 35% of the dung disappeared in 62 days.

It was also observed that other factors like fauna presence e.g. the flying beetles which recorded

to reach the dung pat within the average of three seconds after the dung was deposited by the selected herbivores, wind, sun and rainfall influenced the breakdown rate. Dung can be incorporated into the soil through physical breakdown by soil macrofauna (earthworms and dung beetles), rainfall and the invasion of plant roots into the dung material. It is well established that the rate of breakdown is mainly affected by climate; if the dung remains moist it is rapidly decomposed but if it dries out, then the decomposition is slow [35,36].

4.1.5 Soil pH change and monthly rainfall of the study sites

The pH was changing over time but later turned average to its original state and this shows that the dung pats not only improve soil nutrients but also help monitor soil pH to its normal state. In all the four sites the soil pH increased over time after the application of the dung pats on the soil surface and after 12 weeks the pH started to fall. This can be due to, with other factors, monthly rainfall changes that were fluctuating during the period of the dung pat experiment. McNaughton [40] found that soil pH ranged from 5.1 in the north to 8.4 on the Serengeti Plains and the mean annual rainfall and soil pH were negatively correlated in the different soil textures of Serengeti at $P < 0.001$. This was due to that water-holding capacity which varied from 10% in a sandy hilltop soil to 45% in a clayey lowland soil. This also had an effect to N content which ranged from 0.036% in hilltop soil to 0.208% in a clay loam on the Serengeti plains. Similar findings in other soil nutrients were reported by MacDiarmid and Watkin [35] that dung application initially increased phosphate, sulphate, K, Mg and Na especially in a depth of 0-10 cm. With time pH increased too, and by the end of the experiment pH was lower than the initial value. Further findings were documented by Vanlauwe *et al.* [41] that cow dung had an efficiency of minerals by improving the soil properties including soil pH, inorganic N and ameliorated acidity. They concluded that bovine excrete produces temporal soil acidification, in a 90 day-process, then the organic matter buffer capacity returns the pH to the original level.

4.1.6 General overview of nutrients cycling

The amount of nutrients in the soil is contributed by both plant materials and animal excreta (Fig. 12). For the case of our study, to ensure the contribution was mainly by the species dung

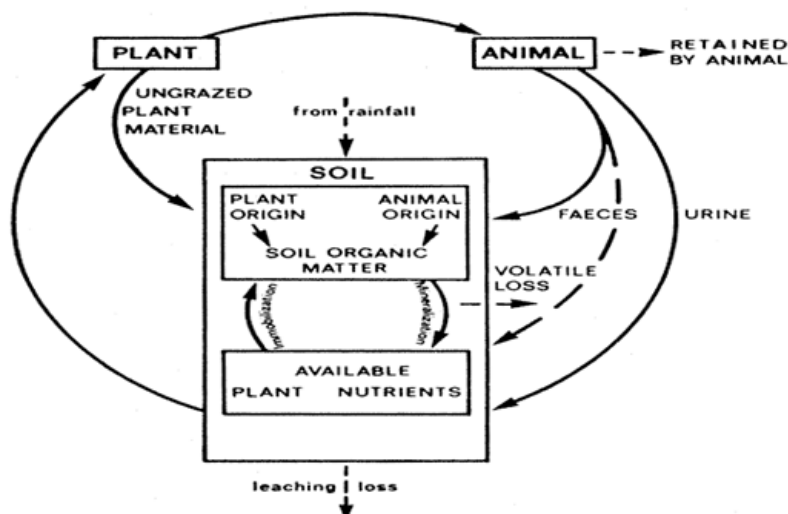


Fig. 12. The generalised cycles of nutrients in grazed pasture [42]

pats, the soil surface was cleared before placing the artificial dung pats created in the study sites with the assumption that the contributed nutrients are only from the dung pats and the controls were used to monitor the changes in the level of nutrients. And it is true that not all the nutrients that enter the animal digestive system are excreted as some are absorbed by their body. A small percent is absorbed by their body and the other amount is excreted and before it enters the soil, some is lost through volatilisation [42]. So, at the end of the day only a little amount is incorporated into the soil over time and only a small percent becomes available for plant uptake that involves complex biochemical processes.

In a grazed pasture, loss of nutrients is inevitable through removal in animal products via leaching and volatilisation [42]. This was also explored during the rainy season that the amount of N and OC tend to be high for the months with lower rainfall of 50 mm in November and December 2011 compared to 250 mm in March with high rainfall that indicates the nutrients have been leached down the soil below 15cm deep. This can explain short term effects of dung pats on the soil nutrient fluctuations compared to the long term effects.

It has been reported that dung deposition has an important effect on the chemical properties of the soil. Although a significant proportion of the dung N is lost by NH₃ volatilisation [35], dung deposition represents a prospective source of available nutrients for plants uptake [43,44]. The question raised in this study was to find out whether the species dung pats of herbivores

have an effect on the soil N and OC and if the species dung pats contribute to soil nutrients differently in different soil textures of Serengeti National Park grazing areas.

Furthermore, for the five months of the experiment during the short rains in Serengeti, soils organic carbon and nitrogen were still higher beneath the dung pats of the selected herbivores than in control experiments. Williams and Haynes [42] also observed that twelve months after dung application soil organic carbon, nitrate and phosphate were still higher under dung pats than in control plots and some residual effects on organic carbon were still evident three years after cattle dung deposition in the grazed pastures.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results in the study indicate that herbivores' deposits have a great and strong contribution to nutrient addition into the soil although their effect vary from one nutrient to another, from one animal to another and from one area to another over time. But, they all have a potential effect to the soils as they increase soil fertility and productivity. These effects can be seen in the short or long term basis in function of both physical and chemical properties of the dung pats, soils, weather condition and nature of the area. This study shades a remarkable variation in dung characteristics for both the treatments and their effect in different soil textures.

The presence of large number of herbivores in an ecosystem can maintain the soil fertility and thus potential productivity of the areas in which they are conserved. In particular, it can be pointed out that the movement of herbivores in different areas of the Serengeti ecosystem is crucial, as they fertilise the area which increases the soil resilience and productivity. The results of the current study show that herbivores contribute to the stock of soil OC and N and weather conditions have an implication on the effect of dung pats on the soil nutrients.

5.2 Recommendations

Although convincing results have been obtained to show the contribution of herbivores in the soil organic carbon and nitrogen within the short period of 18 weeks, more time (over years) is suggested for the coming research to obtain more detailed findings. Furthermore, as herbivores showed a potential contribution on the soil carbon and nitrogen, other nutrients need to be studied to account for the effect of dung pats on the soil nutrients pool. This is to insist that critical measurements for multi-effect on the soils nutrients loss are still need to be highlighted to estimate the exact amount of nutrient loss attributed to each factor such as rainfall, wind, volatilisation and others.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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