Assessing the nutrient status of elephant dung in the Aberdare National Park, Kenya

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Abstract

The African elephant (*Loxodonta africana*) is a keystone species that occupies an integral niche within African ecosystems. Elephants serve as ecosystem engineers due to their wide-ranging ecosystem functions, such as seed dispersal, production of manure compost and as agents of habitat modification. Studies assessing the nutrient status of elephant dung have thus far concentrated on semi-arid grasslands. This study presents the first analysis of the composition of elephant dung obtained from elephants located within a forested Afromontane biome, that of the Aberdare National Park, adding to established literature; and expanding on the beneficial role elephants play in promoting forest ecosystem functioning through the deposition of dung which is rich in carbon, nitrogen, phosphorus, and potassium. Dung deposition *per* elephant resulted in 0.01 kg N/ha, 0.26 kg C/ha, 0.01 kg P/ha, and 0.01 kg K/ha added to the Aberdare forest ecosystem *per annum*. This study highlights the need to understand both the direct and indirect repercussions of continued elephant decline on ecosystem functioning.

Résumé

L'éléphant d'Afrique (*Loxodonta africana*) est une espèce clé qui occupe une niche intégrante au sein des écosystèmes africains. Les éléphants servent d'ingénieurs de l'écosystème en raison de leurs vastes fonctions écosystémiques, telles que la dispersion des graines, la production de compost de fumier et en tant qu'agents de modification de l'habitat. Les études qui analysent l'état nutritionnel des crottes d'éléphants se sont jusqu'ici concentrées sur les herbages semi-arides. Cette étude présente la première analyse de la composition des crottes d'éléphants obtenues à partir des éléphants situés dans un biome forestier de l'Afromontaine, celui du Parc national Aberdare, ce qui ajoute à la littérature établie et donne plus de détails sur le rôle bénéfique des éléphants dans la promotion du fonctionnement des écosystèmes forestiers par le dépôt de crottes riches en carbone, azote, phosphore et potassium. Le dépôt de crottes par éléphant a entraîné une augmentation de 0,01 kg N/ha, 0,26 kg C/ha, 0,01 kg P/ha et 0,01 kg K/ha par année dans la forêt d'Aberdare. Cette étude met en exergue la nécessité de comprendre les répercussions du déclin continu des éléphants sur le fonctionnement des écosystèmes.

Introduction

Animal manure as a fertiliser has been recognized for centuries as an economical, nutrient-rich method of replenishing soil organic matter. In forests, plant growth and habitat distribution is largely regulated by nutrient availability (Treseder and Vitousek 2001). The deposition of herbivore dung forms the first of many steps in the process of nutrient cycling. Most mammals use only a small proportion of the nutrients they ingest, with 60–99% of the ingested nutrients returned to the soil in the form of dung and urine (Williams and Haynes 1990) and this dung provides a considerable source of nutrients essential for plant productivity in the form of available elements. Many tropical soils are poor in nutrients and rely on the recycling of nutrients from organic matter to maintain soil health and plant productivity. Elephant dung is a copious resource with over 150 kg (wet weight) of dung deposited per elephant per day (Coe 1972). Although widely used in the tropics as a fertilizer (Sannigrahi 2015), its nutrient status has not been described in terms of its potential in nutrient cycling. This is significant as many of the important minerals for plant growth, such as N, P and K, which occur within elephant dung are present at higher concentrations within the dung than in the ingested food material (Anderson and Coe 1974; Greyling 2004).

There is a general paucity of scientific literature on the nutrient status of faeces of free-ranging mammals in African biomes, which are dominated principally by large herbivores. The largest of these herbivores, the African elephant (*Loxodonta africana*) is a keystone species that occupies an integral niche within African ecosystems. Elephants serve as ecosystem engineers due their wide-ranging ecosystem functions, for example seed dispersal (e.g. Campos-Arceiz and Blake 2011), and as agents of habitat modification (de Boer et al. 2015). Similar studies assessing the nutrient status of elephant dung have concentrated on semi-arid grasslands (Masunga et al. 2006) and bushland and woodlands (Dougall 1962; Weir 1972; Anderson and Coe 1974). Here we present the first analysis of the composition of elephant dung obtained from elephants located within a forested Afromontane biome. The Aberdare National Park (ANP) occupies an area of 756 km^2 and is located in the central Kenyan highlands. The entire ANP has recently been ring-fenced to protect wildlife and reduce illegal timber extraction; the latter vital to protect the water catchment of the Afromontane ecosystem, and coordinated by the charitable trust Rhino Ark. It is estimated there are around 2,000 elephants living in the park at a moderately high density but the actual population status remains unclear as recent surveys are based on an informed guess rather than direct counts (Kenya Wildlife Service 2017). Field work was undertaken by the author together with Geofrey Wafula, a KWS ranger. We assess the potential of elephant dung in nutrient cycling, describe its composition in terms of macronutrients essential for plant growth, analyse dung composition between sexes, and compare the results with those of studies in other biomes. We expect greater concentrations of essential macronutrients in elephant dung from Afromontane forest due to a higher availability of nutrients found in forest vegetation compared to grassland and bushland biomes.

Dung collection and analysis

An observation post was established adjacent to the Treetops Lodge in the Salient sector of the Aberdare National Park (ANP), Kenya from 28 May to 1 June 2015. A herd of elephants (n = 10) were observed defecating. Their dung collected immediately after the event and their sex was recorded. Seven samples of 40 g freshly defecated dung was obtained from the adult elephants present (3 females and 4 males) and then frozen at –20°C. Faecal samples were collected by removing the top section of boli, leaving behind the dung that made contact with the ground to avoid soil contamination; similarly, dung tainted by urine was ignored. Dung samples were dried at 80°C and then pulverized in a ceramic mortar to pass through a 2 mm sieve prior to analysis. Phosphorous (P) and potassium (K) concentrations were determined using the Mehlich-3 (Mehlich 1984) extraction procedure as follows: 5 g of dung was added to 20 ml of 0.05 M HCl in 0.025 M H_2SO_4, and the filtrate was analysed by inductively coupled plasma Atomic emission spectrometry (ICP-AES). Then, 0.5 g of dried and weighed dung were decarbonized with 1 M solution of HCl before being analysed for total carbon (C) and nitrogen (N) concentrations with a LECO TruSpec analyser using the combustion (Dumas) method.

Results and discussion

Carbon/nitrogen ratio

Carbon and nitrogen are the most important of the many elements required for microbial decomposition of organic matter to produce compost (Melillo et al. 1989). The C/N ratio is an important factor determining how easily bacteria are able to decompose organic material and indicative of the decomposition rate of organic matter (Taylor et al. 1989). The presence of woody material, while taking a longer time to complete the composting process, encourages fungal activity that results in compost that is excellent as a soil conditioner. The C/N ratio was calculated as the ratio of dry weights, based on average values from the dung collected from individual elephants in the ANP and is displayed in Table 1. The ratio in the forested habit of ANP is lower than in semi-arid grasslands but consistent with those found with bush and woodland habitats (Table 1) and still falls within the optimum range outlined by (Fong et al. 1999) for effective microbial decomposition of plant matter.

Sex differences in the chemical composition of elephant dung

Previous studies note that values obtained from elephant faecal samples are correlated with those found in the diet (Woolley et al. 2009) and, in elephants, differences in diet selection between sexes have been observed when resources become limited. According to (Stokke and du Toit 2000), during dry season browsing adult male elephants ingest a less diverse range of plant species and feed on a greater proportion of woody material. A Mann-Whitney U test was used to compare the median nutrient concentration between male and female elephants. The results indicate that there was no statistically significant difference in dung composition between sexes across all nutrients: (C: $U = 4$, $p = 0.629$; N: $U = 7$, $p = 0.877$; K: $U = 5$, $p = 0.857$; P: $U = 8$, $p = 0.629$). We hypothesized that the lack of seasonal variation in vegetative composition and stability in the diversity of vegetation found within the study site is reflected in homogeneity of the dung composition and accounts for the general similarity in dung composition between sexes.

Nutrient availability for plant growth

When our results are extrapolated to assess the total deposition of dung per elephant per year it may be inferred that the elephants within the ANP are responsible for the addition of total N equivalent to 963.6 kg/yr per elephant; (N_{total}=1.76 mg/kg ×150 kg × 365); total C equivalent to 20,120.6 kg/yr (C_{total}=36.75 mg/kg ×150 kg ×365); available P equivalent to 969 kg/yr ($P_{avail.}$=1.77 mg/kg ×150 kg × 365); and available K equivalent to 892.4 kg/yr ($K_{avail.}$=1.63 mg/kg ×150 kg × 365). When these results are expressed per hectare an individual elephant inputs a remarkable 0.01 kg N/ha, 0.26 kg C/ha, 0.01 kg P/ha, and 0.01 kg K/ha into the Aberdare forest ecosystem every year. Using the atomic weight of the N, P, K elements found in the ANP (Table 2) we can convert the macronutrients measured in mg/kg to percentage concentration by weight. This conversion allows comparison with elephant dung to those found in commercial and other organic fertilisers. Elephant dung does not contain as much N,P,K percentage concentration by weight (1.76 N;1.09 P; 1.89 K per kg) as most commercial agricultural fertilisers (15 N; 6.54; P 12.45 per kg) (*www.fao.org*) but does compare favourably against other types of dung used as manure especially commercially available bat guano (5.5,N;4,P;1.5,K) (Penhallegon 2003).Bat guano has been known to increase plant growth and has been shown to induce greater growth when compared to chemical fertilizer despite its lower NPK content (Sothearen, Furey, and Jurgens 2014). These results are attributed to the fact that in addition to elevated concentrations of N, P, K, guano also contains organic matter, other important micronutrients and microflora which chemical fertiliser lacks.

Table 1. Levels of nitrogen (N), carbon (C), phosphorus (P), potassium (K), and C/N ratio within the faeces of individual adult female (f) and adult male (m) elephants (n = 7). %C and %N values were determined through combustion; available P (mg/kg) and K (mg/kg) were determined using Mehlich-3 extraction. All values are expressed as proportions of dry matter. *Mean values for all samples; † Standard Deviation for all samples.

Sample	Sex	N%	%C	C/N	P (mg/kg)	K (mg/kg)
1	m	1.909	38.64	20.24096	1.90000	**2.71**
2	m	1.839	35.77	19.45079	6.00000	**1.86**
3	m	1.572	34.89	22.19466	1.21970	**1.31**
4	m	1.778	36.84	20.71991	0.31454	**1.38**
5	f	1.812	37.22	20.54084	0.86506	**2.10**
6	f	1.561	35.91	23.00448	1.34610	**2.0**
7	f	1.899	38.01	20.01580	0.78853	**1.65**
*mean		1.76	36.75	-	1.77	**1.82**
†sd±		**0.14**	**1.32**	**-**	**1.92**	**0.59**

Phosphorus availability is a major limiting factor of plant growth in terrestrial ecosystems (Agren et al. 2012) and the observations of Quesada et al. (2012) suggest that soil P availability may be the key modulator of the above-ground net primary productivity of tropical forests. The mean available P content of dung in this study was six times greater than elephant dung found within grassland and bushland biomes (Table 1). This very high in P content is indicative of (1) a tightly bound P cycle within the soil,

Table 2. Mean levels of nitrogen (N), carbon (C), phosphorus (P), potassium (K), and C/N ratio in dung obtained from adult elephants in Aberdare National Park (NP), Kenya. All values are expressed as a percentage dry matter. Error values are standard deviations from the mean.

Study	Sample size (n)	Habitat / study area	N_{total} (%)	C_{total} (%)	C/N	P (mg/ kg)	K (mg/ kg)
		Semi-arid grassland					
Dougall (1963)	1	Tsavo NP	1.28	-	-	0.25	0.58
Anderson and Coe (1974)*	4	Tsavo NP	1.39	49.82	36:1	0.25	0.58
		Bushland/woodland					
Weir (1972)	14	Serengeti NP	-	-	-	-	0.95
	7	Manyara NP	-	-	-	-	0.64
	2	Arusha NP	-	-	-	-	1.42
Masunga et al. (2006)	2	Chobe NP	1.62	39.3	24:1	0.28	1.66
		Afromontane forest					
This study	7	Aberdare NP	1.76 ± 0.14	36.75 ±1.32	21:1	1.77 ± 1.92	1.82 ± 0.59

*Elephant diet supplemented with *Medicago sativ*.

forest vegetation and organisms, (2) the presence of strong mechanisms to mobilize and distribute P among the ecosystem constituents (e.g. Dalling et al. 2016) and (3) low levels of leakage of P from the system.

Potassium is important for the productivity and sustenance of many forests (Tripler et al. 2006). The K content of the dung from the ANP was found to be within range of values reported in previous studies (Table 1) and similar to those in the bushland and woodland habitats described by Weir (1972) and Masunga et al. (2006). This suggests that the ingested plant materials contain a high level of K, and that the K cycle in all three habitats functions with similar efficiency.

Conclusion

To conclude, the dung from elephants that reside in forested areas may provide an effective and rich fertilizer that is comparatively higher in C and P compared with dung from elephants in grasslands and woodlands. This is pertinent as C and P are essential macronutrients on which plants are dependent to maintain ecosystem productivity and growth. These observations provide further support for the hypothesis that elephants, as ‘gardeners of the forest’, are not just ecosystem engineers and effective seed dispersers, but also play a key role in nutrient cycling to support soil health. East Africa’s elephant population has halved since 2007 (Thouless et al. 2016) and this decline in elephant abundance continues unabated. Anthropogenic drivers are responsible for both this decline and the reduction of habitat in which elephants live. The effects of trophic cascades and the decline of taxa with a high capacity to transport nutrients are increasing reported in scientific literature, highlighting the need to understand both the direct and indirect repercussions of elephant decline on ecosystem functioning in general and nutrient cycling in particular. This study confirms the importance of elephants to ecosystem functioning and the health and continuing productivity of Africa’s tropical forests.

Acknowledgements

I thank the Kenya Wildlife Service, especially Corporal Geofrey Wabomba Wafula and the rangers of the Aberdare National Park. I also thank David McKendry, Dr Christopher Fields and Dr Robin Sen at Manchester Metropolitan University, and the helpful comments of two anonymous reviewers.

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