Discover Agriculture

RESEARCH Open Access

# Chemical analysis of elephant dung as a potential organic fertilizer in Malawian agricultural systems: a preliminary study

Chris McCarthy[1,2*], Cornelius Chisambi[3*], Lumbani Benedicto Banda[4,5], Daud Jones Kachamba[2], Emmanuel Junior Zuza[6], Troy Sternberg[7], Leonard Moyo[8], Ndaona Kumanga[8], William Mtawale[8], Chunala Njombwa[9], Yamikani Nyoni[2] and Luciano Lawrence[4]

*Correspondence:
Chris McCarthy
cmccar27@jh.edu
Cornelius Chisambi
corneliuschisambi79@gmail.com

Full list of author information is available at the end of the article

**Abstract**
Soil fertility decline and land degradation threaten food security and ecosystem health across sub-Saharan Africa, including Malawi. Our preliminary study provides a chemical characterization of elephant dung to establish a foundation for evaluating its potential as an organic fertilizer in Malawian agroecosystems. We compared the nutrient content and chemical properties of elephant dung with common organic and synthetic fertilizers. Our findings indicate that elephant dung exhibits chemical properties comparable to other organic fertilizers commonly used in Malawi, including a neutral to slightly alkaline pH (7.21–7.71), moderate electrical conductivity (736–913 mS/m), and a carbon-to-nitrogen ratio (21.89–25.07) suitable for slow-release soil amendment. We assess these properties against relevant standards such as those set by the European Union for organic fertilizers. This chemical analysis suggests that elephant dung merits further investigation through comprehensive field trials to determine its agricultural efficacy. Should such field trials demonstrate benefits, the application of elephant dung as a fertilizer could potentially create valuable connections between conservation and agriculture. While this study focuses exclusively on chemical properties, it provides essential baseline data to inform future research exploring whether elephant dung could contribute to both sustainable agriculture and biodiversity conservation efforts.

**Keywords** Agroecosystem, Biodiversity conservation, Elephant dung, Malawi, Soil fertility, Sustainable agriculture

## 1 Introduction

The growing global population, which is projected to rise significantly by 2050, necessitates a corresponding increase in agricultural productivity to ensure food security while conserving the environment and biodiversity [1, 2]. However, the current reliance on intensive, often unsustainable, monoculture agricultural practices pose significant threats to the environment.

While synthetic fertilizers have historically assisted in improving crop yields, their use has been linked to soil degradation, water pollution, greenhouse gas emissions, and biodiversity loss [3]. These environmental consequences disrupt essential ecosystem services including pollination and water purification, jeopardizing the long-term sustainability of food production and biodiversity conservation [4].

In this context, organic fertilizers, derived from plant or animal matter are a viable option touted for their environmental benefits and capacity to improve soil health [5]. Unlike their synthetic counterparts, organic fertilizers release nutrients slowly, enhancing soil structure, and minimizing the risk of environmental contamination through leaching and runoff [6]. Furthermore, the use of organic fertilizers aligns with the principles of agroecology, which emphasizes fostering biodiversity and ecological balance within farming systems [7].

One such organic material with potential, yet remains underutilized, is elephant dung. As keystone species in many African ecosystems, elephants produce significant quantities of dung rich in organic matter and essential plant nutrients. In regions with abundant elephant populations, particularly around national parks and reserves, this dung represents a readily available, renewable resource. However, the specific chemical properties of elephant dung in the context of Malawian agroecosystems and its potential implications for agricultural use have not been comprehensively characterized [8].

The chemical composition of organic materials is a critical first step in evaluating their potential as fertilizers. Elephant dung likely contains organic matter that plays a crucial role in maintaining soil health by influencing water retention capacity, soil structure, and nutrient availability [9]. The gradual release of nutrients from organic matter is essential for sustainable crop growth and reduces the need for frequent synthetic fertilizer application [10].

Additionally, organic materials like animal manure typically contain beneficial microorganisms that can aid in soil aeration and nutrient cycling, thereby enhancing soil biodiversity and resilience against pests and diseases. Beyond these benefits, organic amendments can contribute to climate change mitigation through carbon sequestration [8].

The characterization of elephant dung as a potential fertilizer also relates to broader conservation issues. In many parts of Africa, human-elephant conflict is a pressing issue, with elephants often seen as a threat to crops and livelihoods [11, 12]. Chemical characterization of elephant dung is an essential preliminary step in exploring whether this perceived nuisance could eventually be transformed into a valuable agricultural resource. This first step could contribute to future work examining whether such transformations might foster a more harmonious relationship between communities and elephants, promoting coexistence and conservation.

Elephants are exceptional among herbivores due to the sheer volume of dung they produce. An adult elephant can generate up to 150 kg of dung per day [13]. This vast quantity sets elephants apart from other herbivorous mammals and potentially makes their dung a significant resource for agricultural applications, particularly in areas where elephants are abundant.

Despite these potential benefits, significant challenges would need to be addressed before practical application of elephant dung as a fertilizer becomes feasible. These include concerns about pathogen transfer, variable nutrient content, and logistical issues related to collection and processing [14]. Understanding the perceptions and willingness of farmers to use elephant dung would also be crucial for any successful integration into agricultural practices [15, 16]. Additionally, the sustainability of using elephant dung as a fertilizer, given the ongoing human-elephant conflict, requires careful consideration.

This study provides a comprehensive chemical characterization of elephant dung from Malawian protected areas as a necessary first step toward evaluating its potential as an organic fertilizer. We hypothesize that elephant dung contains a favorable nutrient profile and chemical properties suitable for soil amendment applications. This chemical analysis serves as an essential foundation for potential future field trials that would more definitively establish agricultural efficacy. Should such future work prove elephant dung effective as a fertilizer, this knowledge could contribute to both sustainable agricultural practices and biodiversity conservation efforts in the region.

### 1.1 Study area

Samples for this study were collected from Kasungu National Park (KNP) and Vwaza Marsh Wildlife Reserve (VMWR), located in the central and northern regions of Malawi, respectively. Figure 1 shows the locations of the parks. Distinguished by its expansive miombo woodlands, KNP is interspersed with lush grasslands and wet dambos. This park, as one of Malawi's principal conservation areas, is home to a significant elephant population alongside a myriad of other species, contributing to its rich biodiversity. The park's ecosystem, predominantly miombo woodland, plays a vital role in sustaining the diverse fauna, including the elephants central to this study's focus. Figure 2 shows a family of elephants within Kasungu National Park, demonstrating the elephant population that the park supports.

The recent translocation of 250 elephants from Liwonde National Park to Kasungu in July 2022, aimed at reducing overcrowding and fostering ecological balance, has unfortunately escalated human-elephant conflicts around KNP. This increase in conflict, marked by several reported fatalities, underscores the intricate challenges at the intersection of wildlife conservation and agricultural sustainability within the park's vicinity [17, 18].

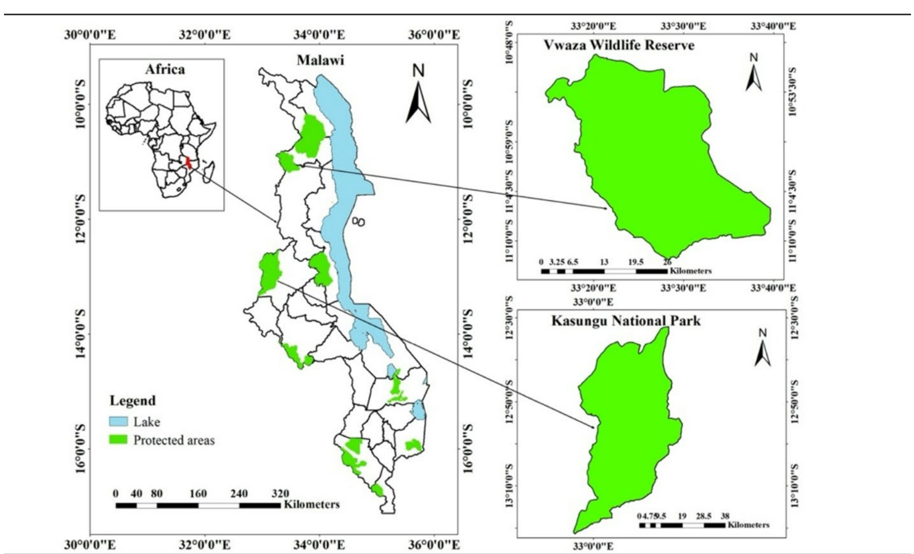


**Fig. 1** Map showing locations of study areas and protected areas in Malawi

**Fig. 2** A small family of elephants photographed in Kasungu National Park, representing the elephant population studied in this research

Conversely, VMWR encompasses a varied landscape of woodlands, grasslands, and marshes. The reserve is a critical habitat for elephants, hippos, various antelope species, and an array of avian life, underscoring its ecological significance. The juxtaposition of these ecosystems within the reserve forms a complex matrix that supports a high level of biodiversity.

Adjacent to both KNP and VMWR are numerous villages whose inhabitants rely heavily on subsistence agriculture for their livelihoods. The communities face significant challenges, notably the scarcity of affordable, environmentally sustainable fertilizers, which hampers efforts to improve agricultural productivity.

## 2 Materials and methods

### 2.1 Sampling

Fresh elephant dung samples, no older than 24 h, were collected from various locations within KNP and VMWR to ensure consistency in nutrient content. The age of the dung was determined based on its appearance, moisture content, and the presence of insects. Fresh elephant dung (< 24 h) was identified by specific characteristics: intact bolus structure, moist interior when broken open (approximately 40–60% moisture content by visual estimation), minimal insect activity (only initial colonization by dung beetles), and distinct, strong odor. Older dung typically exhibits drier texture, extensive beetle tunneling, and fragmented structure. Samples were collected during the dry season (June-August) to minimize variation in nutrient content due to seasonal factors. The other organic fertilizers (Bokashi, cattle dung, Mbeya fertilizer compound, Mbeya fertilizer UREA, Changu, Windrow) and the chemical fertilizers (chemical fertilizer compound, chemical fertilizer UREA) were collected at Lunyangwa Agricultural Research Station and served as comparative treatments.

The comparative fertilizers used in this study had varying compositions and sources. Mbeya fertilizer compound and Mbeya fertilizer UREA are blended fertilizers containing both organic materials and synthetic components. Mbeya compound contains synthetic compounds with elevated phosphorus content (approximately 10%) [19], while Mbeya UREA combines organic matter with UREA fertilizer (46% N), along with additional ingredients such as maize bran, chicken droppings, and wood ash. Bokashi is a fermented organic fertilizer made from kitchen waste, cattle manure, and rice husks. Changu and Windrow are compost fertilizers made using different composting methods. The synthetic chemical fertilizers (chemical compound and chemical UREA) are standard commercial products containing 10% P and 46% N, respectively.

These samples underwent air-drying and were then sifted through a 2 mm sieve to ensure uniformity prior to laboratory analysis at the Soil Science Laboratory of Lunyangwa Agricultural Research Station, which is part of the Department of Agriculture and Research Service (DARS). A total of 6 elephant dung samples were collected from KNP and 6 samples from VMWR. For the other organic and chemical fertilizers, we collected 6 samples of each type from Lunyangwa Agricultural Research Station. Figures 3 and 4 show the sampling location and processing of elephant dung, respectively.

### 2.2 Laboratory analysis

Chemical analysis of the fertilizers was conducted at two locations: Lunyangwa Agricultural Research Station in Mzuzu and Bvumbwe Agricultural Research Station in Blantyre, both operated under DARS. Key parameters assessed included pH levels, $H_2O$ and Ec, total nitrogen (TN) content, phosphorus (P), concentrations of exchangeable cations, calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), potassium ($K^+$). For the chemical fertilizer carbon, pH and Ec were not analyzed. Dung pH was determined by suspending 5 g of dung sample in 25 ml of distilled water (DW), making a ratio of 1:5. The suspension was vigorously shaken for a duration of 1 h and subsequently assessed using a glass electrode pH meter and Ec meter (Model F-70 Series, Horiba). Carbon (C) content was determined using the Walkley-Black method [20], Total nitrogen (N) content was determined using the micro Kjeldahl method [21]. Available P and exchangeable cations, calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), potassium ($K^+$), were determined using the Mehlich-3 solution (0.2 M $CH_3COOH$, 0.25 M $NH_4NO_3$, 0015 M $NH_4F$, 0.013 M $HNO_3$, and 0.001 M ethylene

**Fig. 3** Setting where sample elephant dung was collected in Kasungu National Park

**Fig. 4** Elephant dung drying in a greenhouse at Lunyangwa Agricultural Research Station

**Table 1** pH ($H_2O$) values for eight types of fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 7.21bc | 0.16 | 2.25 | 6.99 | 7.46 | 7.20 |
| Elephant Dung (VMWR) | 7.71ab | 0.47 | 6.14 | 6.97 | 8.24 | 7.73 |
| Bokashi (BKS) | 8.67a | 0.39 | 4.54 | 8.29 | 9.33 | 8.61 |
| Cattle Dung (CaDn) | 7.55ab | 0.10 | 1.36 | 7.41 | 7.66 | 7.55 |
| Mbeya Fertilizer Compound (MFC) | 8.48a | 0.16 | 1.84 | 8.23 | 8.62 | 8.54 |
| Mbeya Fertilizer UREA (MFU) | 8.27a | 0.32 | 3.85 | 7.95 | 8.81 | 8.21 |
| Changu (CNG) | 6.97bc | 0.25 | 3.61 | 6.73 | 7.41 | 6.91 |
| Windrow (WR) | 6.92c | 0.19 | 2.78 | 6.58 | 7.12 | 6.97 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

diamine tetra-acetic acid (EDTA)), according to Mehlich [22]. The Mehlich-3 method is suitable for extracting phosphorus in the studied samples due to its ability to extract nutrients from a wide range of sample types, including acidic samples [22]. Using the filtered Mehlich-3 solution, available P was determined by molybdenum blue method with a UV-visible spectrophotometer (Bellstone WSP-UV800A), and exchangeable cations determination was conducted by microwave plasma atomic emission spectroscopy (MP-AES; Agilent 4200 MP-AES, Agilent, Santa Clara, CA, USA).

### 2.3 Statistical analysis

One way ANOVA assuming equal variances was used to find the difference in the chemical parameters. A posthoc Tukey HSD was used for mean separation, and the significance level was 0.05. All analyses were completed using Origin 2023 software (Table 1).

## 3 Results

### 3.1 Soil pH ($H_2O$) and electrical conductivity (Ec)

The average pH levels of the fertilizers examined in our study ranged from almost neutral to moderately alkaline (6.92–8.67). The average pH of elephant dung from KNP was

**Table 2** Electrical conductivity (mS/m) values for eight types of fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 736.89b | 90.61 | 12.30 | 687.03 | 921.11 | 703.59 |
| Elephant Dung (VMWR) | 912.78a | 43.22 | 4.74 | 857.22 | 984.09 | 908.26 |
| Bokashi (BKS) | 307.97d | 150.87 | 49.00 | 13.05 | 400.95 | 353.68 |
| Cattle Dung (CaDn) | 957.79a | 26.87 | 2.81 | 930.53 | 999.04 | 953.90 |
| Mbeya Fertilizer Compound (MFC) | 545.03c | 8.96 | 1.64 | 534.09 | 555.67 | 546.59 |
| Mbeya Fertilizer UREA (MFU) | 320.06d | 33.70 | 10.53 | 279.42 | 377.06 | 315.57 |
| Changu (CNG) | 531.79c | 65.98 | 12.41 | 417.32 | 607.07 | 549.23 |
| Windrow (WR) | 429.63d | 33.58 | 7.82 | 398.73 | 476.99 | 414.42 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, *VMWR - Vwaza Marsh Wildlife Reserve*

**Table 3** Total nitrogen (%) values for the ten fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 0.52e | 0.12 | 23.55 | 0.33 | 0.69 | 0.53 |
| Elephant Dung (VMWR) | 0.58e | 0.06 | 10.73 | 0.49 | 0.65 | 0.58 |
| Bokashi (BKS) | 0.78e | 0.08 | 9.95 | 0.67 | 0.88 | 0.77 |
| Cattle Dung (CaDn) | 0.85e | 0.08 | 9.85 | 0.71 | 0.95 | 0.85 |
| Mbeya Fertilizer Compound (MFC) | 5.38d | 0.32 | 6.00 | 5.09 | 5.98 | 5.30 |
| Mbeya Fertilizer UREA (MFU) | 8.26c | 0.41 | 4.95 | 7.94 | 9.05 | 8.14 |
| Changu (CNG) | 0.56e | 0.04 | 7.84 | 0.51 | 0.63 | 0.55 |
| Windrow (WR) | 0.43e | 0.08 | 19.01 | 0.33 | 0.53 | 0.42 |
| Chemical Fertilizer Compound (CFC) | 22.65b | 0.38 | 2.00 | 22.09 | 23.02 | 22.71 |
| Chemical Fertilizer UREA (CFU) | 45.68a | 0.46 | 1.00 | 44.99 | 46.14 | 45.85 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

7.21 with a minimum of 6.99 and maximum of 7.46. VMWR elephant dung had an average pH of 7.71 with a minimum of 6.97 and a maximum of 8.24.

The electrical conductivity values are presented in Table 2. Elephant dung from VMWR (912.78 mS/m) had similar EC values to cattle dung (957.79 mS/m), both classified in statistical group "a". Elephant dung from KNP showed intermediate EC values (736.89 mS/m), significantly higher than Bokashi, Mbeya UREA, and Windrow fertilizers.

### 3.2 Total nitrogen content

The total nitrogen content in all fertilizers is presented in Table 3. Elephant dung from KNP and VMWR contained 0.52% and 0.58% nitrogen respectively, which was statistically similar to other organic fertilizers such as Bokashi (0.78%), Cattle Dung (0.85%), Changu (0.56%), and Windrow (0.43%), all classified in statistical group "e". Mbeya organic-synthetic blend fertilizers showed intermediate nitrogen content (5.38–8.26%), while chemical fertilizers exhibited the highest nitrogen values (22.65–45.68%).

.

### 3.3 Total carbon and CN ratio

Total carbon content results are presented in Table 4. Cattle dung contained the highest carbon levels at 16.49% (group "a"), followed by elephant dung from VMWR at 12.71% (group "b") and KNP at 12.49% (group "bc"). The other organic fertilizers contained carbon levels ranging from 7.86% to 10.39%.

**Table 4** Total carbon (%) values for the eight fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 12.49bc | 3.38 | 27.02 | 9.08 | 17.93 | 11.79 |
| Elephant Dung (VMWR) | 12.71b | 4.05 | 31.88 | 9.62 | 18.66 | 10.41 |
| Bokashi (BKS) | 7.86 cd | 0.88 | 11.23 | 6.79 | 9.43 | 7.72 |
| Cattle Dung (CaDn) | 16.49a | 1.78 | 10.76 | 13.56 | 18.07 | 17.05 |
| Mbeya Fertilizer Compound (MFC) | 9.82c | 0.40 | 4.02 | 9.37 | 10.11 | 9.98 |
| Mbeya Fertilizer UREA (MFU) | 10.39c | 0.74 | 7.11 | 9.88 | 11.24 | 10.06 |
| Changu (CNG) | 8.83 cd | 3.36 | 38.08 | 6.81 | 15.22 | 7.04 |
| Windrow (WR) | 8.58d | 1.75 | 20.34 | 5.13 | 10.03 | 9.03 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

**Table 5** Carbon to nitrogen (C: N) ratios of the eight organic fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 25.07a | 8.29 | 33.06 | 13.16 | 35.16 | 26.78 |
| Elephant Dung (VMWR) | 21.89a | 6.25 | 28.54 | 16.52 | 31.70 | 18.83 |
| Bokashi (BKS) | 10.19c | 1.30 | 12.75 | 8.43 | 11.94 | 10.16 |
| Cattle Dung (CaDn) | 19.35b | 1.57 | 8.11 | 17.47 | 21.63 | 19.38 |
| Mbeya Fertilizer Compound (MFC) | 1.71d | 0.12 | 7.01 | 1.60 | 1.93 | 1.69 |
| Mbeya Fertilizer UREA (MFU) | 1.24d | 0.15 | 12.10 | 1.11 | 1.40 | 1.20 |
| Changu (CNG) | 15.94bc | 7.10 | 44.54 | 10.90 | 28.19 | 13.07 |
| Windrow (WR) | 20.48ab | 5.67 | 27.68 | 13.50 | 28.64 | 19.68 |

Means that do not share a letter are significantly different at $p < 0.05$. Note: C:N ratios below 10 indicate rapid nutrient release, 10–20 indicate moderate release rates ideal for most crops, and > 20 indicate slower nutrient release with potential for temporary nitrogen immobilization

Carbon-to-nitrogen ratios are shown in Table 5. Elephant dung from both sites had the highest C: N ratios (25.07 and 21.89, group "a"), followed by Windrow (20.48, group "ab") and Cattle dung (19.35, group "b"). Mbeya fertilizers had the lowest C: N ratios (1.71 and 1.24, group "d").

### 3.4 Phosphorus

Phosphorus content results are presented in Table 6. Elephant dung from both KNP and VMWR contained identical phosphorus levels (0.07%, group "d"), which were statistically similar to Bokashi (0.12%), Cattle dung (0.08%), Changu (0.05%), and Windrow (0.05%). Chemical Fertilizer Compound contained the highest phosphorus level (9.54%, group "a"), followed by Mbeya Fertilizer Compound (1.05%, group "b").

### 3.5 Exchangeable potassium

Potassium content is shown in Table 7. Elephant dung samples from both sites contained 0.08% potassium (group "cd"), which was statistically similar to cattle dung (0.09%, group "cd"). Chemical Fertilizer Compound and Mbeya Fertilizer Compound showed the highest potassium levels (4.92% and 2.26% respectively, both in group "a").

### 3.6 Exchangeable magnesium & calcium

Exchangeable magnesium results are presented in Table 8. Elephant dung from KNP and VMWR contained 0.06% and 0.07% magnesium respectively (group "ab"), statistically similar to cattle dung (0.06%) and Bokashi (0.07%). Mbeya fertilizers contained significantly higher magnesium levels (0.42% and 0.35%, group "a"), while Changu and Windrow had the lowest levels (both 0.03%, group "b").

**Table 6** Phosphorus (%) values of the nine fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 0.07d | 0.02 | 25.35 | 0.04 | 0.09 | 0.07 |
| Elephant Dung (VMWR) | 0.07d | 0.01 | 9.62 | 0.06 | 0.08 | 0.07 |
| Bokashi (BKS) | 0.12d | 0.18 | 150.00 | 0.03 | 0.50 | 0.05 |
| Cattle Dung (CaDn) | 0.08d | 0.01 | 13.55 | 0.06 | 0.09 | 0.08 |
| Mbeya Fertilizer Compound (MFC) | 1.05b | 0.32 | 30.48 | 0.47 | 1.43 | 1.11 |
| Mbeya Fertilizer UREA (MFU) | 0.42c | 0.05 | 11.90 | 0.34 | 0.48 | 0.43 |
| Changu (CNG) | 0.05d | 0.01 | 16.97 | 0.04 | 0.06 | 0.05 |
| Windrow (WR) | 0.05d | 0.01 | 13.86 | 0.04 | 0.05 | 0.05 |
| Chemical Fertilizer Compound (CFC) | 9.54a | 0.42 | 4.40 | 8.99 | 10.00 | 9.65 |

Means that do not share a letter are significantly different at $p < 0.05$

Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

**Table 7** Exchangeable potassium (%) values of the nine fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 0.08 cd | 0.01 | 15.96 | 0.06 | 0.09 | 0.08 |
| Elephant Dung (VMWR) | 0.08 cd | 0.01 | 14.05 | 0.07 | 0.10 | 0.08 |
| Bokashi (BKS) | 0.56b | 0.06 | 11.32 | 0.44 | 0.61 | 0.58 |
| Cattle Dung (CaDn) | 0.09 cd | 0.01 | 10.77 | 0.08 | 0.11 | 0.09 |
| Mbeya Fertilizer Compound (MFC) | 2.26a | 0.31 | 13.71 | 1.97 | 2.67 | 2.21 |
| Mbeya Fertilizer UREA (MFU) | 1.12b | 0.16 | 14.21 | 0.98 | 1.39 | 1.07 |
| Changu (CNG) | 0.35c | 0.04 | 12.60 | 0.28 | 0.41 | 0.35 |
| Windrow (WR) | 0.39c | 0.02 | 5.90 | 0.36 | 0.42 | 0.39 |
| Chemical Fertilizer Compound (CFC) | 4.92a | 0.13 | 2.64 | 4.73 | 5.08 | 4.93 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

**Table 8** Exchangeable magnesium (%) values of the eight fertilizers evaluated ($n = 6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 0.06ab | 0.01 | 24.04 | 0.04 | 0.07 | 0.06 |
| Elephant Dung (VMWR) | 0.07ab | 0.02 | 27.04 | 0.04 | 0.09 | 0.08 |
| Bokashi (BKS) | 0.07ab | 0.01 | 13.45 | 0.06 | 0.08 | 0.07 |
| Cattle Dung (CaDn) | 0.06ab | 0.01 | 24.45 | 0.04 | 0.08 | 0.07 |
| Mbeya Fertilizer Compound (MFC) | 0.42a | 0.06 | 13.92 | 0.37 | 0.52 | 0.41 |
| Mbeya Fertilizer UREA (MFU) | 0.35a | 0.07 | 19.56 | 0.27 | 0.43 | 0.34 |
| Changu (CNG) | 0.03b | 0.01 | 26.73 | 0.02 | 0.04 | 0.03 |
| Windrow (WR) | 0.03b | 0.01 | 37.27 | 0.02 | 0.05 | 0.03 |

Means that do not share a letter are significantly different at $p < 0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

Calcium content is shown in Table 9. Elephant dung from KNP and VMWR contained the lowest calcium levels (0.19% and 0.20% respectively, group “bc”). Bokashi, Mbeya fertilizers, Changu, and Windrow all contained significantly higher calcium levels (0.75–1.01%, group “a”).

## 4 Discussion

Our research into the chemical composition of elephant dung offers insights into its potential as an organic fertilizer within African agroecosystems. The findings demonstrate that elephant dung exhibits several promising nutritional characteristics, notably a neutral to slightly alkaline pH, moderate electrical conductivity, and a comprehensive nutrient profile with a specific carbon-to-nitrogen ratio. While field studies are

**Table 9** Exchangeable calcium (%) values of the eight fertilizers evaluated ($n=6$)

| Fertilizer Type | Mean | SD | CV (%) | Min | Max | Median |
|---|---|---|---|---|---|---|
| Elephant Dung (KNP) | 0.19bc | 0.03 | 15.69 | 0.13 | 0.22 | 0.19 |
| Elephant Dung (VMWR) | 0.20bc | 0.03 | 16.01 | 0.17 | 0.26 | 0.19 |
| Bokashi (BKS) | 0.98a | 0.06 | 5.63 | 0.88 | 1.02 | 1.00 |
| Cattle Dung (CaDn) | 0.33b | 0.07 | 21.89 | 0.23 | 0.43 | 0.32 |
| Mbeya Fertilizer Compound (MFC) | 0.85a | 0.07 | 8.55 | 0.78 | 0.99 | 0.84 |
| Mbeya Fertilizer UREA (MFU) | 1.01a | 0.20 | 19.85 | 0.77 | 1.26 | 1.02 |
| Changu (CNG) | 0.86a | 0.05 | 5.22 | 0.79 | 0.92 | 0.86 |
| Windrow (WR) | 0.75a | 0.07 | 8.95 | 0.66 | 0.82 | 0.75 |

Means that do not share a letter are significantly different at $p<0.05$. Key: KNP - Kasungu National Park, VMWR - Vwaza Marsh Wildlife Reserve

necessary to confirm its efficacy in agricultural settings, an essential next step beyond our chemical analysis, this initial characterization provides a foundation for understanding its potential applications and designing appropriate field trials.

### 4.1 Interpreting chemical properties: pH, electrical conductivity, and nutrient content

The chemical properties of elephant dung indicate agricultural suitability consistent with established organic fertilizers. Soil pH significantly influences nutrient availability and microbial activity [23], and our analysis shows elephant dung has a neutral to slightly alkaline pH (7.21–7.71). This pH range falls within the European Union standards for organic fertilizers (5.5–8.5) [24], as does the electrical conductivity (736.89-912.78 mS/m, below the EU limit of 2,000 mS/m). This pH profile could be particularly relevant in Malawian agricultural contexts where soil acidity can constrain crop productivity [19, 25]. Unlike nitrogen-rich synthetic fertilizers that often contribute to soil acidification through ammonium uptake and nitrification processes, materials with neutral pH and organic matter content like elephant dung may help buffer soil pH through the release of basic cations during decomposition.

Our analysis demonstrates that elephant dung's chemical properties are broadly comparable to cattle dung and commercial composts already used in Malawi. This comparability is itself significant: elephant dung meets the threshold for agricultural consideration while representing an abundant, underutilized resource near protected areas. The Government of Malawi recommends a standard application rate of 92 kg N/ha for hybrid maize production [26]. Based on our measured nitrogen content of 0.52–0.58% and recommended organic manure application rates of 10–15 tonnes/ha [27], elephant dung applications within this range would contribute approximately 52–87 kg N/ha, approaching but not fully meeting maize nitrogen requirements without supplementation. The practical advantage lies in availability: a single elephant produces up to 150 kg of dung daily [13], and collection near park boundaries could provide a local fertilizer source where synthetic options remain expensive for smallholder farmers. Regarding electrical conductivity, our measured values (736–913 mS/m) fall well within the EU limit of 2,000 mS/m [24] and are comparable to cattle dung (958 mS/m). At application rates of 10–15 tonnes/ha, salt accumulation risk is minimal, though repeated annual applications at higher rates would warrant periodic soil EC monitoring to maintain levels suitable for crop production [23].

Our nitrogen content analysis revealed moderate levels in elephant dung (0.52–0.58%), significantly lower than synthetic fertilizers but comparable to other organic fertilizers commonly used in Malawi. The substantial organic carbon content (12.49–12.71%) contributes to soil physical properties, as demonstrated in studies of cattle manure with comparable carbon levels [27, 28].

The C: N ratios of elephant dung (21.89–25.07) indicate a slower nutrient release pattern compared to materials with lower ratios. This characteristic indicates that elephant dung is more suitable for long-term soil improvement rather than as an immediate nutrient source for crops with high nitrogen demands. Field trials would be necessary to determine optimal application rates and timing, potentially exploring co-application with faster-release nitrogen sources.

For phosphorus, potassium, magnesium, and calcium, elephant dung contains modest amounts of these essential nutrients. The phosphorus (0.07%) and potassium (0.08%) levels are substantially lower than synthetic or blended fertilizers, suggesting that in potential field applications, elephant dung would likely need supplementation to meet crop requirements for these nutrients.

A notable limitation of our chemical characterization is the absence of micronutrient analysis. Organic fertilizers often provide valuable micronutrients essential for plant growth and development. Future research should include comprehensive micronutrient profiling of elephant dung, examining elements such as zinc, iron, manganese, copper, boron, and molybdenum. This is particularly important in the context of Malawian soils, where micronutrient deficiencies can limit crop productivity even when macronutrients are adequately supplied.

### 4.2 Contextualizing chemical properties within conservation frameworks

Our chemical analysis represents only the first step in exploring potential agricultural applications of elephant dung. Similar studies on other organic fertilizers typically follow a sequential research approach, beginning with chemical characterization followed by field trials. For example, studies on cow dung fertilizer [27] first established chemical properties before determining optimal application rates.

The economic valorization of elephant dung could shift community perceptions in buffer zones where human-elephant conflict is most acute. Research demonstrates that communities show greater tolerance for wildlife when they derive tangible benefits from its presence [11, 12]. Transforming elephant dung from an incidental byproduct of a perceived threat into a sought-after agricultural input could complement existing conservation strategies.

If future field trials demonstrate agricultural benefits, elephant dung utilization would require careful implementation frameworks. Collection would need to be conducted exclusively by trained park rangers within designated areas of national parks, potentially integrated with existing conservation activities. This approach would ensure that only authorized personnel enter elephant habitats, maintaining protected area integrity.

Based on our chemical analysis, particularly the C: N ratios of 21.89–25.07 and modest macronutrient content, we suggest that initial field trials should test elephant dung at multiple application rates, potentially in combination with nitrogen-rich supplements to address the relatively high C: N ratio.

### 4.3 Addressing limitations and future research directions

This chemical characterization establishes that elephant dung meets fundamental criteria for consideration as an organic fertilizer: appropriate pH, acceptable EC levels, and nutrient content comparable to amendments already in agricultural use. Following the standard research progression demonstrated in cattle manure studies [27], this baseline analysis enables the design of targeted field trials with informed hypotheses about application rates and supplementation requirements.

Future research should address several key areas:

1. Micronutrient analysis: Conduct comprehensive profiling of micronutrients in elephant dung to understand its complete nutritional contribution.
2. Processing and pathogen management: Investigate methods such as composting or co-composting elephant dung with other materials to optimize nutrient content, reduce pathogen load, and address the relatively high C: N ratio.
3. Field trials: Conduct controlled experiments comparing elephant dung, other organic fertilizers, and synthetic options across various crops and soil conditions to determine practical agricultural value.
4. Seed dispersal management: Address the risk of endozoochory seed dispersal, as elephant dung may contain viable seeds that could potentially introduce invasive species to cropland.
5. Availability and logistics: Assess practically available quantities considering factors such as elephant population densities, seasonal variations, and collection logistics.
6. Economic viability: Compare the costs and benefits of elephant dung collection, processing, and application against other fertilizer options.
7. Social aspects: Evaluate local communities' perceptions and willingness to use elephant dung-derived fertilizers.
8. Environmental impact: Assess long-term effects on soil health, nutrient cycling, and ecosystem functioning.

Our chemical analysis provides an essential foundation for these future research directions, establishing baseline nutrient parameters that can guide the design of comprehensive field trials to more definitively evaluate elephant dung's agricultural potential in Malawian contexts.

## 5 Conclusion

This preliminary study examines the chemical composition of elephant dung from Malawian protected areas as a first step in assessing its potential as an organic fertilizer. Our chemical analysis establishes that elephant dung possesses soil-enhancing properties comparable to organic fertilizers currently used in Malawian agriculture, with appropriate pH, acceptable electrical conductivity, and a nutrient profile suitable for slow-release soil amendment. By aligning with agroecological principles, the use of elephant dung could foster biodiversity, improve soil structure, and aid in climate change mitigation through carbon sequestration. Despite facing challenges such as nutrient variability, lacking micronutrient data, and potential pathogen presence, our findings underscore the need for further research to refine processing methods and explore the economic benefits of elephant dung utilization. This study not only highlights elephant dung's potential role in sustainable agriculture but also emphasizes the critical balance between ecological conservation and agricultural productivity, advocating for a holistic approach to ensure food security, environmental sustainability, and the well-being of communities coexisting with wildlife.

**Acknowledgements**
The authors would like to thank the staff of Soil Science Laboratory of Lunyangwa Agricultural Research Station and Bvumbwe Agricultural Research Station or their assistance with our analysis.

**Author contributions**
Conceptualization, C.M., C.C., L.B.B., E.J.Z., D.J.K., T.S.; Methodology, C.M., C.C., L.B.B., D.J.K., T.S.; Investigation, C.M., C.C., L.B.B., Y.N., L.L.; Writing – Original Draft, C.M., C.C.; Writing – Review & Editing, C.M., C.C., L.B.B., E.J.Z., D.J.K., T.S.; Resources, L.M., N.K., W.M.; Data Analysis, C.M., C.C., L.B.B., E.J.Z., D.J.K., C.N.; Laboratory Analysis, C.C., Y.N., L.L.

**Funding**
The authors did not receive support from any organization for the submitted work.

**Data availability**
The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request. The chemical analysis data for elephant dung and other fertilizer samples are stored at the Soil Science Laboratory of Lunyangwa Agricultural Research Station and Bvumbwe Agricultural Research Station.

**Code availability**
Not applicable as no custom code was developed for this study.

## Declarations

**Ethics approval and consent to participate**
Ethics approval was not required for this study as it involved the collection and analysis of elephant dung samples from protected areas with permission from the Department of National Parks and Wildlife in Malawi, and did not involve any direct interaction with animals or human subjects.

**Consent for publication**
This manuscript includes images of individuals. Verbal consent for the publication of these images was obtained from the individuals depicted. No identifying details (such as names, dates of birth, identity numbers, or biometric characteristics) were disclosed in the manuscript apart from the images themselves, which are essential for scholarly purposes.

**Competing interests**
The authors declare no competing interests.

**Author details**
[1]Zanvyl Krieger School of Arts & Sciences, Johns Hopkins University, Baltimore 21218, MD, USA
[2]Department of Forestry, Bunda College of Agriculture Campus, Lilongwe University of Agriculture and Natural Resources (LUANAR), P.O. Box 219 Lilongwe, Malawi
[3]Graduate School of Global Environmental Studies, Kyoto University, Kyoto 606-8501, Japan
[4]Bunda College of Agriculture Campus, Department of Environment and Natural Resources, Lilongwe University of Agriculture and Natural Resources (LUANAR), P.O. Box 219, Lilongwe, Malawi
[5]Africa Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation, Haramaya University, PO Box 138 Dire Dawa, Ethiopia
[6]School of Agricultural Science and Practice, Royal Agricultural University, GL7 6JS, Cirencester, Glouces-tershire, UK
[7]School of Geography, University of Oxford, Oxford OX2 6HY, UK
[8]Kasungu National Park, Department of National Parks and Wildlife, Lilongwe, Malawi
[9]University of Livingstonia, P.O. Box 112 Mzuzu, Malawi

Received: 12 December 2024 / Accepted: 9 December 2025

Published online: 30 December 2025

**References**

1. Godfray HCJ, Robinson S. Contrasting approaches to projecting long-run global food security. Oxf Rev Econ Policy. 2015;31:26–44. https://doi.org/10.1093/oxrep/grv006.
2. Van Dijk M, Meijerink GW. A review of global food security scenario and assessment studies: Results, gaps and research priorities. Global Food Secur. 2014;3:227–38. https://doi.org/10.1016/j.gfs.2014.09.004.
3. Menegat S, Ledo A, Tirado R. Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. Sci Rep. 2022;12:14490. https://doi.org/10.1038/s41598-022-18773-w.
4. Litskas VD. Environmental impact assessment for animal Waste, organic and synthetic fertilizers. Nitrogen. 2023;4:16–25. https://doi.org/10.3390/nitrogen4010002.
5. Muller A, Schader C, El-Hage Scialabba N, Brüggemann J, Isensee A, Erb K-H, et al. Strategies for feeding the world more sustainably with organic agriculture. Nat Commun. 2017;8:1290. https://doi.org/10.1038/s41467-017-01410-w.
6. Scialabba NE-H, Müller-Lindenlauf M. Organic agriculture and climate change. Renew Agric Food Syst. 2010;25:158–69. https://doi.org/10.1017/S1742170510000116.

7. Wezel A, Bellon S, Doré T, Francis C, Vallod D, David C. Agroecology as a science, a movement and a practice. A review. Agron Sustain Dev. 2009;29:503–15. https://doi.org/10.1051/agro/2009004.
8. Stępień Świechowski, Hnat, Kugler, Stegenta-Dąbrowska K, et al. Waste to carbon: Biocoal from elephant Dung as new cooking fuel. Energies. 2019;12:4344. https://doi.org/10.3390/en12224344.
9. Suma Y, Pasukphun N, Eaktasang N. Adsorption of methylene blue by Low-Cost Biochar derived from elephant Dung. App Envi Res 2021:34–44. https://doi.org/10.35762/AER.2021.43.3.3
10. Rout PR, Shahid MK, Dash RR, Bhunia P, Liu D, Varjani S, et al. Nutrient removal from domestic wastewater: A comprehensive review on conventional and advanced technologies. J Environ Manage. 2021;296:113246. https://doi.org/10.1016/j.jenvman.2021.113246.
11. Di Minin E, Slotow R, Fink C, Bauer H, Packer C. A pan-African Spatial assessment of human conflicts with lions and elephants. Nat Commun. 2021;12:2978. https://doi.org/10.1038/s41467-021-23283-w.
12. Nyumba TO, Emenye OE, Leader-Williams N. Assessing impacts of human-elephant conflict on human wellbeing: an empirical analysis of communities living with elephants around Maasai Mara National reserve in Kenya. PLoS ONE. 2020;15:e0239545. https://doi.org/10.1371/journal.pone.0239545.
13. Campos-Arceiz A, Blake S. Megagardeners of the forest – the role of elephants in seed dispersal. Acta Oecol. 2011;37:542–53. https://doi.org/10.1016/j.actao.2011.01.014.
14. Westerman PW, Bicudo JR. Management considerations for organic waste use in agriculture. Bioresour Technol. 2005;96:215–21. https://doi.org/10.1016/j.biortech.2004.05.011.
15. Waithaka MM, Thornton PK, Shepherd KD, Ndiwa NN. Factors affecting the use of fertilizers and manure by smallholders: the case of Vihiga, Western Kenya. Nutr Cycl Agroecosyst. 2007;78:211–24. https://doi.org/10.1007/s10705-006-9087-x.
16. Zeweld W, Van Huylenbroeck G, Tesfay G, Speelman S. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. J Environ Manage. 2017;187:71–81. https://doi.org/10.1016/j.jenvman.2016.11.014.
17. Greenfield P. Death toll rises to seven in Malawi elephant relocation project linked to Prince Harry NGO 2024.
18. Mpaka C. accessed November 10,. Jumbo task as Malawi moves 263 elephants to restock a degraded national park 2022. https://news.mongabay.com/2022/08/jumbo-task-as-malawi-moves-263-elephants-to-restock-a-degraded-national-park/ (2023).
19. Ministry of Agriculture. Lilongwe, Malawi. National Fertilizer Policy; 2021.
20. Walkley A. An examination of methods for determining organic carbon and nitrogen in Soils. (With one Text-figure). J Agric Sci. 1935;25:598–609. https://doi.org/10.1017/S0021859600019687.
21. Feldsine P, Abeyta C, Andrews WH, AOAC INTERNATIONAL Methods Committee Guidelines for Validation of Qualitative and Quantitative Food Microbiological Official Methods of Analysis. J AOAC Int. 2002;85:1187–200. https://doi.org/10.1093/jaoac/85.5.1187.
22. Mehlich A. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun Soil Sci Plant Anal. 1984;15:1409–16. https://doi.org/10.1080/00103628409367568.
23. Brady NC, Weil RR. The nature and properties of soils. Rev. 14. ed. Upper Saddle River, NJ: Pearson/Prentice Hall; 2008.
24. European Commission. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending regulations (EC) 1069/2009 and (EC) 1107/2009 and repealing regulation (EC) 2003/2003 2019.
25. Ministry of Agriculture. Lilongwe, Malawi. Guide to Agriculture Book of Malawi. 2014.
26. Nguma E, Munthali C, Murayama D, Onishi K, Mori M, Kinoshita R, et al. Fertilizer effects on endosperm physicochemical properties and resistance to larger grain Borer, prostephanus truncatus (Coleoptera: Bostrichidae), in Malawian local maize (Zea Mays L.) varieties: potential for utilization of Ca and Mg nutrition. Agronomy. 2021;12:46. https://doi.org/10.3390/agronomy12010046.
27. Haynes RJ, Naidu R. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr Cycl Agrosyst. 1998;51:123–37. https://doi.org/10.1023/A:1009738307837.
28. Mosaddeghi MR, Mahboubi AA, Safadoust A. Short-term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in Western Iran. Soil Tillage Res. 2009;104:173–9. https://doi.org/10.1016/j.still.2008.10.011.

## Publisher's note