Exploration of the potential of elephant manure as fertilizer and/or soil improver

Deliverable D4.5 | Evaluation of sideflows for upcycling, soil improvement and fertilizing resource: Elephant manurex

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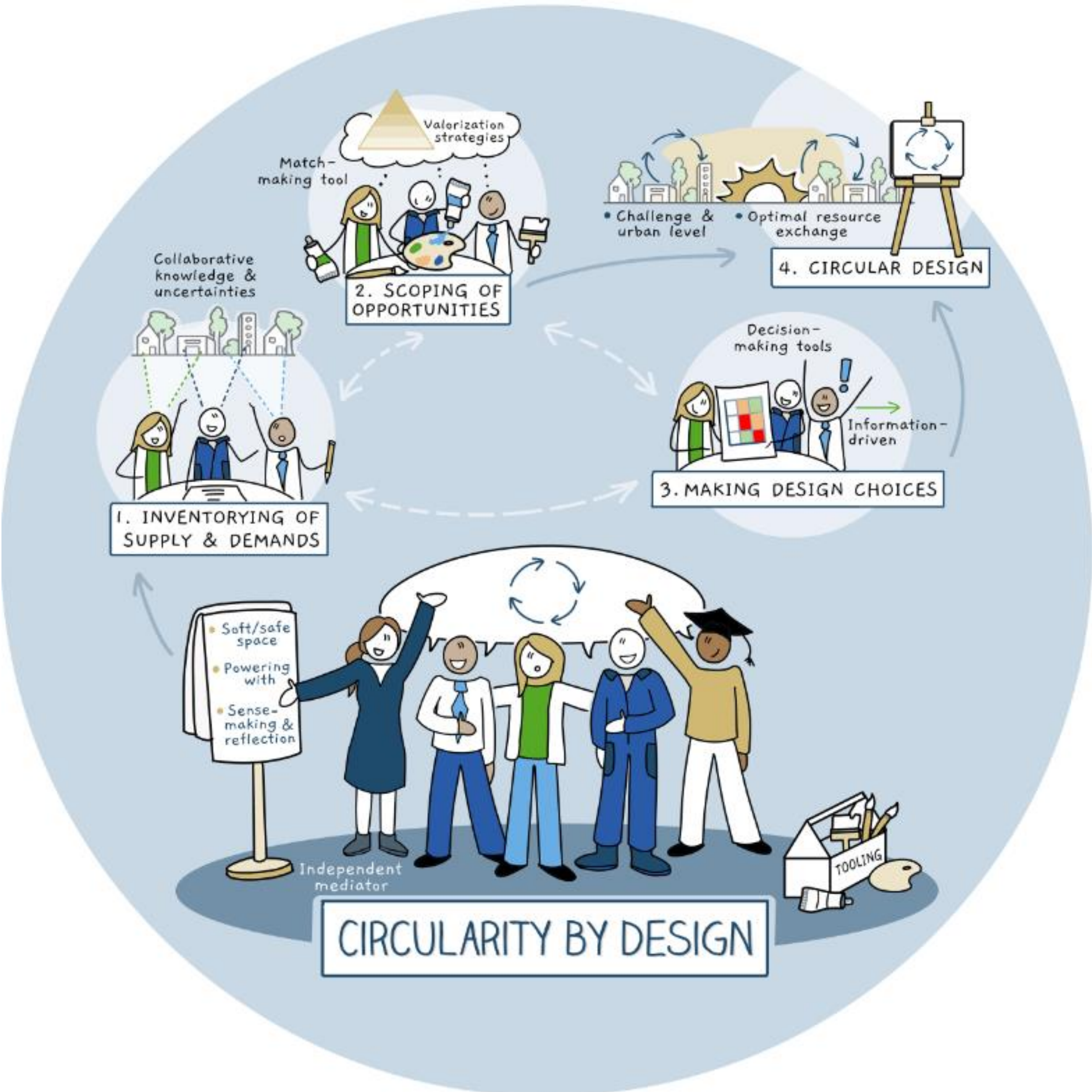
Preface

This report is part of the WUR flagship project Circularity by Design, embedded within the strategic investment theme Connected Circularity. The project aims to apply (re)design principles to develop a sustainable agri-food system within the Amsterdam Metropolitan Region. A critical question to design for circularity, is how to optimise the allocation of resources, including the current waste streams in the city, with the ambition to (re)use them in the agri-food system. Creating a coherent chain in which both the final product and the waste streams are recycled requires an integrated approach.

Within the project, we have developed a 4-step approach (figure below) to translate a circular bio-economy within the urban environment. This requires close collaboration between stakeholders involved, and a connection between technological opportunities and societal needs. Collaboration is key! Based on experiences in creating circular designs within four Amsterdam Challenges, we have created and tested tools to support stakeholders with inventorying, data collection, scoping of opportunities, design choices and how to translate circular dreams into practice. This allows us to support decision making processes, including repurposing of side streams and upcycling of agri-food resources within different scenarios.

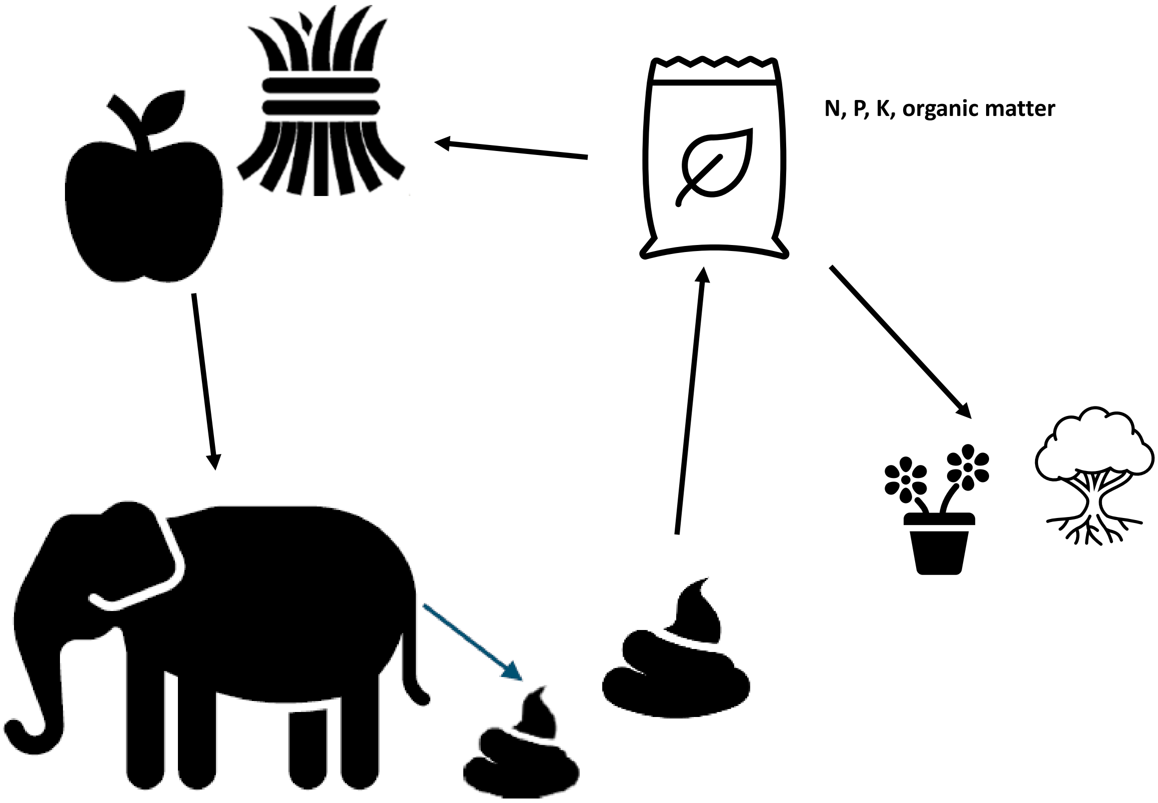


The 4-step Circularity by Design approach (Graphic designer: Bureau voor Beeldzaken, 2022).

The following challenges have been identified:

- Urban food systems
- Organic household waste
- Urban food production
- Circular way of living

In a joint effort between the AMS Institute, researchers from 12 different expertise areas of Wageningen University and Research (WUR) and local stakeholders ('Challenge Owners') in Amsterdam, we have created a scientific foundation for Circular Designs in the urban environment. This report shows the results of a study on the mineralisation potential and agricultural value of elephant manure from Artis zoo to evaluate options for upcycling this organic waste stream.



Summary

Elephants in Artis Zoo (Amsterdam, the Netherlands) produce high quantities of manure daily, which is currently being discarded as waste. Potentially, elephant manure could be used as a fertiliser and/or soil improver. To explore this, an aerobic incubation experiment was carried out in the laboratory. Results were evaluated by modelling, using default values of dairy cow slurry (DCS) for comparison. It was hypothesised that 1) elephant manure would mineralise slowly and, 2) release relatively small amounts of N compared to dairy cow slurry. The carbon content and C:N-ratio in elephant manure were 419 g kg^{-1} and 36:1, respectively. The estimated humification coefficient of elephant manure was 0.32, indicating faster mineralisation than of DCS in The Netherlands (0.7). Modelling the results showed that after 10 years of annual additions of 100 kg N_{org} ha^{-1}, total carbon build-up from elephant manure and DCS was ca. 4800 and 6800 kg ha^{-1}, and total nitrogen mineralisation was 540 and 490 kg N ha^{-1}, respectively. The higher mineralisation rate from elephant manure compared to DCS could be due to occurrence of priming during the incubation experiment and/or different qualities of organic matter fractions. It was concluded from this experiment that elephant manure could be suitable as both a soil improver and fertiliser, and recommendations for follow-up research are given.

Keywords: elephant manure, mineralisation, fertiliser, soil improver, modelling

1 Introduction

Elephants in Artis Zoo (Amsterdam, the Netherlands) produce high quantities of manure daily, which is currently being discarded as waste. In their original habitat, elephants feed on savanna grasses with high fibre and low N-content. Given these characteristics, elephant manure could potentially be used as a fertiliser (delivering N) and/or soil improver (increasing soil organic carbon (SOC)). Tentatively, this could lead to other, useful forms of manure disposal in Artis Zoo, e.g. as a specialty manure made available to visitors for household use, and/or to farmers for agricultural purposes. A first exploration of the potential uses of elephant manure was made within the program Circularity by Design, a cooperation between the Amsterdam Metropolitan Area and Wageningen University & Research. The research involved the assessment of manure characteristics followed by modelling both carbon and nitrogen mineralisation. It was hypothesised that 1) elephant manure would mineralise slowly, and 2) release small amounts of N compared to common manures in the Netherlands, e.g. dairy cow slurry (DCS). Results are interpreted in view of possible sustainable use of the manure for plant growth, as soil improver (adding carbon) and/or nitrogen fertilizer.

2 Materials and methods

To assess the carbon mineralisation rate of elephant manure, an aerobic incubation experiment was performed in the laboratory with elephant manure added to soil, and a control soil sample. Elephant manure was obtained from Artis Zoo. The soil consisted of loamy fine sand from a plot that had been used for grass growth and was fertilized with dairy manure (Oostelijk Zandgebied, Achterhoek, the Netherlands) (details can be found in De Haan et al, 2021). The soil was dried at 40 °C and sieved at 2 mm before the start of the incubation experiment. Initial carbon (C) and nitrogen (N) contents in manure and soil were determined with a CHN analyser (LECO Corporation, St Joseph, Michigan, USA). Given the explorative character of this study, the experiment was conducted in singular, following the procedure described in Van Groenigen and Zwart (2007).
The carbon mineralization experiment was performed through incubation of 200 g dry soil in 0.575 L incubation flasks. The water holding capacity (WHC) was determined visually by adding water to the soil until the point where the soil becomes saturated. The WHC was 360 ml/kg and the soil was incubated at 60 % of the WHC. The soil was thoroughly mixed with the elephant manure (200 g dry soil with 15 g fresh elephant manure) and thereafter brought to 60 % of the WHC. The amount of water added was corrected for the amount of water already supplied with the elephant manure. A conditioning period of 3 days was kept before measuring CO_2-evolution, and in the calculations, emissions at day 3 were taken as first measuring point (t=0). The experiment was conducted at a temperature of 20 °C. The flasks were initially flushed with air and thereafter closed for 1 up to 6 hours in order to allow CO_2 to accumulate. The gas composition was measured by a photo acoustic infra-red gas monitor (Innova 112). The headspace volume amounted to 531 ml and was determined at the end of the experiment by determining the volume of water needed to fill the flask.
The CO_2 evolution was measured at day 3, 14 and 56. For each sample, CO_2-emission data were averaged over the two periods 0 – 14 and 14 – 56 days, respectively. The amount of C remaining in the two flasks at the three time points was calculated, taking into account the closing time needed in the measurement. The amount of C in the elephant manure at each time point was calculated by subtracting the calculated C in the soil sample from the calculated C in the soil + manure sample. According to the temperature correction factor in MINIP (Janssen, 1996), the number of 182 days in the laboratory at 20 °C may be considered equivalent to 365 field days in for the Netherlands. Thus the curve of the three time-points was extrapolated to 182 days, for which a general exponential model ($y = b*m^x$; $t \geq 0$) was used. Subsequently, the fraction of remaining C from elephant manure after 1 year relative to initial C from elephant manure was calculated, which is generally known as the humification coefficient (HC).
HC was subsequently used for modelling the N-mineralisation from elephant manure and DCS, using the MINIP-model, which can calculate the build-up of organic matter and N mineralisation under different circumstances (Janssen, 1984, 1996). Comparison was made on the base of yearly additions of 100 kg N_{org} per hectare over a period of 10 years. Data for DCS were taken from Handboek Bodem and Bemesting, online, i.e. HC = 0.70; N_{org}-content 2.1 kg per 1000 kg product). Total N content was 1.4 and NH_3 was 0.02 g/100 g DM (Table 4). Considering the elephant's diet (mix of dry feed, twigs/branches, hay and fruit/vegetables), it was assumed that all nitrogen in elephant manure would be in the form of organic nitrogen. In the modelling, assessment was made specific to the manure characteristics, assuming optimal temperature and moisture conditions.

3 Results

The C- and N-contents, and the C/N-ratio of the fresh elephant manure (Table 1) were comparable to those found previously (Cone and Bosch (2020, Table 4) and may be considered high compared to the dried soil. Using 15 g of fresh elephant manure with 200 g dry soil resulted in a sample with C/N-ratio of 12.5, suitable for an incubation experiment of 8 weeks without risking microbial N shortage, should immobilisation of N occur. Also, from the respiration data of the soil sample without elephant manure, the average breakdown of soil organic matter was estimated at 2.700 kg ha^{-1} $year^{-1}$, which is a common figure for soils in The Netherlands. Hence the data were found suitable for further analysis.

Table 1 Measured characteristics of soil and elephant manure.

Substrate	Dry matter (%)	C_{tot} (g kg^{-1} DM)	N_{tot} (g kg^{-1} DM)	C_{tot}/N_{tot} ratio
Soil (dry)	99.1	16.7	1.7	10
Elephant manure (fresh)	20.3	419	11.8	36

For DCS, the following data are taken from the literature: dry matter 92 %, organic matter 7.1 %, N 4.0 (g kg^{-1}) (Handboek Bodem and Bemesting, online). As a rule of thumb, C-content in organic matter is 50 % in manures and 45 % in composts (Hanegraaf et al., 2021). From this, assessed values for the C-content and C_{tot}/N_{tot}-ratio of elephant manure, are 36 and 9, respectively (see also Table 3).
Respiration declined rapidly during the first two weeks of the experiment, followed by slower rates towards the end. Furthermore, it was found that respiration was proportionally higher in the treatment with soil + elephant manure as compared to soil alone (Figure 1).

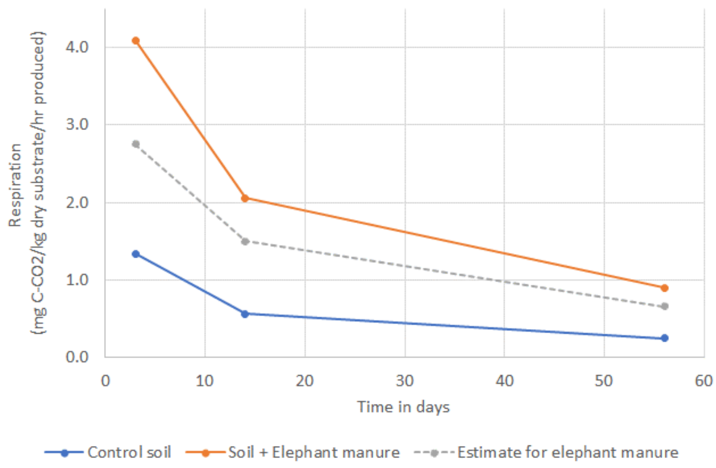


Figure 1 Respiration rates in the aerobic incubation experiment from soil with and without elephant manure

The calculated amounts of remaining C show that indeed a larger fraction of C is mineralised from elephant manure than from C from soil organic matter (Table 2). The estimated HC of the elephant manure is 0.32, indicating a faster mineralisation as compared to the currently used value of 0.7 for DCS (Handboek Bodem and Bemesting, online).

Table 2 Remaining C in elephant manure over time.

Substrate	Remaining C (g kg^{-1} dry substrate), T= 20 °C)			
	t=0	t=14	t=56	t=182*
Soil	16.7	16.4	16.0	14.5
Soil + elephant manure	22.7	21.7	20.2	15.6
Elephant manure	6.0	5.3	4.2	1.1

* Calculated value

Using the data from Table 1, an application of 100 kg N_{org} per hectare refers to 45 x 10^3 kg fresh elephant manure and 48 x 10^3 kg DCS, which in turn is equivalent to 3600 and 1700 kg C ha^{-1}, respectively. Modelling results showed that after 10 years of annual additions, carbon built-up from elephant manure was lower than from DCS (Figure 2, left). The results also show that the difference between the manures becomes already clear after the 2nd year of application. As for the mineralisation of nitrogen, it was found that the contribution of elephant manure was similar to that of DCS (Figure 2, right). Model results further indicate that in the 1st year after addition of elephant manure, nitrogen immobilisation may occur. This is counteracted by net nitrogen mineralisation arising from the manure at the 2nd year after application. After 6 years, elephant manure is, based on the model, expected to exceed DCS in terms of N mineralisation.

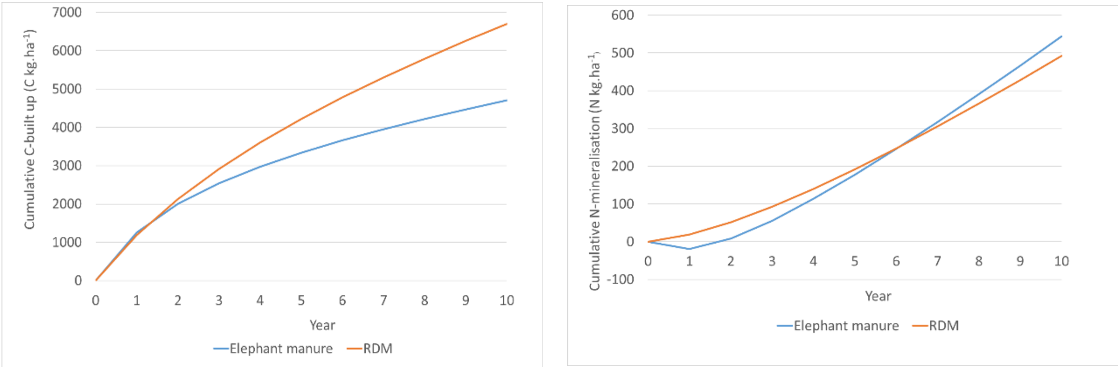


Figure 2 ***Modelled carbon build-up and nitrogen mineralisation of elephant manure as compared to DCS (=RDM) (addition of 100 kg N each year; left: carbon; right: nitrogen).***

4 Discussion

Elephant manure stands out for its high carbon content (419 g C_{tot}/kg DM) and C/N-ratio (36) when compared to other livestock manures and other organic materials (Table 3) current in Dutch agriculture. Based on the HC (0.32), elephant manure is similar to pig and poultry manure.

Table 3 Default values of some common organic fertilisers and soil improvers (taken from Handboek Bodem en Bemesting, online) and values for elephant manure

Organic product	HC	C_{tot}	N_{tot}	N_{org}	C_{tot}/N_{org}-ratio
		kg per 1000 kg product			
DCS	0.70	36	4.0	2.1	17
Pig manure	0.33	40	7.0	3.3	12
Poultry manure	0.33	208	28.4	25.7	8
FYM	0.70	78	7.7	6.6	12
Horse manure	n.a.	80	4.6	4.1	20
VFG compost	0.90	109	8.9	8.1	15

Model results as shown in Figure 2 suggest a high value of elephant manure as soil improver when applied annually over the course of 10 years. The relatively fast mineralisation is contradictory to our 1st hypothesis, assuming a slow mineralisation. However, since the experiment was performed in singular and HC values are known to show variations (Yuan, 2019; Hanegraaf et al., 2021), no hard conclusions can be drawn from this. In addition, our 2nd hypothesis did not hold either. It was calculated that the nitrogen delivery of elephant manure over years is comparable to DCS, even if not all nitrogen would be in organic form as was assumed here. However, for use as a fertiliser, care would have to be taken as to which crops elephant manure may be given, as some immobilisation of nitrogen may occur during the 1st year of application.

In general terms, before using elephant manure as either soil improver or nitrogen fertiliser, it is essential to know its full composition. It is known that elephant manure may contain useful contents of macronutrients P and K as well as several micronutrients (Table 4). However, no data is available regarding zoonoses and/or possible contaminants.

The results in this experiment do not indicate why elephant manure, given its high C/N-ratio, would mineralise so fast. A high C/N ratio generally indicates a stable product, suited as soil improver rather than fertiliser. However, this does not always have to be the case since the carbon fraction may consist of varying proportions of easily degradable sugars and fibres. The latter may be expressed, in order of increasing degradability, as Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), and Acid Detergent Lignine (ADL). Relevant data for elephant manure are given (Table 4). For DCS, corresponding data are 43, 24, and 8 g 100 g^{-1} DW (Schoumans et al., 2022, in prep.). The higher NDF fraction in elephant manure compared to DCS may, at least partly, explain the higher mineralisation of organic matter in elephant manure as compared to DCS. Varying quality of the fractions organic matter may account for higher nitrogen mineralization of elephant manure. In addition, it is possible that the mixture of fresh elephant manure and a dry soil led to accelerated mineralisation of organic matter from both manure and the soil origin (priming). Hence the calculated HC may be inflated due to the occurrence of priming in the incubation experiment.

Table 4 Chemical composition (g 100 g^{-1} dry matter unless stated otherwise) of manure from Asian elephants (Elephas maximus) in Artis (Amsterdam, the Netherlands) (Cone and Bosch, unpublished).

Parameter	Content
Dry matter	23.0
Crude ash	13.6
NDF	68.8
ADF	47.8
ADL	13.0
N	1.4
C	45.1
C:N ratio	33.4
P	0.38
CP	8.4
K	1.05
Mg	0.24
Na	0.18
NH_3, mg/g fresh weight	0.216
NH_3, mg/l	0.277
Ca	1.35

5 Conclusions and recommendations

In this study the potential use of elephant manure as a soil improver and/or fertiliser was explored, showing it may be suitable for both purposes as it adds average amounts of carbon and nitrogen to the soil within a medium time frame. As a next step, extended incubations (replications, measuring frequencies, running time) and pot- and/or field trials are advised to establish specific recommendations for soil quality and/or crop growth. Such trials should also include the measurement of organic N- and P-contents in the elephant manure, to assess their concentrations (and resulting application rates) in light of the current nutrient regulations. In addition, the risks of zoonoses must be assessed. Future work could also include options for manure management, i.e. digestion. This could result in a lower moisture content of the solid fraction and thus, combined with treatment of the liquid fraction onsite, facilitate handling and transport, due to lower volumes.

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