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Dry Matter Allocation and Yield Response of Carrot (*Daucus carota L.)* to Fertilization with *Moringa oleifera* and *Tithonia diversifolia* Leaf Extracts

C.Chuulu [a], P. Yooma [a], E. Manda [a] and N. Bbebe [a*]

[a] *School of Agriculture and Natural Resources, Mulungushi University, Kabwe, Zambia.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study evaluated the effects of various fertilizers—Moringa leaf extract, Tithonia leaf extract, a mixture of both (Mix), and a standard inorganic NPK+Urea fertilizer—on carrot (*Daucus carota)* growth, root development, and overall yield. Initial growth parameters, including leaf area index, plant height, and leaf count, showed no significant differences among treatments. However, significant variations emerged in biomass accumulation and root morphology as the carrots matured.

The study established a significant effect of fertilizer type on several key metrics. Fresh shoot weight was significantly higher with the Moringa treatment (0.430kg/plot) compared to the Mix (0.290 kg/plot)) and NPK+Urea (0.390kg/plot) treatments. In contrast, fresh root weight was highest with NPK+Urea (2.39 kg/plot)), followed by Moringa (2.08 kg/plot), Tithonia (1.88 kg/plot)), and the

**Corresponding author: E-mail: nchybe@gmail.com;*

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Mix (1.66 kg/plot)). In terms of root dry weight, Moringa (0.0539 kg/plot)) significantly outperformed the Mix (0.0422kg/plot), Tithonia (0.0426 kg/plot) and NPK+Urea (0.04 kg/plot)
For root morphology, root length was highest with NPK+Urea (16.8 cm) and Moringa (16.7 cm), both outperforming the Mix and Tithonia treatments. Similarly, root diameter was highest with NPK+Urea (36.3 mm), followed by Moringa (34.3 mm). Total yield was significantly affected, with NPK+Urea leading (8.08 t/ha), while Moringa (6.39 t/ha) and Tithonia (6.49 t/ha) demonstrated similar yields, proving to be strong organic alternatives to the Mix (5.42 t/ha).
In conclusion, although the inorganic NPK+Urea fertilizer resulted in the highest overall yield, the Moringa leaf extract demonstrated strong potential as a competitive organic alternative. It significantly enhanced fresh shoot weight and achieved root dry weight and root length comparable to the inorganic standard, highlighting its viability for sustainable carrot production systems.

Keywords: Moringa oleifera; Tithonia diversifolia; leaf extracts; organic fertilizer.

1. INTRODUCTION

Carrot (*Daucus carota L.*) is one of the world's most economically important root vegetables, valued both for its nutritional composition and global market significance (FAO, 2022). As demand continues to grow in both developed and developing nations, production systems face increasing pressure to optimize yield while addressing sustainability concerns (Smith et al., 2024). This dual challenge has brought renewed attention to fertilization strategies, particularly the comparative efficacy of organic versus inorganic nutrient sources in carrot cultivation (Sah et al., 2024: Mugwe et al., 2019)

The physiological response of carrots to nutrient availability presents unique considerations among vegetable crops. As a root vegetable, carrot exhibits distinct patterns of biomass partitioning and morphological development that differ fundamentally from fruit or leaf crops (Mazed et al., 2015; Adekiya et al., 2022). The crop's sensitivity to nutrient timing and form is well-documented, with particular responsiveness to nitrogen availability during critical growth stages (Babu et al., 2014). However, the broader implications of fertilizer selection extend beyond yield alone, encompassing root morphology, nutritional quality, and postharvest characteristics (Mbuyisa et al., 2023).

Conventional production systems have traditionally relied on synthetic inorganic fertilizers to meet crop demands, offering predictable nutrient release and high yield potential (Agbede et al. 2017). Yet growing environmental concerns, including soil degradation and nutrient runoff, have prompted examination of alternative approaches to carrot nutrition (Akpan et al., 2021; Akhtar et al., 2023). Organic alternatives such as *Moringa oleifera and Tithonia diversifolia* leaf extracts present potentially sustainable alternatives, although their variable nutrient composition and mineralization rates introduce new management considerations (Aboyeji, 2022: Okonji, 2023). Some studies suggest these organic sources of crop nutrition may influence not only yield but also root architecture and phytochemical content (Ahkter et al., 2024).

Despite this growing body of research, significant knowledge gaps persist regarding the growth, yield and dry matter dynamics associated with carrot responses to different nutrient sources (Sah et al., 2024). Most existing studies have focused narrowly on yield outcomes or nutrient uptake efficiency, with limited examination of how fertilizers influence developmental patterns and dry matter dynamics (Uddin et al., 2021).

This study evaluates how organic (*Moringa oleifera leaf* extract, *Tithonia diversifolia* leaf extract*)*, inorganic (NPK+Urea), mixture of *Moringa oleifera,* and *Tithonia diversifolia* leaf extracts fertilization affect carrot growth, yield, and dry matter partitioning.

2. MATERIALS AND METHODS

2.1 Study Area and Duration

The experiment was conducted at the Mulungushi University main campus greenhouse in Kabwe, Central Province, Zambia (Latitude 646395 m E, Longitude 8431002 m N, UTM zone 35S). The study spanned from December 26, 2024, to April 1, 2025, allowing carrots to reach maturity. Loam soils were used, prepared into 0.6 m 0.12 m beds. Agricultural lime was applied to the soil prior to planting to achieve an optimal pH for carrot growth. Each bed was planted with 25 carrot seeds.

Table 1. Soil characteristics of the study site

Soil Characteristic	Description
Soil Texture	Sandy Loam
pH	6.4
Olsen P	12.8g/ka
Kex	2.7mmol/kg
N	750mg/kg
Organic matter	1.6%

2.2 Experimental Design and Treatments

A Randomized Complete Block Design (RCBD) was employed, consisting of four treatments replicated three times, totaling 16 experimental units. The treatments included: M (Moringa leaf extract), T (Tithonia leaf extract), Mix (a mixture of Moringa and Tithonia leaf extracts), and NPK+Urea (Urea (46%N) and D-compound (NPK 10:20:10) as a reference control. Materials used included 500g each of Urea, Compound D, fresh Moringa leaves, and fresh Tithonia leaves per application, along with 5L buckets and a 1.5L spray bottle. Treatments were randomly assigned to plots within four blocks.

2.3 Preparation of Leaf Extracts

Fresh moringa and tithonia leaves (500g each) were separately pounded using a pestle and mortar. Each pounded leaf material was then transferred to a 5L bucket and mixed with 1.5L of warm water (500g leaves to 1.5L water ratio). The solutions were left to soak for 24 hours. For application, the soaked leaf extracts were diluted at a ratio of 500ml extract to 1.5L water.

2.4 Crop Establishment

Land preparation commenced on November 19, 2024, involving loosening the soil to a depth of approximately 20 cm, removing stones, and leveling the seedbed. Lime was applied to adjust soil pH to 6.0–6.8 and thoroughly incorporated. On December 26, 2024, Nantes carrot seeds (Zamseed variety) were sown at a depth of approximately 1 cm, maintaining 25 cm spacing between rows. Beds were gently watered and mulched to retain moisture. Weeding and soil aeration were performed regularly.

2.5 Pest Control

On January 23, 2025, an insecticide (PestGuard, containing Acetamiprid, Emamectin Benzoate, and Abamectin) was sprayed at 5 PM to control white grubs (Phyllophaga) and other insects. The concentration used was 0.0625 mL per liter, applied every two weeks due to high infestation levels. Pest populations were regularly monitored to adjust application frequency.

2.6 Treatment Application

The first application of bio-fertilizer treatments (Moringa, Tithonia, and Mix leaf extracts) was conducted on January 10, 2025, 14 days after planting and 7 days after emergence. Subsequent foliar applications were performed every two weeks. For the NPK+Urea treatment, Compound D (basal dressing) was applied on January 10, 2025. Urea (top dressing) was applied four weeks after the Compound D application. Both inorganic fertilizers were applied using the broadcasting method into narrow lines and covered with soil to prevent wash-off during the rainy season.

2.7 Data Collection

Data were collected on various growth and yield parameters as follows: Root Length was determined by measuring the length of harvested carrot roots using a 30cm ruler. Four carrots per plot were measured, and averages recorded. Root Diameter was measured using a Vernier caliper at the middle of freshly harvested roots. Four carrots per plot were measured, and averages recorded. Leaf Area Index (LAI) was estimated by measuring the length (L) and maximum width (W) of leaves from four representative plants (Area = L × W). Total leaf area was summed, multiplied by the total number of plants per bed, and divided by the ground area of the bed. Plant Height was measured by placing a ruler vertically from the base to the tip of the longest leaf of four randomly selected plants per bed.

Harvesting: The crop was harvested manually by hand pulling on April 1, 2025 (96 days after planting). Total yield, fresh root weight, and fresh leaf weight were recorded.

2.8 Yield and Biomass Determination

Total Yield: Estimated by randomly selecting 20 carrots from each plot, weighing them, and multiplying the weight by the total area (in hectares) for the respective treatment. Fresh Root and Leaves Weight: Five fresh carrot roots and five fresh carrot leaves were randomly selected from each treatment, packed separately, and weighed using a beam balance scale. Dry Root and Leaves Weight: Five fresh roots and five fresh leaves from each treatment were cut into smaller pieces, packed into A2 envelopes (separately), and dried in a natural science lab oven at 80∘C for 48 hours.

2.9 Data Analysis

All collected data were subjected to Analysis of Variance (ANOVA) at a 5% level of significance to determine treatment effects. Where significant differences were observed, Tukey's Honestly Significant Difference (HSD) post-hoc test was performed for mean separation.

3. RESULTS

The effects of different treatments (MIX: *Tithonia* + *Moringa*, *Moringa* alone, NPK+Urea fertilizer, and *Tithonia* alone) on carrot growth and yield components revealed significant variations across multiple parameters.

3.1 Vegetative Growth Parameters

Leaf Area Index (LAI) did not differ significantly among treatments though NPK+Urea (2.38cm^2) and MIX (2.34cm^2) had numerically higher values than *Tithonia* (1.66cm^2). Plant height and number of leaves were also unaffected by treatments, with means ranging between 33.6–37.3 cm and 7.40–8.40, respectively.

3.2 Fresh and Dry Biomass

Fresh Shoot weight (F.S.W) varied significantly with *Moringa* (0.430kg/plot) outperforming MIX (0.290kg/plot), p=0.003) and NPK+Urea (0.390 kg/plot), p=0.027).

Fresh root weight (F.R.W) showed highly significant treatment effects where NPK+Urea (2.39kg/plot) > *Moringa* (2.08kg/plot) > *Tithonia* (1.88kg/plot) > MIX (1.66kg/plot) (all p<0.001 except *Moringa* vs. *Tithonia*, p=0.001).

Root dry weight (R.D.W) differed significantly with *Moringa* (0.0539kg/plot) surpassing MIX (0.0422kg/plot), p<0.001) and *Tithonia* (0.0426 kg/plot), p<0.001), but not NPK+Urea (0.0436 kg/plot), p=0.854).

Shoot dry weight (S.D.W) also varied significantly with *Moringa* and *Tithonia* (both 0.0734 kg/plot) g) exceeding MIX (0.0448 kg/plot) p<0.001) and NPK+Urea (0.0544 kg/plot), p<0.001).

3.3 Root Morphology and Yield

Root length (R.L) was highest under NPK+Urea (16.8 cm) and *Moringa* (16.7 cm), both surpassing MIX (15.4 cm, p<0.001) and *Tithonia* (15.6 cm, p<0.001 for NPK+Urea only). Root diameter (R.D) varied significantly (F=295.780, p<0.001), with NPK+Urea (36.3 mm) > *Moringa* (34.3 mm) > MIX (32.3 mm) > *Tithonia* (31.5 mm) (all p≤0.003)

Table 2. Analysis of variance for carrot yield and physiological parameters

Trait	df	MS	F-Value	P-value	Treatment effect (η^2)
Leaf Area Index	3	0.624	2.38	0.121	0.059
Plant Height	3	15.08	2.37	0.121	0.031
Number of Leaves	3	1.133	1.68	0.224	0.018
Fresh biomass	3	0.2046	10.04	0.001	0.656
Dry biomass	3	0.00104	168.8	<.001	0.969
Fresh Root Weight	3	0.476	130.7	<.001	0.970
Root Dry Weight	3	0.000164	21.37	<.001	0.799
Root length	3	2.64	113.7	<.001	0.943
Root Diameter	3	23.09	300.8	<.001	0.985
Total Yield	3	6.0582	193.1	<.001	0.974
Plant height: Root Length	3	0.0871	3.46	0.05	0.044
Root Diameter: Root Length	3	0.01902	48.0	<.001	0.863
Root DryWeight:Shoot Dry weight	3	0.1158	34.93	<.001	0.854

Table 3. Means separation for carrot yield and physiological traits (Tukey, 0.05)

Treatment	FSW (kg)	DSW (kg)	FRW (kg)	RDW (kg)	RL (cm)	RD (mm)	TY (ton/ha)	RD:RL	RDW: SDW
Moringa (M)	0.43c	0.0738c	2.08c	0.054b	16.7b	34.3c	6.38b	2.05a	0.74b
Tithonia (T)	0.32ab	0.0734c	1.88b	0.043a	15.6a	31.5a	6.49b	2.02a	0.58a
Mix (M&T)	0.29a	0.0448a	1.66a	0.042a	15.4a	32.3b	5.42a	2.10b	0.95c
NPK+Urea	0.39ab	0.0544b	2.39d	0.040a	16.8b	36.3d	8.08c	2.16c	0.80b
Grand Mean	0.35	0.062	1.75	0.046	16.13	33.6	6.59	2.08	0.77
CV (%)	5.2	4.02	3.02	6.07	0.94	0.82	2.69	0.96	7.51
LSD(5%)	0.012	0.004	0.107	0.005	0.27	0.49	0.32	0.04	0.10

Values followed by the same letters within a column are not statistically different at p=0.05. FSW-Fresh shoot weight, DSW-Dry shoot weight, FRW-Fresh root weight, RDW-Root Dry weight, RL-Root length, RD-Root Diameter, TY-Total Yield

Total yield was significantly affected by treatment effects, ranking NPK+Urea (8.08 t/ha) > *Moringa* (6.39 t/ha) ≈ *Tithonia* (6.49 t/ha) > MIX (5.42 t/ha) (all $p<0.001$ except *Moringa* vs. *Tithonia*, $p=0.858$).

3.4 Physiological Ratios

The root diameter-to-length ratio was highly and significantly affected by treatment effects with NPK+Urea (2.16) > MIX (2.10) > Moringa (2.06) > Tithonia (2.02) ($p \le 0.002$ for NPK+Urea vs. others). Root-to-shoot dry weight ratio (RDW/SDW) also varied significantly where MIX (0.947) > NPK+Urea (0.803) > Moringa (0.737) > Tithonia (0.580) (all $p \le 0.009$ except Moringa vs. NPK+Urea, $p=0.326$).

4. DISCUSSION

The present study investigated the influence of two botanical leaf extracts (*Moringa oleifera* and *Tithonia diversifolia*, inorganic (NPK+Urea), and mixed organic mixture of moringa and tithonia) fertilization strategies on the growth, biomass allocation, root morphology, and yield of carrot (*Daucus carota* L.). The differential responses observed across various parameters highlight the importance of nutrient source selection in optimizing carrot production systems.

Vegetative Growth Parameters The initial phases of vegetative growth, including Leaf Area Index (LAI), plant height, and leaf number, did not exhibit significant differences across treatments. This suggests that early canopy development in carrots might be less sensitive to distinct fertilizer types when basic nutrient availability is met by soil supplied nutrients. While NPK+Urea and the moringa+tithonia extract treatments numerically presented higher LAI values compared to tithonia, these differences did not translate into statistically significant canopy size variations, a phenomenon also noted in other carrot trials with organic amendments where initial growth parity was observed despite varying nutrient sources (El-Sayed et al., 2022). This indicates that the inherent growth vigor of 'Nantes' carrot or the baseline soil fertility of the experimental site may have buffered against immediate observable differences in vegetative parameters.

4.1 Biomass Allocation Patterns

Despite the lack of early vegetative differences, significant variations emerged in biomass accumulation. Moringa-treated plants exhibited superior fresh shoot weight compared to MIX and NPK+Urea. This finding aligns with previous research highlighting the beneficial effects of *Moringa oleifera* on foliar growth, often attributed to its rich content of phytohormones, such as cytokinin-like compounds, and micronutrients (El-Sayed et al., 2022). Conversely, NPK+Urea fertilization clearly dominated in terms of fresh root weight, surpassing all other treatments. This underscores carrots' well-documented strong responsiveness to readily available synthetic nutrients, particularly nitrogen and phosphorus, during the critical root tuberization phase (Babul et al., 2025). This rapid availability allows for efficient nutrient uptake and allocation to the developing storage root.

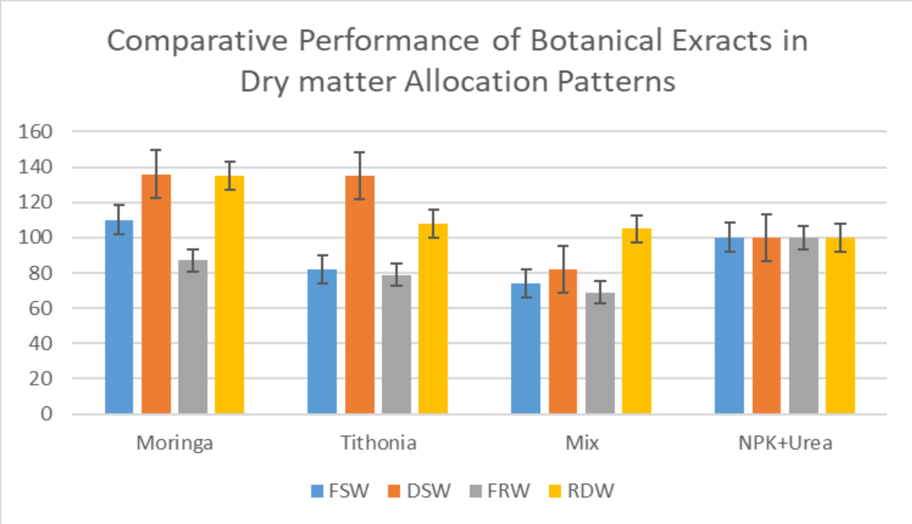

Fig. 1. Comparative effects of botanical extracts on dry matter allocation patterns in carrots

Despite NPK+Urea's highest rank in fresh root weight, moringa's performance in root dry weight was statistically comparable to NPK+Urea and significantly higher than MIX and Tithonia. This indicates that while NPK+Urea promoted greater water uptake leading to higher fresh weight, moringa's organic nutrients were highly effective in sustaining actual dry matter accumulation in the roots, a crucial advantage for organic carrot production where nutrient forms might be expected to influence dry matter content more directly. Furthermore, both moringa and tithonia significantly enhanced leaf dry weight, exceeding both MIX and NPK+Urea. This indicates that the botanical extracts were highly effective in promoting photosynthetic biomass development, which is essential for overall plant productivity (Fig. 1). These findings are well aligned with those of Sanusi et al (2025) as well as Farni et al., (2022) who established biomass yield increases in cucumber and maize respectively

4.2 Root Architecture and Yield Determinants

The impact of fertilizer treatments on root morphology was pronounced and directly translated into yield outcomes. For root length (R.L), NPK+Urea and Moringa performed comparably, both significantly surpassing MIX and Tithonia. This suggests that both conventional NPK+Urea and organic Moringa provided conditions conducive to root elongation, potentially through enhanced phosphorus and potassium availability and efficient utilization. Root diameter (R.D) followed a clear hierarchy: NPK+Urea (36.3 mm) > Moringa (34.3 mm) > MIX (32.3 mm) > Tithonia (31.5 mm), with all pairwise comparisons being statistically significant ($p \leq 0.003$). This strong response in radial root expansion to NPK+Urea, and subsequently to Moringa, mirrors carrot's known plasticity in response to optimal nutrient availability, especially potassium (Musana et al., 2025: Amartey et al., 2025).

These morphological advantages directly influenced total yield. NPK+Urea delivered the highest total yield (8.08 t/ha), significantly surpassing all organic treatments (Moringa: 6.38 t/ha; Tithonia: 6.49 t/ha; MIX: 5.42 t/ha; all $p<0.001$). While NPK+Urea's superior yield aligns with its rapid and precise nutrient delivery for high-demand crops, the comparable performance of Moringa and Tithonia suggests their viability as competitive organic alternatives. Moringa, in particular, demonstrated strong potential, achieving a yield statistically similar to Tithonia and significantly higher than the MIX treatment, highlighting its efficacy in enhancing key yield components.

4.3 Biomass Allocation Ratios

The analysis of physiological ratios provided further insights into how carrots allocate resources under different fertilization regimes. The root diameter-to-length ratio was significantly affected, with NPK+Urea (2.16) > MIX (2.10) > Moringa (2.05) > Tithonia (2.02). This indicates that NPK+Urea promoted thicker, though not necessarily longer, roots relative to their length, a trait often desired for marketability.

The root-to-shoot dry weight ratio (RDW/LDW) also revealed distinct resource allocation strategies among the treatments (F=34.93, p<.001).

- ***Tithonia* (0.580a):** Exhibited the lowest RDW/LDW ratio, statistically distinct from all other treatments. This suggests a preferential allocation of dry matter towards shoot growth (leaves) rather than roots. This finding aligns with the common use of *Tithonia diversifolia* as a green manure or mulch, where its rapid decomposition and nutrient release might favor initial vegetative vigor and leaf development (Abeyrathne et al., 2021). For a root crop like carrot, this lower root dry matter partitioning relative to shoot could imply a less efficient conversion of photosynthetic products into marketable root biomass.
- ***Moringa* (0.735b) and NPK+Urea (0.803b)**: Formed an intermediate group that was not statistically different from each other. While numerically NPK+Urea had a slightly higher ratio, their statistical similarity indicates that both treatments fostered a comparable balance between root and shoot dry matter partitioning. This is a crucial finding, suggesting that Moringa leaf extract, an organic amendment, can mimic the balanced biomass allocation promoted by conventional NPK+Urea fertilizer, which is generally considered optimal for dual-purpose crops or root crops where both shoot and root development are important. This result is well aligned with that obtained by Islam et al.,(2021) and Haque et al, (2025) who established synergistic dynamics between organic and inorganic nutrient sources in chili and radish.
- **MIX (0.947c):** Recorded the highest RDW/LDW ratio, significantly different from all other treatments. This indicates a strong preferential allocation of dry matter towards root biomass relative to shoot biomass. Such high root investment can be due to compensatory growth mechanism under suboptimal or unbalanced nutrient release from the mixture of Tithonia and Moringa (Mantja et al., 2023), where the plant prioritizes root development to explore a wider soil volume for limited or unevenly distributed nutrients. Alternatively, an antagonistic interaction between the two organic sources in the "MIX" treatment might have led to less efficient nutrient uptake for shoot development, thus artificially inflating the RDW/LDW ratio.

These physiological trade-offs are critical for understanding overall plant health and productivity. While a very low RDW/LDW (like Tithonia) might indicate sufficient above-ground biomass for photosynthesis, it could also signal insufficient resource allocation to the primary economic part of the carrot (the root). Conversely, an extremely high RDW/LDW (like MIX) could suggest stress or inefficient partitioning, where the plant invests heavily in roots at the expense of necessary shoot development. The balanced ratios observed in Moringa and NPK+Urea treatments, therefore, are indicative of more optimal resource partitioning for carrot production. Further studies incorporating multiple locations to capture wider soil and other edaphic factors are recommended.

5. CONCLUSION

This study established that NPK+Urea fertilizer delivered the highest overall carrot yield and root diameter. However, Moringa leaf extract proved to be a strong organic alternative, significantly boosting fresh shoot weight and achieving root dry weight and root length comparable to NPK+Urea. Moringa also promoted a balanced root-to-shoot dry weight ratio. While Tithonia favored shoot biomass, and a mix of Moringa and Tithonia favored root biomass, Moringa leaf extract delivered a balanced biomass allocation pattern comparable to the NPK+Urea treatment. These findings indicate that Moringa is a viable and sustainable fertilization option for carrot production, especially for growers seeking to reduce reliance on synthetic fertilizers.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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