

Oribatid Mites and Soil Health

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Abstract

The growing demand for arable land to meet the food needs of human and animal populations, at a global level, appears to be the main cause of deterioration in soil health. The most serious consequence is the loss of biodiversity, which leads to the reduction of ecosystem services offered by the animal communities that inhabit it. As part of these services, fauna participates in the decomposition of organic matter, the promotion of biogeochemical cycles, carbon fixation, and the sequestration of greenhouse gas emissions. Healthy soils are essential for the sustainability of ecosystems, improving productivity and influencing the promotion of the well-being of living beings. Evaluating soil health allows us to know the impacts associated with management and agroclimatic conditions. Indicators serve to measure the state of health and contribute to safeguarding ecosystem services. Oribatid mites are one of the main bioindicators used for this purpose, due to their reduced dispersion and great sensitivity to respond in the short term to changes in the soil. The abundance, richness, diversity, and/or dominance of species are indicators of seasonal variations in abiotic resources, changes in soil structure or the effects of anthropogenic disturbances (deep tillage, logging, heavy metal contamination, and fires, among others).

Keywords: Bioindicators, Mesofauna, Ecosystem services, Soil productivity, Biodiversity

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Introduction

Soil is a non-renewable natural resource, essential for life on the planet, due to the multiple functions it performs. As a fundamental component in food production, it provides plants with the oxygen, water and nutrients essential for their growth. It is the habitat of a wide variety of organisms, equivalent to about 50% of the total biodiversity on the planet (Anthony et al., 2023). They participate in different processes, providing ecosystem services to the well-being of humans, plants and animals, due to their contributions to soil fertility, productivity and sustainability. Likewise, soils play a key role in climate change management, due to the carbon sequestration they fulfill (Neher & Barbercheck, 2019; Remelli et al., 2024).

The growing production of food and the extraction of energy and minerals have imposed increasing pressure on the soil. Agricultural intensification, inappropriate practices, the use of pesticides and chemical fertilizers to maximize yields, as well as the expansion of crop areas, are affecting soil health and compromising the natural potential of this resource. In many regions of the world, various areas have been prematurely depleted or abandoned due to poor management processes during crop cycles, contamination with heavy metals, or tailings from mines. The effects are extensive to both biotic and abiotic factors of the soil (Wahl et al., 2012; Pervaiz et al., 2020; Núñez-Peñaloza et al., 2023).

Under these circumstances, determining the health status of soils is essential to promote strategies and improvements of agroecosystems. Soil health depends on its physical, chemical and biological characteristics. Previously, assessment integrated organic matter content and the Carbon: Nitrogen ratio, characteristics that change slowly. However, the use of biological indicators represents a better reference due to the rapid response of soil fauna to changes in the environment. Within the soil fauna, oribatid mites stand out as bioindicators, due to the presence of a large number of organisms, reduced dispersion and great sensitivity to detect changes in the short term. Their abundance, richness, and species dominance are indicators of seasonal variations in abiotic resources, changes in soil structure or the effect of anthropogenic disturbances (Solascasas et al., 2022; Mioulet et al., 2024).

Soil Fauna, Biodiversity and Ecosystem Services

Soil fauna represents a key factor in soil health and sustainability. It integrates a variety of organisms, which fulfill different functions within the soil dynamics. Based on the size of the organisms, the classification includes three groups: microfauna, mesofauna and macrofauna (Table 1). Each group has a role in soil biology, associated with the habits and functions of type and number of species present. The great biodiversity enhances ecological processes of great relevance for the integration and functioning of the soil. Thanks to the complex networks they form, soil fauna generates important impacts on the productivity of ecosystems. This includes organisms that live on the soil surface (epiedaphic species), in the superficial layers (hemiedaphic) or in the deep or underground layers (euedaphic), assigning biodiversity a key role

in the performance of ecosystems (Menta & Remelli, 2020; Lumley et al., 2023; Reilly et al., 2023).

Table 1: Classification and functions of soil fauna

Category/Functions	DIMENSIONS		Soil Portion	Groups	References
	Length	Diameter			
MICROFAUNA Decomposition of plant residues, increases the availability of nutrients, production of hormones that promote plant growth, inhibition of pathogens by the production of antibiotics Improvements to soil structure	<200 µm	<100 µm	Water deposited between soil particles	Nematodes Protozoans Rotifers Tardigrades	(de Pádua et al., 2019; Meehan et al., 2019; Shyamrao et al., 2020; Reilly et al., 2023)
MESOFAUNA Decomposition and mineralization of organic matter. Regulation of nutrient cycles. Fundamental in soil-plant interaction and soil formation. Important consumers of fungal hyphae and microbial films. Participation in the opening of drainage and aeration channels (soil structure), by the elimination of roots. Indicator of the state of the soil (it is very sensitive to environmental changes). Fauna feces are a source of food for microorganisms, stimulating microbial activity.	4 mm	From 200 µm to 2 mm	Leaf litter (superficial portion)	Mites Arachnids Collembolans Diplurans Pauropods Proturans Psocoptera Symphylans Trips	(Meehan et al., 2019; Shyamrao et al., 2020; dos Santos et al., 2021; Hernández et al., 2023; Vanolli et al., 2024)
MACROFAUNA Decomposition of organic matter, recycling of nutrients in the soil, maintenance of soil structure, helps water infiltrate the soil, participation in surface and underground food webs Sequestration and release of carbon (natural sink) Regulation of the composition of atmospheric gases	≥10 mm	>2 mm	On the ground or the most superficial layer	the Earthworms Isopods Molluscs Millipedes Centipedes Arachnids Various insects (immature and adult stages)	(de Pádua et al., 2019; Meehan et al., 2019; Shyamrao et al., 2020)

The benefits offered by a healthy soil correspond to ecosystem services, which are entirely associated with the activity of soil organisms, which include:

- Organic matter decomposition: Essential for water retention and filtration, increased substrate moisture levels, regulation of microbial activity, soil fertility, plant productivity, reduction of water stress and biodiversity (Neher & Barbercheck, 2019; Reilly et al., 2023).
- Nutrient regulation: Supply of essential elements for plant productivity. Both macronutrients required in greater quantities (N, P, K, Ca, Mg, and S) and micronutrients (B, Cl, Co, Cu, Fe, Mn, Mo, and Zn) (Jernigan et al., 2020).
- Mineralization of organic matter: Formation of inorganic compounds (salts) from organic amendments (manure or plant residues), useful for agricultural productivity (Monsalve et al., 2017).
- Hydrological cycle: Filtration and storage of water, favoring the recharge of aquifers. They also contribute to climate regulation, through their participation in the control of atmospheric temperature and humidity (Meehan et al., 2019).
- Soil bioturbation: Modification of the soil structure by the formation of aggregates pores and channels because of the excavation, ingestion and defecation of soil fauna. Creation of new habitats, improvements in water quality, increased soil fertility (Alves et al., 2019; Lumley et al., 2023).
- Nutrient cycle: Recycling of essential elements (C, O₂, N, P, S and H₂O) between living beings and the environment (Burbano-Orjuela, 2016; Vanolli et al., 2024).
- Biological Nitrogen Fixation: Transformation of atmospheric nitrogen into nitrates, nitrites, and ammonia, which stimulates plant growth (Pervaiz et al., 2020).
- Carbon sequestration, transformation and release: Largest sink in nature, it prevents CO₂ (one of the greenhouse gases) from accumulating in the atmosphere, reducing its effects. The plant-soil interaction transforms C into organic matter (Junggebauer et al., 2024).
- Biological pest control: Natural soil predators, they can feed on eggs and immature stages of insects and plant-parasitic nematodes, mainly (Remelli et al., 2024).
- Ecological resilience: Adaptive capacity of the ecosystem to return to a functional state of equilibrium after a disturbance has occurred (Ludwig et al., 2018).

In all these processes, the soil mesofauna has a special relevance in maintaining soil health and fertility. It includes microarthropods, which represent about 85% of the soil fauna, and which make the largest contributions to biomass, occupying a wide range of trophic levels. Mites and springtails stand out for their diversity and abundance. Likewise, for their participation in soil structuring, the processing of organic matter, the promotion of trophic interactions such as predation and non-trophic interactions, such as facilitation and competition, and the

regulation of humic substances, among other aspects (Pervaiz et al., 2020; Gedoz et al., 2021).

Soil Health and Quality

Soil health and quality are two concepts that some tend to use as synonyms; however, there is a differentiation between them. Quality is a holistic-functional concept aimed at assessing soil sustainability. It is related to the soil's capacity to fulfill a variety of functions related to plant and animal productivity, the maintenance and improvement of water and air quality, the maintenance of biological activity, biodiversity, human and animal health, the filtration, buffering and immobilization of contaminants, the storage and recycling of nutrients, mainly (Estrada-Herrera et al., 2017). Health, refers to the sustained capacity of the soil to fulfill these functions dynamically, as a vital ecosystem capable of generating returns or benefits (ecosystem services) to satisfy the needs of human beings (Pervaiz et al., 2020; Reilly et al., 2023).

To assess soil health, it is necessary to determine whether its inherent capabilities are consistent enough to ensure its productivity. Soil health depends on the interrelation of many factors as texture, colour, bulk density, temperature and humidity, chemical (cation exchange capacity, pH, and concentration of chemical substances), and biological factors (bacteria, viruses, fungi, algae and soil fauna). Initially, the assessment included analyses of the organic matter content, texture and density of the soil, as well as the C: N ratio, as a reference for the rate of biogeochemical cycles and the quality of organic matter. The results provided general information on the existence or not of conditions conducive to the development of fauna in the soil, and therefore of its functions in the ecosystem. Despite their usefulness, the length of time required for soil changes to be perceptible is a disadvantage for these soil health indicators (Pator & Ray, 2018; Meehan et al., 2019; Mioulet et al., 2024).

In contrast, biological indicators offer more assessments that are precise. They integrate the monitoring of the effects caused by associated factors, the ecological conditions of ecosystems, as well as the impacts on biodiversity (Solascasas et al., 2022). Of all soil microarthropods, mites are the most widely used as biological indicators of soil health. They include free-living predators (Mesostigmata), predators and fungivores (Prostigmata) and mainly, detritivores and fungivores, which are the most abundant (Oribatida) (Ortiz-Ramírez et al., 2023; Yin et al., 2023).

The high sensitivity of mites to environmental changes facilitates the short-term detection of alterations in this habitat. Variations in the interactions and spatiotemporal patterns of distribution (regulated by climatic variables, soil properties and microtopography), as well as in the structure of the communities (abundance, richness and diversity), are indicators of soil health. A high abundance of mites correlates with high contents of organic matter and nitrogen, while the uniformity index correlates with potassium content. Negatively, the decrease in the number of organisms and species generally corresponds to environmental changes in the soil, generated by natural causes (temperature, humidity) or by anthropogenic factors (fires, heavy metals, etc.). Sometimes, based on the premise that each group responds uniquely to a certain type of disturbance, the analysis includes all mite taxa. As with the OM/PA index, (Oribatida + Mesostigmata/Prostigmata + Astigmata) (Bedano et al., 2011; dos Santos et al., 2021; Alves et al., 2024).

Oribatid Mites as Bioindicators of Soil Health

Oribatida are the most abundant and diverse group of soil microarthropods. Their large, shell-shaped body has earned them the name “beetle mites” or “armored mites” (Figure 1). Their exoskeleton (cuticle) has different concentrations of chitin, varying in hardness and color at different stages of development. The shades include mainly pale pink, yellowish, reddish, and dark brown. They can reproduce sexually or parthenogenetically (Norton & Behan-Pelletier, 2009; Colín & García-Estrada, 2016; Gong et al., 2023). Their abundance varies depending on the type of soil. In forest soils, the number of organisms varies between 20,000 and 400,000/m². These mites make a great contribution to soil fertility due to their active participation in the digestion and disintegration of organic matter, which promotes the mobilization of nutrients. They have a large presence in different climates, both due to their varied feeding habits and their adaptation to the natural environmental conditions. For example, in arid systems where food webs based on the presence of fungi prevail, these mites, by grazing on fungal hyphae and spores, control their dispersion, as well as the mobilization of nutrients (Almeida-Alcántara et al., 2017; Sánchez-Chávez et al., 2023).



Fig. 1: Soil oribatid mites (Photographs by the author).

Table 2: Soil health research using oribatids as bioindicators.

LOCATION	METHODOLOGICAL ASPECTS	MAIN FINDINGS	REFERENCE
Ismalia Canal, EGYPT	Response of oribatid communities to heavy metal contamination from wastewater irrigation. Comparison in 5 mango plantations: Nefisha (1), Abou-Souier (2), Old Kasaseen (3), Old Mahsama (4) and Aldaheriya village (5).	Average concentrations of heavy metals in the canal, significantly higher than those recommended (Cd 0.01/0.34, Cu 0.20/15.81, Pb 5.0/20.83 and Zn 2.0/23.73). Differences in density, abundance and diversity of oribatid species. In (4) higher density and abundance, but lower diversity. In (1) lower abundance. Higher richness in (3) and (5), lower in (1). Cu accumulation is different to Cd. Higher levels of Cu in (2), lower in (5). Higher concentration of Pb in (2), and of Zn in (3), similar between species. Microphytophagous mites with higher accumulation of Zn. General trend of concentrations in oribatid species Zn>Pb>Cu>Cd.	(El-Sharabasy & Ibrahim, 2010)
La Colacha Basin, Córdoba, ARGENTINA	Evaluating soil degradation using mesofauna as a bioindicator. Comparison between soils from Reference Sites (RS) and Intensive Management Sites (IMS).	IMS are biologically degraded. Oribatid mite density in RS>IMS. Bioindicators were effective in discriminating against RS from IMS. The OM/PA index (Oribatida+Mesostigmata)/ (Prostigmata+Astigmata) was useful for discriminating between RS and IMS and distinguishing degradation levels in IMS. Bioindicators respond to tillage and a combination of soil management variables. Biological degradation of soil RS~IMS.	(Bedano et al., 2011)
Taita Taveta, KENYA	Comparison of abundance, richness and diversity of soil mites in soils with different uses. Soils from five agro-food systems (AS) corn, coffee, horticulture, elephant grass and fallow. Three forest systems (FS): natural, cypress and pine.	Significantly higher abundance, richness and diversity in FS than in AS. Higher values in the cypress forest (413.8, 15.5 and 2.20, respectively). Richness: Of the 37 families identified 54.05% Oribatida, 27.03% Mesostigmata and 18.92% Prostigmata. In AS, less complex community structures, due to reduced diversity and abundance.	(Maribie et al., 2011)
Quzhou, CHINA	Changes in abundance, diversity and community structure of soil mites under organic fertilizer (OF) and chemical fertilizer (CF) treatments. Unfertilized soil as control (NF).	Organic matter, K, N, and hydrolysable N-higher in OF and CF reduced the abundance and diversity of soil mites. Oribatida more abundant (67.5%). Despite the reduction in abundance due to phosphorus content in fertilizers. Significant increase in predatory Mesostigmata with OF.	(Cao et al., 2011)
North-West Province, SOUTH AFRICA	Using mesofauna as a bioindicator to assess disturbance caused by a platinum mine.	Most frequent metals in platinum tailings: Cu, Cr and Ni, with strong influences on soil fauna. Lower abundance and diversity of Oribatida, Mesostigmata and Prostigmata mite species than in natural environments not contaminated by mining waste. Increased rainfall increased the leaching of metals into the soil.	(Wahl et al., 2012)

Al-Fayoum, EGYPT	Effects of changing from conventional (CM) to organic (OM) management of clover fields on the abundance and composition of the oribatid community.	Greater abundance and ecological range of oribatida in OM. Similarity: Qualitative (79%) and quantitative (38.2%) Diversity (Shannon-Wiener): 2.79 (OM) and 2.36 (CM) Evenness: 0.931 (OM) and 0.920 (CM) Degree of dominance CM>OM	(Khalil et al., 2016)
BSWM, Marawi, PHILIPPINES	Comparative assessment of species abundance and diversity/similarity index of the arthropod community, using two collection methods in organic (OH) and inorganic (IH) habitats.	Community analysis: Almost similar or overlapping in both collection methods in organic (OH) and inorganic (IH) habitats. PT more effective than S. OH=94.91% vs 5.09, IH=93.25% vs 6.75%. Individual species (OH>IH): S= 70.57% vs 29.43%. PT=76.40% vs 23.60%. Collection: By sieving (S), 14 species of soil and leaf litter from OH and 10 from IH. Pitfall traps (PT) 11 and 8 species, respectively.	(Mobarak & Escomen, 2018)
Municipality of San Salvador, Hidalgo, MEXICO	Composition and density of oribatid communities in two agricultural plots with different types of irrigation. Irrigation: Wastewater (RW), well water (WW). Soil parameters: pH, porosity, EC, Mg, Ca, K, Na.	Different species at each site. Oribatida, 6% of individuals collected. WW>RW in abundance, diversity, evenness and species richness values. Similarity coefficient (Sørensen) between both communities, 75% Diversity (Shannon), without significant differences. Soil parameters and collection date had an effect on the values, except for organic matter.	(Iglesias et al., 2019)
Minas Gerais, BRAZIL	To evaluate the effects of different management methods on soil mites in coffee plantations and compare them with the biota of native forests.	Greater abundance of mites in MW, lower in RH. Greater species richness in NF, NW and MW. Significantly lower RH abundance and richness. Oribatida were the most abundant in all soils (MW, followed by NW and NF). Management methods: No weeding (NW), manual weeding (MW), agricultural grid (AG), contact herbicide (glyphosate) (CH), residual herbicide (oxyfluorfen) (RH), mechanical cultivator (CM) and mechanical mower (MM). Greater richness and diversity in NF. Comparison with native forest area (NF).	(de Pádua et al., 2019)
Boreal Forest Alberta, CANADA	Comparison of two groups of soil mites (Oribatida and Mesostigmata) as bioindicators of three types of disturbances in a boreal forest: Fire, forest harvest and linear features (seismic lines and roads).	Richness and diversity (Shannon-Wiener) M>50 µm lower in SD than in (Meehan et al., 2019) as SUD, in the three TL. Oribatida lower in harvest and fire (3 TL), lower richness in linear, at TL of family. Structure of the assembly: M>50 µm: Indicators of fire and linear in 3 TLs. Oribatida (O) 1 group, individuals > 300 µm M>300 µm: Indicators of the 3 disturbances at species level and Mesostigmata (M), 2 groups: > 300 µm and > 50 µm disturbance by harvest at TL of genus and family. O: Indicators of fire in 3 TL and linear disturbance, at TL of genus and family. Assessment at three taxonomic levels (TL): family, genus and species. Disturbed (SD)-undisturbed (SUD) site pairs: Fire (13 pairs); harvest (11), linear (7).	(Meehan et al., 2019)
Mörfelden-Walldorf, GERMANY	Cumulative effects of three disturbance events on oribatid communities in different microhabitats, comparing 2016 and 2020. Events: Drought (D), wind-blown (WB) and forestry operation (FO). Microhabitats: Leaf litter (L), dead wood (DW), moss (M) and bare ground (BG)	D, WB and FO significantly reduced the abundance and diversity of oribatida, affecting their ecosystem services. BG: No comparative data. Records only for 2020. Generalized reduction in abundance, DW (86.4%), M (85.9%), H (69.5%). Decrease in species richness, M (57.8%), DW (29.1%) and H (15.9%). Communities in M were the most affected (65% lower diversity). Sexual species are more affected than parthenogenetic in L and M. Of the 54 species of oribatida identified in 2016, nine were absent in 2020.	(Wehner et al., 2021)
Saxony, GERMANY	Measure the impact on organic matter degradation by manipulating the abundance and composition of the mesofauna with the application of two divergent insecticides. Insecticides: Lindane and methamidophos.	Both insecticides reduced the abundance of mites and springtails by 80%. Temporal fluctuations in biodiversity. No significant changes in organic matter degradation.	(Pamminger et al., 2021)

Catalonia, SPAIN	Evaluate oribatida as indicators of soil quality under different land uses. Evaluate the suitability of oribatida for better pre-fertilization management (mineral and organic) in forage crops Land uses: Forage crops (FC), grasslands (G) and forests (F). Mineral fertilizers (MF), organic fertilizer factor. (livestock manure) (OF).	MF and OF without significant differences in abundance. Significant differences in abundance, diversity and dominance in different land uses. Maximum abundance lower than previous average values in Mediterranean climate conditions F with greater abundance and diversity, but lower dominance. Mesofauna is sensitive to climate changes. Humidity as the most influential	(Bosch-Serra et al., 2024)
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Community composition is associated with biotic and abiotic factors; any variation affects it, as well as the living habits and behavior of organisms. Despite the great adaptive capacity of Oribatida to specific local conditions, their high sensitivity to seasonal or environmental changes or disturbances caused by human activities can have negative effects on their abundance, richness and diversity (Wehner et al., 2021). Agricultural intensification, changes in land use, industrial and mining processes, pollution and meteorological events associated with climate change are among the main causes of the deterioration of soil health (Pamminger et al., 2021; Solascasas et al., 2022).

Variations in soil temperature and humidity caused by climate change significantly reduce oribatid populations, particularly of drought-intolerant species. Erosion, landslides and floods also affect the dynamics of this soil fauna (Pator & Ray, 2018; Santana et al., 2021). However, anthropogenic activities are the ones that cause the greatest damage. Excessive grazing, land clearing, the accumulation of heavy metals due to the use of wastewater for irrigation, forest and post-harvest fires, and mainly intensive agriculture, cause severe damage to the soil. Changes in soil structure, reflected in the increase in bulk density, decrease in porosity and compaction, are the result of the cultivation techniques used. They highlight the use of agricultural machinery for tillage, which tends to invert the soil layers, as well as the application of chemical products for fertilization and pest control (herbicides and insecticides), which create a surface layer. The harmful effects of intensive agriculture cause damage to both the soil structure and its biota, threatening the ecosystem services they offer (Castro-Huerta et al., 2021; Todria et al., 2021; Alves et al., 2024).

Attributes such as a long lifespan, high adult longevity, slow growth rates, low fecundity and dispersal capacity make Oribatida highly susceptible to changes in the soil, and therefore, make them ideal indicators to determine the health status of this resource (Lumley et al., 2023; Junggebauer et al., 2024). Research on the use of Oribatida, as bioindicators has recently increased. Based on the abundance, richness and dominance of species, these investigations are generally oriented to the assessment of the effects of specific conditions and processes that affect soil health:

1. Agricultural Production Processes

- Land preparation: plowing, tilling and weed control
- Fertilization: use of organic fertilizers (manure, compost, digested sludge) or chemical fertilizers
- Sowing: Rotation, sustainable cover crops, organic and conventional sowing, others.
- Irrigation: Use of wastewater (domestic, agricultural and industrial) or natural water, from underground sources and reservoirs.
- Pest control: Application of herbicides, insecticides, fungicides, pesticides and others (Cao et al., 2011; Khalil et al., 2016; Iglesias et al., 2019; de Pádua et al., 2019; Bosch-Serra et al., 2024).
- Land uses, Forest, cultivated, zero tillage (native vegetation, forests and grasslands) (Maribie et al., 2011 ; Pamminger et al., 2021).

2. Environmental Deterioration and Climate Change

- Ecotoxicity by heavy metals (Cd, Hg, Pb, Cu, Zn, Cr, Ni).
- Disturbances: Fires, forest harvesting, landslides, droughts and floods.
- Soil degradation.
- Pollution by aromatic hydrocarbons, plastics, smelting activities, asphalt production and mining waste and Urban impact (Sharabasy & Ibrahim, 2010; Bedano et al., 2011; Wahl et al., 2012; Meehan et al., 2019; Wehner et al., 2021).

Table 2 compiles the objectives and main findings of research related to some of these topics, which use oribatid mites as bioindicators of soil health.

Conclusions

All regions of the world face the dilemma of increasing food production, knowing that intensive agriculture is one of the main causes of damage to soil health. The emission of greenhouse gases, soil and water pollution, as well as the physical deterioration caused by the cultivation techniques used, are contributing to the loss of biodiversity, the consequences of which can be catastrophic. Soil microarthropods communities, among other things, are responsible for the nutrient cycle and the degradation of organic matter, which determine soil fertility and crop growth. They are also responsible for the sequestration and transformation of carbon, which is essential to reduce the impacts of climate change and the sustainability of agroecosystems. The current challenge is to develop strategies from a holistic vision such as the *One Health* perspective, from which, in order to generate optimal results, it must be recognized that human well-being is intrinsically linked to the good shape of other components of the ecosystem, such as plants, animals and soil. Healthy soil, in addition to sustainably supporting productivity, improves air and water quality and promotes robustness ecosystems.

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