

Review

# Disentangling Human–Plant–Animal Dynamics at the Microscale: Geo-Ethnoarchaeological Case Studies from North Africa and the Near East

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**Abstract:** Livestock dung is a suitable material for delineating the complexity of interactions between people, plants and animals as it contains critical information on environmental and ecological issues as well as socio-economic dynamics and cultural lifeways. However, animal faecal remains and other coprogenic materials are commonly overlooked in most archaeological research programs due, in part, to methodological challenges in its recovery and identification. This paper evaluates the contribution of integrated geoarchaeological approaches, together with comparative reference ethnoarchaeological records, to interdisciplinary microscopic analyses on the identification of animal dung and its archaeological significance within farming built environments. It brings together records from a selection of recent geo-ethnoarchaeological case studies across the Near East, one of the heartlands of plant and animal domestication, and from northern Africa, an understudied key area with critical implications for neighbouring regions such as the Sahara. This article examines the state-of-the-art of dung material identifications within agricultural and pastoral settlements and their potential for tracing ecological diversity, animal management strategies, penning, grazing and foddering, seasonality, and dung use. This review highlights the value of modern reference frameworks of livestock dung as a primary source of information for disentangling human–plant–animal dynamics through time and space.

**Keywords:** Northern Africa; Near East; Neolithic; Iron Age; geo-ethnoarchaeology; livestock dung; coprolite; micromorphology; phytoliths; biomarkers



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## 1. Introduction

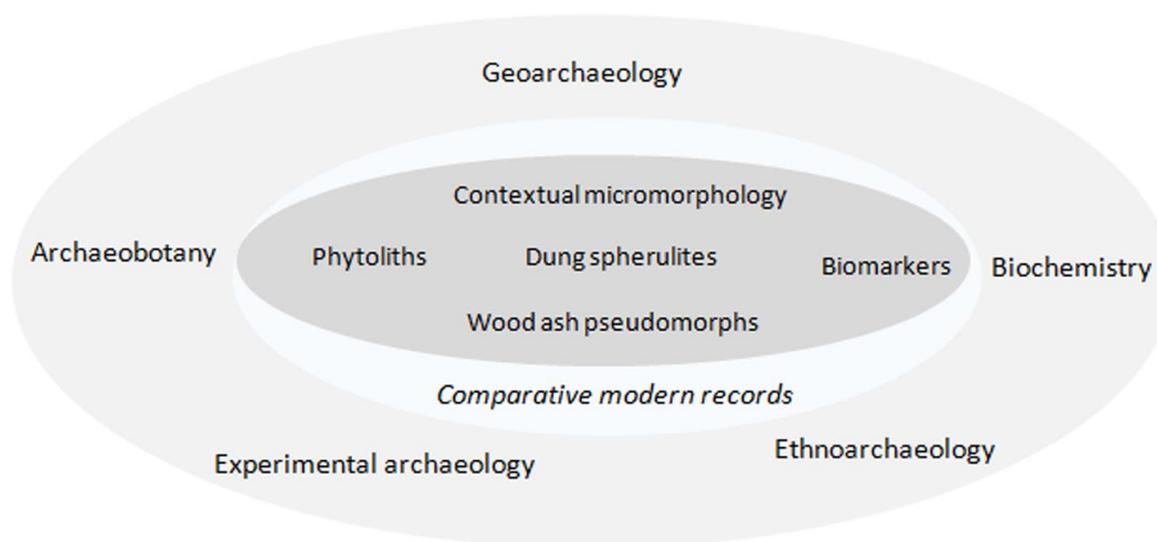
The shift towards a sedentary lifestyle at the beginning of the Holocene entailed a key transformation in the ways prehistoric communities related to animals and the environment. The emergence of animal domesticates, in particular, provided a regular and predictable supply of services and products such as meat, milk, leather, fibres, and dung that had a profound effect on human populations. However, archaeological models of the changes in the relationship between people and animals, leading to the domestication of the latter, have traditionally over-focused on the consideration of animals as food sources [1], and insufficient research has been devoted to investigating the socio-economic role of other secondary products in this process, particularly of dung materials.

Animal faecal matter, especially when derived from herbivores, is an essential secondary product and has excellent properties as a fuel source since it burns more evenly and for longer than wood when dried [2], characteristics that have made this material widely appreciated by both past and modern societies. However, ethnographic literature illustrates that the use of dung as fuel relates not only to its availability but to its many other

uses, including fertiliser and building material, and also to a range of cultural choices and social values [3]. The occurrence of dung in prehistoric sites preceding domestication is an indicator of greater human proximity to animals and of the emergence of herd management practices [4]. The collection and burning of dung from wild herbivores were suggested by archaeobotanical studies to be an occasional practice in Levantine hunter–gatherer communities undergoing an initial process of sedentarisation [5]. However, these early studies came under scrutiny mainly due to the difficulties entailed in securely detecting faecal matter in the archaeological record, a material particularly prone to degradation. In addition, the nature and components of dung pellets and coprolites can vary significantly depending on a series of factors, including the defecating species, the diet, sex and age of the individual, husbandry practices, environmental conditions, human manipulation, and depositional processes [6,7]. Since animal faecal matter constitutes a highly valuable and culturally charged material, defining the circumstances under which the earliest management of dung by humans developed is critically important for our understanding of how and why the cultural control of animals began.

A review of early human collection and manipulation of animal dung is timely as innovative methodological advances in analytical techniques enable accurate contextual identification and interpretation of microscopic dung traces and uses through integrated ethnoarchaeological approaches. The first pioneering geo-ethnoarchaeological works on faecal materials were undertaken in the 1990s [7] and were followed by many other studies and increasingly developed over recent decades across the Mediterranean region and the Sahara [8–12], the northern and southern Levant [13–16], the central Zagros [17,18], central and southern Asia [19–21], and eastern Africa [22–24], for example. The presence and use of animal dung in these investigations were routinely assessed through various techniques, including plant macro- and microfossil analysis, dung spherulite analysis, thin-section micromorphology, and chemical analyses. However, all these techniques can be unreliable when identifying faecal materials preserved in archaeological contexts, especially when used singularly. An integrated analytical approach is best to characterise ancient faecal matter; the effective linking of palaeoenvironmental, geoarchaeological, biomolecular and ethnographic datasets continues to prove challenging, in spite of the emergence of high-resolution analytical methods and recent developments in a range of areas as highlighted in recent reviews [25–29].

This paper assesses the contributions of integrated microscopic and ethnographic studies to the high-resolution identification and analysis of animal faecal matter in the archaeological record by evaluating evidence from selected early/middle Holocene and modern settlements in North Africa and the Near East. The examination of archaeological dung based on comparative modern livestock reference materials and ethnoarchaeological records from these key regions in multiple studies has allowed the characterisation of various types of faecal aggregates and their components, providing critical insights on the diet, health, seasonality, and mobility of early domesticates (Figure 1). The reported case studies are primarily from the central Zagros, central Anatolia, and the northern and southern Levant, core regions in the emergence and developments of sedentism and farming in southwest Asia, with additional comparative ethnoarchaeological reference from the poorly investigated Eastern Maghreb in northern Africa. In particular, the arid and semi-arid areas in the core study regions favour the preservation of a range of dung remains within built environments, which protects them from several agents such as wind, rain, and erosion, as well as in discarding areas and middens through rapid burial, preventing the impact of faecal decomposers (e.g., mites, fungi, and flies).



**Figure 1.** Schematic diagram showing a model for the identification and characterisation of archaeological livestock dung based on comparative modern reference records and ethnoarchaeological studies conducted in the research areas.

The main objectives of this paper are: (i) to deliver an overview of geo-ethnoarchaeological studies that have been recently conducted in core areas in North Africa and the Near East in light of the accurate identification, characterisation, and interpretation of faecal materials in modern and early/middle Holocene settlements through integrated high-resolution microscopic analyses; (ii) to assess how this research has contributed to the investigation of human–plant–animal relationships and local landscapes, with an emphasis on insights on livestock management, seasonality, animal diets, dung manipulation, and its secondary use and discard by humans across territories through time. The paper evaluates methods of field identification, sampling, data collection, and analysis of faecal materials as a fundamental source of information, providing a state-of-the-art review of the topic and directions for future research in two geographical areas key for our understanding of the emergence and spread of agropastoral systems. Therefore, this review provides a unique window to explore the heterogeneity of husbandry practices, opening a much-needed comparative path for the examination of local trajectories in dung collection and use and their role in the origins and developments of animal management strategies.

## 2. Materials and Methodological Framework

Table 1 summarises the main methods used in the geo-ethnoarchaeological case studies reviewed in this paper, based on comparative modern reference dung materials and models. The focus is on contextual thin-section micromorphology, calcitic dung spherulites that originate in the digestive system of many animals, particularly ruminants, in addition to plant microfossils such as opal phytoliths and wood ash pseudomorphs, the latter resulting from the heating of calcium oxalates. These proxies derive from both archaeological and modern reference livestock dung matter and dung products (e.g., fresh dung pellets, soils from animal penning, building materials including threshing floors and roofing, dung cakes for fuel purposes, and dung-dominated or mixed fuel remains).

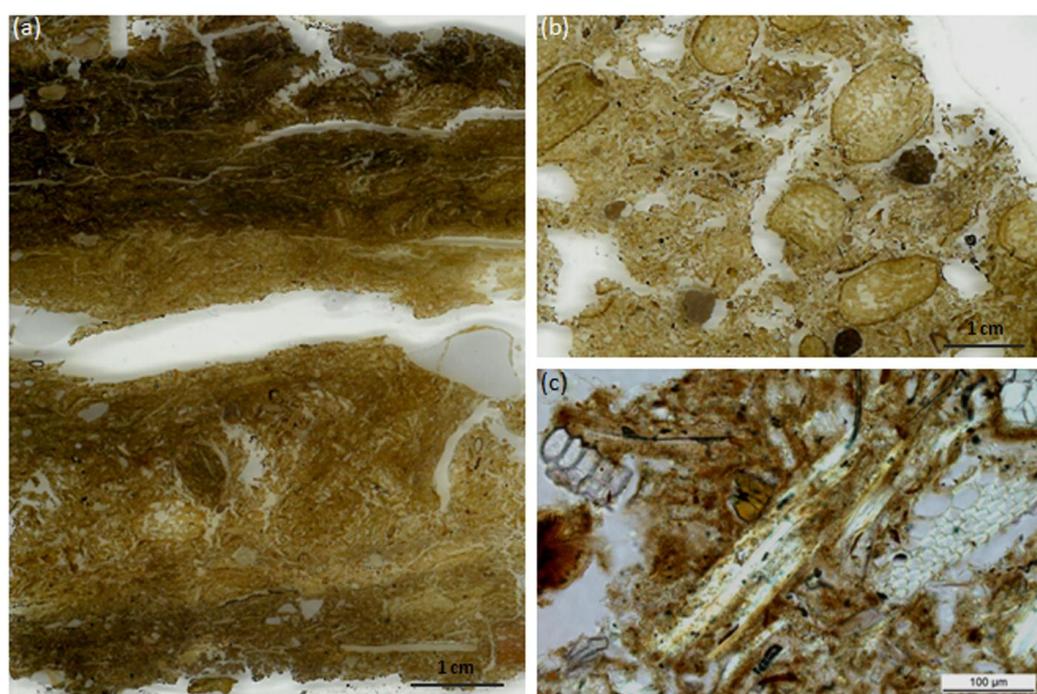
**Table 1.** Summary of the main methods and analytical techniques used in the geo-ethnoarchaeological case studies to investigate modern livestock dung (based on [3,18,29] and personal observations).

Method	Abilities, Advantages, and Appropriate Application	Inabilities and Disadvantages
Contextual thin-section micromorphology	Allows examination of microfossils and other microscopic remains in situ and establishes their associations (e.g., herbivore vs. omnivore dung); preserves the original size of multicelled phytoliths; supports diet reconstruction; may be extrapolated to reconstruct local landscape, environmental conditions, and land use. Identifies the specific depositional context (e.g., microlaminated structure, trampling within an enclosure); helps understand site formation, depositional pathways, and taphonomic processes (e.g., bioturbation, dissolution, burning).	Associations may be diet-based (e.g., phytoliths scarce or absent in grass-poor diets) and diagenesis-based (e.g., spherulites absent due to dissolution); microlamination may be absent in grass-poor diets and obliterated due to bioturbation. Accurate identification of microfossils is hindered by the thickness of the thin section, sample size (e.g., not enough recognisable phytoliths for proper morphological analysis), 2D views, and they may be masked by other embedded material. Time-consuming thin-section preparation.
Dung spherulite analyses	Determines amount of spherulites per gram of material/sediment. They serve as a direct indicator to identify dung. Quick method that can be used in the field through smear microscope slides of suspected dung remains.	Absence may be due to dissolution, calcination, and increased heating (burning) particularly under oxidising conditions. They cannot be used solely to identify livestock dung, as they may be produced by wild animals and humans.
Phytolith analyses	Establishes amount of phytoliths per gram of material/sediment. They are resistant to a variety of soil pH conditions, burial environments, and increased heating (burning). Allows identification of different plant/part types and animal diet. May contribute to reconstructing animal ecology, environment, seasonality, as well as foddering and grazing activity and land use. Allows 3D microscopic examination, making their identification easier.	They cannot be related to dung by themselves, as they may derive from both dung and non-dung sources. Over-representation of grass relative amounts (due to differential phytolith production) and selection of feed by humans and animals may affect environmental reconstruction. Time-consuming chemical extraction that may disaggregate multicelled phytoliths and remove associated material that may help with interpretation.
Wood ash pseudomorph analyses	Establishes amount of wood ash pseudomorphs per gram of ashed material/sediment. Their abundances may indicate a diet that is either based or includes a component of dicotyledonous matter. As these are common in wood ash, ratios ash pseudomorphs/dung spherulites may allow distinction between wood and dung fuel remains or mixtures of both. Rapid method that can be used in the field.	They do not have a clear taxonomic value and may be absent in grass-poor dietary regimes. Similarly to other plant remains (e.g., phytoliths), they cannot be related to dung or dung-derived material by themselves. Their absence may also be due to dissolution or calcination.

During fieldwork, it is possible to improve the frequency with which herbivore dung materials are being detected through the quick screening of calcitic spherulites from suspected faecal deposits by mounting smear microscope slides (e.g., [29]). Further, the application of methodological techniques for elemental analysis, such as portable X-ray fluorescence (pXRF) for detecting the presence of phosphates in sediments, has yielded promising results for the rapid identification of faecal deposits in the field, rather than in laboratory conditions (e.g., [16,17]).

In micromorphological thin-section (Figure 2a,b), it becomes possible to distinguish between ovicaprines, cattle, and pigs, which are the species most frequently responsible

for the deposition of livestock dung remains in archaeological contexts from the study areas throughout the early/middle Holocene. Herbivorous dung pellets are generally porous, loosely packed, and composed of poorly digested to undigested plant epidermal tissues, seeds, and fruits, along with other plant microscopic remains such as phytoliths and calcium oxalates, cellulose, and mineral inclusions, which can be found embedded in the organic groundmass frequently displaying phosphate staining. Other components include distinctive dung microremains such as calcitic spherulites and coprophilous spores, although its composition may be highly variable, depending on animal species, age/sex of the individual, grazing/foddering regimes, and ecological diversity [29,30]. In cases of grass-dominated diets, dung matter deposited within an enclosure becomes compacted and trampled by the animals, resulting over time in a microlaminated dung deposit embedding plants and other components, commonly oriented sub-parallel to the penning floor (Figure 2a).



**Figure 2.** Modern dung cakes from Central Anatolia in Turkey (ethnographic and sample descriptions can be found in [6,29]). (a) Scan of a resin-impregnated thin-section illustrating the trampled structure of compacted cattle faeces from an enclosure containing organic material and other mineral inclusions; (b) scan of a thin-section from a dung cake manufactured in winter composed of sheep dung pellets, organic matter, and mineral inclusions; (c) detail of the same sheep dung cake displaying anatomically connected or multicelled phytoliths from leaf epidermal tissues (200×).

Geochemical and biomolecular markers have also been applied in some of the core study regions, such as the foothills of the Zagros mountains in Iraqi Kurdistan and the Konya Plain in central Anatolia in Turkey, following geo-ethnoarchaeological research in order to contribute to the accurate identification and interpretation of faecal materials, although in many research areas the latter remain underdeveloped [31,32]. Biomolecular signatures from sterols and bile acids by Gas Chromatography/Mass Spectroscopy (GC/MS) have been used to discriminate between animal and human faeces, as well as studies of intestinal parasites from coprolitic materials, techniques that have contributed to our understanding of the health conditions of animals and humans in early sedentary communities [33–36]. Several emerging analytical methods, including DNA and stable nitrogen and carbon isotopic analyses on dung deposits, have not been extensively applied in the study regions yet, in spite of their potential for identifying dung deposition and investigating dietary regimes, health, and gut biomes at high resolution [11,21,37–39].

This evaluation builds on recent ethnoarchaeological work conducted on livestock management, grazing, foddering, seasonality, penning, dung collection, manipulation, and use, as well as on modern reference dung sampling, followed by geoarchaeological, archaeobotanical, zooarchaeological, geochemical, biochemical, and isotope analyses from different core regions, including, from east to west: (i) the foothills of the Zagros mountains of Iraqi Kurdistan [17,18,40–42]; (ii) the Konya plain in central Anatolia, Turkey [6,29]; (iii) the Upper Khabur in northeastern Syria, northern Levant [15]; (iv) the Wadi Faynan in southern Jordan, southern Levant [16]; (v) the Negev Highlands, southern Israel, southern Levant [14]; and (vi) the High Tell in northwestern Tunisia, Eastern Maghreb [9,10].

The geo-ethnoarchaeological methodological approach has been further used as a comparative modern reference framework in integrated studies of dung deposits at the microscale in a number of recently excavated archaeological settlement sites: early Neolithic Bestansur (eighth millennium cal BC) in the central Zagros in Iraqi Kurdistan [31,32]; Neolithic Boncuklu (ninth–eighth millennium cal BC), Pınarbaşı (seventh millennium cal BC) and Çatalhöyük (eighth–sixth millennium cal BC) in the Konya plain, central Anatolia, Turkey [28,43–45]; early Neolithic Tell Seker Al-Aheimar in the Upper Khabur, northeastern Syria (eighth–seventh millennium cal BC) [15]; Epipaleolithic (Capsian) Kef Hamda (eighth millennium cal BC) and nearby Neolithic Doukanet el Khoutifa (eighth–seventh millennium cal BC) in the north border of the Tunisian Dorsale mountains [46]; Iron Age Atar Haroa, Negev Highlands, southern Israel [14], and Numidian Althiburos (first millennium BC) in the High Tell, northwestern Tunisia [9,10,47,48].

### 3. Case Studies and Archaeological Significance: Brief Overview, Main Highlights, and Future Research Directions

Through the synthesis of several case studies from across the Fertile Crescent and Northeastern Africa, this section brings together recent geo-ethnoarchaeological research on livestock dung that has followed a range of laboratory-based analytical methods for linking animal faecal deposits and human activity as a reference framework for tracking current debates on the origin and spread of farming and their potential for delineating continuity and change in human–environment interactions and ecological diversity more widely.

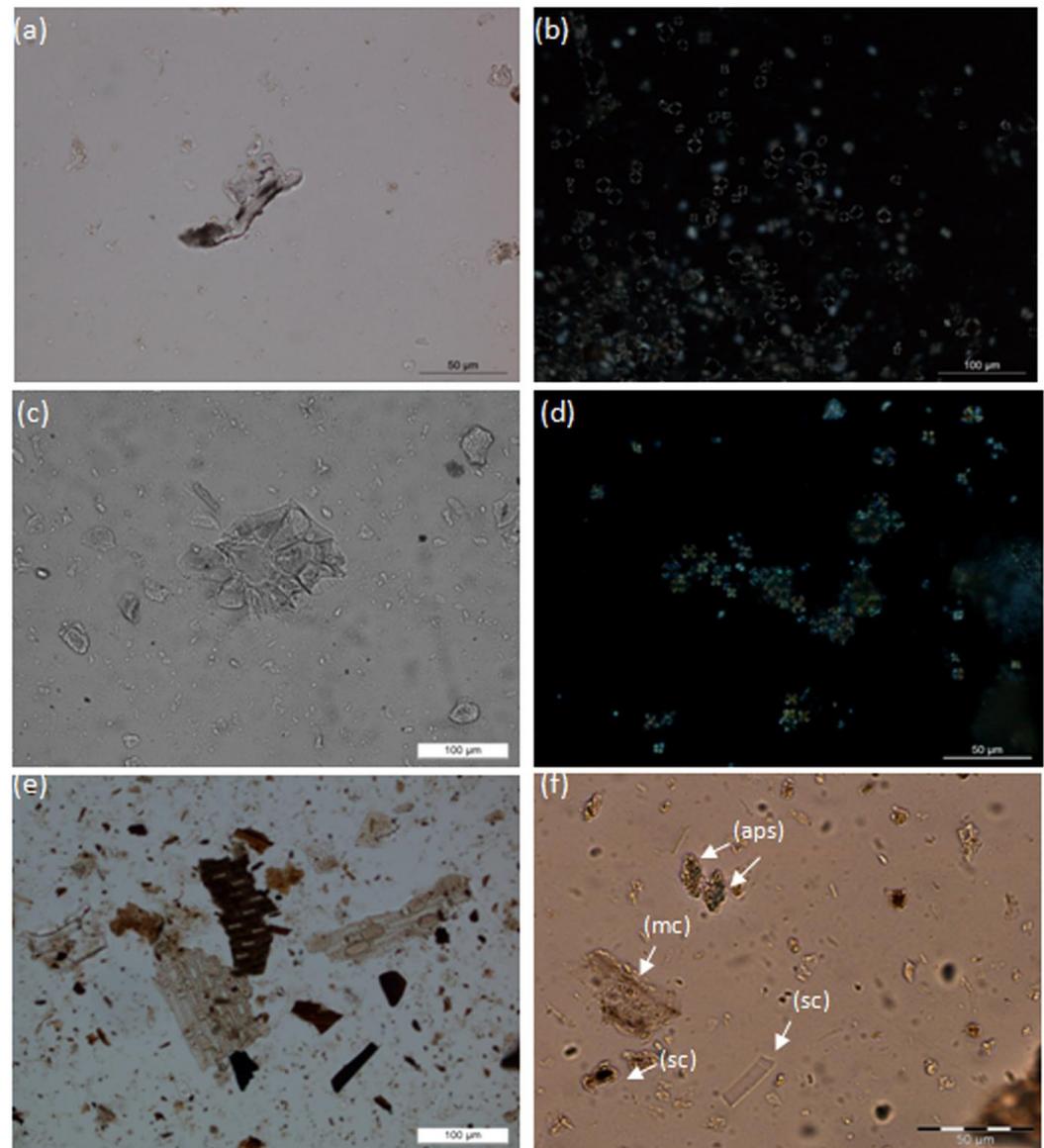
#### 3.1. The Foothills of the Zagros Mountains, Iraqi Kurdistan

Geo-ethnoarchaeological work conducted over recent years in the lower Zagros mountains has focused on livestock management, penning, grazing, foddering, manuring and other domestic activities, as well as on modern dung sampling, within the framework of ongoing archaeological excavations at Early Neolithic Bestansur, located on the western edge of the Shahrizor Plain in Iraqi Kurdistan, included on the UNESCO World Heritage Tentative List. These studies were followed by zooarchaeological, phytolith, dung spherulite, isotope, and soil analyses, in addition to comparative experimental burning of fresh dung pellets under laboratory-controlled conditions [17,18,40–42]. These investigations have explored how several households from the modern village of Bestansur (ca. 400 m north of the Neolithic mound), placed in an alluvial plain that supports arable farming based on cereal agriculture, horticultural crops, and the husbandry of sheep, goat and cattle, used and managed their livestock, with particular interest on dung exploitation and its secondary use, primarily as fertiliser and as a source of fuel for cooking and heating until the introduction of gas in the village in the 1980s. Through ethnographic fieldwork that included semi-structured interviews with villagers using questionnaires and photography under full permission following rigorous ethical protocols, the research gathered information on farming practices and dung management over time, including the collection of modern reference dung materials for integrated phosphorous and microfossil analyses from households, pasture grounds from the vicinity, and the lower foothills. By comparing phosphorous records to the concentrations of phytoliths and, particularly, to the quantities of calcitic spherulites that are excreted with the dung across samples from different animal producers (cattle and ovicaprines), results pointed to differences according

to dietary regimens rather than to diverse animal species, although higher amounts of dung spherulites among sheep and goat samples were consistent with previous studies on spherulite production [49], thus providing a region-specific reference dataset within the environmental context of the archaeological study area [17]. Further, strontium isotope signatures pointed towards variations in environmental conditions between the lower foothills, where herds graze daily during the warm and dry months, particularly from spring onwards, and the alluvial floodplain. The dataset, however, was limited in size, and it needs to be expanded in the future to assess whether these observed differences are also significant in the archaeological sites located within the wider study region, in addition to approaching seasonal and yearly rhythms and patterns.

Building on further ethnoarchaeological fieldwork conducted in the modern farming village of Bestansur and its pasture grounds, comprising the floodplain and the lower foothills, an integrated experimental study focused on the burning (heating) of fresh pellets under laboratory-controlled conditions was undertaken in order to investigate microfossil taphonomy and its implications for identifying fuel dung remains in archaeological contexts [18]. This study aimed at shedding light on the long-term uses of dung as both fuel and fertiliser, either in its organic form or after being burned, and on the scarcity at present of ethnographical dung fuel materials from the study area since the introduction of gas. One of the main goals of these experiments was to assess variations in ingested phytolith and dung spherulite abundances, as well as composition and preservation conditions within cattle and ovicaprine dung, as the manner in which heating affects both microfossil types remained understudied. These experimental records indicated significant changes in phytolith stability, integrity, and morphotype composition at temperatures ca. 800 °C (for example, melted or completely opaque and deformed morphologies can no longer be assigned to specific phytolith morphotypes, Figure 3a), whereas darkened spherulites, covering almost the whole spherulite as a result of increased heating, (Figure 3b) occur within a range between 500 and 700 °C, but particularly at temperatures 550 °C and higher, with maximum production at 650 °C under reducing combustion conditions, as reported in previous experimental work on sheep dung pellets [50]. In summary, the reported integrated ethnoarchaeological and experimental approach demonstrates the contribution of the much-needed modern reference records of livestock dung to our understanding of its formation and taphonomic issues, which are critical for the accurate identification and interpretation of this overlooked material in the archaeological record, especially in early sedentary settlements.

Integrated geo-ethnoarchaeological and burning experimental records were conducted at the nearby Early Neolithic settlement site of Bestansur for comparative purposes in order to better understand the deposition, composition, and preservation of archaeological dung remains. Integrated micromorphological and microfossil studies demonstrated the use of herbivorous dung as fuel through the identification of spherulitic ashes, darkened spherulites, and phytoliths melting within firing installations such as ovens, as well as within domestic refuse deposits from building areas [31,32,51]. In addition, biomolecular markers from sterols by Gas Chromatography-Mass Spectroscopy (GC/MS) enabled the identification of coprolitic herbivore, omnivore, and human faecal matter found in open areas at the settlement. Combined dung spherulite and phytolith analyses on these materials pointed to variable diet or feed regimes that are linked to both biomolecular signatures and thin-section micromorphological results. Further analyses of lipid biomarkers on these materials are expected to clarify their nature to discriminate between human and animal remains, contributing to current debates on transformations in animal management practices and the built environment, as well as on dietary habits, health, and hygiene in early Neolithic communities [32].



**Figure 3.** Photomicrographs of phytoliths and calcitic microfossils from modern and archaeological dung samples (200× or 400×). (a) Partially melted multicellular (articulated) phytoliths from sheep/goat dung after 800 °C of experimentally produced combustion in a furnace oven, Bestansur, Iraqui Kurdistan (PPL); (b) clusters of dung spherulites (mostly darkened), from sheep/goat dung burned at 650 °C in a furnace oven under reducing conditions, Bestansur, Iraqui Kurdistan (XPL); (c) epidermal appendage base with attached (articulated) hair from the leaves of dicotyledonous plants from herbivorous penning deposits at early Neolithic Çatalhöyük, Central Anatolia, Turkey; (d) clusters of dung spherulites (none of which are darkened) from the same penning deposits at Çatalhöyük; (e) multicellular (articulated) phytoliths from the leaves and culms of Pooideae grasses and reeds from burnt-herbivore dung deposits at Late Neolithic Pınarbaşı, Central Anatolia, Turkey; (f) calcitic wood ash pseudomorphs (coded as aps) along with multicellular phytoliths (mc) and single-celled or individual phytoliths (sc), from mixed woody/ovicaprine dung fuel remains from a modern *tannur* type (*tabouna*) oven used daily for cooking and baking at El Souidat, northeastern Tunisia.

### 3.2. The Konya Plain in Central Anatolia, Turkey

Detailed ethnographic surveys on modern husbandry and ethnobotanical studies of foddering and dung materials were carried out during the 1990s in two farming villages from central Anatolia, in Turkey: Pınarbaşı, a small settlement on the edge of the Taurus mountains, in the Karaman district, and Kizilkaya, a larger rural village on the Melendiz

Plain, in the Aksaray district [6,52,53]. Ethnographic fieldwork enabled the examination of animal dung materials, or *tezek* (the generic Turkish name for dung), and the manufacture, storage, and use of the so-called dung cakes for fuel purposes, as well as the analysis of the macro-botanical components of these dung materials, mainly from cattle and sheep defecators [6]. A variety of different types of dung cakes was reported, mostly manufactured during spring and summer, as well as a wide range of firing installations fuelled with dung cakes, including the locally called *tandır*, a mud oven similar to near eastern *tannurs*, used daily for cooking and baking. More recently, the examination of micromorphological thin-sections of dung cakes and fuel residues from the firing installations collected by Anderson and Ertuğ-Yaras allowed the analysis of their microfossil plant and faecal contents [29], used as comparative records in a selection of archaeological contexts from neighbouring early Holocene sites in the Konya Plain [28,43–45].

The phytolith and dung spherulite study of the modern reference micromorphological thin-sections indicated differences between dung records that were related to animal diet regimes and the ethnography-reported foddering and grazing patterns, in addition to seasonality [29]. Yet, phytolith results showed some degree of difference in phytolith morphologies, particularly among sheep dung collected in different seasons (summer vs. winter, Figure 2b,c). In particular, summer-rich diets were dominated by multicelled or anatomically interconnected phytoliths from the floral parts of cereals, which were consistent with previous ethnobotanical records pointing to the presence of a wide range of cereal grains, primarily wheat, barley, rye, and oat, in addition to wild and weed seeds [6]. These authors caution, however, that variations between dung types and their components may be difficult to assess in the archaeological record due to differences in selection of feed by animals and human manipulation, pointing that dung from different herding regimes and seasons may be stored for a long time, even several years. Further, plant matter not present in the dung itself or not ingested by animals may be included in the manufacturing process of dung cakes or during fire lighting, such as reeds, which are common in the archaeobotanical records in this region.

These comparative geo-ethnoarchaeological records were more recently used in order to inform interpretations of dung deposits from open areas and firing contexts from three key sites in the Konya Plain: early Neolithic Boncuklu, Late Neolithic Pınarbaşı, and the UNESCO World Heritage site of Çatalhöyük [28,43–45]. By comparing thin-section micromorphological, microfossil, and biomolecular records with reference geo-ethnoarchaeological datasets, this integrated approach has contributed to the investigation of formation processes in all three Neolithic settlements, showing the variability of dung deposits and other coprogenic materials found in open spaces within built environments (including omnivorous human faeces), with in situ penning areas at Çatalhöyük, displaying variations in animal diet, including both grass-based and dicotyledonous regimes (Figure 3c,d), livestock management within the local landscape and its environmental impact, as well as the use of dung as secondary products (Figure 3e), with critical implications for human diet, health and sanitary conditions, and the complexity of interactions between people and animals. Further, these patterns of cohabitation of people and domestic animals imply a greater exposure to pathogenic micro-organisms such as bacteria, viruses, and parasites and the potential spread of diseases among early farming communities [36,54]. Although dietary practices have been approached by isotopic markers of crops and faunal remains from several sites in the Konya Plain [55–62], isotopic analyses of dung are still underdeveloped. Therefore, a range of issues remains to be addressed more systematically in future research, such as the use of dung materials as seasonality markers to distinguish between dietary patterns, and investigating direct dung isotopic indicators to further explore both human and livestock life conditions and health in this critical geographical area through time.

### 3.3. The Northern and Southern Levant

In the modern rural village of Tell Seker al-Aheimar, in the Upper Khabur in north-eastern Syria, northern Levant, a geo-ethnoarchaeological approach explored plant and faecal microfossils excreted with dung by different animals, predominantly ruminants with additional comparative records from dogs, hens, and commensals including rodents (house mouse), corresponding to a variety of ecologies, environments, animal control practices, and known diets, as recorded through ethnographic fieldwork conducted during the archaeological excavations at the Neolithic mound located in the same village [15]. A number of modern reference samples were obtained from soils from fallow agricultural fields and pasture grounds, cattle, sheep, and goat penning deposits, mud-brick manufacturing areas, firing installations (including hearths and *tannur* ovens fuelled with wood-dominated or mixed ovicaprine dung matter), agricultural by-products, and a wide range of household storage installations and discarding areas. By comparing integrated phytolith and spherulite contents associated with household activity areas at the Neolithic site of Tell Seker al-Aheimar [15,63], as further inferred from ethnographic records and modern reference materials [15], the research focused on the identification of household activities and their spatial arrangements, and on assessing the nature of the microfossil records deposited on-site within indoor and 'dirty' open spaces. The results indicated that a varied range of plant materials derived from agricultural products and by-products were deposited on site, such as crop storage and crop-processing, animal fodder, building materials, and household debris, but also as derived from livestock dung, including the use of dung for fuel purposes, as in many other regions across the Near East [28,64].

In addition to the above case study in northeastern Syria, aimed at producing comparative reference records for the identification of archaeological dung remains linked to household activity, more spatially localised approaches emerged from the examination of recently abandoned Bedouin campsites in different regions within the southern Levant using geo-ethnoarchaeological methods [14,16]. Short-lived or ephemeral occupations are characteristic among many pastoral nomadic populations and foragers, whose settlement patterns reflect the demands of their highly mobile lifestyles [16]. Ethnoarchaeological studies of Bedouin campsites have long been applied to better understand many aspects of archaeological pastoral nomadic occupations, which are critical for tracking the emergence and spread of sedentism and farming, including formation processes associated with their abandonment and the spatial analysis of campsite floors through thin-section micromorphology (e.g., [65–67]). A recent study adopted a geo-ethnoarchaeological approach using a dual geochemical and phytolith methodology for identifying activity areas in seasonally occupied Bedouin campsites at Wadi Faynan, in southern Jordan [16]. The use of a portable X-ray fluorescence (pXRF) instrument and of phytolith analysis of sediment samples from six campsites (five abandoned for six months and up to fifteen years; only one occupied at the time of sampling) were found to be useful for distinguishing between activity areas, including sheep and goat penning, floors, and firing installations (hearths fuelled with dung cakes), providing insights into anthropogenic enrichment patterns and the impact of short periods of abandonment on the assemblages. The results indicated that both geochemical and phytolith signatures can be recorded in soils at the locations where activities took place and that these may be preserved even when the depositional contexts were left exposed to erosion, wind, and rain for several years. The ethnographic work recorded the use of dung cakes for fuel purposes as a common activity that may make difficult to distinguish between activity areas and that can potentially mask other traces. Although in this case study the efficacy of the chemical elements to indicate variation within the data was observed to be greater than that of the phytoliths, specific trends within the phytolith records were more useful in identifying particular activities. More often than not, both methods complemented and supplemented each other and provided information about different aspects of activities for addressing animal–human interrelations that might prove relevant in future archaeological studies [16].

In the arid Negev Highlands, southern Israel, a geo-ethnoarchaeological study has also focused on Bedouin abandoned camps—one encampment was abandoned only a few weeks before fieldwork was conducted, and the other one was in use in the middle 1980s and it had not been frequented since then [14]. This case study focused on herd management practices, particularly on the identification of degraded dung remains as evidence for pastoralism at the enclosed compound at Atar Haroa. The fieldwork included the collection of modern fodder plants and dung materials, primarily from goats, sheep, and camels. The main objective was to determine whether the early Iron Age inhabitants had a way of life based on herding and agriculture by comparing geo-ethnoarchaeological indicators for agro-pastoralism from modern Bedouin abandoned camps. Micromorphological, mineralogical, dung spherulite, phytolith, and isotopic analyses conducted on the occupation layers from the rooms revealed that they originated from wood ash and dung used as fuel materials, whereas the sediments in the courtyard were composed of degraded livestock dung [14]. This study reported similarities between the phytolith records within the goats, and the archaeological samples and the comparative modern dung materials associated with winter free-grazing desert livestock and lichen-grazing black dwarf goats. These results supported the hypothesis that early Iron Age Atar Haroa was most probably used by pastoralists who subsisted on herding.

These case studies illustrate the fundamental importance of geo-ethnoarchaeological approaches to livestock dung records for understanding broader issues related to a subsistence economy, energy sources, and socio-cultural practices in arid areas of the southern Levant and beyond, issues that have not been yet fully addressed in archaeological syntheses on the emergence and developments of farming in this core region.

### 3.4. The High Tell in Tunisia, Eastern Maghreb

In the High Tell in northwestern Tunisia, Eastern Maghreb, geo-ethnoarchaeological research has focused on livestock dung production, management, and storage, waste disposal, as well as on dung use for building, manuring, and cooking in cylindrical mud *tabouna* (*tannur* type) ovens [9,10]. Ethnoarchaeological studies were conducted in two small villages, El Souidat and Guasdya, located in the vicinity of the Iron Age Numidian site of Althiburos. The study area is inhabited by families that subsist on herding, primarily of sheep and goats, in addition to cereal agriculture, where their livestock provide the main source of fuel. The fieldwork comprised informal interviews and ethnographic observations under full permission, as well as the collection of modern reference dung and plant materials from agricultural fields, pasture grounds, and road margins, in addition to household activity areas such as livestock enclosures, dung fuel residues from ovens, and building materials (dung-tempered floors and roofing). The ethnographic studies reported dung production and drying in open spaces, dung management and storage in specific stony installations (locally called *Kamur*), waste disposal and its re-use, manuring with domestic fuel remains in household gardens, as well as traditional means of baking and cooking in *tabouna* ovens. The sampling of both modern dung and plant materials was followed by microfossil analyses [9,10], primarily of phytoliths and dung spherulites, complemented with a pilot calcitic plant microfossil reference collection from wood ash pseudomorphs to distinguish between wood and dung ashes related to firing activity [20], as these microfossils may be better preserved within archaeological contexts than macro-botanical remains such as wood charcoal, seeds, and fruits, or charred dung pellets preserving their morphological integrity (Table 1). The wood ash pseudomorph reference materials were obtained from the burning of branches to ashes in a laboratory furnace oven at 550 °C, and comprised mainly plant species that were common in the Iron Age archaeobotanical records, including Aleppo pine (*Pinus halepensis*) and olive trees (*Olea europaea*), recently expanded with additional modern taxa such as oaks, and new woody plants such as pine seed scales and oak cupules, potentially more resistant plant matter found in early/middle Holocene macrobotanical records from the study region in Eastern Maghreb [9,10,46,47,68–70]. The overall aim of this geo-ethnoarchaeological

research was to improve the interpretation of living spaces and energy sources to better understand the trajectories of farming communities in this poorly investigated region in northeastern Africa.

The geo-ethnoarchaeological research included firing measurements within *tabouna* ovens fuelled with sheep and goat dung and used daily for baking and cooking, using a portable thermometer that enabled the recording of temperatures over time, showing a rapid initial increase (up to 800 °C in a few minutes) and, 30 min later, a marked drop in temperatures to around 400 °C within the fuel and 100–120 °C within the oven wall during the 5 min baking of bread cakes (namely *Khobz*), whereas fuel at the oven-base remained at ca. 200 °C about 4 h later. These recordings were consistent with previous experimental records and geo-ethnoarchaeological datasets obtained in rural Uzbekistan [20], as well as with baking measurements in *tannur* ovens from the Upper Khabur in the northern Levant (see Section 3.3), where the main fuel source was woody material, while animal dung was only residually used, as previously argued [15]. Samples were collected from non-burned fuels, mixed-burned fuels obtained from previous combustions and re-used in the same firing installation, and fuel residues (Figure 3f). Then, the samples were analysed following the same methodological approach. Microfossil records served as dung-dominated and wood-dominated fuel records, respectively, for comparative purposes.

The microfossil assemblages recovered from a range of combustion installations, including from hearths and ovens in Iron Age Althiburos, compared favourably with modern reference ethnoarchaeological materials (Figure 3f) and allowed the identification of fuel remains: dung, wood, and a mix of dung and plant matter (wood and agricultural by-products), indicating that dung was used as a source of fuel materials across time at the Numidian settlement, at least from the tenth century BC to the last centuries BC. More recently, these geo-ethnoarchaeological datasets have been applied as modern reference standards in investigations of early/middle Holocene archaeological contexts from the north border of the Tunisian Dorsale mountains [46], pointing to the use of animal dung as fuel at early Neolithic Doukanet el Khoutifa by the presence of spherulitic ashes within combustion installations, and the identification of dung deposits within occupational layers at nearby Epipaleolithic (Capsian) Kef Hamda. This suggests animal manipulation and, therefore, dung use prior to the appearance of morphological changes in animal skeletons indicative of domesticated taxa [4,71].

These integrated geo-ethnoarchaeological and experimental approaches enabled burning experiments in a context more comparable to archaeological sites than to situations reconstructed under laboratory-controlled conditions, as reported earlier (Section 3.1, e.g., [18,50,72]). Current ongoing research on experimentally constructed firing installations commonly found during the Iron Age in the Western Mediterranean area, including different types of hearths and ovens made of a variety of raw earthy materials and fuelled with different sources, including animal dung, is exploring combustion temperatures over time in both open-air and indoor settlement locations from northeastern Iberia, Spain. This study comprises a systematic sampling of reference materials for integrated geoarchaeological, archaeobotanical, and biochemical analyses, and it is expected to become a comprehensive framework to better understand combustion installations, energy supply, and pyrogenic activity by prehistoric communities through time.

#### 4. Conclusions

This paper highlights the integration of diverse analytical methods from the geosciences, such as thin-section micromorphology and microfossil analyses, and including geochemical and biomolecular indicators, to establishing ethnoarchaeological comparative records of livestock dung, a material often difficult to detect using conventional excavation and sampling procedures in most sites. The arid and semi-arid regions of the study areas provide favourable conditions for the preservation of archaeological faecal materials via rapid desiccation [73], particularly within earthen architecture, which shelters these remains from environmental agents and erosion, and in middens, where rapid burial

prevents the action of faecal decomposers such as mites, fungi, and flies [74]. The visibility of dung and coprolites in these contexts depends on a variety of factors, including composition and formation processes, and pre- and post-depositional taphonomic alterations. Whereas ethnographic research has proven valuable in the study areas for establishing a comparative framework of reference with the materials recovered from archaeological contexts, improving our understanding of dung deposition, activities, seasonality, and burial conditions, methodological techniques such as pXRF for detecting the presence of phosphates in sediments have yielded promising results for the rapid identification of faecal materials during excavations [16,17]. Similarly, the examples from these core regions suggest that rapid screening of suspected dung deposits through smear spherulite slides could improve the frequency with which herbivore faecal materials are being detected during archaeological fieldwork [29].

Due to the large number of components frequently contained in archaeological faecal matter, from plant remains to parasites, multiproxy approaches are the most suitable for extracting all the information contained within them to help in our understanding of past diets and ecological strategies. However, as this review has shown, there is currently no general agreement on how to approach faecal residues methodologically, and archaeologists have to choose from a wide range of analytical techniques based on research questions, a methodological variability that often makes comparative studies between sites and regions difficult. Micro-contextual methods such as thin-section micromorphology are particularly useful for examining the depositional context of dung and have proven crucial for understanding continuity and change in the use of space within settlements over time and animal management strategies, as well as the impact of burial conditions on the preservation of faecal materials [43–45]. Phytoliths are particularly abundant in archaeological faecal matter from the study areas, especially in herbivore dung, and are substantially resistant to heating and to a variety of soil pH and burial environments. Phytolith analysis has revealed important dietary and seasonal patterns in the study areas, often geographically specific [15,17,18,43], although their presence in faecal matter varies significantly depending on which plants were consumed and which plant parts were ingested, since phytolith production differs notably between species and plant parts.

Recent developments in archaeological science have led to the increasing application of biomolecular techniques, including lipids, proteins, and DNA analyses [33–35,37,38,75]. These rapidly emerging techniques have not yet been extensively applied to faecal materials in the study regions, in spite of their potential for shedding light into dietary patterns, health conditions, and gut biomes at very high resolution. A frequent challenge is the potential cross-contamination during sample collection and the availability of suitable preservation and storage conditions. Future research needs to focus on improving these two aspects to allow for the standard application of highly sensitive multi-proxy analyses to faecal remains.

This review also shows that most of the studies of archaeological faecal matter from early/middle Holocene contexts in North Africa and the Near East have focused on herbivorous livestock, mainly for the investigation of early animal management and its impact on sedentary communities and environments. Therefore, and in light of the excellent preservation of faecal remains in these two regions, there is still much scope for the analysis of dung from omnivorous and human coprolites to create a more nuanced picture of diet, health, and sanitation in sedentarising populations. Archaeological faecal materials have the potential to make important contributions to interpretative frameworks of reference for disentangling the relationships between people, plants, and animals and the origins and spread of farming across geographical regions beyond the core areas of the Fertile Crescent and northeastern Africa. Geo-ethnoarchaeological, experimental, and biomolecular approaches within built environments are increasingly being applied to wider studies of human–plant–animal dynamics, and further studies aiming to integrate dung studies through such methodologies, analytical techniques, and reference standards will contribute significantly to the investigation of archaeological sites at different scales, shedding light

on seasonality, taphonomic formation and alteration, and nature of occupation, even in sites preceding the domestication of herd animals.

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