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Interactive comment on “Origin, distribution, and characteristics of Archaeological Dark Earth soils – A review” *by* Michael O. Asare et al.

Michael O. Asare et al.

asare@fzp.czu.cz

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Comments from Referee 2

This manuscript sets out to present a review of anthropogenic dark earths in a global perspective. It aims to make generalisations about an archaeological phenomenon, and summarize different dark earths’ evolution, distribution, physico-chemical properties, as well as to propose further directions for future research. The presentation and language of the paper are good, however, the remaining two principal review criteria have not been attained. The scientific quality in particular is severely lacking. While the basic premise of this manuscript could be promising if executed in a systematic manner that takes all the existing archaeological and pedological information into consideration, this is unfortunately not the case. The literature review on which this paper is based is in its own right insufficient to such a degree that it would have to be completely re-executed in order to be of acceptable quality. It contains considerable omissions and errors, meaning that its acceptance for publication would be misleading and pose a risk for subsequent scholarship, as researchers unfamiliar with this topic would be considerably misinformed. Thus, I am afraid I must advise to reject this manuscript. Several key concepts in dark earth studies are omitted or misrepresented, and the manuscript contains significant scientific errors. The authors have failed to engage with the large, existing body of literature, and misrepresent some of the cited data. Concerning European Dark Earths, most of what is written is either based on outdated information, cites authors incorrectly, or is factually incorrect. Important sites have been disregarded. In the case of Europe, only three (!) sites are used for the discussion, while well over 40 can easily be found in published work, not including excavation reports or grey literature. This is partly true for the Amazonian dark earths as well, for instance, recent work on Belize is disregarded. Finally, the sites' evolution nor distribution is correctly represented. Anecdotal evidence is used to justify incorrect blanket statements. In addition, for several of the archaeological cases, descriptions are confused with interpretation. The term “dark earth” has for the past ten years been used as a descriptive rather than interpretative term, and the statement that “All types of ADE developed as a result of deliberate and/or unintentional deposition of domestic/occupational wastes, charred residues, bones, shells, and biomass ashes from prehistoric up to recent times” is extremely problematic and misleading. For European dark earths in particular, it is well established that many different types of activities, in combination with post-depositional processes, can lead to the formation of dark earths. The ever-growing body of scholarship explicitly contradicts the statement that dark earths are the result of a uniform set of depositional and post-depositional processes, and instead demonstrates that every dark earth must be studied individually to capture their high degree of variability, within their specific archaeological and societal context. As such, it is nonsensical to attempt to establish one set, or even

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a trend, of physico-chemical properties to characterise ADE, at least in the case of European dark earths, beyond their descriptive criteria. Also, from an archaeological point of view, this manuscript contains major flaws. Response: Thank you for all your comments, however, recent papers have been reviewed and discussed well. The paper again has been thoroughly improved by including updated Tables 1, 2 and Figure 1 which explain the exact locations of developed ABEs and detailed of their physicochemical characteristics when compared with the surrounding control. Quantitative evaluation of these properties has been again added to provide better understanding. Again, the development of ABEs are mostly connected with the deliberate or indeliberate disposition of past human activities. In many of the papers studied especially where micromorphological analyses were applied has helped to construct and test hypotheses concerning how the site (ABE) formed over time, what materials and elements contributed to the character of the sediments, and how the modern surface soils acquired the appearance of ABE. Almost all ABE studied share critical characteristics, such as the ubiquitous presence of charcoal. For example, the repeated slash-and-burn of abandoned settlement sites could have produced Terra preta (Denevan, 1998). Several anthropogenic activities, e.g., the use of low heat, smoldering fires for food and pottery preparations, and spiritual reasons contribute to biochar accumulation or biochar amendments to home gardens, leading to the formation of Terra preta (Glaser et al., 2001). Thus, Terra preta formation is a combination of both unintentional soil modification as well as intentional amendments to improve small-scale home gardens. Therefore, this explains why the majority of Terra preta occupy a relatively smaller land size.

A few specific points: - anthropogenic deposits with a clear interpretation, such as shell middens, should not be included in a review on ADE Response: In the context of this paper, shells are sometimes additional component of many ABEs, however, discussions on shell middens have been omitted from this work as they form different category of archaeological soils. - a few recent key works on dark earths have been cited (e.g. Devos et al., Nicosia et al., Arroyo-Kalin et al.), however, next to none of

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the works cited in these articles, nor other seminal papers on the topic, have been consulted. This manuscript shows a worrying lack of insight into the recent scholarship and research questions regarding European dark earths, and the small number of recent and past references is extremely problematic, especially for a manuscript that claims to be a review article. For instance, the complex and varied formation trajectories, including anthropogenic and natural formation processes, of European dark earths are disregarded, while authors in the field have focused on these for decades. Response: Recent analysis of ABE comparing the physicochemical properties to reference soil has been discussed in the manuscript. We have extensively read and included recent papers in the manuscript. However, because most of these ABEs have similar chemical composition which is higher and different from than surrounding soils (non-ABE), we have generalized them as specific characteristics of EDEs. Moreover, the formation of ABEs mainly results from a complex combination of the processes of accumulation and transformation associated with the use of space and the nature of prevalent materials. Please see some of the references included in the manuscript below Asare, M.O., Horák, J., Šmejda, L., JanovskÃ¡, M., Hejcman, M.: A medieval hillfort as an island of extraordinary fertile Archaeological Dark Earth soil in the Czech Republic. Eur. J. Soil Sci. https://doi.org/10.1111/ejss.12965, 2020b. Arroyo-Kalin, M.: The amazonian formative: crop domestication and anthropogenic soils. Diversity, 2, 473-504. https://doi.org/10.3390/d2040473, 2010 Arroyo-Kalin, M.: Amazonian Dark Earths: geoarchaeology. In: Smith C. (Ed.). Encyclopedia of Global Archaeology, Springer, New York. pp. 168-178. https://doi.org/10.1007/978-1-4419-0465-2_2252, 2014

Several key concepts in dark earth studies are omitted or misrepresented, and the manuscript contains significant scientific errors. The authors have failed to engage with the large, existing body of literature, and misrepresent some of the cited data. Concerning European Dark Earths, most of what is written is either based on outdated information, cites authors incorrectly, or is factually incorrect. Important sites have been disregarded. In the case of Europe, only three (!) sites are used for the discussion, while well over 40 can easily be found in published work, not including excavation reports or grey literature. This is partly true for the Amazonian dark earths as well, for instance, recent work on Belize is disregarded. Finally, the sites' evolution nor distribution is correctly represented. Response: The manuscript has been thoroughly rearranged with addition of important details. The distribution and evolution of the ABE have been revised. In the case of EDE more recent articles has been reviewed and discussed in our manuscript to give deeper insight. Please see some of the references on EDEs included in the manuscript below Asare, M.O., Horák, J., Šmejda, L., JanovskÃ¡, M., Hejcman, M.: A medieval hillfort as an island of extraordinary fertile Archaeological Dark Earth soil in the Czech Republic. Eur. J. Soil Sci. https://doi.org/10.1111/ejss.12965, 2020b. Arroyo-Kalin, M.: The amazonian formative: crop domestication and anthropogenic soils. Diversity, 2, 473-504. https://doi.org/10.3390/d2040473, 2010 Arroyo-Kalin, M.: Amazonian Dark Earths: geoarchaeology. In: Smith C. (Ed.). Encyclopedia of Global Archaeology, Springer, New York. pp. 168-178. https://doi.org/10.1007/978-1-4419-0465-2_2252, 2014 We have also discussed the Belize paper among others in the manuscript. Please see below In using soil micromorphological analyses in Marco Gonzalez, on the island of Ambergris Caye, Belize (Maya dark earth), Macphail et al. (2016) determined the effects of human population habits on black earth formation and the materials and elements which contribute to the character of the sediments. The black earth was characterized by pieces of charcoal, burnt and leached coprolitic bone, bryozoan-rich limestone bioclasts, shell fragments, fine to coarse relict lime floor fragments and organo-mineral excrements. Bulk soil analyses confirmed the calcareous nature of the Black Earth (>50% carbonate, ranging from 50 - 59% Ca) – owing to the very high carbonate content in reefstone, lime plaster fragments, and ash nodules. Increased content of total P in these soils was recorded ranging from 3660 mg kg-1 to 7250 mg kg-1. However, unlike the Amazonian Dark earth which have a neutral to acid pH and relatively low Ca content (Arroyo-Kalin, 2010, Arroyo-Kalin, 2014), the Maya Dark Earth – as a Calcaric Brown Soils may have more in common with Roman/post-Roman European Dark Earth formed in the remains of lime-based Roman building

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materials (plasters and mortars), which have a high base status and carbonate-rich character (Macphail, 1994, Nicosia et al., 2016).

- the study lacks a systematic literature review, preferably presented as a table per geographic region, citing all relevant work that has been conducted. In addition, no systematic review (as a table, map, or in other form) of the specific sites where dark earths have been encountered has been included, which in my opinion counts as a major flaw in a review manuscript. Their spatial variation within Europe, but also within specific towns, is ignored. Hence, the discussion and conclusions are by default invalid. Response Sites with the development of ABEs have been cited in the manuscript and in a diagrammatic representation giving clearer interpretations. Examples of the description of sites identified with ABE and area occupied have been supplied in a tabular form. Such information offers the individual extent of these soils and their wide distribution across the globe. Please see Figure 1 and Table 1 - no insight in archaeological interpretations, implications or research questions is presented in the text, which seems like a major omission in a manuscript discussing an archaeological phenomenon. For instance, lines 299-304 make no archaeological sense. Several such instances occur.

Response: We have provided as much as possible archaeological interpretations throughout the manuscript including the date, site names as well as the kind of human activities which contributed to the development of these soils. Please see below In the 10 - 11th century AD, Slavic settlement activities (disposition of human and animal excrements and charred organic matter) in the Wendland region, Northern Germany created dark patches of soil horizon in the settlement area. Multi-elemental analysis of the soil indicated significantly higher content of C, N, P, Ca, Mg, Na, Fe, Cu, Zn, Mn, Ba and, pH (H2O) ranging from 5.0 to 6.7 compared to neighboring soil (Wiedner et al., 2015). These soils related to the first millennium AD dark earth from settlement context (often urbanized), which is known from the site in post-Roman Britain (Macphail, 1983) and partly from the migration period and Viking age size in Scandinavia (Wiedner et al., 2015).

- the paper fails to demonstrate the relevance of a discussion focusing only on (the highly variable!) physico-chemical properties of ADE. In the least, one would expect a discussion of the methodological frameworks used to study different types of dark earths, and how this has an impact on the type of data collected, and the interpretations reached. In general, the significance of focusing on dark earths' physico-chemical properties is not made clear in relation to archaeological relevance.

Response: Quantitative interpretation of obtained data for this study have been included in the manuscript to clearly provide an immense impact of past human activities. Additionally, methodological approaches used in the analysis ABEs have been well documented in tabular form and within the manuscript and this has been explained in the discussion section of this work. We further assert that the use of the common analytical methods in estimating the enrichment of EDE by different elements still has not been studied. We have further demonstrated throughout the manuscript about how human activities have influenced the formation of ABEs. From our point of view, however, the association of the site with ABE formation provides an example in which intensive human activity can be linked to the elemental composition of soil. Nonetheless the association tells us that even inadvertent human behaviour–living, working, discarding, leaving debris, dying–can potentially affect soils positively. All these are possible through the use of archaeological research and analytical methods to elucidate the specific types of activities that formed the ABEs. Please see line The accumulation of the elements is predominantly due to the deposition of organic wastes and wood ashes. The depth of ABEs is influenced by the duration and intensity of ancient human activities. Studied ABEs across the world represent nutrient-rich landscapes resulting from ancient human activities. Different types of studied ABEs have the same principle of formation and similar chemical properties. However, many authors have used different methodologies to quantify the elemental composition of ABEs from Africa to arctic regions (Lehmann et al., 2003b; Nicosia et al., 2013; Solomon et al., 2016). These methodological approaches were focused on the quantitative analysis of plants-available nutrients using different extraction approaches or on the total

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content of elements in the soil using dry analytical methods of XRF. Although different methods were used, there was a clear pattern recorded by all approaches – an enrichment of ABEs by C, N, P, Ca, Mg, Mn, Cu, Zn, Sr, and Ba in comparison to surrounding soils. The question which is still unsolved is how large the enrichment for different elements is and ABEs as every researcher uses a different analytical approach which gives different enrichment factors. In this respect, the total content of elements gives clear enrichment factors as obtained values for different elements are less affected by soil properties and reactions. Plant available contents of elements are generally highly affected by pH; thus, extraction of the plant-available fraction can increase the unreliability of enrichment factors as most elements can relate to soil matrix and they may not be released by extractants. Measurement using XRF and ICP-OES for the total content of the element can be compared since they correlate strongly with high precisions (Šmejda et al., 2018).

- Figure 1 and tables 1 and 2 are problematic. The map presented in figure 1 is not sufficient, and should at the very least also include a more detailed overview for each geographic region that is discussed. Many important sites are missing, or cannot be discerned due to the map's scale. The sites on the map are unnumbered and unlabelled. Table 1 is based on a single site and cannot be extrapolated at all, this this division is highly specific for the site(s) in question and may by no means be generalised to dark earths as a phenomenon. As such, the table is completely obsolete. Table 2 presents 3 sites used for the discussion of European dark earths, while many dozens exist. This is unacceptable for a review article. Figure 1 has been well explained. Since one or more studies within a country has been studied, individual sites with developed ABE has been presented in Table 1 (Revised). The map indicates countries where ABE has developed and may be more than one site in a country See attached Table 2 (formerly table 1) has been well explained. In this explanation we cited a typical example of profile description of EDE with further explanation, Please see below Pedological studies of EDE have been based on the topsoil with very little knowledge on the subsoil. The physical description of EDE usually divides the depth of the soil into four distinct horizons with the upper horizon mostly made of midden materials in the form of charcoal, bone, plaster, burnt bricks, etc. (Table 1; Courty et al., 1989). Furthermore, Courty et al. (1989), categorized EDE from their studies in London into two stratigraphic units; the lower 'pale Dark Earth' unit and the upper 'Dark Earth' unit. The pale Dark Earth unit was found on the relict of Roman floor levels which contained Roman coins and burials and was crosscut by later Roman features including debris from burning, collapse, and decay of buildings. The upper layer was typically 20 to 90 cm thick but ranged up to 2 m in thickness and was characterized by blackish color (Fig. 3c). Notwithstanding, the stratigraphical classification (cultural layers) of EDE can be connected with different past settlements from different archeological timelines.

- the conclusions are incorrect considering the fact the acquisition and review of the data is highly incomplete and anecdotal. Also, the meaning and implications of the "The principles leading to the physicochemical formation of ADEs are similar except for certain human activities peculiar to the cultural setting of the regions where ADEs are formed." are not made clear. "ADEs have higher C, N, P, Ca, Mn, Cu, Zn, Mn, Mg, Fe, Sr, and Ba content than surrounding soils." – this is only applicable to a select number of cases and can by no means be generalised.

Response: The conclusions of the manuscript have been upgraded. Please see below The principles leading to the formation of ABEs are similar except for certain human activities peculiar to the cultural setting of the regions. For example, whereas disposition of wastes, charred materials, faeces, bones are general characteristics of ABE formation around the world, the production and processing of palm kernel is peculiar to AfDEs. This was evident from archaeological finds in recent studies of AfDEs in Ghana. Please see the reference; Asare, M. O., Apoh, W., Afriyie, J. O., Horák, J., Šmejda, L., and Hejcman, M.: Traces of German and British settlement in soils of the Volta Region of Ghana. Geoder. Reg. 521, e00270. https://doi.org/10.1016/j.geodrs.2020.e00270, 2020a. The fertility of ABE is mostly associated with stable organic matter stock, microbial abundance, as well as higher CEC, pH, and nutrient (C, N, P, Ca, Mn, Cu, Zn, Mn, Mg, Fe, Sr, Rb, and Ba) content. The retention of the nutrients relates to the fraction of the size of soil particles, suitable pH, and homogenous distribution charcoal, predominantly responsible for the black color.

To conclude, this manuscript poses a missed opportunity, since a proper review paper addressing dark earths on a global scale, taking into account their nuances and variation does indeed have potential (with the remark that the inclusion of kitchen middens in this category seems misplaced). However, it would require a truly systematic review including all available literature per region, rather than basing conclusions on a small fraction of the existing data. In its current form, the paper contains a flawed attempt at review, without presenting any novel concepts, ideas, tools, or data. Multidisciplinary methodologies used to study dark earths are ignored, and a one-sided focus on physico-chemical properties results in a complete disregard of other existing methods and their results, as well as in the richness of archaeological data and interpretations. The rationale behind this approach is not made clear. A review of ADE origins or evolutions, as set out in the introduction, is not attained. All this implies that a thorough revision of the research that this manuscript is based on would be needed, including the reading and systematic inclusion of all available published work, as well as a complete re-write in order to mitigate incorrect statements and conclusions.

Response: Thank you for all the constructive comments. Additional analysis and discussions have been made and the paper has been substantially improve

See complete manuscript

Origin, distribution, and characteristics of Archaeological black earth soils- A review Michael O. Asare a, Jerry Owusu Afriyieb, Michal Hejcmana*

a Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences, Prague, KamÃ¡cká 129, Prague 6 – Suchdol CZ165 00, Czech Republic. b Department of Animal Science and Food Processing in the Tropics, Faculty of Tropical AgriSciences, Czech University of Life Sciences, Kamycka 129, Prague 6 – Suchdol

CZ165 00, Czech Republic.

*Corresponding author- hejcman@fzp.czu.cz (Hejcman M.)

Abstract Archaeological black earth (ABE) can be classified as a layer of anthrosol (syn. anthroposol) visually characterized by black color mainly due to homogenous charcoal inclusion, and substantial enrichment by nutrients compared to surrounding soils. The study aimed to provide a detailed overview of the variability, distributions, and characteristics of ABEs relating to their classifications as well as the physicochemical properties. Archaeological black earth is distributed from the tropics (Amazonian Terra preta, African dark earth), moderate climatic zones (European dark earth) up to the Arctic (kitchen middens). The development of the ABEs are connected with the deliberate and/or unintentional deposition of domestic and occupational wastes, charred residues, bones, and biomass ashes from prehistoric up to recent times. ABEs exhibit optimum C: N ratio for effective mineralization, stable organic matter content, and higher CEC compared to surrounding soils. Archaeological Black Earths are characterized by slightly acidic to neutral soil reactions and a substantially enriched by C, N, P, Ca, Mn, Cu, Zn, Mn, Mg, Fe, Sr, Rb, and Ba in comparison to surrounding control. The unclear remains the level of ABEs enrichment by these elements as enrichment factors for different elements are based on different analytical approaches from plants-available up to total contents in the soil. Although generally highly productive, comparison of herbage production and crop yields between ABEs and natural soils are still rare. The distribution and persistence of anthropogenic activities leading to the formation of ABEs indicate that they are subject to continual formation.

Keywords Anthrosol; Biomass ashes; Charcoal; Physicochemical property; Terra Preta

1. Introduction Human influenced historical events, such as plants and animals' domestication and metallurgy, have been responsible for changes in natural landscapes (Peverill et al., 1999; Howard, 2017). Many human activities are responsible for soil alteration; a blatant example is the creation of dark cultural horizons, mainly termed as

archaeological black earth (ABE). They usually belong to anthropogenic soils, classified as Anthrosols (Howard, 2017; World Reference Base (WRB), 2015) or termed as HAHT (human-altered and human-transported) soils (Soil Survey Staff, 2015). ABE formation consisted of a deliberate and/or unintentional accumulation of layers because of settlement activities, wastes deposition, charred residues, bones, shells, and biomass ashes from prehistoric up to recent times. Such anthropogenic soils are usually characterized by higher concentrations in macro- (e.g., N, P, K, and Ca) and micronutrients (e.g., Mn, Cu, and Zn), that determines a difference in terms of main physical-chemical properties in comparison to neighboring (natural) soils. (WinklerPrins, 2014; Nicosia et al., 2017). Archaeological black earth soils are physically characterized by black, dark brown, or dark grey color (Asare et al., 2020a, b). However, in some regions, soils from past human activities are light without any accumulation of black soil organic matter. For example, although the large-scale accumulation of P, K, S, Zn, and Cu were in comparison to adjacent rangelands and arable fields, at Tel Burna in Israel, even more than 2000 years after its abandonment, the color of the soil was light gray (Šmejda et al., 2017). Thus, ABEs can hardly develop in semi-arid and arid regions because of the high decomposition rate of accumulated organic matter. The depth of the ABE horizon normally ranges from 0.4 to 0.8 m and can extend up to 1m or more (Courty et al., 1989; Macphail et al., 2003), with increasing depth indicating increasing longevity and intensity of settlement activities. Archaeological black earth soils have been studied by many authors (Runge, 1973; Mücher et al., 1990; van Smeerdijk et al., 1995) but were previously limited to visual descriptions of different organic and inorganic inclusions, archaeological features, artifacts, and post-depositional modifications. More recently, micromorphological analyses were used to determine the variability of ABEs concerning the position in local catena's, parent materials, and broader landscape locations (e.g., Glaser et al., 2003a, 2003bWoods et al., 2009). Other studies have emphasized the timescales involved in the creation of ABEs taking hundreds of years (Richter, 2007; Kawa and Oyuela-Caycedo, 2008). Today, multi-elemental techniques are used to quantify different elements in ABEs to trace specific ancient anthropogenic activi-

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ties connected with the accumulation of these elements. For example, using different analytical tools such as X-Ray florescence (XRF) spectrometry for the determination of near-total contents of elements, inductively-couple plasma optical emission spectroscopy (ICP-OES) in connection with different extraction procedures for estimation of plant available up to total contents of elements (Nicosia et al., 2012). Although many papers studying ABEs are available from different regions (Table 1), a review summarizing the distribution, evolution, and properties of different ABEs has never been published according to our knowledge. The aim of this review was, therefore, i) to provide an overview of different types of ABEs and their distributions, ii) to describe their physicochemical properties, and iii) to identify under-studied questions for the future development of new research activities.

2. Historical characterization and classification of archaeological black earth

This part of the review discusses the widely studied ABEs from the tropics up to the arctic zones; Amazonian Dark Earth, African Dark Earth, European Dark Earth, and kitchen middens (middens). Except for middens, the other types have been designated by their regional names. The geographical distribution of ABEs motivated the compilation of different types from different parts of the world (Fig. 1). The black color of all the ABEs is anthropogenically influenced and does not contradict natural dark soils.

2.1. Amazonian Dark Earth Amazonian Dark Earth is attributed to the vanished complex civilization that once thrived during the Pre-Columbian settlements in the Amazon regions of South American. Recorded use of this soil date at least 5000 Cal Years BP, with the majority forming between 1000 – 2000 Cal Years BP (Whitehead et al., 2010). Statistical modeling indicates that more than 150 000 km2 representing 3.2% of the Amazon forest may harbor dark earth soils from past settlement sites (McMichael et al., 2014). Although Amazonian dark earth occurs throughout Amazonia, they are mostly found in the central and eastern forests, and in riverine settings (Sombroek et al., 2002; Glaser and Birk, 2012). Amazonian Dark Earth soil is most widely studied in Brazil where they occupy relatively large areas with thick altered soil mantles and higher chemical fertility than the surrounding soils not affected by anthropogenic activities (Corrêa, 2007). These sites are known by designations such as black earth (Terra preta), Indian black earth (Terra preta de Indio), anthropogenic black earth (Terra preta antropogenica), and archaeological black earth (Terra preta arqueologica) collectively termed as Amazonian Dark Earths (Lehmann et al., 2003b). According to Lehmann et al. (2003b), Terra preta is found on a variety of soil reference groups such as Acrisols, Arenosols, Cambisols, Ferralsols, Latosols, Luvisols, Nitisols (WRB, 2015). Their extent is not large, most patches range in size from 2 to 350 ha with the majority being at the smaller end of that range. Most of these pre-historic people lived in small groups along the rivers and lakes. The size of Terra preta usually depends on the number of inhabitants and duration of settlement in the area (Smith, 1980) The areas where this soil usually occurs are well-drained, and near running water (Sombroek, 1966). However, Terra preta is not only restricted to areas near rivers but also occurs at higher elevations (Smith, 1999). Past human activities have significantly distinguished the elemental composition of these soils compared to neighboring soils. Terra preta rarely appears as individual classes of soil on soil maps of the region because of their generally small individual extent but are included in more spatially extensive soil classes.

2.2. African Dark Earth African Dark Earth (AfDE) are found around edges of nucleated villages and ancient towns in tropical regions of Africa (Solomon et al., 2016), typically in rain forest suggesting that verdant rainforest is long-abandoned farmlands and settlement sites enriched by the wastes created by ancient humans. In a first-time analysis of indigenous soil management system in West Africa, radiocarbon dating (14C) of black C (charcoal) found in most identified AfDEs indicated that these soils developed ca 115 to 692 cal Years BP (Solomon et al., 2016) the only dated AfDEs in Africa so far. The discovery of pottery fragments and charred remains of burnt wood from fires set by humans, along with organic macro-remains from crop residues, animal, and bones have been identified as components of AfDE (Asare et al., 2020a). However, Frausin et al. (2014), reported that only particular human activities are responsible for AfDE formation and are highly differentiated by gender. Women are directly engaged in the deposition of charred organic materials from oil palm processing and potash production which are the major contributing activities in the formation processes. AfDEs are spatial distributed across most tropical regions of the African landscape, especially rain forest zones of Ghana, Cameroon, Chad, Guinea, Congo, Malawi, Sierra Leone, Liberia, and rarely in Ethiopia (Fairhead and Leach, 2009) engineered mostly by shifting households and settlement practices. In a recent study by Asare et al. (2020a), the authors identified the influence of past settlement activities, including burning observed from ashy deposits and burnt palm kernel shells in the formation of AfDE in Ghana. Although several discoveries of charred materials and pottery fragments were identified in AfDEs by Frausin et al. (2014), their study was limited to the factors of formation processes and did not determine the age of these objects. However, oral histories and landscape mapping confirmed that these indigenous soil management practices created AfDE in ancient times and has continued up to the present day, probably older than had been known (Fraser et al., 2014; Solomon et al., 2016). Inhabitants of identified AfDE sites from ethnographic accounts lived several thousand years in nucleated villages with subsistence focused on farming, hunting, etc. Thus, most studied AfDEs have rural origins (Frausin et al., 2014) unlike European dark earth and Terra preta which traces its origin from ancient civilization (Nicosia et al., 2012; WinklerPrins, 2014). Until now, there are so studies reporting the prehistoric origin of AfDE. According to (Solomon et al., 2016) local inhabitants of areas with human-impacted dark earth in a study in Ghana and Liberia reported high crop yields compared to the surrounding soils. Dark earths in Liberia and Ghana contained significantly ($p < 0.01$) higher plant-available P (280 mg kg-1), (150 mg kg-1), respectively, compared to their respective (60 mg kg-1and 20 mg kg-1) surrounding soils (Solomon et al., 2016).

2.3. European Dark Earth European dark Earth (EDE) is mostly found in the Roman (27 BC – 476 AD) or postâĂŘRoman urban contexts observed predominantly, if not exclusively, in Europe (Courty et al., 1989; Nicosia et al., 2012; Wiedner et al., 2015). However, in a recent analysis of EDE from an 8th – 12th century AD settlement of Dřevíč hillfort, Czech Republic, the authors identified that the development of this anthrosol can predate the Roman age (Asare et al. 2020b). This was because the site was settled from the Neolithic up the medieval ages. In an archaeological context, EDE indicates urban dark-colored, poorly stratified units, often formed over several centuries, frequently rich in anthropogenic remains such as biomass ashes, burnt bricks from the building/destruction of buildings, bones, charcoal, mortar, and pottery fragments (Figure 3c; Courty et al., 1989; Asare et al., 2020b). Micromorphological analyses of EDEs has indicated that dumping of wastes (house sweeping, hearth functioning and maintenance, and more especially food preparation) is an activity commonly identified to contribute immensely to the formation of EDE (Nicosia et al., 2012). The latter has often developed from middening deposits, for example in open areas or within abandoned house shells. Thus, the extent of EDE can vary from relatively small land size to a complete settlement site (Reference). Several pedological studies on EDE has been conducted in most European countries in the 1980s and 90s. However, maiden studies appeared in early 1980 in Britain and later in Italy where the expression Terre Nere. In France, EDE studies on Terres Noires date back to the early 1990s (Gebhardt, 1997). The earliest studies on EDE in Belgium have been carried out since 1996 in the city of Ghent and later in Brussels (Stoops et al., 2001; Devos et al., 2016). Several articles based on comparisons between EDEs contexts in different European countries were published (Macphail, 2014; Nicosia and Devos, 2014).

2.4. Kitchen Midden Kitchen middens are localized patches of dark-colored earth with artifact inclusion resulting from the deliberate deposition of food remain, domestic materials such as broken and exhausted tools as other human occupations (Hirst, 2017). Middens are named according to their major composition, e.g., bone midden. However, kitchen maiden may contain both a high proportion of bones and shells. Middens are found everywhere humans have lived and have been connected to the Mesolithic period, ca 12000 Cal Years BP (Hirst, 2017). The size of a kitchen midden is a function of population size and the length of time the site was active. Kitchen midden usually develops in non-urban areas, where people discard food and other domestic waste into the soil at the same place (Howard, 2017). Over many years or centuries of waste disposal, midden developed a thick black, organic-rich topsoil usually containing animal bones, mollusk shells, charcoal, ash, etc. and can be in the form of a mound, a pit, or a layer in stratigraphic of the soil. Midden may represent individual periods of settlement at a place. For instance, the different layers of kitchen midden found in Qajaa, Greenland represent three different periods of settlement (Hollesen et al., 2013). The first 120 cm thick layer from the bottom represents the Saqqaq people who lived at the site from around 2000 – 1000 BC, followed by 20 – 30 cm peat without evidence of human activity (1000 – 400 BC). This was overlaid by a 2 – 30 cm thick layer representing the hunters of the Dorset people living in the area from about 400 – 200 BC. The uppermost archaeological layer (in some places up to 1 m thick) has been dated to represent the last immigration of Eskimos to Greenland (The Thule people; 1200 –1750 AD).

3. Physicochemical characteristics of Archaeological black earth Generally, ABEs have been reported to exhibit unique physical and chemical characteristics in comparison to their neighboring soils. This section is an overview of the physicochemical attributes of the different types of ABEs discussed above.

3.1. Physicochemical properties of Amazonian dark earth Terra Preta is formed by a unique combination of intentional management of the soil for farming and unintentional outcome of human occupations and discard of wastes with various inputs of organic and inorganic materials (Glaser et al., 2001). There is a reported possibility that agricultural practices in home gardens contributed to the genesis of Terra preta (Hecht 2003; Schmidt and Heckenberger, 2009). In recent times, midden areas are used as home gardens or home gardens are used as trash areas by indigenous groups in the Amazon basin such as the Ameridians. Amendments of biochar to home gardens are responsible for the high amounts of black C. Therefore, Terra preta genesis can be explained by formation from midden areas and home garden agriculture as also practiced today (Fig. 2). Also, the repeated slash-and-burn of abandoned settlement sites could have produced Terra preta (Denevan, 1998). Several anthropogenic activities, e.g., the use of low heat, smoldering fires for food and pottery preparations, and spiritual

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reasons contribute to biochar accumulation or biochar amendments to home gardens, leading to the formation of Terra preta (Glaser et al., 2001). Thus, Terra preta formation is a combination of both unintentional soil modification as well as intentional amendments to improve small-scale home gardens. Therefore, this explains why the majority of Terra preta occupy a relatively smaller land size. According to Ricigliano, (2011) the profile of Terra preta can be physically divided into three; i) horizon A, representing a deep, dark, and nutrient-rich layer with an abundance of pottery fragments, lithics, and charcoal. ii) horizon B/B1, which is a transitional horizon with a large quantity of peds and root linings thickly coated in organic matter, and iii) the third horizon (B2) representing more thinly coated peds due to a lower percentage of organic matter with the soil lighter in color. However, in the field, Terra preta is identified by unusual features for Amazonian upland soils, such as topsoil with dark matrix colors (dark brown to black) at a variety of depth and presence of potsherds and lithic artifacts corroborated with the homogenous high amount of charcoal (Fig. 3a). The most extraordinary chemical characteristics of Terra preta is their high fertility because they have persisted in environments that generally have high rainfall and high humidity which facilitate soil organic matter mineralization and nutrient leaching. Terra preta has been reported having 2 to 3 times increased content of Ca, K, Mg, Mn, Cu, and Zn in comparison to surrounding soils since their discovery in the 1860s and 70s (Smith, 1980; Glaser, 2007; Winkler-Prins, 2014). Moreover, Kern (1996) reported (in mg kg-1) 4900, 1810, 634, 393, and 208 total content of P, Ca, Mg, Mn, and Zn in Terra preta in an archaeological site in Quatipuru, Pará, Brazil compared to P, 100; Ca, 500; Mg, 1000; Mn, 1000; Zn, 90; in control (Malavolta, 1976). On the same site, the fertility of the Terra preta was confirmed by 700 mg kg-1 extractable P (32% of total P) compared to < 5 mg kg-1 in control (Lehmann et al., 2003a). The unique nature of high C content in Terra preta is the key to the stability of the organic matter. The C found in Terra preta is aromatic (black or pyrogenic carbon) and other organic materials (biochar) that are likely a consequence of the incorporation of charcoal into the soil (Golchin et al., 1997). This initiates a set of biological and chemical processes that have confirmed increased soil organic matter,

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microbial biomass, and diversity, cation-exchange capacity (CEC), pH, and nutrient retention (Lehmann et al., 2003a, b; WinklerPrins, 2014). Terra preta has been reported to contain C content of up to 150 g kg-1, as opposed to 20 to 30 g kg-1in surrounding soils (Novotny et al., 2009). The C compounds in charcoal form loose chemical bonds with soluble plant nutrients so they are not as readily washed away by rain and irrigation. Even though charcoal addition to the soil has the potential to bind up N, it may not necessarily provide essential nutrients to the soil. It is, therefore, important to add a nutrient source, e.g., K and Mg along with charcoal amendments due to charcoal's high C: N ratio (Tenenbaum, 2009). Moreover, Lehmann et al. (2003a) studied Terra preta in Embrapa Amazônia Occidental, Manaus, Amazonas, Brazil and reported significantly higher contents of C (84.7 g kg-1), P (318.4 mg kg-1), and Ca (32.8 mmolc kg$-$1) compared to 39.7, 8.1, and 14.7, respectively, of same elements in surrounding soil. The content of available P was 318.4 mg kg-1 compared to 8.1-24.1 mg kg-1 in control, even with the addition of mineral fertilizers, manure, and charcoal. Additionally, increased contents of plant-available P (average of 175 mg kg-1) in 29 Terra preta sites formed on oxisols and ultisols compared to 21.83 mg kg-1 of naturally occurring P in these soils. have been reported (Smith, 1980). The Ca content in these sites was comparably higher averaging 21 mg kg-1 and is also consistent with Sombroek's (1966) studies in five Terra preta sites where Ca ranged up to 109 mg kg-1. In a similar study on the chemical signatures of Terra preta by Kern (1988), anomalous increase by total P (320 mg kg-1), Zn (56 mg kg-1), and Mn (686 mg kg-1) contents compared to their respective surrounding soils of 46 mg kg-1P and 0 Zn and Mn were recorded near the shores of the Trombetas-Nhamundá River. Kern (1988) correlated these data with the former human occupation of the area. Similar enrichment was obtained for two Terra preta sites in Santarém, Pará state, Brazil, where the contents of total P (366 – 460 mg kg-1), Zn (21 - 26 mg kg-1), and Mn (25 - 32 mg kg-1) was significantly higher in comparison to respective surrounding soils of 54-772 mg kg-1 P, 2 - 4 mg kg-1 Zn, and 3 - 5 mg kg-1 Mn (WinklerPrins and Falcão, 2010)). Some authors have worked on the chemical content of fragmented potteries found in the Terra preta in the Amazon Basin (Da Costa et al., 2011; Costa et al., 2013). Most of these studies revealed that areas with the highest density of pottery fragments coincide with the highest contents of elements such as Zn, Cu, Mn, Ba, and Sr. These elements are indicative of human occupation and thus related to domestic units such as cabins, food storage, food preparation, and food consumption areas. Thus, Terra preta relates to increased contents of organic C, P, Ca, Mg, Mn, and Zn regardless of soil type on which it was formed in contrast to the usually highly weathered and nutrient-poor surrounding soils. Terra Preta is characterized by reduced acidity with pH usually ranging from 5.2 to 6.4 (Falcão et al., 2009; WinklerPrins, 2014) in comparison with surrounding soils with pH ranging from 3.0 to 4.2 (Souza et al., 2016). Terra preta is characterized by higher moisture-holding capacity and CEC in comparison with surrounding soils (Sombroek, 1966; Smith, 1980). Souza et al. (2016) recorded higher CEC ranging from 33.4 to 41.9 cmol dm-3 in Terra preta in comparison to only 14.2 cmol dm-3 in the surrounding soil. The combination of land use and ecological factors that led to the formation of Terra preta is still not known with precision.

3.2. Physicochemical properties of African dark earth Processes that lead to the formation of AfDE are quite similar to those of Terra preta except for certain activities that are peculiar to African regions. Therefore, AfDE is human-made analogous to Amazonian Terra preta yet subject to the continual formation. Although the physical characteristics of AfDEs are analogous to those of Terra preta, representative profile in comparison to other surrounding profile indicates that AfDE is dark-colored with the accumulation of pyrogenic carbon (PyC) in these black piles of the earth extending to a depth of 1.80 m (Fig. 3b). Studies carried out by Solomon et al. (2016) in Ghana and Liberia identified that AfDEs have a higher content of nutrients in comparison to surrounding soils. They determined from 400-450 Mg ha-1 organic matter stock in the AfDEs, representing enrichment approximately 200 – 300% compared to the surrounding soils (120-150 Mg ha-1). Plant-available N and P contents in the arable layer (0-.02 m) ranged from (in mg kg-1) 1-3 and 150-400, respectively, compared to about 0.5-1.9 and 5-60 in the surrounding soils. The contents of Ca K, and Mg were substantially higher in AfDE

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than in surrounding soils (Solomon et al., 2016). They recorded a pH range from 5.6 to 6.4 (moderately to slightly acidic) quite analogous to those noted in many studied Terra preta compared to 4.3-5.3 (very strongly to strongly acidic) in the control. There was significantly higher pyrogenic carbon (4.94-37.74%) and cation-exchange capacity (120-150 mmolc kg-1) in the AfDE sites, representing 2 – 26 and 1.4 – 3.6, respectively, enrichment compared to surrounding soils. And this contributed to the retention of the elements. Except for increased plant-available N which has been recorded in the study of AfDEs, the high pH, CEC, and increased content of C, P, Ca, Mg mimics that of Terra Preta and other types of ABEs. In a recent study of AfDE in Ghana, the content of total P, K, Ca, and Mn was (in %) 0.16- 0.65, 0.8- 1.44, 0.9-.02, 0.08- 0.27, respectively, higher than the control (Asare et al., 2020a). In addition to substantially higher plant-available P, K, Ca, S, Fe, Cu, and Zn in the AfDE compared to the control. The authors further recorded a significantly higher pH ranging from 6.1-6.9 in the AfDE compared to 4.4 in the control. Hence, the retention of the elements in the AfDE is related to reduced soil acidity. Although AfDEs have been identified in small patches of landscapes in many African countries, their classification has generally been based only on physical description lacking proper dating and detailed chemical analysis.

3.3. Physicochemical properties of European dark earth Pedological studies of EDE have been based on the topsoil with very little knowledge on the subsoil. According to Courty et al., (1989), the physical description of EDE usually divides the depth of the soil into four distinct horizons with the upper horizon mostly made of midden materials in the form of charcoal, bone, plaster, burnt bricks, etc. (Table 2). Furthermore, Courty et al. (1989), categorized EDE from their studies in London into two stratigraphic units; the lower ‘pale Dark Earth’ unit and the upper ‘Dark Earth’ unit. The pale Dark Earth unit was found on the relict of Roman floor levels which contained Roman coins and burials and was crosscut by later Roman features including debris from burning, collapse, and decay of buildings. The upper layer was typically 20 to 90 cm thick but ranged up to 2 m in thickness and was characterized by blackish color (Fig. 3c). Notwithstanding, the stratigraphical classification (cultural layers) of EDE can be connected with different past settlements from different archeological timelines. Another important characteristic feature of EDE is the high degree of bioturbation observable in the thin section. On the other hand, part of the EDE results from soil formation on grassland, pasture, or abandoned areas in urban or protoâĂŘurban contexts. Typical features are enhanced organic matter, biogenic porosity, and earthworm granules. Human activities such as house sweeping, hearth functioning and maintenance, food preparation, construction, leatherworking, manuring, quarrying, metal production among others have contributed to the formation of EDE. Butchery and leatherâĂŘworking waste have been reported by Stoops et al. (2001) from the Dark Earth in the center of Ghent, Belgium, and is a typical component at the London Guildhall (Macphail et al., 2008). Nicosia et al. (2017) reported that pedo-features associated with Dark Earth are mostly the outcomes of the formation of carbonates, Fe/Mn (hydr) oxides, and/or phosphates. The most common carbonate pedo-features are typic calcite nodules and hypo-coatings, the calcite deriving from the natural parent material (e.g., calcareous alluvium), or the dissolution of ashes, plaster, or mortar. The presence of fecal material such as latrine wastes and coprolites, charcoal, pottery, and enhanced values of P, organic matter, and exchangeable basic cations in Rue de Dinant, Brussels confirms the use of manure (Devos et al., 2009). Most EDEs have high biomass ashes and contain brick earth and mortar fragments. The availability of P and other elements are from the decomposition of plant materials, excrements, urine, ashes, bones or fish bones, and charcoal. Courty et al. (1989) reported an extremely high content of total P between 1.6 to 2.6% in London impacted by bone, feces, or plant decomposition. Nicosia et al. (2012) in using Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM/EDS) in Dark Earth in a medieval settlement in Florence, Italy revealed that the neoformations consisted predominantly of calcium-iron phosphates or calcium phosphates with associated iron oxides. They further discussed that there is a limited variability of most of the physicochemical characteristics such as organic C, N, CEC, base saturation, dithionite extractable Fe, and Mn with depth in Dark Earth. Moreover, in comparing dark earth formed beneath the alluvial sediments, the dark

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earth soil horizons contained from 0.48 – 1.25% organic carbon when compared to the alluvial sediments of 0.43%. Further, N recorded in the dark earth horizons ranged from 0.07 – 0.112% but no content of N was recorded in the alluvial sediments. A pH value ranging from 5 to 8.2 has also been reported in EDE by several authors (Courty et al., 1989; Nicosia et al., 2012; Wiedner et al. 2015; Asare et al., 2020). In the 10 - 11th century AD, Slavic settlement activities (disposition of human and animal excrements and charred organic matter) in the Wendland region, Northern Germany created dark patches of soil horizon in the settlement area. Multi-elemental analysis of the soil indicated significantly higher content of C, N, P, Ca, Mg, Na, Fe, Cu, Zn, Mn, Ba and, pH (H2O) ranging from 5.0 to 6.7 compared to neighboring soil (Wiedner et al., 2015). These soils related to the first millennium AD dark earth from settlement context (often urbanized), which is known from the site in post-Roman Britain (Macphail, 1983) and partly from the migration period and Viking age size in Scandinavia (Wiedner et al., 2015). EDE in the past hillfort settlement, Czech Republic was reported of 40, 350, 900, 100, 140, 100, 35, 40, 30 and 90% enrichment by total N (0.3%), P (0.34%), Ca (2.4%), Mn (0.065%), Fe (2.4%), Al (4.8%), Sr (0.012%), Rb (0.011%), Cu (40 mg kg-1), and Zn (110 mg kg-1), respectively, in comparison to the control (Asare et al., 2020b). The soil was 2.5, 2.4, 4.3, and 1.5 times enriched by plant-available (in mg kg-1) P (451), K (384), Ca (7494), and Mg (188), respectively, compared to the control. Although the reduced pH (6.5) contributed to the retention of the elements, physical parameters such as the relatively high fraction of silt and clay and homogenous distribution of charcoal were vital in providing high sorption for the elements. The influence of past human activities in the hillfort were supported by high density of medieval age pottery fragments.

3.4. Physicochemical properties of Kitchen middens Middens are generally localized sites, ranging from < 0.5 to several hectares in size, and are unrestricted in their distributions. Kitchen middens usually form because of repeated dumping but may be created by a single ceremonial feast (Howard, 2017). The kitchen midden is analogous to Terra preta due to their accumulation of abundant archaeological debris and

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sometimes generically referred to as Dark Earth (Fig. 3d). The dark color of kitchen midden is due to prolonged anthropogenic influence mainly by the accumulation of half-burnt organic matter (Lima, 2001). In some cases, midden environments have excellent preservation of organic materials like wood, basketry, and plant food. Most studied kitchen middens have higher nutrients content in comparison to surrounding soils (Schaefer et al., 2004; Kämpf and Kern, 2005) which can be attributed to the presence of incompletely weathered nutrient sources and abundant pottery fragments. Eberl et al. (2012) observed that human activities including the preparation of pigments explained the obscure distribution of different elements. High P levels were useful to detect middens, but they provided incomplete data and required contextualization by comprehensive archaeological interpretations. Migliavacca et al. (2013) confirmed that high total P content among soil samples ranged from 11409 – 30663 mg kg−1 and organic P content (up to 28423 mg kg−1) was due to the accumulation of organic matter in a garbage hole. The contrast between domestic activities and garbage accumulation is indicated by the highest values of the C: N ratio in the latter. Moreover, in a phosphate analysis in Piedras Negras, Guatemala, Parnell (2001), concluded that areas of highest phosphate content (> 100 mg kg−1) were areas with a high ceramic density as well as bone fragments, charcoal, shells, and artifacts indicative of a kitchen midden Pettry and Bense (1989) studied midden-mound soils in north-eastern Mississippi, USA. They confirmed that these soils were generally enriched in organic C (0.9 – 1.9%), exchangeable bases, and P (203 – 408 mg kg-1), Ca (11.3 – 15 cmol kg−1), and had wider C: N ratios (16.9 – 22.1) than the natural soil. They had abundant evidence of biological activities, pH ranged from 5.5 to 6.0 compared with pH (H2O) 5.2 or less in natural soils, and they contained 1 to 5% charcoal in volume. In an analysis of the chemical signature of a late classic Maya residential complex, Guatemala increased content of P, Fe, Sr, Cu, Mn, and Zn coincided with specific pits identified as a midden area (Eberl et al., 2012). However, the content of metals such as Pb and Cd may reflect occupational wastes.

4. Discussion The review present for the first-time detailed characterization and activ-

ities leading to the formation of the types of ABE from different geographical locations (Table 3). There are diverse factors that contributed to their formation processes from different geographical locations, which are generally the same in all ABEs. ABEs have stable organic matter stock, optimum C: N ratio for mineralization and release of elements, higher pH, CEC, and contents of C, N, P, Ca, Mg, Mn, Cu, Zn, Sr, and Ba mostly corroborated with a higher amount of charcoal compared to surrounding soils. The accumulation of the elements is predominantly due to the deposition of organic wastes and wood ashes. The depth of ABEs is influenced by the duration and intensity of ancient human activities. Studied ABEs across the world represent nutrient-rich landscapes resulting from ancient human activities. Different types of studied ABEs have the same principle of formation and similar chemical properties. However, many authors have used different methodologies to quantify the elemental composition of ABEs from Africa to arctic regions (Lehmann et al., 2003b; Nicosia et al., 2013; Solomon et al., 2016). These methodological approaches were focused on the quantitative analysis of plants-available nutrients using different extraction approaches or on the total content of elements in the soil using dry analytical methods of XRF. Although different methods were used, there was a clear pattern recorded by all approaches – an enrichment of ABEs by C, N, P, Ca, Mg, Mn, Cu, Zn, Sr, and Ba in comparison to surrounding soils. The question which is still unsolved is how large the enrichment for different elements is and ABEs as every researcher uses a different analytical approach which gives different enrichment factors. In this respect, the total content of elements gives clear enrichment factors as obtained values for different elements are less affected by soil properties and reactions. Plant available contents of elements are generally highly affected by pH; thus, extraction of the plant-available fraction can increase the unreliability of enrichment factors as most elements can relate to soil matrix and they may not be released by extractants. Measurement using XRF and ICP-OES for the total content of the element can be compared since they correlate strongly with high precisions (Šmejda et al., 2018). Different types of ABEs have a different date of origin and geographic location as well as other peculiar activities pertinent within the cultural setting of the site where they are formed (Nicosia et al., 2012; Frausin et al., 2014). However, the formation of Terra preta and AfDE are generally more analogous as they both represent human formed soil from the tropical regions especially the rainforest zone in contrast with poorly drained surrounding soils (Sombroek, 1966; Solomon et al., 2016). A scattered range of these soils exist but perhaps have a different designation as observed in some countries in Asia and the arctic regions or not studied at all, especially in some parts of Africa. The deposition of domestic wastes has been noted as a factor in the formation of ABEs. Meanwhile, this is a major factor contributing to the formation of kitchen middens thus, kitchen middens form part of all the types of ABEs. The increased pH and stability of high organic matter content of ABEs provide suitable conditions for the persistence of other elements, high CEC, favorable C: N ratio for effective mineralization to enable higher crop growth. Studies on ancient dark anthrosols using different dating approaches and elemental analysis have generally been conducted in different parts of the world. However, in many studies, the soil may either not be named as a type of ABE or lacked proper dating (Fenger-Nielsen et al., 2018). However, the physicochemical features of such soil are similar to most identified and studied ABEs. In a study by Fenger-Nielsen et al. (2018), in five artic archaeological sites in Greenland, extractable (in kg m-2) P (12.51-29.01), water-extractable nitrate (0.18-0.53), and ammonium (0.47-0.85) were 2 - 6 times higher in dark deposit compared to surrounding soils. The increased content of elements and the black color of soil resulted from past human activities. The cold, wet climate of the Arctic led to the extraordinary preservation of archaeological sites and materials that offer important contributions to the understanding of our common cultural and ecological history (Hollesen et al., 2018). They concluded that soil-vegetation interaction at archaeological sites is markedly different and less affected by the natural environment and regional climate variations. Although such a conclusion was made, crop and herbage production in ancient anthropogenically black soil in comparison to control are not well-known. Moreover, in using soil micromorphological analyses in Marco Gonzalez, on the island of Ambergris Caye, Belize (Maya dark earth), Macphail et al. (2016) determined the effects of human population habits on black earth formation and the materials and elements which contribute to the character of the sediments. The black earth was characterized by pieces of charcoal, burnt and leached coprolitic bone, bryozoan-rich limestone bioclasts, shell fragments, fine to coarse relict lime floor fragments and organo-mineral excrements. Bulk soil analyses confirmed the calcareous nature of the Black Earth (>50% carbonate; ranging from 50 – 59% Ca) – owing to the very high carbonate content in reef stone, lime plaster fragments, and ash nodules. Increased content of total P in these soils was recorded ranging from 3660 mg kg-1 to 7250 mg kg-1. However, unlike the Amazonian Dark earth which have a neutral to acid pH and relatively low Ca content (Arroyo-Kalin, 2010, Arroyo-Kalin, 2014), the Maya Dark Earth – as a Calcaric Brown Soils may have more in common with Roman/post-Roman European Dark Earth formed in the remains of lime-based Roman building materials (plasters and mortars), which have a high base status and carbonate-rich character (Macphail, 1994, Nicosia et al., 2016). The formation of ABEs on existing natural dark soils e.g., chernozems has also received a lot of attention recently. In Central Europe, there has been no consensus on the formation of Chernozems as they are not only formed under steppe conditions but may be formed under forest vegetation (Schmidt et al., 2002). Given the extent and agricultural importance of this soil type recent studies indicate that factors including vegetation burning for agricultural purposes and other anthropogenic activities could contribute to the formation of this soil. However, no absolute time and age of chernozems have been stated since radiocarbon dating from charred materials conducted only provided the mean ages of fire events and mean residence time of soil organic matter based on stratigraphic records which provided Holocene age spreading over 3700 years. However, in a study by Carsten and Thomas (2010) on anthropogenic pedogenesis of chernozems in Germany, they concluded that the black C was formed through natural or anthropogenic burning can only be speculated as to the widespread destruction of forests by extended human fire clearance during the Early Neolithic period is rather unlikely. Meanwhile, remarkable evidence exists that Neolithic settlements were mostly situated at the edges of black soil patches

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confirming the idea that black soils as relics of agriculture (Gehrt et al., 2002; Eckmeier et al., 2007). Therefore, chernozems have completely different formation histories with most of them still under discussion. These observations have raised opportunities for further investigation into their distribution, land-use history, and dating to obtain more conclusive findings. In tropical Asia, in the interior of Borneo, East Kalimantan, Indonesia, preliminary evidence exists that several sites exhibit similar characteristics of Terra preta; riverside location, dark color with few pieces of charcoal (10 cm radius), higher pH, C, P, and Ca, and improved soil fertility in comparison to neighboring soils (Sheil et al., 2012). However, the ages of these soils are yet unknown even though humans have been present in East Kalimantan for 10,000 years (Mcdonagh, 2003). Ethnographic accounts suggested that swidden farming, which primarily involves slash and burns, and rotational farming was practiced there. The existence of such proves indicate that several patches of ABEs have been left unstudied or unclassified in nucleated abandoned villages, reserve areas as much attention are mostly paid on urban dark soils.

5. Conclusions and outlook The study revealed that the types of ABEs (Amazonian Terra preta, African Dark Earth, European Dark Earth, and kitchen middens) are distributed from tropics, moderate climatic zones up to the Arctic regions and relates with past human activities such as slash-and-char and disposition of excrements, bones, and wood ashes. The principles leading to the formation of ABEs are similar except for certain human activities peculiar to the cultural setting of the regions. The fertility of ABE is mostly associated with stable organic matter stock, microbial abundance, as well as higher CEC, pH, and nutrient (C, N, P, Ca, Mn, Cu, Zn, Mn, Mg, Fe, Sr, Rb, and Ba) content. The retention of the nutrients relates to the fraction of the size of soil particles, suitable pH, and homogenous distribution charcoal, predominantly responsible for the black color. There is a strong call for research in the study of some aspect of ABEs. Even with distinguishable features of ABEs, compared to the surrounding soil, not much is known about ABE in some parts of the world, e.g., Asia and North America. The direct estimate of the positive effects of ABE on crop yield in comparison

to surrounding soils has been done in few cases only on Terra preta, but not on other ABEs. Even though AfDEs are mostly used for crop production and are reportedly known for high yields, a practical comparison of yields with surrounding soils has not been performed. The opportunities for C sequestration and the reduction of Greenhouse gas emissions in ABEs are potentially important for detailed studies. Hence, systematic research into the origin, chemistry, crop nutrient uptake, production potential, and application of stable isotope analysis of ABEs is necessary to provide better insight and attention to this category of soil.

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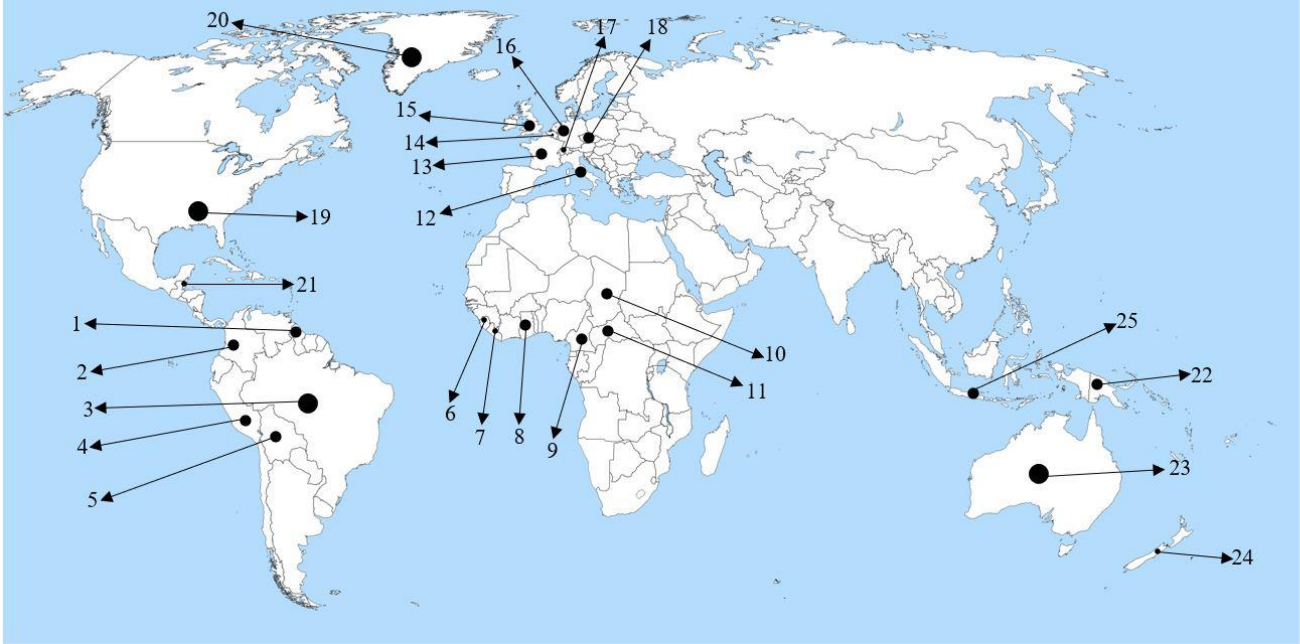

Fig. 1 Geographical distributions of Archaeological black earth (ABE) (a) *Terra preta*; 1 – Guyana, 2 – Columbia, 3 – Brazil, 4 – Peru, 5 – Bolivia, (b) African dark earth; 6 – Sierra Leone, 7 – Liberia, 8 – Ghana, 9 – Cameroun, 10 – Chad, 11 – Central African Republic, (c) European dark earth; 12 – Italy, 13 – France, 14 – Belgium, 15 – Wales, 16 – Germany, 17 – Switzerland, 18 – Czech

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Table 1. Some studies on Archaeological black earth from different localities and analytical approaches involved.

ABE	Location	Duration of human activities	Area (ha)	Analytical methods	Reference
Terra preta	Dubulay, Guyana	ca 5270-4710 BP	8-10 ha		Whitehead et al. (2010)
	Hatabara, Lago Grande, Osvaldo, Açutuba, Nova Cidade (Brazil)	1st millenium AD; 150-920 AD	16, 3.1, 4, 30, 6 ha respectively	ICP-AES; Bartington MS2/MS2B dual frequency sensor; Leco induction furnance	Arroyo-Kalin et al. (2009)
	Quebrada Tacana, Colombia	1270 to 1060 yr BP	2 ha	ICP-MS; X-ray diffraction (XRD) powder method (PANalytical diffractometer)	da Costa et al. (2011)
	Planalto, near Manaus, Brazil		2 ha	Elementar Vario EL C/N analyser; scanning electron microscopy (SEM)	Glaser et al. (2003a)
	Jabuti, Bragança, Pará state, Brazil	2,900 yrs BP		Mehlich-1; Walkley-Black method (wet oxidation with dichromate)	Souza et al. (2016)
	Mato Grosso and Pará, South and Eastern Amazonia, Brazil	750-500 cal BP	1ha; 0.25ha		De Oliveira et al. (2020)
	Hatahara, Açutuba, southwest of Santarém at the lower Tapajós (Belterra), Caldeirão Embrapa research station (Manaus, Brazil)			5β-stanols	Birk et al. (2011)

Table 3 Studies on a detailed description of different types of Archaeological Black Earth.

Types of ABE	**Origin/period**	**Ancient human activities**	**Avg. pH, Other chemical properties**	**References**
Amazonian dark earth	South America (5000 cal Years BP)	Human occupation, heating, slash-and-burn agricultural practices, smoldering fires for food, and pottery preparation.	pH (5.2-6.4), High CEC, C, N, P, Ca, Zn, Cu, Mn, Ba, Sr	Kern et al (1999); Leh b); Hecht (2 Heckenberg et al. (201 (2014)
African dark earth	Mostly tropical African Regions (115–692 cal Years BP)	Char materials, animal-based organic inputs e.g., bones from food preparation; harvest residues from plant-biomass, deposition of domestic refuse such as palm thatch, palm-fruit heads, rice straw, oil palm processing, and potash production.	pH (5.6-6.9), High CEC, C, N, P, K, Ca, Mn	Frausin et al al. (2014); (2016); Asa
European dark earth	Europe (Roman to post Roman period)	Debris from burning, collapse and decayed buildings, house sweeping, hearth functioning and maintenance, food preparation, leatherworking, manuring, quarrying, metal production, and butchery.	pH (5-8.2), High CEC, C, N, P, Ca, Mn, Fe	Courty et a et al. (2012 (2015); Asa
Kitchen Midden	Localized; part of the Arctic zone	Deposition of domestic wastes associated with food preparation; human occupation	pH (5.5-6), High CEC, P, Ca, Mn,	Kämpf an Eberl et a

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