SOIL Discuss.,
https://doi.org/10.5194/soil-2020-51-AC4, 2020

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

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Received and published: 14 November 2020

Abstract Archaeological black earth (ABE) can be classified as a layer of anthrosol visually characterized by black color mainly due to homogenous charcoal inclusion and a substantial nutrient enrichment compared to surrounding control soil. 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. The study revealed that ABE mostly is distributed from the tropics (Amazonian and African dark earth), moderate climatic zone (European dark earth) up to the Arctic (kitchen middens). The development of the ABEs relates the deliberate and 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 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 as enrichment factors of elements often relate to different analytical methods from plants-available up to total contents. Although generally highly productive, comparison of herbage production and crop yields between ABEs and natural soils are not well-known. The persistence of anthropogenic activities leading to the development of ABEs indicates that these soils are still subject to the formation of ABE.

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

1. Introduction Humans 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 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 usually are 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 mostly 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. Many studies on ABE previously were limited to visual descriptions of different organic and inorganic inclusions, archaeological features, artifacts, and post-depositional modifications (Runge, 1973; Mücher et al., 1990; van Smeerdijk et al., 1995). More recently, some authors used micromorphological analyses 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, 2003b; Woods 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 useful to quantify different elements in ABEs to trace specific ancient anthropogenic activities connected with the accumulation of these elements. For example, 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 are adopted (Nicosia et al., 2012). Although many papers studying ABEs are available from different regions (Table 1), an overview of the distribution, evolution, and properties of different ABEs according to our knowledge is not known. 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 The development of Amazonian Dark Earth relates 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, however, mostly found in the central and eastern forests and riverine settings (Sombroek et al., 2002; Glaser and Birk, 2012). Amazonian Dark Earth soils most widely are studied in Brazil, where it occupies relatively large areas, with higher chemical signatures compared to surrounding soil unaffected by anthropogenic activities (Corrêa, 2007). These sites most often 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, ranging from 2 to 350 ha, with the majority being at the smaller end of that range. As most of the 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). Terra preta rarely appears as individual classes on soil maps of the region because of their small extent but are included in more spatially extensive soil classes. Past human activities have significantly distinguished the elemental composition of these soils compared to neighboring soils.

2.2. African Dark Earth African Dark Earth (AfDE) are found around edges of nucleated villages and ancient towns in Africa (Solomon et al., 2016), typically in rain forest suggesting that verdant rainforest long-abandoned farmlands and settlement sites enriched by the wastes created by ancient humans. In a maiden 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 and animal bones characterized the components of AfDE (Asare et al., 2020a). However, Frausin et al. (2014) reported that only particular human activities are responsible for AfDE formation and 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 spatially distributed across the landscape of tropical regions, 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 date these materials. However, oral histories and landscape mapping confirmed that these indigenous soil management practices created AfDE in ancient times and have 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 no studies that report 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 earth 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 and 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, Dřevíč hillfort in the Czech Republic, the authors identified that the development of the Anthrosol predates the Roman age (Asare et al. 2020b). Notably, the site was settled from the Neolithic up to the medieval ages. In an archaeological context, EDE indicates urban dark-colored, poorly stratified units, often formed over several centuries, 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 (Wiedner et al. 2015; Asare et al., 2020b). Several pedological studies on EDE exist 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 previously 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 by their main 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 related 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 can represent individual periods of settlement at a place. For instance, Hollesen et al. (2013) identified different layers of kitchen midden in Qajaa, Greenland, which represented three different periods of settlement. The first 120 cm thick layer from the bottom represented 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). However, the surface was covered by an upper 2 – 30 cm thick layer representing the hunters of the Dorset people living in the area from 400 – 200 BC. The uppermost archaeological layer (in some places up to 1 m thick) was 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 reportedly 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 ABE 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 reasons, contribute to biochar accumulation or 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 physically can be 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 gen-

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erally have high rainfall and high humidity, which facilitate soil organic matter mineralization and nutrient leaching. Terra preta reportedly has 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; WinklerPrins, 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). However, this initiates a set of biological and chemical processes that have confirmed increased soil organic matter, microbial biomass, and diversity, cation-exchange capacity (CEC), pH, and nutrient retention (Lehmann et al., 2003a, b; WinklerPrins, 2014). Terra preta reportedly contains 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 soils has the potential to bind up N, it may not necessarily provide essential nutrients. It is, therefore, vital to add a nutrient source, e.g., K and Mg, along with charcoal amendments due to its 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, Smith (1980) reported 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. The Ca content in these sites was comparably higher, averaging 21 mg kg-1, and 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), 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 near the shores of the Trombetas-Nhamundá River. Kern (1988) correlated these data with the former human occupation of the area. Enrichment by total P (366 – 460 mg kg-1), Zn (21 - 26 mg kg-1), and Mn (25 - 32 mg kg-1) again was obtained for two Terra preta sites in Santarém, Brazil, in comparison to control 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 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 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 than in surrounding soils (Solomon et al., 2016). They recorded a pH range (5.6-6.4; 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 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 in the studied AfDEs, the high pH, CEC, and increased content of C, P, Ca, Mg mimic that of Terra Preta and other 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 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, and burnt bricks (Table 2). Furthermore, Courty et al. (1989) categorized EDE from their studies in London into two stratigraphic units; the lower pale dark earth and the upper dark earth. 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 typically was from 20- 90 cm but ranged up to 2 m in thickness and was characterized by blackish color (Fig. 3c). Notwithstanding, the stratigraphical classification (cultural layers) of EDE relates to 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 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

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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) to analyze 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. Furthermore, they concluded that there is a limited variation in the physicochemical characteristics of the dark earth, e.g., organic C, N, CEC, base saturation, extractable Fe, and Mn, with increasing depth. Moreover, in a study of dark earth formed beneath alluvial sediments, the dark earth horizons contained from 0.48 – 1.25% organic carbon compared to 0.43%. of the alluvial sediments. Additionally, the content of N in the dark earth horizons ranged from 0.07 – 0.112% but absent in the alluvial sediment. 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- 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), 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, compared 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 ability. The influence of past human activities in the hillfort was consistent with the 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 the accumulation of archaeological debris and 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 compared to surrounding soils (Schaefer et al., 2004; Kämpf and Kern, 2005), which related to the presence of incompletely weathered nutrients 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 contents were useful to determine middens. However, this provided incomplete data and required contextualization by comprehensive archaeological interpretations. Migliavacca et al. (2013) confirmed that high total P content among soil samples ranging 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 was well-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

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that the soils generally were enriched in organic C (0.9-1.9%), exchangeable bases, and P (203-408 mg kg-1), Ca (11.3-15 cmol kg−1), with a higher C: N ratios (16.9-22.1) than the natural soil. They had abundant evidence of biological activities, pH ranged from 5.5-6.0 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 In this overview, we present for the first-time detailed characterization and activities leading to the formation 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 depths of ABEs more often are 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 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 analytical methods adopted in the various studies, there was a clear pattern recorded by all approaches – an enrichment of ABEs by C, N, P, Ca, Mg, Mn, Fe, Cu, Zn, Sr, and Ba in comparison to surrounding soils. The question which is still unsolved is how large the enrichment for different elements, as different analytical

approach gives varied enrichment factors. However, the total content of elements is the most suitable compared to plant available as enrichment factors are less affected by soil properties and reactions. Generally, the content of plant-available elements is affected by many soil chemical properties, e.g., pH. Hence, the extraction of plant-available content increases the unreliability of enrichment factors of most elements. The use of XRF is, therefore, suitable for a fast and cost-effective approach in the determination of the total content of elements (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 contributes to the formation of ABEs. Meanwhile, this is a pertinent contributing factor to the formation of kitchen middens. Thus, kitchen middens form part of all the types of ABE. 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 mineralization to enable higher crop growth. Studies on elemental compositions of ancient dark anthrosols, have generally been conducted in many 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 soils 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 P (12.51-29.01 kg m-2), H2O-extractable nitrate (0.18-0.53 kg m-2), and NH4 (0.47-0.85 kg m-2) were 2 - 6 times higher in dark deposit compared to the 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 the sites and materials (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, using micromorphological analyses in Marco Gonzalez, 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 characteristics 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 the soils ranged from 3660 mg kg-1 to 7250 mg kg-1. However, unlike the Amazonian dark earth with relatively neutral pH and low Ca content (Arroyo-Kalin, 2010, Arroyo-Kalin, 2014), the Maya dark earth – as a Calcaric Brown Soils can have more in common with Roman/post-Roman European dark earth from the remains of lime-based Roman building materials, with high base status and carbonate-rich (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 is still no consensus on the formation of Chernozems as they are not only formed under steppe conditions but also 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 so far stated. The radiocarbon dating from charred materials only provided the mean age of fire events and mean residence time of soil organic matter based on stratigraphic records, which indicated 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 either formed through natural or anthropogenic burning. 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 mostly were situated at the edges of black soil patches, confirming that the 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, evidence exists that several sites exhibit similar characteristics as Terra preta; riverside location, dark color with few pieces of charcoal (10 cm radius), higher pH, C, P, and Ca, and improved soil fertility compared 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 indicates that several patches of ABEs are still not studied or unclassified in abandoned villages and reserve areas.

5. Conclusions and outlook The study revealed that the types of ABE (Amazonian Terra preta, African Dark Earth, European Dark Earth, and kitchen midden) 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 excrement, bones, and wood ash. 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.

Author contributions. MOA conceived and executed the research and wrote the paper. JOA gave suggestions about the approach and wrote the paper. MH gave suggestions about the approach. All authors reviewed the paper. Competing interests. The authors declare that they have no conflict of interest.

Acknowledgments We acknowledge the support of the project HERA. 15.055 (DEEP-DEAD: Deploying the Dead-Artefacts and Human Bodies in Socio-Cultural transformations). This project has also received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 649307.

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