Research and Application of Biochar in Europe

Pellegrino Conte,* Hans-Peter Schmidt, and Giulia Cimò

Abstract

Biochar is a porous material recognized for its usefulness in improving soil quality and C sequestration in soils. This chapter presents the latest developments of biochar uses and applications in Europe. In particular, attention is focused on how European scientists are acting to aid decision makers to establish precise rules for assessment of biochar reliability and usability. This aim is achieved by the elaboration of a European Biochar Certificate containing a precise definition of what biochar is, the elucidation of the exact biochar chemical–physical characteristics, the recommendation on the nature of the biomass feedstock to be used for biochar production, and guidelines on the pyrolysis conditions to be applied.

Abbreviations: Corg, organic C; COST, European Cooperation in Science and Technology; EBC, European Biochar Foundation; eBRN, European Biochar Research Network.

Pellegrino Conte and Giulia Cimò (giulia.cimo@unipa.it), Dipartimento di Scienze Agrarie e Forestali, Università degli Studi di Palermo, v.le delle Scienze ed.4, 90128–Palermo, Italy. Hans-Peter Schmidt, Ithaka Institute for Carbon Intelligence, Ancienne Eglise 9, 1974–Arbaz, Switzerland (schmidt@ithaka-institut.org). *Corresponding author (pellegrino.conte@unipa.it).

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Charcoal has been civilization's basic material for thousands of years because of its applications in cooking, space heating, and the forging of metal tools (European Biochar Foundation, 2012). For centuries it has also been used as soil amendment, as animal bedding, as medicine, and as a feed additive. However, over the centuries, knowledge of these charcoal uses has been partly lost and only recently rediscovered. In fact, in the last decade, charcoal has become a major topic of research for many scientific groups. The main reason for such great attention derives from charcoal's potential impact on slowing global warming and on its capacity to restore degraded soils (Ogawa et al., 2006; Laird, 2008; Mathews, 2008; Lehmann and Joseph, 2009; Lehmann et al., 2009). Photosynthesis produces carbonaceous plant metabolites, which are decomposed back to CO_2 when plant materials are allowed to decompose. However, if plant residues are pyrolyzed, up to 60% of the original plant C can be transformed into charcoal. Charcoal mineralization to CO_2 is extremely slow when charcoal is applied to soils, providing a pathway for subtraction of CO_2 from the global C cycle and reducing the concentration of CO_2 in the atmosphere (Lehmann and Joseph, 2009). The discovery of *terra preta do indio*, historical Māori gardens, and plaggen soils in Brazil, New Zealand, and Europe, respectively (Pape, 1970; Glaser et al., 2002; Calvelo Pereira et al., 2014), has confirmed the importance of charcoal's role in soil fertility. The native soils found in these regions suffer from low fertility: the soils of Amazon rain forest are usually thin, red, acidic, and infertile; those in southern New Zealand do not support the horticultural production possible in the warmer and more fertile volcanic areas found in the northern part of the country (Envirohistorynz, 2010); while many areas of The Netherlands, Germany, and Belgium are characterized by sandy soils with a relatively high content of easily weathered minerals (Pape, 1970). Surprisingly, all the aforementioned areas were made more fertile by addition—in ancient times—of charcoal, thereby leading to the conclusion that such a material ameliorates soil properties and improves crop production.

Lehmann et al. (2006), Lehmann and Rondon (2006), and Lehmann and Joseph (2009) proposed that charcoal applied deliberately to soils should be referred to as *biochar*. Biochar is understood as a pulverized charcoal made from biomass for the purpose of enhancing fertility when mixed with soils. However, this definition appears weak because it is only oriented toward agronomic uses. It does not consider production methodologies, and it does not include the very important greenhouse gas reduction property. Moreover, Lehman and coworkers' definition did not account for the nature of the biomass to be used for biochar production. In fact, according to the aforementioned definition, any kind of contaminant-free biomass feedstock can be used to produce biochar regardless of the sustainability of its procurement. As an example, many plant biomass species take a long time to grow. If not controlled by sustainability standards, their use for biochar production may pose serious problems for biodiversity protection, wildlife habitats, soil protection, and water production, thereby limiting the eco-sustainability of biochar applications. In 2012, the European Biochar Foundation (EBC) proposed a more detailed definition of biochar: "Biochar is a charcoal-like substance that is pyrolysed from sustainable obtained biomass under controlled conditions and which is used for any purpose which does not involve its rapid mineralization to CO_2" (EBC, 2012). According to this view on biochar, only fast growing plants, plant residues from certified forestry management, agricultural residues, and organic wastes from urban areas may be used for biochar production. This ensures compliance with the sustainability criteria outlined in a report prepared for the European Commission (Vis et al., 2008). However, to account for all the possible uses of biochar as a new material (e.g., biochar use in the paper and cellulose industry, biochar for advanced building materials, biochar electronics, 3-D printing, decontamination such as in water and sewage treatment, mining, air filtration, textile industry, and animal farming) (Schmidt and Wilson, 2014), the EBC (EBC, 2015) modified the aforementioned definition as follows: "biochar is a heterogeneous substance rich in aromatic carbon and minerals. It is produced by pyrolysis of sustainably obtained biomass under controlled conditions with clean technology and it is used for any purpose that does not involve its rapid mineralization to CO_2 and preserves its capacity to become eventually a soil amendment." This newest biochar definition goes a decisive step beyond the limits of a solely precautionary principle related to the agronomical use of such a material (Bates, 2010). In fact, according to EBC, biochar must be considered not only as a soil amendment but also as a basic material for the synthesis of new products for the biobased economy such as those aforementioned.

It is noteworthy that opposition to biochar applications, because of the precautionary principle, rests on the assumption that studies on the long-term effects of biochar are lacking (Bates, 2010) and does not account for the worldwide exponential growth of studies appearing in the last decade (Fig. 1). Among those studies, the majority show that biochar is quite stable in soils. This indicates that the possibility of groundwater contamination through leaching of biochar components coming from its degradation (e.g., polycyclic aromatic hydrocarbons, PCBs and dioxins) is either very limited or nonexistent on a long-term scale (Bruun et al., 2011b; 2014; Calvelo Pereira et al., 2011; Cross and Sohi, 2011; Jones et al., 2011; Luo et al., 2011; Wilson and Reed, 2012; Ameloot et al., 2013; Farrell et al., 2013; Mukome et al., 2013; Maestrini et al., 2014). Moreover, biochar shows a very good adsorption potential for hydrophobic materials (i.e., PAHs, and various hydrophobic herbicides and pesticides as well as dioxins) (Oleszczuk et al., 2012). For this reason, the USEPA suggests charcoal as the best available technology for

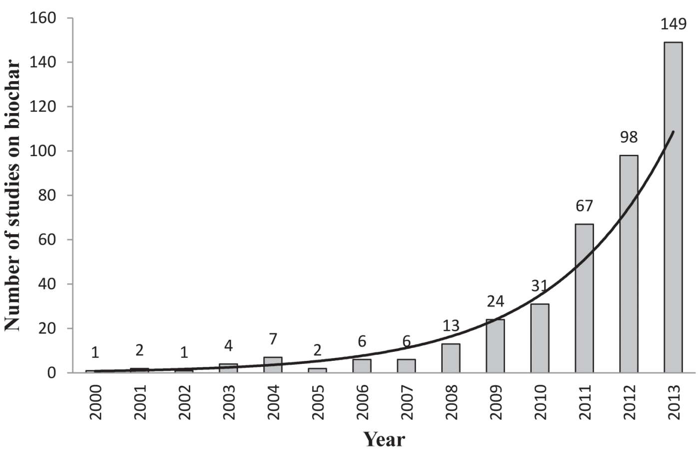

Fig. 1. Exponential increment of the number of studies on biochar appearing in literature only from European researchers. Source: Scopus database (http://www.scopus.com/).

the treatment of hydrophobic contamination (Wilson and Reed, 2012). According to Hale et al. (2011) and Wilson and Reed (2012), the concern about possible dioxin content in biochars is overstated. On the one hand, the amount of dioxins in biochars that have been analyzed to date was very low (Hale et al., 2011; Wilson and Reed, 2012). On the other hand, any dioxins present are strongly bound to biochar, thereby being unavailable for plant nutrition and to the food chain (Wilson and Reed, 2012).

Biochar Research In Europe

A map of the distribution of biochar research field trials across Europe updated in November 2014 from the European Biochar Research Network (eBRN) is reported in Fig. 2. All of the experiments are performed in fields (either open fields or greenhouses) to reveal the effect of biochar on soil fertility and crop production as well as to assess environmental impacts of biochar use, thereby sharpening a promising global change mitigation tool up to the stage where economically feasible application may begin. The map, coordinated by the eBRN team, shows experiments that are part of a European Cooperation in Science and Technology (COST) Action project designed to organize an integrated research program in a more systematic way than the previous widely fragmented research efforts in Europe (e.g., De Pasquale et al., 2012; Genesio et al., 2012; Kammann et al., 2012;

Fig. 2. Map of the distribution of European biochar research projects as reported by the European Biochar Research Network (eBRN) at http://cost.european-biochar.org/en/projects/map.

Verheijen et al., 2013; Conte et al., 2013; Khan et al., 2013; Marchal et al., 2013; Swaine et al., 2013; Baiamonte et al., 2014; Bargmann et al., 2014; Cimò et al., 2014; Conte et al., 2014; Oleszczuk et al., 2014; Paz-Ferreiro et al., 2014; Rees et al., 2014).

The main research is focused on the following points:

- Biochar production parameters
- Biochar properties and evaluation of its effects following soil application
- Biochar's potential to sequester C, enhance soil fertility, and reduce erosion
- Development of methodological approaches to estimate the economic effects and the CO_2 mitigation potential of biochars applied to agricultural soils as part of a life-cycle assessment
- Application of meta-analysis tools to compare different biochar systems' effects across Europe's soil types, agroecosystems, and climate regimes
- Evaluation of biochar potential to replace soil substrates deriving from peat lands

Figure 2 has been used to account for the number of biochar field trials per European country as indicated in Fig. 3.

Leader countries on biochar research appear to be the northernmost regions. In fact, more than 70% of the biochar projects are realized in non-Mediterranean regions such as the UK, Germany, Finland, Norway, Denmark, Belgium, Estonia, Poland, Switzerland, Slovakia, and Austria; whereas, less than 30% are done in Mediterranean countries such as Greece, Italy, Spain, and France (Fig. 3). Israel and Libya, two Mediterranean non-European countries, are also involved in the biochar network (Fig. 2 and 3).

The northernmost-oriented distribution of biochar research initiatives is justified by the podzol nature of the northern soils (http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116). In fact, the general unfavorable chemical–physical soil properties (e.g., severe acidity, high Al levels, and cool climate) make the aforementioned soils unsuitable for arable cropping unless soil

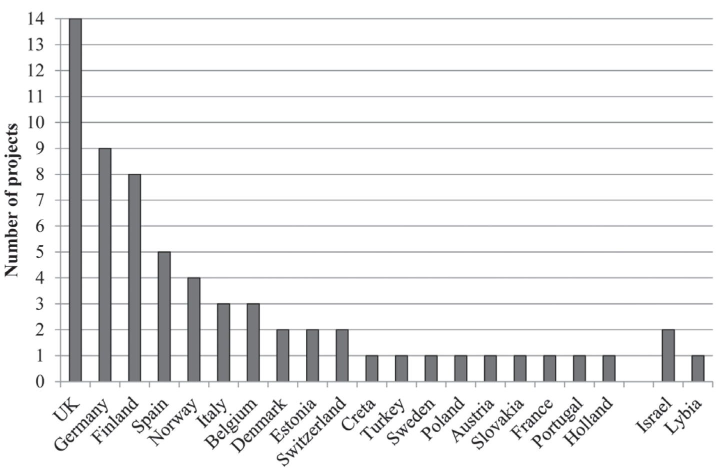

Fig. 3. Number of biochar projects per country as obtained by the visual inspection of the map reported in Fig. 2.

quality improvement is made by deep plowing and fertilization. The latter can be achieved with a rational application of biochar to soils as reported by, for example, Awad et al. (2012), Abel et al. (2013), Hiemstra et al. (2013), Alburquerque et al. (2014), Oleszczuk et al. (2014), and Paz-Ferreiro et al. (2014). However, other studies revealed that biochar has the potential to improve fertility in soils from temperate and desert areas (Atkinson et al., 2010; Verheijen et al., 2010; Castaldi et al., 2011; Kammann et al., 2011; Baronti et al., 2014), thereby explaining the presence of Israel and Libya in the eBRN data (Fig. 2 and 3).

Interestingly, an additional reason explaining the wide attention of northern European countries for biochar applications is related to efficient urban waste management in those countries. The majority of the northernmost European regions divert urban wastes toward recycling and composting with great efficiency, whereas the effectiveness of the aforementioned waste transformations in the southernmost countries is still at a primary stage (Eurostat, 2015). Biomasses from urban wastes are among the main feedstocks used for energy production via several methodologies as indicated in literature (Murphy and McKeogh, 2004; Demirbas and Balat, 2006; Montanarella and Lugato, 2013). As biochar represents an important by-product from the energy production in many countries (such as Denmark, Austria, and Germany) at an industrial level (Sohi et al., 2010; Montanarella and Lugato, 2013), great concern arises from its possible disposal, thereby accounting for the importance that the northernmost European countries assume in biochar field trials.

Biochar Uses in Europe

Studies to date have dealt with many possible applications of biochar in many different fields. As already mentioned, biochar improves soil fertility (Awad et al., 2012; Abel et al., 2013; Hiemstra et al., 2013; Alburquerque et al., 2014; Oleszczuk et al., 2014; Paz-Ferreiro et al., 2014), reduces greenhouse gas emissions (Augustenborg et al., 2012; Case et al., 2012; Dempster et al., 2012; Cayuela et al., 2013; Fungo et al., 2014; Nelissen et al., 2014), influences pollutant fates in the environment (Hagner et al., 2013; Marchal et al., 2013; Agrafioti et al., 2014; Boutsika et al., 2014; Fellet et al., 2014; Rees et al., 2014), affects soil micro- and mesofauna activities (Ameloot et al., 2013; Anders et al., 2013; Prayogo et al., 2014; Doan et al., 2014; Domene et al., 2014), and can be used as a reagent in the synthesis of new products in agriculture and materials chemistry (Sahu et al., 2010; Hansen et al., 2012; Agrafioti et al., 2013; Cao and Pawłowski, 2012, 2013; Di Lonardo et al., 2013; González et al., 2013; Troy et al., 2013; Plaza et al., 2014). Notwithstanding the number of studies showing biochar potential in many different applications, there is no intra-European common policy about biochar uses in agriculture.

Under the European regulations, biochar is considered as a by-product of the energy industry (Montanarella and Lugato, 2013) and, as such, is classified as a waste. For this reason it is subjected to the European Directive on Waste (EU, 2008), which hinders its possible agricultural use (Montanarella and Lugato, 2013). Although complex interpretation of the European regulations can address potential agricultural biochar applications (Montanarella and Lugato, 2013), the national regulations of almost all EU countries have not been implemented yet to include biochar as an agricultural resource. However, even though the national regulations are not designed for biochar, they include other waste materials (e.g., sewage sludge and amendments), thereby establishing threshold limits that may be adopted for biochar regulations, though they differ from country to country. Very recently, Kammann and Schmidt (2014) stated that biochar direct soil applications have become legal in Switzerland (which is geographically in Europe, but not within the European Community) and Austria, whereas "in Germany, the use of 'charcoal' is legal […] without a clear definition of what 'charcoal' exactly is." The authors also indicate that in many European countries, "the economic [biochar] use is largely restricted to the production of special horticultural substrates or nutrient-rich soil enhancers where the biochar has been preloaded with nutrients and has subsequently been aged by co-composting" (Kammann and Schmidt, 2014). As a general remark, Kammann and Schmidt report that, "the predominant biochar implementation pathway that ultimately delivers biochar to soils is currently the cascading use in animal husbandry. In particular, in Germany, Switzerland and Austria, the use of biochar in animal husbandry is implemented by small-to-medium scale farmers, and rapidly spreads by word-of-mouth recommendation, while scientific studies are largely lacking. First statistics suggest that bad odor, ammonia and methane emissions can be reduced in animal barns, feed efficiency increases and animal health improves to the point where veterinary costs are considerably reduced. In animal husbandry, biochar is used as an ingredient in probiotic animal feed ("carbon feed"), as silage additive, bedding material, or manure and slurry conditioner (together with lactobacilli)" (Kammann and Schmidt, 2014).

The European Biochar Certificate

The main question arising from the discussion above is what the scientific world can do to aid decision makers to establish precise rules for assessment of biochar reliability and usability. The answer to this question is not only a precise definition of what biochar is, but also the elucidation of the exact biochar chemical–physical characteristics, a recommendation on the nature of the biomass feedstock to be used for biochar production, and guidelines on the pyrolysis conditions to be applied. Moreover, biochar application parameters (i.e., which kind of biochar can be applied, where, and how) must be also be developed to use the right biochar for any given agricultural practice.

The European Biochar Foundation elaborated the first guidelines in 2012 with the aim to ensure control of biochar production and biochar quality based on well-researched, legally defensible, economically viable, and practically applicable processes.

The entire set of questions posed above is incorporated in a certificate that is continuously updated to aid users and decision makers in the correct application of biochar and biochar-based products in agriculture and in all the industries where they are potentially useful (EBC, 2012). At the end of 2014, seven industrial biochar producers in four European countries (representing a total biochar production of 9000 t yr^{-1}) were EBC certified (EBC, 2013).

As stated in the first paragraph of the present chapter, the European Biochar Foundation suggested that biochar must be understood as a heterogeneous substance, rich in aromatic C and minerals that is produced by pyrolysis of sustainable biomasses. The technology applied for biochar production must use controlled conditions and be clean. Moreover, biochar must not be applied for any purpose that involves its rapid mineralization to CO_2, and its capacity to become a soil amendment should be preserved.

Biochar definition implies the concept of sustainability, which can be interpreted at different levels according to the sector where it is applied (Brown et al., 1987). In particular, sustainability is defined as the ability to manage "a resource for maximum continuing production, consistent with the maintenance of a constantly renewable stock" as it deals with biological resources (Brown et al., 1987). In agriculture, sustainability is "the ability of a system to maintain productivity in spite of a major disturbance" (Brown et al., 1987), while in the energy field, the term is associated with the "transition from a global energy system based on consuming depletable fossil fuels to a sustainable system based on nondepletable fuels" (Brown et al., 1987).

Thermal decomposition of biological resources (i.e., biomasses) to produce energy (as an alternative to fossil fuels) can potentially produce biochar as a byproduct that can be applied in agriculture to improve soil quality (i.e., fertility). For this reason, we can argue that a biochar is sustainable when at least the parameters to contemporarily achieve biological, agricultural, and energy sustainability are accounted for. However, once applied to soils, biochar must also maintain nutrient, air, and water cycles, as well as a healthy environment. The latter are the conditions to achieve ecological sustainability (i.e., the conservation of the micro- and macroenvironments where flora and fauna can survive). As a consequence, to consider biochar use as sustainable, it must fulfill also the conditions for the ecological sustainability. Based on this holistic biochar sustainability approach, the only biomass feedstocks usable for biochar production are listed in Table 1. Table 2 lists the values of the main chemical parameters that are important to define biochar quality.

The total organic C (C_{org}) content must be >50% (w/w) of the dry mass. The large C content, together with the high chemical stability of biochar, accounts for the ability of such material to sequester C into soils, thereby preventing greenhouse gas problems.

The H/C_{org} ratio has to be below 0.7. This is an indicator of the degree of carbonization. The lower the H/C_{org} value, the higher the degree of polycondensation of the organic material, thereby increasing its environmental stability. Values exceeding 0.7 are an indication of pyrolysis deficiencies or of nonpyrolytic chars like hydrochar or char from torrification processes (Schimmelpfennig and Glaser, 2012).

The O/C_{org} ratio (set to <0.4) is a further indication of the quality of the pyrolysis conditions. In fact, as the O/C_{org} ratio exceeds 0.4, oxidation prevails over pyrolysis, resulting in low quality biochar.

As for all the soil amendments, biochar must also be low in heavy metals and other organic contaminants. In fact, biochars containing amounts of organic and inorganic contaminants above the limits indicated in Table 2 risk pollution of soils. Polluted biochars make soils unavailable for food production, thereby reducing environmental resources available to future generations.

According to the biochar definition and the threshold values of the chemical indicators reported in Table 2, pyrolysis of biomass must be conducted according to the following suggestions (European Biochar Foundation, 2012):

1. Biomass pyrolysis must take place in an energy-autonomous process.
2. The composition of the pyrolyzed biomasses must not fluctuate more than 15%.
3. Complete production records must be kept, providing detailed descriptions and dates of any production problems or halts.

Table 1. Biomass feedstock to be used for biochar production. All the biomasses indicated account for biological, agricultural, energy, and ecological sustainability criteria (see the text). The list is incomplete; it has been modified from the European Biochar Certificate guidelines (European Biochar Foundation [2012] http://www.european-biochar.org/en/download).

Origin	Biomass feedstock
Local waste collection services with waste separation	Biodegradable waste, biodegradable waste with kitchen waste, biodegradable waste with kitchen waste and leftovers
Garden wastes	Leaves, flowers, vegetables, roots, pruning from trees, vines and bushes, clippings from nature conservation measures, hay, grass
Agriculture and forestry	Harvest leftovers, straw, used straw, husks and grain dust, grain, feedstuffs, pruning from biomass plantations grown for energy or biomass uses (renewable resources), pruning from trees, vines and bushes, seeds and plants, bark, chipping, wood, sawdust, wood shaving, wood wool
Kitchens and canteens	Kitchen, canteen, restaurant leftovers
Vegetable productions	Material from washing, cleaning, peeling, centrifuging and separation
Waterway maintenance (vegetable material)	Raked material, flotsam, fishing residues, harvested material, water plants
Animal by-products	Hides and skins, bristles, feathers, hairs, bones, manure
Materials from food and packaging	Seasoning residues; residues from potatoes, corn, rice and starch production; residues from dairy processing; fruit and grain residues; marc; residues from beer production
Textiles	Cellulose, cotton, vegetable fibers, hemp, wool leftovers and wool dust
Paper	Paper fiber sludge
Biogas plants	Fermentation residues

Table 2. Technical parameters for biochars as included in the European Biochar Certificate. The list is incomplete. The complete list is available at http://www.european-biochar.org/en/download (European Biochar Foundation (2012).

Parameter	
Carbon content	>50%
H/C	<0.7
O/C	<0.4
Heavy metal content	Pb < 150 g Mg^{-1}; Cd < 1.5 g Mg^{-1}; Cu < 100 g Mg^{-1}; Ni < 50 g Mg^{-1}; Hg < 1 g Mg^{-1}; Zn < 400 g Mg^{-1}; Cr < 90 g Mg^{-1}
pH, bulk density, water and ash content	There are not fixed values. They must be measured and indicated
Polycyclic aromatic hydrocarbons (PAH)	PAH content (sum of the EPA 16 priority pollutants) must be under 12 mg kg^{-1}
Polychlorinated-biphenyls (PCB)	<0.2 mg kg^{-1}

4. The gases produced during pyrolysis must be trapped. They are not allowed to escape into the atmosphere.
5. The heat produced by the reactor must be recycled.

Conclusions

This chapter is not intended to provide a complete review of the most recent studies on biochar done in Europe. It deals rather with the description of the European research directions, which are based on questions having general and worldwide interests.

The main aim of European researchers is to understand the role played by biochar in affecting soil characteristics for fertility and crop production enhancement while preserving environmental resources for the future generations.

The chapter also summarizes the practical uses of biochar in Europe and provides evidence that a discrepancy between science and policy occurs. In fact, while scientists are accumulating data showing that biochar use in agriculture is safe, politicians, mainly following people's unfounded fears, apply a general precautionary principle based on a hypothetical absence of scientific consensus on biochar risks. The latter is the reason why European countries act independently of each other concerning agricultural biochar applications.

At the moment, national (national biochar associations) and transnational (the European Biochar Foundation, the International Biochar Initiative, and the European Biochar Research Network) organizations are actively soliciting European governments to design special rules for biochar environmental applications. For this reason, the European Biochar Foundation has drawn guidelines (the European Biochar Certificate) to precisely define the purpose of biochar, its composition, and the correct procedures to be applied for its production and analysis.

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