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Biochar from residual biomass in Turkey, and possibility of return to the soil: an estimation of the supply and demand

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Abstract: The aim of the study was to analyse the potential of production and utilization of biochar as a marketable product in agriculture for Turkey. Towards this aim, the distribution of arable land, crop residues and soil types of Turkey were identified. The biochar production potential was evaluated depending on prominent residual biomass streams in Turkey. In addition, how much biochar would be needed for arable soil types found in Turkey was estimated according to previous studies which investigated the effect of biochar on similar soil taxonomy and/or plant grown. Total crop production is focused on southern, western and central Anatolia, although the arable lands of Turkey prevail in seven regions. The residues of wheat, barley, corn and cotton stalk, tea, banana, hazelnuts and forest were found to be higher than other residuals in different regions and they could be suitable for biochar production. Furthermore, it was highlighted that the low water holding capacity of soil, alkalinity, salinity and soil pollution impeded the crop productivity. Although, the biochar produced from prominent residues was one-fiftieth less than that of total estimated amount of biochar needed for arable soils, it obviously improves the plant growth and soil characteristics, when used together with fertilizer, especially for zonal and intrazonal soils. At this point, it could be focused on the long-term field experiments due to determine the special and productive addition rate of biochar for Turkey, and biochar addition to the soil could be channelled into threatened priority arable lands by the public authorities.

keywords: biochar, torrefaction, slow pyrolysis, soil amendment, soil taxonomy of Turkey, agriculture, crop residues

INTRODUCTION

Technologies for the thermochemical conversion of biomass are a priority for R&D funding in Turkey (Tubitak, 2016). These biomass conversion methods have been applied in different fields such as energy, environmental science and chemistry. Their most important advantage is that they allow obtaining the required form (solid, liquid or gas) of a product. Products can be used as a fuel for heating and electricity or sold as chemical substances. Biochar is a carbonaceous solid product typically produced by a thermal process known as "torrefaction". It can also be produced by other thermal processes to improve properties of biochar depending on the application area. Nowadays, biochar can be used as an alternative fuel to lignite or as a component of other processes such as gasification (Bergman et al., 2005; Prins et al., 2006; Deng et al., 2009; Svoboda et al., 2009; Chen et al., 2011; Berrueco et al., 2014; Tsalidis et al., 2014; Toptas et al., 2015). Marousek et al. (2017) indicated that commercial application of biochar in near future would focus on other fields of the industry, such as building materials or waste management. Besides to these industries, the agricultural use of biochar is expected to increase significantly within a few years, especially in soil amendment, compost additives, litter (bedding) material and silage additives (EBC, 2016a).

According to investigations of soil amendment via biochar, increase in plant growth was obtained (Baronti et al., 2010), and soil properties such as pH or cation exchange capacity were enhanced (Prayogo et al., 2014; Novak et al., 2009). These positive effects were deeply attached to plant type and soil texture (Bargmann et al., 2014; Bamminger et al., 2014; Ahmed and Schoenau, 2015). In addition, the effect of biochar was increased by different biochar application rates (1–96 tonnes biochar ha^{-1}) in various soils (Zeng et al., 2013; Bruun et al., 2014; Sun et al., 2014; Rogovska et al., 2014; Yang et al., 2015).

Turkey is an agricultural country and biochar is the object of growing attention due to the wide application area. Most of the people in rural areas have financial problems, because their livelihood depends on agriculture. To overcome this problem, agricultural productivity should be increased and new marketable products such as biochar should be developed from agricultural residues. For this

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reason, the production potential and utilization of biochar in agriculture for Turkey were qualitatively assessed in this study. After screening on the topic of biochar in a broad perspective, the biochar production potential from prominent biomass residuals for the whole of Turkey was determined according to the amount and distribution of crop production. The soil types and arable lands of Turkey were assessed with the aim to estimate how much biochar would be needed for arable soil types found in Turkey. By this way, the supply and demand of biochar in agriculture sector was overviewed depending on this qualitative assessment.

OVERVIEW OVER BIOCHAR PRODUCTION AND APPLICATION

Process mechanisms

Torrefaction is a so-called "mild" pyrolysis; it is carried out under anaerobic conditions in the low and narrow temperature range of 200–300°C depending on the characteristics of the biomass (Bergman et al., 2005; Prins et al., 2006; Basu, 2013). Although such high temperature product has the generic name charcoal, the biochar can be produced by other processes carried out at much higher temperature (Basu, 2013). The important difference of torrefaction from other thermochemical conversion processes is its slow heating rate for maximizing the solid product yield. The desired results are the degradation of structure by breaking hydrogen bonds, the removal of moisture and a minimum loss of volatiles (Basu, 2013; Nhuchhen et al., 2014). During the process, condensable hydrocarbons, hydrogen (H), oxygen (O) and some carbon (C) content from the biomass are released in the form of water, carbon monoxide, carbon dioxide and tar (Pach et al., 2002; Nhuchhen et al., 2014). This leads to form a blackened hydrophobic energy dense product – in other words biochar, in the solid phase due to breaking inter- and intra-molecular hydrogen, C-O and C-H bonds (Tumuluru et al., 2011; Nhuchhen et al., 2014).

Characterization of biochar

The properties of biochar are closely related to the biomass feedstock used and to the operating conditions of the process. Temperature is a major operating parameter affecting the properties of the resulting biochar. Biochar has similar properties to lignite and peat, and biochar produced above 350°C can have several characteristics in common with charcoal, which has a lower H/C and O/C ratio than biomass. In numerous studies, the H/C ratio of biochar could be decreased from about 1.6 to 0.7, as a result of using higher temperature than 300°C and prolonged reaction times (Novak et al., 2009; Nguyen and Lehmann, 2009; Nguyen et al., 2010; Schneider et al., 2010; Lehmann et al., 2011; van der Stelt et al., 2011; Spokas et al., 2011; Mimmo et al., 2014). Spokas (2010) also indicated that the O/C ratio could provide a more robust indicator of biochar stability than the production parameters. In addition to atomic ratios, the grindability and energy density of biomass is improved when under the form of biochar (Li et al., 2012; Duncan et al., 2013; Nhuchhen et al., 2014). The net calorific values of woody and non-woody biomass are in the range of 18–20 MJ kg^{-1} (dry and ash free) and 15–19 MJ kg^{-1} (dry and ash free), respectively (Chew and Doshi, 2011). Chew and Doshi (2011) indicated that the increase in higher heating value (HHV) of 1–58% could be obtained when biomass is torrefied.

The European Biochar Foundation and International Biochar Initiative (IBI) have set standards for the properties of biochar. The European Biochar Certificate (EBC) has been developed to cover both the product and the production process, and the biochar properties identified by IBI and EBC are compiled for comparison in Table 1. In these standards, biochar is essentially (but not only) defined as a function of its carbon content, H/C ratio, heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), furan and surface area. Often, carbon content alone is used to classify the biochar. In Europe, the carbon content of biochar must be higher than 50% dry basis (db). In IBI standards, a minimum of 10% carbon content is acceptable, but the biochar is classified according to three carbon content ranges. For Class 3, the range has been specified as 10% to 30%. For Class 2, the carbon content range has been specified as 30% to 60%, and Class 1 is defined as having above 60% carbon content. Based on the numerous studies summarized by Chew and Doshi (2011), the carbon content of biomass torrefied at different operating parameters was increased in the range of 4% and 32%.

There is a limitation for biochar' heavy metal concentrations in both standards. The biomass used seriously affects the heavy metal concentrations in biochar, and thereby heavy metals at variable concentrations were observed in numerous studies (Novak et al., 2009; Mohanty et al., 2013; Rees et al., 2014; Zhang et al., 2015). The biochar content in specific micro- and macro-nutrient (e.g. phosphorus, potassium), which is highly dependent upon the biomass feedstock used, should also be quantified for standardization (Table 1). Recent studies have shown that thermal conversion could decelerate nutrient release in the soil and in particular, the conversion above 350°C could decrease the fraction of water-extractable nitrogen (N), phosphorus (P) and potassium (K) (Wang et al., 2015a; Zhang et al., 2015). This suggests that the biochar produced at 300–500°C could be used as a direct nutrient source. The biochar having very low nutrient content can also be applied to agricultural soils via using fertilizer at adequate amount for plant nutrition (Zhang et al., 2015). The biochar can enhance fertilizer retention within soils that contain

Table 1. Biochar properties identified by EBC and IBI standards (adapted from EBC (2016b)).

Properties	**EBC standard**	**IBI standard**
Moisture	Declaration[1]	Declaration
Total Ash	Declaration	Declaration
Carbon	C >50% (db[2])	minimum <10% Class 1: ≥60% Class 2: ≥30% and <60% Class 3: ≥10% and <30%
Total N	Declaration	Declaration
H/C_{org} and O/C_{org}	<0.7 and <0.4	<0.7
Heavy metal (As, Cd, Cr, Co, Cu, Ni, Pb, Hg, Mo, Se, Zn, B)[3] [mg kg^{-1} db]	basic: Cd<1.5; Cr<90; Cu<100; Pb<150; Hg<1; Ni<50; Zn<400; As<13 premium: Cd<1; Cr<80; Cu<100; Pb<120; Hg<1; Ni<30; Zn<400; As<13	As 13–100; Cd 1.4–39; Cr 93–1200; Co 34–100; Cu 143–6000; Pb 121–300; Hg 1–17; Mo 5–75; Ni 47–420; Se 2–200; Zn 416–7400; B Declaration
Other nutrients P, Mg[3], Ca[3], K, Na[3]	Declaration	Declaration
PAHs	basic: <12 mg kg^{-1} db premium: <4 mg kg^{-1} db	6–300 mg kg^{-1} db
pH Value	<10	Declaration
Bulk Density	Declaration	Not required
Electrical Conductivity	Declaration	Declaration
BET[4] Surface Area	>150 m^2 g^{-1} db	Declaration
Particle Size Distribution	Not required	50 mm, 25 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, and 0.5 mm
PCBs, Dioxins/Furans	<0.2 mg kg^{-1} db <20 ng kg^{-1}	<0.2 mg kg^{-1} db <17 ng kg^{-1}
WHC[5] <2 mm	Optional	Not required
Volatile Matter	Declaration	Declaration

[1] "Declaration" means that there is no quantitative requirement for this property, but it has to be quantified and declared.
[2] db: dry basis
[3] As: Arsenic; Cd: Cadmium; Cr: Chromium; Co: Cobalt; Cu: Copper; Ni: Nickel; Pb: Lead; Hg: Mercury; Mo: Molybdenum; Se: Selenium; Zn: Zinc; B: Boron; Mg: Magnesium; Ca: Calcium; Na: Sodium
[4] BET: Brunauer, Emmett and Teller
[5] WHC: Water Holding Capacity

low organic material and thereby, the plant can ultimately benefit from the applied fertilizers.

The structure of biochar is rearranged at temperatures higher than 500°C by secondary and tertiary reactions, becoming increasingly polycyclic aromatic and graphite-like carbon (Keiluweit et al., 2012; Zhang et al., 2015); thereby PAHs, dioxins and furans likely ensue. In a study carried out with woody feedstock, lower toxin concentration was found in the temperature range of 500–600°C and longer retention time (Hale et al., 2012). In the study of Keiluweit et al. (2012), the concentration of 'pyrolytic' unsubstituted PAHs was found to be higher for grass than that for wood. The total PAHs content of biochar is highly variable in the available studies, and the results of these demonstrated that biochar is a heterogeneous material depending on biomass type and process conditions (temperature and retention time) (Hale et al., 2012; Freddo et al., 2012; Kloss et al., 2012).

Biochar effects on soil properties and biota

The chemical structure of biochar also affects the mobility of metals and nutrients in soils. Lehmann et al. (2011) indicated that the effects of biochar on the chemical properties of soil have received more attention than its effects on soil biota. In particular, increase in the pH value of acid soil was observed (van Zwieten et al., 2010) and biochar improved nutrient and water retention through cation adsorption (Liang et al., 2006). In a previous study, it was determined that cation adsorption capacity and base saturation increased in soils with incorporated biochars while exchangeable aluminium (Al) and acidity decreased (Yuan and Xu, 2011). In another study carried out by Prayogo et al. (2014), soil pH was slightly increased by the application of 2% biochar after 30 days to coppice soil. Furthermore, organic and inorganic contaminants can be absorbed to biochar surfaces because of their large surface area and cation exchange capacity (CEC), the extent of which is determined by the biomass feedstock used and process temperature. The particle size of biochar also influence metal sorption rate in soil (Beesley et al., 2011; Rees et al., 2014). On the other hand, Novak et al. (2009) suggest that the soil CEC can be increased by the increment of carboxylate groups on the surface of biochar. The researchers also reported the importance of low C:N ratio of biochar and existence of more oxidizable structural groups in biochar than biomass in order to enhance soil fertility and C sequestration.

In general, biochar surfaces are slowly degraded into the soil via biotic and abiotic processes and release of organics and minerals. In particular, earthworms, larvae and other insects bolster the degradation of biochar in soil, and microbial community composition in soil is affected (Steinbeiss et al., 2009; Jindo et al., 2012; Bamminger et al., 2014). The abundance of Gram-negative bacteria and *actinobacteria* in soil amended with biochar was observed and thus the increase in amount of bacterial biomass based on biochar application was reported (Prayogo et al., 2014). In addition, it was found that fungi and Gram-negative bacteria in soil benefited from the yeast-derived biochar and glucose-derived biochar, respectively (Steinbeiss et al., 2009). On the other hand, possible reactions such as dissolution–precipitation, adsorption–desorption, acid–base, and redox reactions may occur after the addition of biochars to soil, and the water in soil could contribute to these processes (Joseph et al., 2010). Joseph et al. (2010) summarize the factors having an impact on the interactions between biochar and soil biota as: (i) feedstock composition; (ii) pyrolysis process conditions; (iii) particle size and proximity of biochars to the rhizosphere (root zone); (iv) soil texture and biota, in particular moisture; (v) local environmental conditions and type of plants grown. Furthermore, the mineral content of biochar can provide nutrients for microorganisms and catalyse the oxidation of organic matter within the soil (Amonette et al., 2006).

Although biochar can enhance soil health, it may cause a direct risk for soil biota. Lehmann et al. (2011) argued that for long-term use, the stability of biochar in soil must be investigated and the interactions between biochar and soil biota unambiguously identified. Recent studies have been focused on this apprehension (Novak et al., 2009; Domene et al., 2014; Zhang et al., 2014; Busch and Glaser, 2015). Although the results of long-term field applications have been contradictory, the C content of soil was increased while N concentrations became more stable. Long-term biochar field application resulted in small agronomic benefits (Jones et al., 2012; Domene et al., 2014). The alkalinity of soil has also been fully neutralized in 3 years via soil amendment with biochar (Jones et al., 2012). On one hand, no negative effects of alkaline biochar on soil enzymes and microbial activity were reported (Case et al., 2014; Domene et al., 2014; Wang et al., 2015b; Foster et al., 2016), and impacts of biochar to extracellular enzyme activities and fungi root colonization of plant were not observed (Elzobair et al., 2016). Conversely, the biochar application in soil sometimes affects negatively the plant growth because of the low application rates or N immobilization. At this point, the attentive N-mineral-fertilization program is proposed (Bargmann et al., 2014), and it was reported that not all types of soil can take advantage of biochar applications (Ippolito et al., 2012). Furthermore, Clough et al. (2013) emphasized the requirement of further systematic studies unlike the studies carried out the individual soil-biochar combination due to the projection of N cycling responses.

DISTRIBUTION OF AGRICULTURAL LAND AND BIOCHAR POTENTIAL FROM AVAILABLE BIOMASS RESIDUES IN TURKEY

Land use and distribution of crop production

According to data from the Turkish Ministry of Food, Agriculture and Livestock, the agricultural land and forest area in Turkey was, in 2015, 60.9 million hectares (TurkStat, 2016). The forest takes up an area of 22.3 million hectares, and it is indicated that the forest area has been changed about 10.6% since 1988. While the forest occupy a large area in land use of Turkey, about 38.6 million hectares is used as agricultural land (TurkStat, 2016). This area is composed of sown area, fallow land, land under permanent crops, meadows and pastures (Figure 1). The total

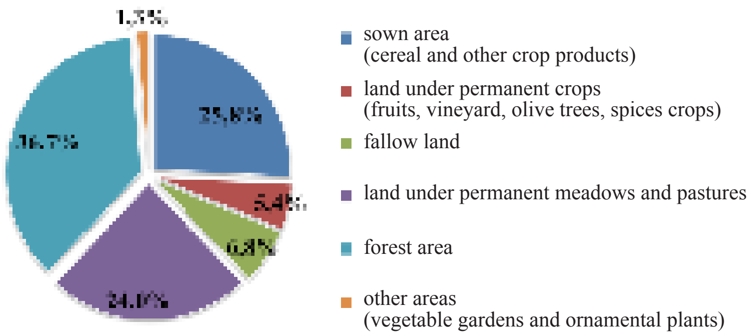

Figure 1. Distribution of agricultural land and forest area in Turkey (2015)

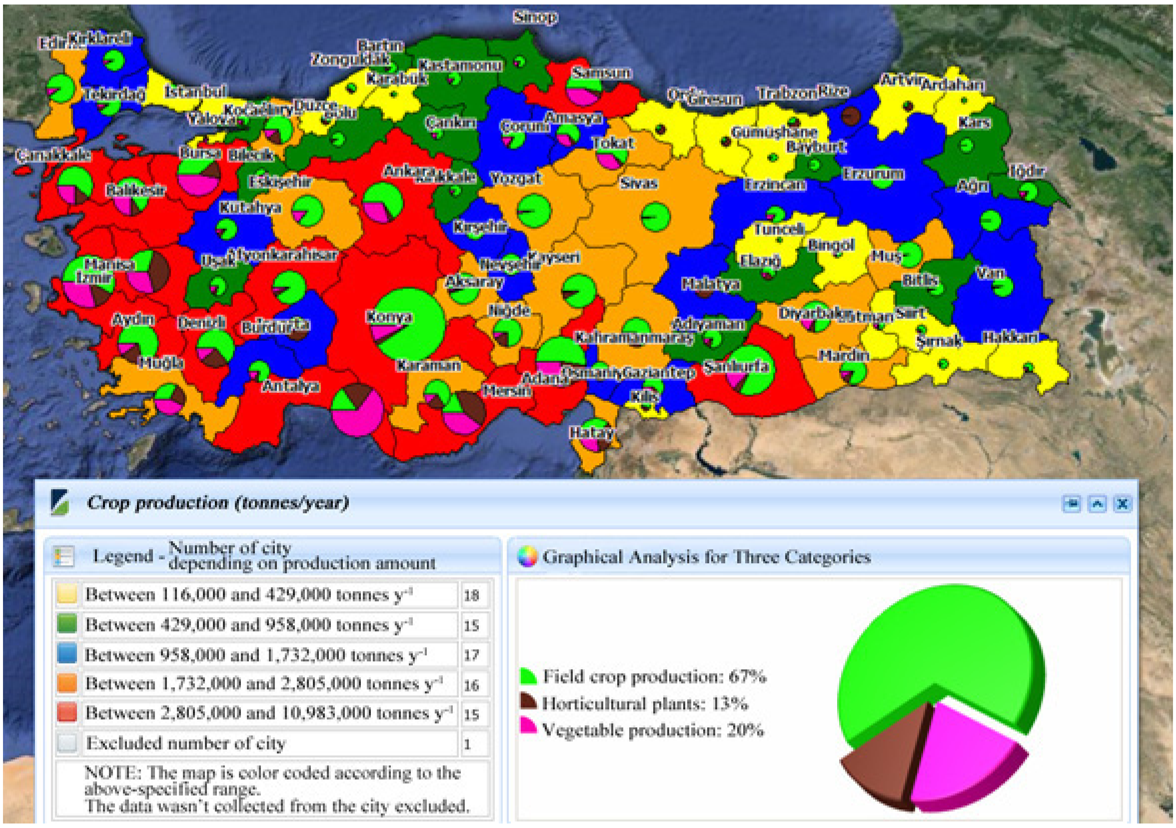

Figure 2. Geographical distribution of crop production (tonnes/year) in Turkey (2015). Retrieved integrally from BEPA (2016).

sown area was approximately 15.7 million hectares, and it includes all land used for cereals, pulses, industrial crops, forage crops and other field crops with a growing cycle of under one year. Fallow land (4.1 million hectares) is defined a non-cultivated area that is resting for a period of time before re-cultivation. In Turkey, fallow land currently takes up a larger area than permanent crops as shown in Figure 1. Meadows and pastures also take up a large area of about 24% of the total agricultural and forest land, because of livestock farming. The other areas represented in Figure 1 stem from vegetable garden and ornamental plants, and cover 0.8 million hectares.

Turkey has seven geo-climatic regions: Marmara, Aegean, Mediterranean, Black Sea, Southeastern, Eastern and Central Anatolia. Total crop production from agricultural land (38.6 million hectares) is scattered throughout the seven regions as shown in Figure 2, retrieved from Turkish Biomass Energy Potential Atlas (BEPA[1]). BEPA divides crop production into five production ranges (from 116,000 to 11,000,000 tonnes y^{-1}) and into three categories (field crop, horticultural plant and vegetable production). As shown in Figure 2, the number of cities is almost the same in each production range. The highest crop production is observed in the southern Marmara, Aegean, Mediterranean and western Central Anatolia regions. The field crop consists of cereals, pulses, forage crops, potato, tobacco, sunflower etc., and the ratio of field crop production to total crop production is substantially higher than that of other productions. Field crop production contributes 67%, vegetable production 20% to total production and the remaining crop production is from horticultural plants. The highest vegetable production is carried out along the coastline. Although the highest field crop production is observed in the Central and Eastern Anatolia regions because of their intensive animal husbandry, generally all regions have field crops (BEPA, 2016). Especially, field crops such as wheat, vicia and medicago sativa, sainfoin, barley, potato and sunflower, are produced far and wide in Turkey. In addition to these products, cotton and tobacco are cultivated along the coastline.

[1] BEPA is a geographical information system designed graphically and numerically biomass energy resources, energy potential of its residues and distribution of them. This atlas was created by General Directorate of Renewable Energy in Turkey.

Estimating the available biomass residues and biochar potential

The data of BEPA was utilized due to estimate the potential of biochar production and biomass residues from agricultural and forest lands except meadows and pastures

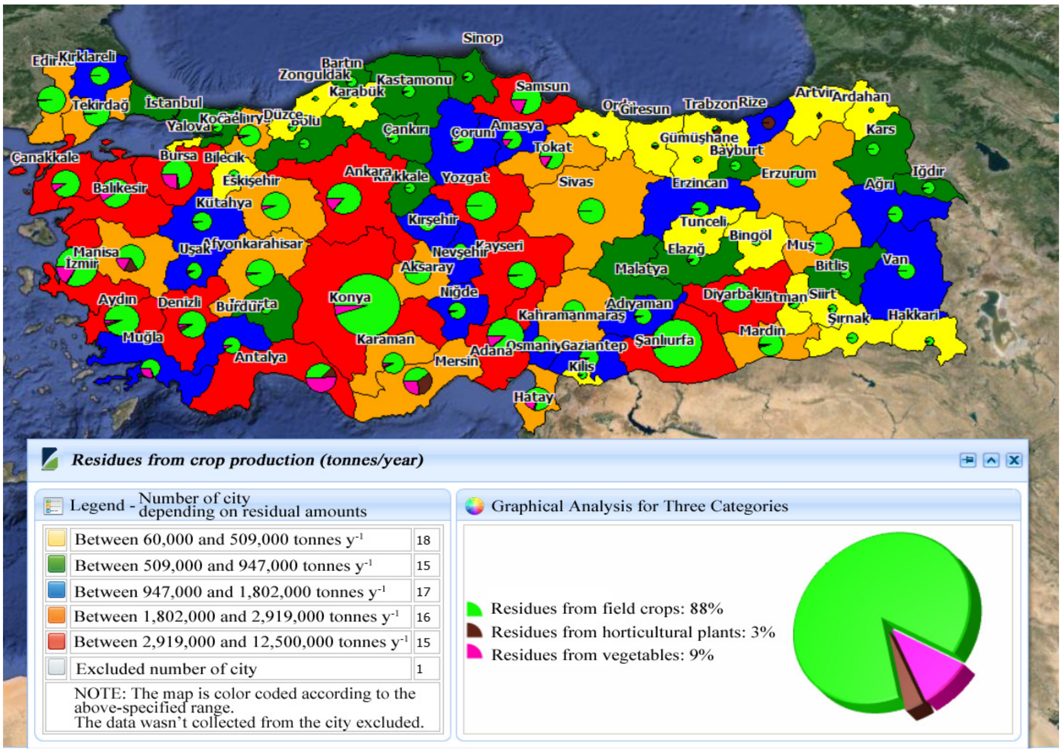

Figure 3. Geographical distribution of residues from crop production (tonnes/year) in Turkey (2015). Retrieved integrally from BEPA (2016).

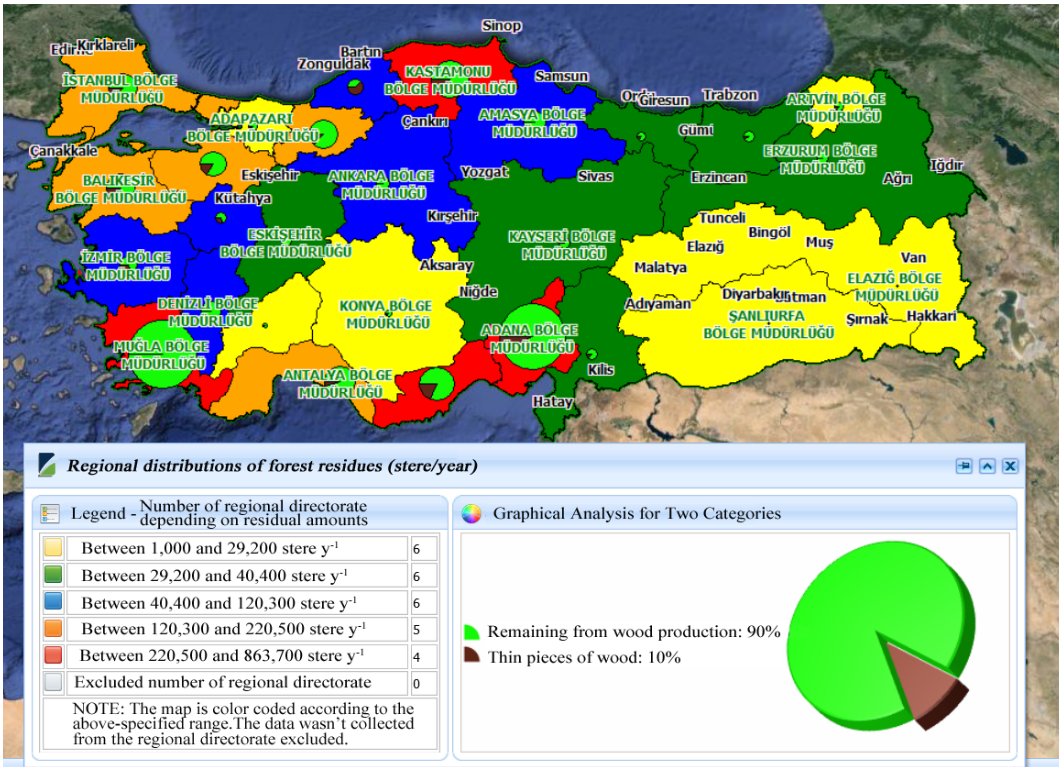

Figure 4. Regional distributions of forest residues ([2]stere/year). Retrieved integrally from BEPA (2016).

[2] Stere is a unit which is used for the production and sale of firewood in Turkey. It is defined as the amount of wood in volume of 1 m^3. General Directorate of Forestry accepts that one stere with an average volume of 0.7 m^3 contains 500 kg wood (Tetik et al., 1992).

area were investigated. The forage crops (millet, sainfoin, vicia and medicago sativa etc.) used for livestock farming, were excluded from the assessment due to uncertain biomass residues of them, and it may not be economically viable for biochar production.

The biomass residues from total crop production showed a similar distribution to total crop production. The number of cities is almost evenly distributed within production ranges, as shown in Figure 3. In the BEPA, the amount of biomass residues from total crop production in Turkey was indicated as 142 million tonnes (wb) y^{-1} in 2015, which corresponds to ca. 669 million GJ y^{-1} (16 M tonnes of oil equivalent; Mtoe y^{-1}). The highest amount of residues stems from wheat and barley, followed by corn stalks and cotton stalks. The total amount of these residues was estimated as about 80 million tonnes y^{-1}. As shown in Figure 3, the residues from vegetable production which are 13 million tonnes (wb) y^{-1}, take the second place in biomass residues. The lowest amount of residues is obtained from the horticultural plant production. Its energy content was 27 million GJ, and 23%, 18% and 10% of it was obtained from tea, banana and hazelnut residues, respectively (BEPA, 2016). The total residuals from vineyard and olive-tree pruning also have an important place in the energy of horticultural residues, by the ratio of 9%. The energy content of forest residues was determined to be 35.7 million GJ (855,000 toe), and the regional distribution of forest residues is shown in Figure 4.

These whole prominent residues have a lignocellulosic structure, and so are potential raw materials for torrefaction. The residue could be evaluated near its sown area due to decrement in cost of biomass transportation. According to this approach; wheat, barley, corn stalk and forest residues could be estimated in all regions, although cotton stalk, banana, vineyard and olive-tree pruning residuals could be evaluated only in coastal areas of the Aegean and Mediterranean regions. The tea and hazelnut residues were valuable along the coastline of the Black Sea region.

According to the data of BEPA, the potential of biochar produced from agricultural and forest residues was calculated 9.5 million tonnes (db) annually. Animal waste especially broiler litter is also problem in Turkey and requires disposal. If it is channelled into biochar production, annually 10.8 million tonnes (db) biochar might be produced. The distribution of potential was represented in Table 2. The results were calculated from the residues evaluated correspond to 60% of biomass residue from total crop production in Turkey. The vegetable production residues were neglected in the calculation of biochar potential because of high moisture (80–90%) and low production capacity than other field crops. In addition, biochar conversion rate in thermal process and moisture content of biochar were assumed as 35% and 5%, respectively. The availabilities ratio was used from data utilized by Bascetincelik (2006) and Sumer et al. (2016). In a previous study of Sumer et al. (2016), the potential of biochar produced from agricultural and animal wastes of Turkey was estimated at about 4 million tonnes (db) annually. However, different biomass residues (sugar beet, rice husk, tomatoes, potatoes, peaches, apricots, cattle manure etc.) were mainly selected for the

Table 2. Total amount of prominent residues and its biochar potential in Turkey.

Residues	Total residues [t y^{-1}]	Availability ratio [%]	Moisture [%]	Available dry residue [t y^{-1}]	Dry biochar potential [t y^{-1}]
Agricultural residues	**84,896,904**			**26,878,254**	**8,937,019**
Wheat	30,044,843	15	15	3,830,717	1,273,714
Barley	10,675,020	15	15	1,361,065	452,554
Cotton	9,103,680	60	15	4,642,877	1,543,757
Corn stalks	29,400,360	60	15	14,994,184	4,985,566
Sunflower	2,807,314	50	15	1,193,108	396,709
Tea	1,250,000	70	70	262,500	87,281
Banana	934,772	70	70	196,302	65,270
Hazelnut	66,000	70	15	39,270	13,057
Vineyard pruning	72,800	70	30	35,672	11,861
Olive-tree pruning	542,116	70	15	322,559	107,251
Animal Waste	**5,507,358**			**4,089,213**	**1,359,663**
Broiler litter	5,507,358	99	25	4,089,213	1,359,663
Forest residues	**1,957,452**	100	25	**1,468,089**	**488,140**
TOTAL					**10,784,822**

biochar potential, and 12% of the biomass residue from total crop production of Turkey was evaluated.

SOIL TAXONOMY OF TURKEY TO ESTIMATE THE NEED FOR BIOCHAR

Turkey is a large peninsula and there is a variety of soil groups and kinds of vegetation as a consequence of variable climatic influences. Typical terra-rossa soils prevail in the Mediterranean climate and podzolic soils typical of cold, humid climates occur in Northern and Western Anatolia. Because Central Anatolia has arid and semi-arid climates, brown earth and reddish brown earth are present in this region. Chestnut soils and reddish chestnut soils are also observed in arid, semi-arid and humid climates (Anon., 2016). Soil map of Turkey created by General Directorate of Soil and Water (TOPRAKSU – Turkish acronym), consists of twenty-three soil groups (Figure 5). TOPRAKSU classifies the soils from A to Z based on old USA Soil Taxonomy (Dizdar, 2003; Dogan, 2012).

According to the older system of classification, the soils were here investigated within three basic soil groups, i.e. zonal, azonal and intrazonal soil, all of which are found in this large peninsula. The observed soils are also classified as alfisols, mollisols, aridisols, vertisols, entisols, inceptisols and histosols based on twelve soil orders in the U.S. Soil Taxonomy (Kilic and Sayar, 2006; Dengiz, 2007; Kilic, 2011; Ozsoy and Aksoy, 2012; Anon. 2016). According to the FAO/UNESCO soil classification, Turkey comprises 32 soil associations, and leptosols are the dominant soil. Leptosol are followed by calcisols, cambisols, kastonozems, fluvisols, vertisols, regosols, arenosols and acrisols (Kapur et al., 2002; Aksoy et al., 2010).

Distribution of zonal soils

Zonal soil types are spread over a large area at Turkey. It can be seen in the Black Sea, Aegean and Mediterranean geographical regions. These soils have a lower content of water-soluble chemical substances than other types and sometimes have more silica, iron oxide and aluminium oxide. These soils are observed to have different characteristic properties if situated in the northeast and southwest regions, which have a humid climate, compared to western and southern regions, due to adequate rainfall. In these regions, the soil is strongly alkaline. For the neutralization of these soils and abundant nutrient source, the biochar produced at 300–500°C was suggested in a previous study (Zhang et al., 2015). Biochar application at a rate of 10 tonnes ha^{-1} in alkaline soil resulted in the mitigation of nitrate leaching and the increase in the total biomass and seed yield (Ventura et al., 2012; de la Rosa et al., 2014; Mete et al., 2015).

Brown earth, limeless brown earth, terra-rossa and chestnut soils are the most frequent zonal soils. Limeless brown earth prevails in the coastline of the Marmara, Aegean, Mediterranean and Black Sea regions, especially Thrace; Thrace is the European part of Turkey, in the Mar-

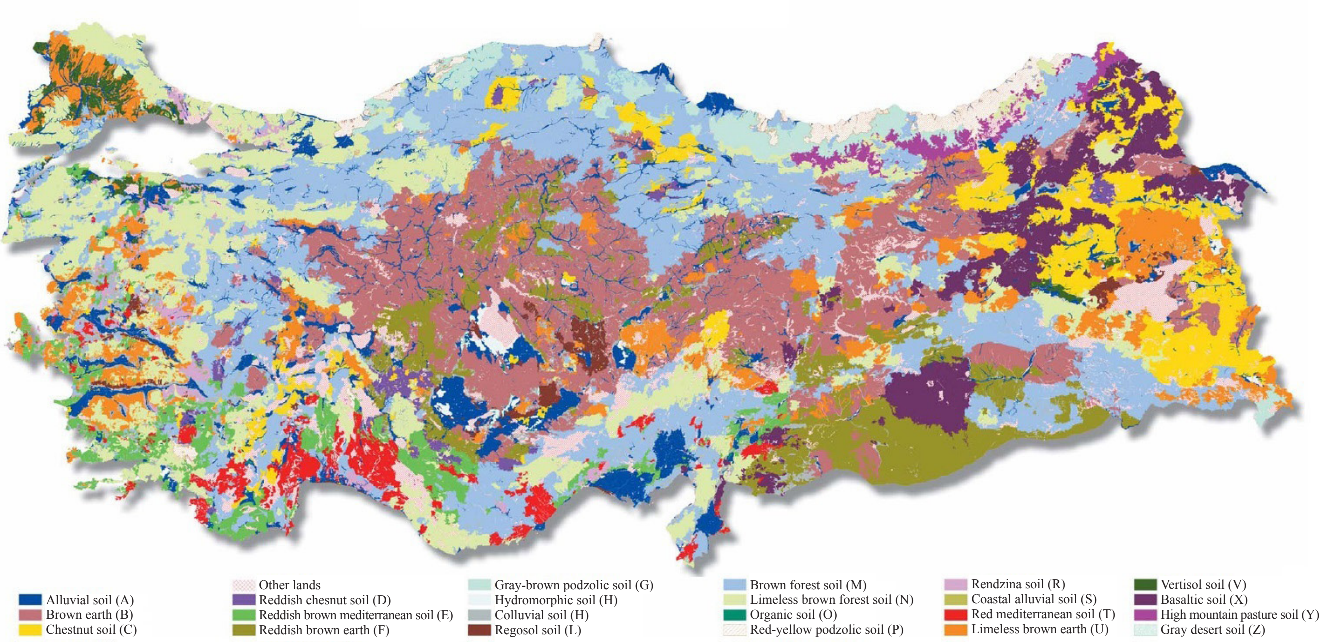

Figure 5. The large soil groups present in Turkey. Retrieved integrally from Karadag (2016).

mara region. About 600,000 ha of limeless brown earth is under cultivation in Turkey, being planted with wheat, sunflowers, legumes and other regional plant species (Anon., 2016). Brown earth dominates on the Central Anatolian plateau, and covers 15% of Turkey's land. Generally, dry farming, i.e. cultivation based on rainfall, is used with fallow lands (Dizdar, 2003). Although the lack of water limits their fertility, about 20% of these lands are cultivated in Turkey (Anon., 2016). In the Kızılırmak river basin and southern Anatolia region reddish brown earth dominates and 80% of the total area is suitable for agriculture. However, dry farming is also used due to the lack of water. Some projects have already been developed to increase the soil fertility.

Terra-rossa is another common soil type in Turkey. The most important property of this soil is its bright red colour and capacity to have free Fe_2O_3 at a rate of 4–6% (Anon., 2016). This soil is distributed around the coastline, like limeless brown earth. Generally, it can be used as pasture area and for olive groves. About 400,000 ha of these lands are under cultivation in Turkey (Anon., 2016). Especially in the Mediterranean region terra-rossa is able to be observed together with reddish brown earth, and greenhouse vegetables, citrus and olive trees are planted. According to working on western Anatolia soils, the pH value of arable soils was neutral and slightly alkaline. It was indicated that 33% and 58% of soil samples contained low lime and low organic material, respectively (Turan et al., 2013). On the other hand, reddish prairie soil is found in Southwestern Anatolia and has similar properties to terra-rossa. Although it is very poor in P and N, high yields can be obtained by fertilization of vegetables, citrus and field crops (Anon., 2016). Generally, irrigated farming techniques are used and cotton is cultivated. A study about biochar application at a rate of 10 g kg^{-1} in poor acidic red soil demonstrated that maize growth can be improved by liming effect of biochar (Zhu et al., 2014).

Chestnut soils in Turkey also provide arable and fertile lands. They occur in the north of the Central Anatolian plateau, Eastern Anatolia and Southern Anatolia. These lands are cultivated for cereal production via dry farming agriculture, while quite a large proportion are left fallow for a period of time before re-cultivation. The remaining part can be used as natural pasture area. A sub-type of chestnut soil named reddish chestnut soil is observed in valleys and plateau in western Anatolia. It has clay, loam and high organic content, and is slightly acidic. Generally, reddish chestnut soils are used for tobacco and legume production. Cotton, vegetable, fruit and vineyard production are grown, if there is no irrigation problem (Anon., 2016). Baronti et al. (2014) investigated the biochar application in a cultivated soil like reddish chestnut soil (shallow acids sandy-clay-loam) in terms of the growth-yield and grape quality of *Vitis vinifera* and found that the available soil water content was increased up to 45% with a biochar application rate of 44 tonnes ha^{-1}.

Podzolic soils being as a sub-type of zonal soil are also observed in humid areas of Turkey, such as the Black Sea region. This region has an oceanic climate with high and evenly distributed rainfall throughout the year. However, very little land can be used as agricultural area because of the water erosion. The arable lands are restricted to valleys and the relatively small slopes of the foothills. Generally, podzolic soils are under forest.

Distribution of azonal soils

Alluvial soil is the most common of the azonal soil types, also classified as entisol based on the U.S. soil orders. Alluvial soil occurs in river basins in all regions such as the basins of the Gediz, Büyük Menderes, Küçük Menderes, Seyhan, Ceyhan, Meriç, Bafra, and Çarşamba rivers, and the lowlands of provinces such as Iğdır and Muş. It constitutes the most fertile soil of Turkey. It can have different ratios of clay, silt, gravel or chlorite based upon the transportation of parent material by river. Alluvial soil covers one-seventh of the arable land in Turkey. Konya province in Central Anatolia has also alluvial calcareous soils which are characterized by heavy granulometric composition and low organic carbon content (Erol et al., 2015). On the other hand, Asi river basin (in the Mediterranean region) was investigated and the most common types of soil such as entisol and inceptisol were found in the youth or adolescence phase. These soils were characterized according to their clay, loam and silt properties (Ozsahin and Atasoy, 2015). The water permeability of alluvial soil is good and its capability rating is higher than other soil types. However, salinity and alkalinity are important problems while during irrigation, its drainage and irrigation must be controlled (Anon., 2016). It is indicated that about 2,800,000 ha and 1,500,000 ha soils are affected via drainage and salinity problem, respectively (Dizdar, 2003). Soil salinity could also be mitigated by the biochar applied with a rate of 10 g kg^{-1} and thereby crop productivity could be enhanced (Akhtar et al., 2015; Sun et al., 2016; Xu et al., 2016; Lin et al., 2015). On the other hand, other azonal soils (regosol and lithosol) occurred in limited locations in Turkey, but these lands are not suitable for agriculture.

Distribution of intrazonal soils

Intrazonal soils occupy a quite limited land area in Turkey. These types of soil contain a high proportion of sand and gravel. They can be found in the foothills of the Taurus Mountains in the Mediterranean region, the lakes region of Central Anatolia and around the Izmir-Foça district in the Aegean region. Rendzina is a type of humus-rich fertile intrazonal soil, which is usually used to grow cereals. In addition, about 20% of rendzina soils are cultivated in Turkey, and they are utilized for tobacco, poaceae, olive and vine cultivation. Another intrazonal soil occurring in Turkey is grumusol soil, about 85% of which is arable (Anon., 2016). This black soil is based upon malm, loam and clay and is rich in calcium and magnesium. It is prevalent in Thrace, the Bursa-Karacabey district in the Southern Marmara region and the Konya basin in the Central Anatolia region. Although many crops, such as vines, horticulture etc., can be cultivated, the most common is sunflower using dry farming agriculture. Other types of intrazonal soils are hydromorphic soil, saline and alkaline soils that are rich in sodium and carbonate. Hydromorphic soil is similar to alluvial soil and 60% of this soil is usually cultivated by water drainage because of high water layer within the soil.

In addition to these intrazonal soils, brown forest soils prevail in numerous regions of Turkey and can frequently be seen locally. The total area of brown forest soils in Turkey is uncertain because of the lack of soil survey mapping. It is considered to be approximately 15 million hectares (Dizdar, 2003). The brown forest soils occupy a large area in the Black Sea region (~40%) (Dizdar, 2003). According to the soil database and mapping for the central and eastern Black Sea region, 26% of the soil texture was found to be clay loam soil and 22% of it was found to be clay soil. The pH value of the arable lands was neutral at a rate of 30% and slightly alkaline at a rate of 24%. Medium levels of organic material were detected in soils that had lower salinity and lime contents. In addition, the arable soils of Black Sea region were rich in terms of N but insufficient in available P (Ozyazici et al., 2013). On the other hand, it was also found that the prevalence of brown forest soil to be 65% in arable land of a city (Siirt) located in Southeastern Anatolia region (Ozyazici et al., 2014).

Estimating the need for biochar

The dominant big soil groups covering 88% of total agricultural land except meadows and pastures in Turkey were assessed. The need for biochar in Turkey was calculated with estimated area of the soil types in arable land and biochar application rates. Depending on the similar soil texture, the biochar application rates for each soil type were selected, and the results were shown in Table 3 with references.

In the light of this information, the amount of biochar necessary for the arable land of zonal soils in Turkey could be predicted in the range of 4–143 million tonnes y^{-1}. This wide range was occurred due to the existence of soils occupied in different land capability classes (from I to VIII) according to American Soil Survey Handbook (Aksoy et al., 2010; Cangir and Boyraz, 2000), and therefore the biochar

Table 3. Estimated arable land and biochar need for different soils in Turkey.

Soils	Total area in Turkey [ha] ###	Estimated arable land [ha]	Biochar application rate [t ha^{-1}]	Reference for application rate	Total biochar need [t y^{-1}]
Zonal soils					
Limeless brown earth soils	4,630,500	600,000#	20	Šimanský et al., 2016	12,000,000
Red mediterranean soils (Terra-Rossa)	1,439,950	400,000#	10	de la Rosa et al., 2014	4,000,000
Chestnut soils	6,981,100	1,170,000#	25	Jones et al., 2012	29,250,000
Brown earth	10,842,450	2,100,000#	10	Ventura et al., 2012	21,000,000
Reddish brown earth	4,840,600	3,250,000#	44	Baronti et al., 2014	143,000,000
Intrazonal soils					
Rendzina soils	728,225	135,000#	30	Vaccari et al., 2011	4,050,000
Grumusol soils	566,450	481,483#	17	Lehndorff et al., 2016	8,185,202
Hydromorfic soils	2,500,000	1,500,000#	15	Njoku et al., 2016	22,500,000
Brown forest soils	15,427,250	3,856,813##	40	Olmo et al., 2014	154,272,500
Limeless brown forest soils	10,477,650	2,619,413##	40	Olmo et al., 2014	104,776,500
Azonal soils					
Alluvial and colluvial soils	7,699,100	3,399,100###	3	Lehndorff et al., 2016	10,197,300
High saline soils		1,500,000###	16	Lin et al., 2015	24,000,000

#Anon, 2016; ##estimated to be 25% of total area; ###Dizdar, 2003 application rates selected also changed in the wide range. For zonal soils, pH can be neutralized through biochar application, and dry farming can be improved by supporting the soil nutrient and water holding capacity.

The biochar need for intrazonal soils was also changed in the wide range as zonal soils due to the same reason. The intrazonal soils cultivated in Turkey have also different land capability, and the amount of biochar necessary for intrazonal soils could be predicted in the range of 4–154 million tonnes y^{-1}.

Azonal soils have some advantage with respect to soil fertility, and so the lower application rate can be sufficient to soil amendment. The amount of biochar necessary for arable azonal soils in Turkey could be predicted in the range of 10–24 million tonnes y^{-1}. On the other hand, high salinity poses major obstacle for agriculture. According to the previous applications, salinity can also be reduced by biochar treatment (Lin et al., 2015; Chaganti et al., 2015; Yue et al., 2016; Sun et al., 2016). However, long-term biochar application to saline soils is recommended due to investigate the effect on N and P availability (Yue et al., 2016; Sun et al., 2016; Xu et al., 2016).

Soil pollution of arable soil in Turkey

The cultivated area has been under threat of pollution as other countries due to the increase in urbanization, industrialization and transportation. The over-fertilization and pesticides application, and exposure to industrial and domestic waste have resulted in the pollution of agricultural soils (Aydinalp, 2000). It was indicated that a potential risk exists for the near future particularly in the Mediterranean, Aegean and Marmara Regions (Duzgun et al., 2006). Yatkin and Bayram (2011) investigated the chemical compositions of urban, industrial, agricultural, and rural topsoils in Izmir city (in the Aegean region). In the north of Izmir, they found higher concentrations of lead (Pb), zinc (Zn) and cadmium (Cd) than other regions because of iron-steel producers situated. Sungur et al. (2016) compared greenhouse soils with field soils of Çanakkale city (in the Marmara region) according to the mobility and environmental impact of heavy metals (chrome (Cr), copper (Cu), nickel (Ni), Cd, Pb and Zn). Mobile fractions of many metals, except for Cu, were higher than immobile fractions because of anthropogenic impacts. Cadmium, which has high environmental risk, was much more mobile in greenhouse samples than field samples. Another research about the concentration of twenty different heavy metals was carried out along Bağaçayı River in the southwestern Anatolia region. The concentration of Cr was found to be 20 times higher than the acceptable limit for Turkey. Besides Cr, the concentrations of cobalt (Co) and Ni were also found to be higher than the acceptable limits. On the other hand, it was reported that anthropogenic activities had potentially led to the increased concentration of many heavy metals in soils (Yalcin et al., 2016). The soil pollution of Turkey has also been analysed by Ministry of Environment and Urbanization; however the total amount of arable land contaminated by heavy metals has been unpublished yet.

Biochar application to soil could mitigate the soil and plant toxicity in terms of heavy metals, such as Cd, Zn, Ni and Cu etc. According to the previous studies carried out in pot and field applications, the heavy metal uptake by plants were reduced, and promoted the microbial abundance and activity (Choppala et al., 2011; Younis et al., 2015; Al-Wabel et al., 2015; Wagner and Kaupenjohann, 2015). Although the total amount of contaminated arable land in Turkey has not been determined yet, it was predicted that the soil amendment with biochar in Turkey would obviously reduce the soil pollution meanwhile the crop production and soil characteristics would be enhanced.

CONCLUSION

In this study, the proportion of agricultural land and forest area, residual biomass potential and soil taxonomy was analysed in terms of the production and utilization of biochar in Turkey. The amount of biochar necessary, the biochar production capacity and the positive or negative effect of biochar application on the crop productivity and soil characteristics in Turkey were revealed by comparing with the previous studies about biochar addition to similar soil taxonomy.

The sown area of Turkey covers 27% of the total agricultural and forest land area. The sum of lands under permanent crops, meadows, pastures and fallow land is higher than the total sown area. These lands should be evaluated to increase the agricultural efficiency of Turkey. Although the arable lands of Turkey prevail in seven regions, crop production seems to be concentrated in southern, western and central Anatolia. Compared to total crop production, the ratio of field crop production was substantially higher than that of other crop types. The highest vegetable production was carried out along the coastline, while the highest field crop production was observed at central and eastern Anatolia regions. The residues of wheat, barley, corn and cotton stalk, tea, banana, hazelnuts and forest were also found to be high in these regions. These residues are lignocellulosic and suitable for biochar production. The tea and hazelnut residues found at the coastline of the Black Sea region, along with cotton stalk and banana residuals in the Aegean and Mediterranean regions could also be valuable for biochar production. Wheat, barley, corn stalk and forest residues could be suitable in all regions as well. If the total annual residues of Turkey are channelled into biochar production, the total biochar potential of Turkey was estimated about 10.8 million tonnes (db) theoretically.

Furthermore, it is clear that there are different soil types in the arable lands of Turkey and therefore soil survey and mapping studies should be performed in detail using current technologies. It is foreseen that biochar, produced from prominent residues in Turkey, would positively affect the plant growth and soil characteristics, if used together with fertilizer. In particular, the zonal soils could be enhanced via biochar application in terms of the increase in water holding capacity and pH of soil. Biochar from residual biomass could also mitigate the salinity and alkalinity problem in alluvial soils, and the soil pollution in Aegean and Mediterranean regions especially. Moreover, farmers would not need to rest the soil for a period of time before re-cultivation and consequently, the ratio of fallow lands would be reduced, and the farmers would get a marketable product as biochar in Turkey. However, it was observed that there was an important limitation. The amount of biochar necessary for the arable soils identified was significantly higher than that of biochar produced from the total annual residues, theoretically. At this point, it is recommended, firstly, that field experiments could be conducted in the soils cultivated by dry farming in order to experimentally determine the special and productive rate of biochar addition in Turkey. Secondly, the arable soils which had some problems like salinity, and were polluted by various factors could be preferred for biochar application in control of public authorities. Thirdly, dry animal wastes based-biochar might be channelled into soil amendment due to the deficiency of biochar.

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