Estimation of Pruning Wastes and Biochar Production Potential of Turkey

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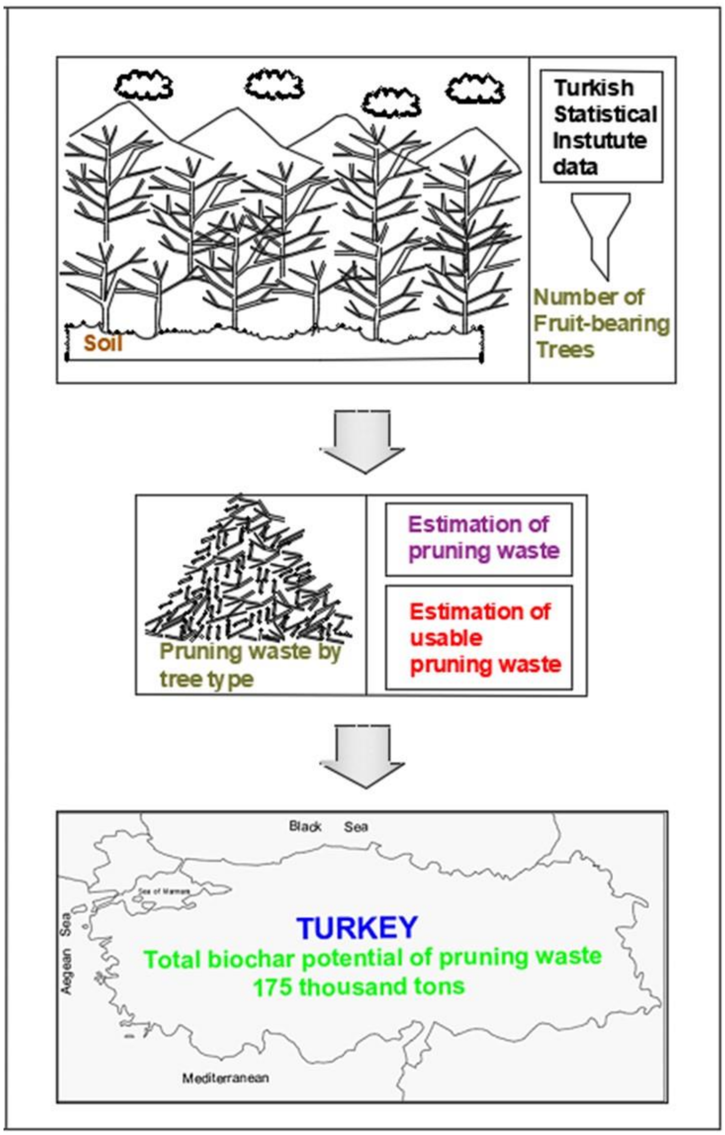
GRAPHICAL ABSTRACT



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In agriculture-producing countries, pruning waste is obtained from fruit-bearing trees during the fruit-growing process. The present study aims to determine the potential of biochar of pruning wastes, obtained as a result of agricultural activities that have economic value. To the best of the author's knowledge, no study has been conducted in Turkey to make a regional estimation of the biochar potential of pruning wastes. Biochar produced from waste provides the advantage of use in various fields, such as soil remediation and water and wastewater treatment. In this study, data on the number of trees bearing fruit (almond, apple, apricot, cherry, peach, pear, plum, and sour cherry) from the Turkish Statistical Institute were used based on the equations specified. First, the amount of pruning waste, then the usable pruning waste, and finally their biochar potential were calculated. It was estimated that the apple tree had the highest total biochar potential (41.5 thousand tons/year). Regarding the regions, the highest biochar potential was in the Central Anatolia Region for the apple tree (19.3 thousand tons), followed by the Eastern Anatolia Region for the apricot tree (13.6 thousand tons). The total biochar potential of pruning wastes from fruit-bearing trees in Turkey was estimated at 175 thousand tons for the year 2021.

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Keywords: Agricultural waste; Pruning coefficient; Pruning waste; Biochar potential; Turkey

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INTRODUCTION

Waste management in agricultural activities is important for contributing to the economy and for encouraging sustainable agricultural practices, primarily as a solution to environmental problems. Today, problems, such as a decrease in crop yield, soil erosion, soil destruction caused by pollution, groundwater pollution, and an increase in greenhouse gas emissions, are some of the long-term harmful effects on sustainable agriculture. Research approaches should focus on environmentally friendly agricultural practices and sustainable waste management. The implementation of biochar has also been recommended to reduce these harmful effects. Biochar application has been reported to have the following advantages: (i) mitigating climate change by soil carbon sequestration (Lehmann 2007; CEC April 2019; Purakayastha *et al.* 2021); (ii) reducing emissions of methane and diazote monoxide (Huang *et al.* 2019); (iii) faster recovery effect in areas with soil destruction due to pollution (Downie and Van Zwieten 2012; CEC February 2019; CEC April 2019); (iv) increasing crop yield by supporting plant growth, thereby improving food security (Downie and Van Zwieten 2012; CEC February 2019); (v) reducing the fertilizer requirement of the soil and enabling it to hold water (Cai *et al.* 2020); (vi) increasing the plant's irrigation water uptake (CEC April 2019); (vii) preventing groundwater and surface water pollution (CEC April 2019); (viii) reducing soil erosion (CEC April 2019; Cai *et al.* 2020); (ix) increasing the drought resistance of bacterial and fungal communities in the soil by developing soil microbial activity (CEC April 2019); and (x) improving land use outcomes by minimizing waste going indirectly to landfills. However, these advantages have been reported to depend on factors such as biochar type, pyrolysis conditions, and biochar application rate. Moreover, the studies propose to investigate the optimum conditions for these factors in the soils where the application is to be made so that the mentioned advantages are obtained. The studies in the literature investigated the production of biochar from coffee husk waste (Kiggundu and Sittamukyoto 2019), industrial orange peel (Sial *et al.* 2019), wood (Tan *et al.* 2020), poultry litter, rice husk, pulp & paper mill sludge (Akhtar and Sarmah 2018), and wheat straw (Ahmad *et al.* 2020) to be used for different purposes. Because of the advantages of biochar, using the generated organic wastes in biochar production is important for countries for both economic advantages and waste management.

Turkey, a leading agricultural country in fruit production, has seven geographical regions (Marmara, Aegean, Mediterranean, Central Anatolia, Black Sea, Eastern Anatolia, and Southeastern Anatolia). Agricultural activities are carried out in different areas in all these regions, depending on their geopolitical and geographical locations. Agricultural activities have brought along an increase in the amount of organic waste of various types, which has required organic waste management. It would be wrong to think of these wastes only as environmental pollutants. Strategies should be developed for the environmentally friendly use of these wastes that have economic value and their use as raw materials. In this context, vegetative production areas are among the areas that generate organic waste. Within the scope of "fruit products, beverage and spice plants", which is a sub-field of herbal production, pruning wastes obtained from fruit trees can be considered an important resource. For this, data on the number of fruit-bearing trees were obtained from the database of the Turkish Statistical Institute (Turkish Statistical Institute 2022).

In agricultural production areas, waste is generated as a result of various activities. The wastes from these activities were examined at certain temperatures for the purpose of biochar production. Studies conducted in this context investigated the following: citrus peels at 300 to 700 °C (Selvarajoo *et al.* 2022), peel, leaf, stem, and empty fruit bunches at 400 to 700 °C during palm oil production (Azman *et al.* 2022), cassava peels at 338 °C (Odeyemi *et al.* 2023), and the combined use of food waste and low-density polyethylene garbage bags at 500 °C (Neha and Remya 2023). Experimental results yielded significant knowledge regarding the reusability of wastes. These results also pointed to the safe disposal of waste. Biochar produced using palm leaves at 500 °C pyrolysis temperature by Bindar *et al.* (2022) for 30 min, biochar produced from chicken manure at 400 to 800 °C pyrolysis temperature by Kuryntseva *et al.* (2022) for 1.0 to 4 h, and biochar produced from wheat straw at 350 °C pyrolysis temperature by Aon *et al.* (2023) were applied to the soil. In these studies, biochar was suggested for soil improvement or planting medium as it does not require significant processing costs, and it reported to improve soil properties. The properties of the resulting biochar may differ depending on wide pyrolysis temperature ranges. In this context, Wang *et al.* (2013) examined the effect of raw material and pyrolysis conditions (temperature, residence time) on biochar properties. Using bamboo and elm as raw materials, the authors obtained biochar at 500 and 700 ºC temperatures with a residence time of 4 hours, 8 hours, and 16 hours. The study reported that as the residence time increased, the ash content and BET surface area of biochar increased, but the efficiency decreased. In addition, when biochar types obtained at these two temperatures were compared, an increase in BET surface area and ash content, but a decrease in efficiency was detected in biochar types obtained at 700 ºC. In their study where they used poplar wood as a raw material in the production of biochar, Chen *et al.* (2016) investigated different pyrolysis temperatures (400, 450, 500, 550, and 600 ºC) and heating rates (10, 30 and 50 ºC/min). The authors reported that pyrolysis temperatures lower than 500 ºC and a low heating rate (10 ºC/min) provided higher biochar yield. Additionally, it was reported that the pyrolysis temperature had a more significant effect on the product properties than the heating rate. Grojzdek *et al.* (2021) examined biochar production by pyrolyzing beech, oak, and spruce trees in the temperature range of 500 to 700 ºC and reported that lower temperature supports higher biochar yield. The literature shows that the yield of biochar obtained at low pyrolysis temperatures is high, while the yield of biochar obtained at high pyrolysis temperatures is low.

There are also studies where the obtained biochar was used for different purposes other than agricultural activities. In one of the studies, *Sargassum* sp., a brown macroalgae that poses an important disposal problem in coastal areas around the world, was examined not only for environmental effects but also for the production of high-value chemicals. From this biomass, bio-oil and biochar were produced at a temperature range of 400 to 600 °C for 10 to 50 min. As a result of the research, it was determined that when the *Sargassum* sp. bio-oil was examined, important compounds could be identified, including furan derivatives, carboxylic acids, N-aromatic compounds, and aliphatic hydrocarbons (Farobie *et al.* 2022). In one of the studies investigating biochar as an adsorbent, ground coffee was mixed in different proportions with a consortium of *Spirogyra* sp., *Microspora*, *Cladophora* sp., and *Rhizoclonium* microalgae, the mixture was pyrolyzed at 400 °C for 60 min, and it was reported that biochars were suitable for soil improvement and could be adsorbed in water treatment to remove some toxic organic and inorganic pollutants (Saiyud *et al.* 2022). In another study, *Sargassum cymosum* algae biomass was converted to biochar at 800 °C and found suitable for use in acetaminophen adsorption (Pimentel-Almeida *et al.* 2023). Sen *et al.* (2023) investigated methylene blue adsorption. The authors produced biochar from the lignocellulosic waste of *Quercus cerris* phloem (at 265 to 765 °C) and achieved high methylene blue removal efficiency.

It was reported that 2.85 thousand trees were grown in an orchard of 1.0 ha, and the estimated pruning waste was 3.0 to 3.5 tons/ha per year (Cara *et al.* 2006; Dyjakon 2018). According to the literature review, a limited number of studies examined the amount of pruning waste. One of these studies was conducted by Fernández-Puratich *et al.* (2021). In the study, the vineyard pruning wastes from agricultural activities in the Maule region were reported at 1.32 thousand tons/year. In another study, Bilandzija *et al.* (2012) reported the annual amount of pruning waste from fruit trees as 5.5 tons/ha for apple trees, 1.6 tons/ha for apricot trees, 1.9 tons/ha for cherry trees, 2.8 tons/ha for peach trees, 5.8 tons/ha for pear trees, 2.0 tons/ha for plum trees, and 2.1 tons/ha for sour cherry trees. While the pruning wastes from almond trees were calculated at 1.6 tons/ha per year in the study conducted by Bilandzija *et al.* (2012), it was estimated at about 2.4 tons/ha per year in the study conducted by Huang and Lapsley (2019). It was stated that the change in the amount of pruning waste depended on pruning density, the age of the tree, and the density of the area (Nati *et al.* 2018; Di Gennaro *et al.* 2020). Table 1 presents some of the leading countries in fruit production in the world in terms of fruit variety and cultivation areas (FAO 2021). In this context, because a large amount of pruning waste will be obtained depending on the number of trees per hectare, these wastes can be used for biochar production. Some countries use these wastes to obtain biochar. The annual biochar production of these countries was reported as 1.7 million tons in the Democratic Republic of the Congo, 1.7 million tons in India, 2.5 million tons in Tanzania, 3.2 million tons in Ethiopia, 3.9 million tons in Thailand, and 9.9 million tons in Brazil (Gangothri and Yuvaraj 2017).

Table 1. Some Leading Countries in Fruit Production - Fruit Variety and Cultivation Areas (FAO 2021)

Fruit Tree	China (ha)	US (ha)	Iran (ha)	Spain (ha)	Italy (ha)	Turkey (ha)
Almond	12.5 thsd	534 thsd	75.6 thsd	744 thsd	53.7 thsd	57.7 thsd
Apple	2.09 mln	117 thsd	132 thsd	29.5 thsd	54.5 thsd	169 thsd
Apricot	21.0 thsd	3.0 thsd	60.3 thsd	19.4 thsd	17.7 thsd	135 thsd
Cherry	8.6 thsd	34.2 thsd	21.8 thsd	29.5 thsd	28.0 thsd	81.5 thsd
Peach	825 thsd	35.4 thsd	38.7 thsd	72.1 thsd	56.5 thsd	50.1 thsd
Pear	986 thsd	16.9 thsd	5.1 thsd	20.0 thsd	26.8 thsd	25.1 thsd
Plum	1.95 mln	20.2 thsd	30.7 thsd	13.7 thsd	12.0 thsd	21.7 thsd
Sour cherry	-	12.3 thsd	26.0 thsd	1.60 hnd	0.9 hnd	20.1 thsd

In light of the above premises, this study aims to determine the amounts of pruning waste obtained from different fruit trees grown in each region of Turkey (81 provinces in total), based on the Turkish Statistical Institute data on the numbers of fruit-bearing trees by provinces, and to calculate the potential of pruning waste's conversion into biochar, taking into account that the biochar potential has not yet been defined. The biochar potential of pruning waste was analyzed separately for each region in terms of fruit tree type, quantity, and potential of conversion into biochar. Moreover, this study is considered to provide a basis for future studies on biochar and building biochar facilities in the regions.

EXPERIMENTAL

Workspace

Turkey has a total land area of about 0.77 million km^2 and seven geographical regions, as given in Fig. 1.

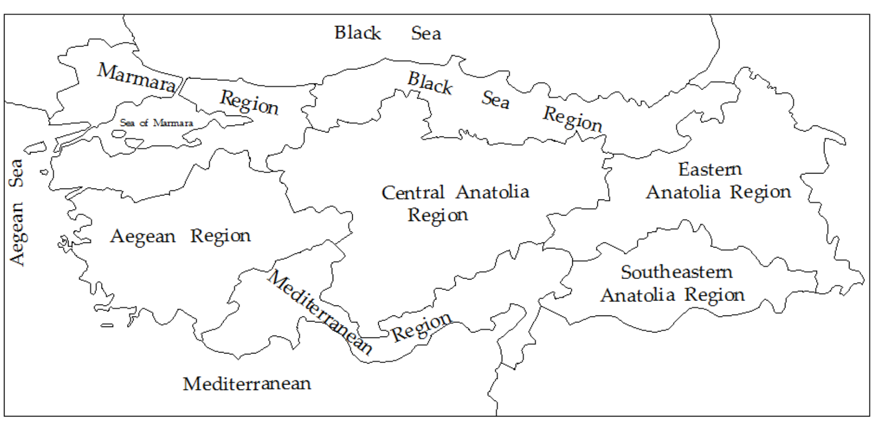

Fig. 1. Geographical regions in Turkey

Turkey is located between the temperate zone and the subtropical zone in terms of climate zones and has a temperate climate in coastal regions because of the sea and a continental climate in other regions in general. Agricultural activities are performed on about 31.1% of the land area of the country.

Calculation of the Biochar Production Potential of Pruning Wastes

The biochar production potential of pruning wastes from fruit-bearing trees in plant production activities was estimated according to the following Eqs. 1 to 3.

$$\text{Pruning waste (ton / year)} = \text{Number of fruit trees (tree)} \times \text{Pruning coefficient (kg / tree year)} \quad (1)$$

$$\text{Usable pruning waste (ton / year)} = \text{Pruning waste (ton / year)} \times \text{Usable ratio (\%)} \quad (2)$$

$$\text{Biochar potential (ton / year)} = \text{Usable pruning waste (ton / year)} \times \text{Biochar conversion rate (\%)} \quad (3)$$

The fruit-bearing trees almond, apple, apricot, cherry, peach, pear, plum, and sour cherry trees, which are grown in almost all provinces in Turkey and pruned every 1 to 2 years, were taken into consideration (Ministry of Agriculture and Forestry 2022). Bilandzija *et al.* (2012) and Sumer *et al.* (2016) reported the pruning coefficients of the almond, apple, apricot, cherry, peach, pear, plum, and sour cherry trees as 5.81, 2.34, 5.79, 5.90, 7.23, 2.45, 7.34, and 5.37 kg/tree year, respectively. These pruning coefficients were used to calculate the potential of pruning wastes conversion into biochar. The amount of annual pruning waste was estimated using Eq. 1. The studies conducted by Kaygusuz (2001), Lora and Andrade (2009), and Sumer *et al.* (2016) report that 70% of the total biomass can be used for generating energy. Therefore, the biomass usable ratio was admittedly 70%. As presented in Table 2, the slow pyrolysis method gives the maximum biochar conversion at 35%, so this method was used in the calculations. Therefore, the annual usable pruning waste was calculated using Eq. 2, and the annual biochar potential was calculated using Eq. 3.

Table 2. Conversion Percentages of Dry Biomass According to Different Pyrolysis Conditions (%) (IEA 2006; Winsley 2007)

	Pyrolysis Method			
	Slow (Carbonization)	Intermediate	Fast	Gasification
Conditions	Time: Too long waiting period; Temperature: about 400 °C	Time:~10-20 s; Temperature: about 500 °C	Time: ~1 s; Temperature: about 500 °C	Time: Long waiting period; Temperature: about 800 °C
Gas	35	30	13	85
Bio-oil	30	50	75	5
Biochar	35	20	12	10

Statistical Data

To determine the potential for biochar conversion from pruning waste in Turkey, data on the number of fruit-bearing trees in the country is required. The Ministry of Agriculture and Forestry is responsible for collecting, processing, and preparing these data for publication, and the Turkish Statistical Institute is responsible for publishing these data. The data on the number of fruit-bearing trees in 2021 were obtained from the Crop Production Statistics tab in the database of the Turkish Statistical Institute. In addition, the regions' biochar potentials from sustainable pruning wastes were calculated using the pruning coefficients, admitted biomass usable ratio, biochar conversion rates, and specified equations.

RESULTS AND DISCUSSION

Biochar Potential of Pruning Wastes in Turkey

In recent years, agricultural production wastes have been one of the biomass sources contributing to renewable energy generation. Tree pruning wastes generated as a result of vegetative production activities are usually used for heating purposes in homes. In some cases, these wastes are left randomly in the area of activity. The environmental problems created by these wastes, which have economic value, can be minimized. As an organic waste, pruning waste can be converted into biochar, which offers several advantages, and it can be an alternative for obtaining environmentally friendly products. In this context, fruit trees cultivated in all regions of Turkey and pruned every 1.0 to 2 years were determined, and the biochar potential of the pruning wastes of these trees was theoretically calculated. According to the Turkish Statistical Institute data (2021), the total number of fruit-bearing trees such as almond, apple, apricot, cherry, peach, pear, plum, and sour cherry trees was 166 million. Of this total number of trees, 7.5% are almond trees, 43.5% are apple trees, 10.7% are apricot trees, 13.4% are cherry trees, 9.2% are peach trees, 6.9% are pear trees, 5.4% are plum trees, and 3.4% are sour cherry trees.

The amount of pruning waste according to the type of fruit-bearing tree was calculated with the pruning coefficient acceptances of 5.81 in almond trees and 2.34 in apple trees (Bilandzija *et al.* 2012). Accordingly, total pruning waste was estimated at 72.4 thousand tons/year for fruit-bearing almond trees and 169 thousand tons/year for fruit-bearing apple trees. The regional distribution of the pruning waste from almond trees in Turkey was 40.2% in the Southeastern Anatolia Region, 18.6% in the Aegean Region, 18.3% in the Mediterranean Region, 8.9% in the Central Anatolia Region, 7.7% in the Marmara Region, 5.3% in the Eastern Anatolia Region, and 1.0% in the Black Sea Region. Accordingly, the provinces where high amounts of almond pruning waste are expected are Adıyaman (3.2 million trees) and Şanlıurfa (0.9 million trees) in the Southeastern Anatolia Region, Manisa (0.7 million trees), and Muğla (0.5 million trees) in the Aegean Region, and Mersin (0.8 million trees) and Antalya (0.5 million trees) in the Mediterranean Region. With a percentage of 46.6%, the Central Anatolia Region ranked first among the regions where high amounts of apple tree pruning waste are expected in Turkey. According to the number of trees in this region, Karaman (10.1 million trees), Niğde (9.4 million trees), Konya (6.4 million trees), and Kayseri (4.7 million trees) are the provinces with considerable waste potential. At 28.5%, the Mediterranean Region is expected to generate the second-highest amount of pruning waste. In this region, Isparta (11.6 million trees), Antalya (4.2 million trees), Mersin (1.9 million trees), and Kahramanmaraş (1.9 million trees) are the notable provinces that generate pruning waste from apple trees. Of the estimated total pruning wastes, 7.3% were generated in the Aegean Region, 6.0% in the Marmara Region, 6.0% in the Black Sea Region, 4.5% in the Eastern Anatolia Region, and 1.1% in the Southeastern Anatolia Region. The biomass-usable percentage was 70% (Kaygusuz 2001; Lora and Andrade 2009; Sumer *et al.* 2016), and the biochar conversion was reported to be 35% (IEA 2006; Winsley 2007). In Turkey, the total biochar potential of almond tree pruning wastes was estimated as 17.7 thousand tons/year (Table 3), and the total biochar potential of apple tree pruning wastes was estimated as 41.5 thousand tons/year (Table 4).

Table 3. Biochar Potential of Pruning Waste from Almond Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	0.96	5.81	5.6	3.9	1.4
Aegean	2.33	5.81	13.5	9.5	3.3
Mediterranean	2.28	5.81	13.2	9.2	3.2
Central Anatolia	1.11	5.81	6.4	4.5	1.6
Black Sea	0.13	5.81	0.8	0.6	0.2
Eastern Anatolia	0.65	5.81	3.8	2.7	0.9
Southeastern Anatolia	5.0	5.81	29.1	20.4	7.1
Total	12.5		72.4	50.8	17.7

Table 4. Biochar Potential of Pruning Waste from Apple Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	4.35	2.34	10.2	7.1	2.5
Aegean	5.26	2.34	12.3	8.6	3.0
Mediterranean	20.6	2.34	48.2	33.7	11.8
Central Anatolia	33.7	2.34	78.9	55.2	19.3
Black Sea	4.35	2.34	10.2	7.1	2.5
Eastern Anatolia	3.24	2.34	7.6	5.3	1.9
Southeastern Anatolia	0.81	2.34	1.9	1.3	0.5
Total	72.3		169	118	41.5

In 2021, it was reported that the area of almond production lands in the USA and Spain, which are leading countries in almond production, was 534 thousand ha and 744 thousand ha, respectively, and the area of apple production lands in China and Iran, which are leading countries in apple production, was 2.09 million ha and 132 thousand ha, respectively (FAO 2021). Assuming that 2.85 thousand trees grow on a hectare of land (Cara *et al.* 2006; Dyjakon 2018), it is estimated that there may be 1.52 billion trees in the USA, 2.12 billion trees in Spain, 6.0 billion trees in China, and 0.38 billion trees in Iran.

In the calculation of pruning wastes, the pruning coefficient, which varies according to the fruit tree type, was reported to be 5.79 for apricot trees and 5.90 for cherry trees (Bilandzija *et al.* 2012). According to these acceptances, the total amount of pruning waste was estimated as 103 thousand tons/year for apricot trees and 131 thousand tons/year for cherry trees, which were among the fruit-bearing trees. Accordingly, the regional distribution of the pruning waste from fruit-bearing apricot trees was 54.0% in the Eastern Anatolia Region, 31.8% in the Mediterranean Region, 8.5% in the Central Anatolia Region, 2.6% in the Aegean Region, 1.2% in the Marmara Region, 1.0% in the Southeastern Anatolia Region, and 0.9% in the Black Sea Region. In Turkey, one of the leading countries in apricot production in the world, the highest rate of waste generation is expected in the Eastern Anatolia Region because more than half of apricot production is obtained from the provinces of Malatya (7.8 million trees) and Elazığ (1.1 million trees). This region is expected to be followed by the Mediterranean Region with the provinces of Mersin (2.2 million trees) and Kahramanmaraş (1.6 million trees). In terms of the cherry tree, it has been calculated that 37.4% of the pruning waste will be generated in the Aegean Region, 17.7% in the Central Anatolia Region, 15.4% in the Mediterranean Region, 15.3% in the Marmara Region, 9.6% in the Black Sea Region, 2.2% in the Eastern Anatolia Region, and 2.4% in the Southeastern Anatolia Region. The most waste generation is expected in the Aegean Region. The wastes to be generated in the Central Anatolia, Mediterranean, and Marmara regions are close to each other. Some provinces where a high amount of pruning waste is expected in these regions are as follows: Izmir (3.3 million trees) and Manisa (2.5 million trees) in the Aegean Region; Konya (1.9 million trees) and Niğde (0.8 million trees) in the Central Anatolia Region; Isparta (1.5 million trees) and Antalya (0.6 million trees) in the Mediterranean Region; Bursa (1.5 million trees) and Canakkale (0.5 million trees) in the Marmara Region. According to the reported biomass usable ratio (70%) and biochar conversion (35%) rates, in Turkey, the biochar potential of pruning wastes from apricot trees was calculated at 25.3 thousand tons/year (Table 5), and the biochar potential of pruning wastes from cherry trees was calculated at 32.1 thousand tons/year (Table 6). Considering other countries, in 2021, it was reported that the area of apricot production lands in Iran and China, which are leading countries in apricot production, was 60.3 thousand ha and 21.0 thousand ha, respectively, and the area of cherry production lands in the USA and Spain, which are the leading countries in cherry production, was 34.2 thousand ha and 29.5 thousand ha, respectively (FAO 2021). According to the assumption that 2.85 thousand trees grow on 1.0 ha, it is calculated that there are 0.17 billion trees in Iran, 0.06 billion trees in China, 0.1 billion trees in the USA, and 0.08 billion trees in Spain.

The total amount of pruning waste from peach trees, which are a fruit-bearing tree type, was estimated as 111 thousand tons/year, and the total amount of pruning waste from pear trees was estimated as 28.1 thousand tons/year. These figures were estimated using the reported pruning coefficients of 7.23 for peach trees and 2.45 for pear trees, as reported by Bilandzija *et al.* (2012). The regional distribution of the pruning waste from fruit-bearing peach trees was 36.9% in the Marmara Region, 29.7% in the Mediterranean Region, 21.1% in the Aegean Region, 7.1% in the Black Sea Region, 2.9% in the Central Anatolia Region, 1.6% in the Eastern Anatolia Region, and 0.7% in the Southeastern Anatolia Region.

Table 5. Biochar Potential of Pruning Waste from Apricot Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	0.21	5.79	1.2	0.8	0.3
Aegean	0.46	5.79	2.7	1.9	0.7
Mediterranean	5.67	5.79	32.8	23.0	8.1
Central Anatolia	1.51	5.79	8.7	6.1	2.1
Black Sea	0.16	5.79	0.9	0.6	0.2
Eastern Anatolia	9.61	5.79	55.6	38.9	13.6
Southeastern Anatolia	0.19	5.79	1.1	0.8	0.3
Total	17.8		103	72.1	25.3

Table 6. Biochar Potential of Pruning Waste from Cherry Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	3.38	5.90	19.9	13.9	4.9
Aegean	8.28	5.90	48.9	34.2	12.0
Mediterranean	3.42	5.90	20.2	14.1	4.9
Central Anatolia	3.93	5.90	23.2	16.2	5.7
Black Sea	2.12	5.90	12.5	8.8	3.1
Eastern Anatolia	0.49	5.90	2.9	2.0	0.7
Southeastern Anatolia	0.54	5.90	3.2	2.2	0.8
Total	22.2		131	91.4	32.1

The Marmara, Mediterranean, and Aegean Regions are expected to generate the highest percentages of pruning waste from peach trees. The provinces that are expected to generate high amounts of waste in these regions are Bursa (2.3 million trees), Canakkale (1.7 million trees), and Bilecik (0.9 million trees) in the Marmara Region, Mersin (2.9 million trees) and Antalya (0.8 million trees) in the Mediterranean Region, and Izmir (1.4 million trees), and Denizli (1.0 million trees) in the Aegean Region. The regional distribution of the pruning waste from fruit-bearing pear trees was 37.7% in the Marmara Region, 16.7% in the Mediterranean Region, 15.9% in the Black Sea Region, 11.4% in the Aegean Region, 10.4% in the Central Anatolia Region, 6.0% in the Eastern Anatolia Region, and 1.9% in the Southeastern Anatolia Region. It is expected that the maximum amount of waste will be generated in the Marmara Region, and only Bursa (3.0 million trees) will generate 69.6% of the waste in the region. This high rate will be followed by the Mediterranean region. Only Antalya (1.2 million trees) is expected to generate 64.0% of the pruning waste in this region. It has been determined that almost all provinces in the other five regions will also generate pruning waste; however, the amounts of waste generated by the provinces in the same regions will not show considerable differences. While a biomass-usable ratio of 70% was reported in the estimation of recoverable pruning waste, a biochar conversion rate of 35% was reported in the estimation of biochar potential (Kaygusuz 2001; IEA 2006; Winsley 2007; Lora and Andrade 2009; Sumer *et al.* 2016). In Turkey, the biochar potential of pruning waste from fruit-bearing peach and pear trees was estimated as 27.2 thousand tons/year and 6.9 thousand tons/year, respectively (Tables 7 and 8).

Table 7. Biochar Potential of Pruning Waste from Peach Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	5.64	7.23	40.8	28.6	10.0
Aegean	3.22	7.23	23.3	16.3	5.7
Mediterranean	4.54	7.23	32.8	23.0	8.1
Central Anatolia	0.44	7.23	3.2	2.2	0.8
Black Sea	1.10	7.23	8.0	5.6	2.0
Eastern Anatolia	0.24	7.23	1.7	1.2	0.4
Southeastern Anatolia	0.11	7.23	0.8	0.6	0.2
Total	15.3		111	77.5	27.2

Table 8. Biochar Potential of Pruning Waste from Pear Trees by Regions

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	4.33	2.45	10.6	7.4	2.6
Aegean	1.32	2.45	3.2	2.2	0.8
Mediterranean	1.92	2.45	4.7	3.3	1.2
Central Anatolia	1.19	2.45	2.9	2.0	0.7
Black Sea	1.83	2.45	4.5	3.2	1.1
Eastern Anatolia	0.70	2.45	1.7	1.2	0.4
Southeastern Anatolia	0.22	2.45	0.5	0.4	0.1
Total	11.5		28.1	19.7	6.9

Considering other leading countries of peach and pear production lands in 2021, it was reported that the areas of peach production lands in China and Spain were 825 thousand ha and 72.1 thousand ha, respectively, while the areas of pear production lands in China and Italy were 986 thousand ha and 26.8 thousand ha, respectively (FAO 2021). Assuming that 2.85 thousand trees grow on a hectare of land (Cara *et al.* 2006; Dyjakon 2018), the number of peach trees was estimated as 2.35 billion in China and 0.21 billion in Spain, while the number of pear trees was estimated as 2.81 billion in China, and 0.08 billion in Italy.

When accepting the pruning coefficient of 7.34 (Bilandzija *et al.* 2012), the pruning waste from fruit-bearing plum trees was estimated as 66.0 thousand tons/year. In contrast, assuming a pruning coefficient of 5.37 (Bilandzija *et al.* 2012), the pruning waste from fruit-bearing cherry trees was estimated as 30.4 thousand tons/year. The regional distribution of the total pruning waste from plum trees in Turkey was calculated as 32.3% in the Mediterranean Region, 20.8% in the Aegean Region, 18.5% in the Marmara Region, 13.0% in the Black Sea Region, 9.0% in the Central Anatolian Region, 4.1% in the Eastern Anatolia Region, and 2.3% in the Southeastern Anatolia Region. In Turkey, which consists of seven regions, it was determined that there would be no considerable differences between the provinces within the regions in terms of the amounts of waste generated. The regional distribution of the total pruning waste from sour cherry trees in Turkey was estimated as 38.5% in the Aegean Region, 28.2% in the Central Anatolia Region, 12.2% in the Mediterranean Region, 8.8% in the Black Sea Region, 5.8% in the Marmara Region, 5.4% in the Eastern Anatolia Region, and 1.1% in the Southeastern Anatolia Region. It is expected that the amount of waste will be high in the Aegean Region where the provinces of Afyon (1.0 million trees) and Kütahya (0.9 million trees) will account for 92.6% of the amount of waste generated in the region. It has been determined that there will be no remarkable differences between the provinces in each of the other six regions in terms of the amount of waste generated. This can be explained by each region has a different number of provinces. The biomass usable rate was reported to be 70% (Kaygusuz 2001; Lora and Andrade 2009; Sumer *et al.* 2016), and the biochar conversion was reported to be 35% (IEA 2006; Winsley 2007). As presented in Table 9, the biochar potential of pruning waste from plum trees was estimated as 16.3 thousand tons/year while the biochar potential of pruning wastes from sour cherry trees was estimated as 7.57 thousand tons/year as given in Table 10. Considering other countries, it was reported that agricultural activities were conducted in an area of 1.95 million ha for plum production in China and in an area of 26.0 thousand ha for sour cherry production in Iran (FAO 2021). According to the assumption that 2.85 thousand trees grow on a hectare of land, the number of trees in China and Iran was calculated as 5.55 billion and 0.07 billion respectively.

The amount of pruning waste varies depending on the tree species due to the pruning coefficient. If pruning waste is used, 175 thousand tons of biochar can be produced in Turkey every year according to the estimates made by considering the slow pyrolysis method in Table 2. It has been reported in the literature that biochar obtained especially at low temperatures gives a high yield. In this regard, the conversion rates of various types of lignocellulosic biomass to biochar at different temperatures are presented in Table 11. According to Table 11, biochar yield varies depending on the raw material types. Despite the high usage potential of biochar due to its various advantages, to the best of our knowledge, there is only one continuous-feed biochar production process in Turkey. In this process, vineyard and pruning wastes are converted to biochar via the pyrolysis process at 500 °C in approximately 90 min with MSE Furnace Biochar S650_F850 (Turkey) device. It has been reported that the obtained biochar contributes remarkably to the reduction of environmental problems because of its various advantages. It has been reported that this process is conducted by Izmir Metropolitan Municipality, and it has a monthly biochar production capacity of 15 tons (Biochar from Garden Waste 2022). Considering the waste management in Turkey, the number of medium- and large-scale biochar production sites should be increased for efficient waste usage based on the pyrolysis process. Because large amounts of pruning waste are usually generated in fruit-growing countries, it is recommended that the planned environmentally friendly investments also cover biochar technologies.

Table 9. Biochar Potential of Pruning Waste from Plum Trees by Region

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	1.66	7.34	12.2	8.5	3.0
Aegean	1.87	7.34	13.7	9.6	3.4
Mediterranean	2.91	7.34	21.4	15.0	5.3
Central Anatolia	0.81	7.34	5.9	4.1	1.4
Black Sea	1.17	7.34	8.6	6.0	2.1
Eastern Anatolia	0.37	7.34	2.7	1.9	0.7
Southeastern Anatolia	0.21	7.34	1.5	1.1	0.4
Total	9.0		66.0	46.2	16.3

Table 10. Biochar Potential of Pruning Waste from Sour Cherry Trees by Region

Regions	Number of Fruit-bearing Trees (million)	Pruning Coefficient (kg/tree.year)	Pruning Waste (thousand ton/year)	Usable Pruning Waste (thousand ton/year)	Biochar Potential (thousand ton/year)
Marmara	0.33	5.37	1.8	1.3	0.5
Aegean	2.18	5.37	11.7	8.2	2.9
Mediterranean	0.69	5.37	3.7	2.6	0.9
Central Anatolia	1.59	5.37	8.5	6.0	2.1
Black Sea	0.50	5.37	2.7	1.9	0.7
Eastern Anatolia	0.31	5.37	1.7	1.2	0.4
Southeastern Anatolia	0.06	5.37	0.3	0.2	0.07
Total	5.66		30.4	21.4	7.57

Table 11. Conversion Rates of Lignocellulosic Biomass to Biochar at Different Temperatures

Feedstock	Pyrolysis temperature (ºC)	Yield (%)	References
Apple wood	300	60.4	Kinney *et al.* (2012)
	400	33.5	
	500	28.2	
	600	25.0	
	700	22.6	
Japanese cedar	400	41	Kameyama *et al.* (2019)
	600	28	
	800	22	
Japanese cypress	400	39	
	600	28	
	800	23	
Moso bamboo	400	28	
	600	28	
	800	25	
Wood	300	45.0-48.3	Huang *et al.* (2021)
	600	23.7-28.0	
Rubber-wood (*Hevea brasilensis*) sawdust	450	41.86	Ghani *et al.* (2013)
	550	37.16	
	650	32.78	
	750	30.96	
	850	28.90	

Biochar Production by Using Wastes

In recent years, many regions in the world have focused on converting agricultural production wastes into useful products. Within the scope of processing and disposal of these wastes according to their characteristics, various decisions can be made for biomass conversion technologies. In biological conversion, wastes with minimal lignin content are preferred to obtain easy decomposition at low temperatures, and the end products include biogas and useful alcohols. In thermochemical conversion, lignocellulosic biomass wastes are preferred. With gasification, H_2, CH_4, CO_2, and trace amounts of other gases are obtained, and with pyrolysis, biochar and bio-oil are obtained. It has been reported that the end products have different usage areas and have the potential to replace existing traditional energy sources (Gupta and Mondal 2020). Various studies have been conducted throughout the world for the processing and disposal of agricultural waste. One study in this regard reported that microorganisms contributed remarkably to the degradation and recycling of agricultural waste. The recycling of agricultural residues and wastes provides benefits that can reduce environmental problems and increase soil biodiversity and agricultural productivity. In this regard, fungi and bacteria have been confirmed to improve the degradation process. The individual and unique functions of microorganisms in the degradation and decomposition of agricultural residues/wastes have made them a priority (Mir *et al.* 2022). Nguyen and Hoang (2020) estimated that approximately 4.5 Mt of corn, 17 to 18 Mt of sugarcane, and 37 Mt of rice were produced annually in Vietnam, thus generating a total of more than 50 Mt of waste from agricultural activity. The authors also reported that significant amounts of straw from the rice-growing activity were burned in the area where the activity takes place. Microorganisms were used in the study, and the study suggested the use of groups of microorganisms capable of degrading agricultural wastes as a potential solution to reduce incineration and use straw containing essential nutrients (nitrogen, phosphorus, potassium) as compost (Nguyen and Hoang 2020). Treatment of agricultural wastes with chemical solutions (such as NaOH, NH_4OH, and polyethylene glycol) and enzymes breaks the bonds between lignocellulosic (hemicellulose, lignin) components (Vadiveloo *et al.* 2009; Simeonov *et al.* 2017; Dereszewska and Cytawa 2019). A study in which pre-treatment was applied to lignocellulosic materials investigated the usability of cellulase obtained from *Streptomyces* species. The study examined the ability of *Streptomyces* sp. CC48 strain to hydrolyze corn and wheat substrates. The study demonstrated the potential of these bacteria to hydrolyze agricultural waste (Celaya-Herrera *et al.* 2021). In another study, agricultural wastes (grass, straw, sawdust), which are raw materials, were pretreated for the purpose of biogas production, using commercial preparations together with enzymes or cellulolytic enzymes obtained from moldy bread (Dereszewska and Cytawa 2019). Research of the literature has shown that agricultural wastes can be converted into useful products mainly by anaerobic digestion and pretreatment. In Turkey, progress has been made in the treatment and disposal of many wastes in general, such as waste vegetable oils, packaging waste, and end-of-life tires. However, the use of agricultural production waste as a resource is currently limited.

Resource recovery from solid waste provides remarkable sustainability and economic benefits. Resource recovery solves the problem of increasing amounts of waste and also eliminates the need for raw materials for biochar production (Adenaike and Omotosho 2020). For this, technologies can be utilized in combination with each other. A study conducted in this context combined anaerobic digestion and pyrolysis technologies. The study examined the application of biochar to the soil to recycle digested nutrients, reduce chemical fertilizers, and improve soil quality. The authors found that the addition of biochar improved soil quality and stated that enriched biochar could partially replace chemical fertilizers. They also reported that combined technologies could double the recoverable energy from recycling and value-added use of agricultural wastes or residues (Kizito *et al.* 2019). For resource recovery, agricultural production waste is rich in organic compounds and energy. For the appropriate reuse and recovery of these economically valuable components, a global approach, starting with a circular economy policy, should be developed with the involvement of the private sector in many agricultural countries, including Turkey.

A study examining the potential of Turkey's hydroelectric and biomass energy resources stated that 70% of the total biomass was usable (Kaygusuz 2001). The biomass usable rate was therefore accepted as 70% in the study. The study determined that Southeastern Anatolia Region had the highest biochar potential from almond tree pruning waste (7.1 thousand tons/year). This region is expected to contribute 40.2% to the biochar potential of almond tree pruning waste. It has been determined that the highest biochar potential of apple tree pruning waste belongs to the Central Anatolia Region (19.3 thousand tons/year) with a rate of 46.6%, followed by the Mediterranean Region (11.8 thousand tons/year). In 2021, it was reported that the apricot production area was 856 thousand decares in Malatya, 102 thousand decares in Elazığ, and 1.35 million decares in the whole country (Turkish Statistical Institute 2021). Accordingly, it is expected that more than half of the biochar potential of apricot tree pruning wastes will belong to the Eastern Anatolia Region due to the provinces of Malatya (856 thousand decares) and Elazığ (102 thousand decares). The trees with the highest pruning waste biochar potential in the regions were estimated as follows: 10.0 thousand tons/year in peach trees and 2.6 thousand tons/year in pear trees in the Marmara Region; 12.0 thousand tons/year in the cherry tree and 2.9

thousand tons/year in the sour cherry tree in the Aegean Region; 5.3 thousand tons/year in the plum tree in the Mediterranean Region. There is a limited number of studies on biochar in Turkey. One of these studies estimated that Turkey's biochar conversion potential from agricultural and animal production wastes was 3.94 million tons in 2015. Of this conversion potential, 0.6% was generated by agricultural waste, 22.5% by garden and vineyard pruning waste, and 77% by animal waste (Sumer *et al.* 2016). The pruning coefficients used by Sumer *et al.* (2016) were also used in this study. In addition, studies examining the biochar conversion potential of agricultural and animal wastes on a provincial basis in Turkey calculated the annual total potential of Malatya as 44.1 thousand tons (Dursun 2020) and the annual total potential of Isparta as 42.9 thousand tons (Kumaş *et al.* 2021).

In Turkey, the zero-waste project launched in 2017 encouraged considerable progress in the treatment and recycling of waste in every region. Electricity is produced from waste in every region of Turkey. For example, in the Southeastern Anatolia Region, a Mechanical Biological Separation Facility was established within the Gaziantep Metropolitan Municipality (Gaziantep, Turkey). In the facility, it is ensured that recyclable wastes contribute to the economy. In the provinces of Diyarbakir and Mardin in the Southeastern Anatolia Region, vegetable and fruit waste from market wastes are converted into compost.

Therefore, waste projects, such as the separation, collection, recovery, and disposal of plastic, glass, paper, and metal wastes, are meticulously carried out and with importance in Turkey. In recent years, studies on the pyrolysis of wastes have gained momentum. The first important step regarding the pyrolysis of waste in the public sector in Turkey was taken by the Karabuk Municipality (Karabuk, Turkey) in 2020 with the use of plastic waste. In this context, plastic wastes collected from industrial facilities and streets are made into grains in the granulator unit and sent to the pyrolysis reactor. In this reactor, plastic waste, which is one of the world environmental problems, is thermally decomposed at 450 to 500 °C, without the release of harmful gases to the environment. As a result, products such as pyrolytic oil, syngas, and carbon black are obtained (Municipality of Karabuk 2020). In addition, two private sector businesses partake in the pyrolysis of plastic waste. The businesses operate in the provinces of Kayseri and Erzincan. For the pyrolysis of pruning waste, the public sector in Turkey has only one continuous feed biochar production process. In this process, vineyard, garden, and pruning wastes are converted into biochar by the pyrolysis process at 500 °C, and it has been reported that the obtained biochar contributes greatly to reducing environmental problems. It has been reported that this process belongs to the Izmir Metropolitan Municipality and has a biochar production capacity of 15 tons per month (Biochar from Garden Waste 2022). The steps towards the pyrolysis of wastes in Turkey are fairly recent.

The management of waste generated as a result of agricultural activities is important for environmentalist agricultural practices and economic value. In this context, the data of almond, apple, apricot, cherry, peach, pear, plum, and sour cherry trees grown and pruned in every region in Turkey, which consists of seven geographical regions (total 81 provinces), were obtained from the Turkish Statistical Institute, and the amount of pruning waste was estimated. To the author's knowledge, there is no study in the literature regarding the regional estimation of Turkey's pruning waste biochar potential, so the biochar potential of pruning wastes was estimated in the study. Pruning waste biochar potential was analyzed separately for each region considering the type, number, and biochar conversion potential of fruit trees. This study is expected to contribute to future research in the field of biochar and the establishment of biochar plants on a regional basis.

Practical Implications and Future Research

The data considered in this study offer practical applications worth studying in the future. In the field of biochar, country-specific analysis of the practical applications of various recyclable wastes has a large impact on new research streams, such as the sustainable management of waste, its viability, and the circular economy. In this regard, it will be valuable to examine the production of biochar from pruning waste, which is categories as agricultural waste, and its contribution to the solution of environmental problems. Moreover, biochar can be produced from pruning wastes at different pyrolysis temperatures and durations, and the obtained biochar can be used in various fields through optimization studies. In addition to the practical applications presented, the study also offers implications for future research on raw materials in biochar production. These implications could help elucidate, rather than the number of fruit trees, the potential for pruning wastes, usable pruning wastes, and their biochar.

Using agricultural waste or residues as raw materials can reduce the gap between energy supply and demand in the future. These wastes/residues can be researched and developed for energy and product recovery to be used in various technologies and perspectives. New sectors can be developed for the appropriate management and use of lignocellulosic waste, in particular. Thus, new income streams can be created, and a circular economy can be achieved. To achieve sustainable and economical waste management, various types of waste should be evaluated, and optimization studies should be completed on the biochar obtained from waste according to the intended use. Although the study extensively discusses the use of waste from various perspectives, waste is fraught with numerous research opportunities due to progress and developments in biochar production. Furthermore, combining the research on biochar obtained from waste with other related research areas, such as water and wastewater treatment, soil conditioning, and improving food safety, can enable broader research.

CONCLUSIONS

1. Global problems can be reduced with environmentally friendly agricultural practices and using biochar focused on sustainable waste management. Turkey's biochar potential of pruning wastes from fruit-bearing trees, such as almond, apple, apricot, cherry, peach, pear, plum, and sour cherry trees, was estimated by region, based on the number of fruiting trees. Accordingly, Southeastern Anatolia Region has the highest biochar potential (7.1 thousand tons/year) with the pruning waste from almond trees. The region is expected to contribute 40.2% to the biochar potential of almond tree pruning waste. In contrast, it was determined that the highest biochar potential of apple tree pruning waste belonged to the Central Anatolia Region (19.3 thousand tons/year) with a rate of 46.6%, followed by the Mediterranean Region with 11.8 thousand tons/year.
2. Turkey's total apricot production area is 1.35 million decares. Accordingly, it is expected that more than half of the biochar potential of apricot tree pruning wastes will belong to the Eastern Anatolia Region due to the provinces of Malatya (856 thousand decares) and Elazığ (102 thousand decares).
3. The trees with the highest pruning waste biochar potential in the regions were estimated as follows: 10.0 thousand tons/year in peach trees and 2.6 thousand tons/year in pear

trees in the Marmara Region; 12.0 thousand tons/year in the cherry tree and 2.9 thousand tons/year in the sour cherry tree in the Aegean Region; 5.3 thousand tons/year in the plum tree in the Mediterranean Region. Regarding the regions, it was determined that apple tree pruning wastes in the Central Anatolia Region had the highest biochar potential with 19.3 thousand tons. It was followed by the Eastern Anatolia Region with 13.6 thousand tons of biochar potential of apricot trees. The highest amount of pruning waste is expected from the apple tree, and the total biochar potential of apple tree pruning waste was surmised as 41.5 thousand tons/year.

4. Overall, the total biochar potential of pruning wastes of fruit-bearing trees in Turkey in 2021 was estimated at 175 thousand tons.

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