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The Importance of Linden (*Tilia sp.*) in terms of Carbon Sequestration: Perspective in the World and in Türkiye

Özlem Ağırman Han*✉, *Ali Ömer Üçler

Karadeniz Technical University Faculty of Forestry, Trabzon/TÜRKİYE

✉***Correspondence***: ozlemm.a@hotmail.com.tr

Abstract: Carbon emission is increasing in the world due to exponential growing of population, excessive usage of natural resources which resulted with environmental pollution and decline in biodiversity. Carbon emission as a result of greenhouse gases and carbon dioxide rising is the main reason of climate change and global warming. Reducing the amount of CO_2 and greenhouse gases released into the atmosphere; is possible by increasing the use of vegetative mass, limit emissions, and increasing the amount of carbon in carbon pools (ocean, soil, vegetation, etc.). In forest ecosystem the soil, biomass and water have essential roles in carbon deposition that is the basic element of carbon dioxide. Since trees have the capacity of storing CO_2 via photosynthesis, they execute important functions for the formation of important sinks by deposition of carbon in plant biomass and under the soil. To reduce the amount of carbon emissions in cities, afforestation is made on the roadsides from tree species that deposit exhaust gases and are resistant to difficult conditions. Lindens are trees that have resistance against, winds air pollution and poor quality soils, also tolerant for variable climate conditions, and sensitive for frost and drought. In literature there exists not enough studies that examines carbon sequestration and storage capacity of lindens while there exist some other papers regarding other species such as scotch pine, larch, red pine, cedar, and poplar. In this study we aimed to investigate the possible role of lindens used for arborization of cities for carbon sequestration and storage. This review, in which various articles were discussed, will be informative for those who are interested in the subject.

Keywords: Linden, *Tilia sp.*, Carbon, Global climate change, Urban trees.

1. INTRODUCTION

Forests are a union containing woody and herbaceous plants, moss, ferns, fungi, microorganisms and fauna, which can create a unique microclimate and exist in a composition and proportion (Aytuğ, 1976).

The increase in the population of countries and the world increases the stress on forest areas, and as a result, forests are disappearing. The world's forest assets, which were reported to be 8 billion hectares in 2000 B.C. have begun to decrease rapidly. According to the latest data, world forest assets have decreased to 3.2 billion hectares (URL-1, 2021). 29% of Türkiye's surface area is covered with forest areas (OGM, 2020). While the productivity area rate of our country's forests is around 44% the productivity rate of the world's forests is over 70% (Tuncer & Kaya, 2010).

FAO defines deforestation as the opening of forests to long-term land uses such as pasture, agriculture and settlement, or their closure falling below 10% (FAO, 2005). Large areas of forest are lost every year due to changes in climate and meteorological conditions brought about by deforestation, poor air quality and decrease in biodiversity (Ayoo, 2022). When deforestation and climate change are examined together, a global environmental problem emerges (Ak et al., 2021). For this reason, important research is being carried out on the protection and development of forests in our country (Karakaya & Sofuoğlu, 2015).

Global climate change emerged as a result of the increase in greenhouse gas emissions after the industrial revolution (Lal, 2008; IPCC, 2014). Destruction of terrestrial sink areas as a result of incorrect and excessive land use is another cause of climate change. Forests are considered as the most important terrestrial carbon sink areas worldwide (FAO, 2016). Forests, which hold 76-78% of the organic carbon in the terrestrial ecosystem (Borucu, 2014), store large amounts of carbon and play an important role in combating climate change (IPCC, 2007; Miles & Kapos, 2008; Güner & Makineci, 2017). Although our country has a low share in the total CO_2 emissions in the world (Karakaya & Sofuoğlu, 2015), many studies are carried out on the protection and development of sink areas, adaptation and reduction in accordance with its international agreements (Türkeş, 2008).

Approaches to the management of urban green areas in planning and design processes in terms of exposure and sensitivity to the negative effects of global climate change in urban areas are clearly expressed within the Intergovernmental Panel on Climate Change (IPCC) and UN 2030 Agenda Sustainable Development Goals reports (Sturiale & Scuderi, 2019). Urban green areas support biodiversity and have positive effects such as improving air quality, water and soil, reducing noise, and improving microclimate conditions (Angold et al., 2006; Barbosa et al., 2007; Jorgensen et al., 2002). With all these positive aspects, urban green areas are useful for strategies to be developed to combat the negative effects of global climate change and to increase the resilience of urban areas in different aspects (Scarlett & Boyd, 2015).

Today, the places where carbon emissions are highest are cities and, accordingly, areas that have a negative impact on the climate. Therefore, urban forestry is one of the important green infrastructure systems that can be used to reduce the negative effects on the climate (Yılmaz et al., 2006).

Urban forests, which have an important place in improving the air quality of the city, absorb aerosols and particles from pollutant sources around the city by holding them on their leaf surfaces and prevent urban air pollution (Keller, 1979). Research on the transport of airborne pollutants through vegetation has shown that plants are very effective in eliminating air pollution. For this reason, vegetation acts as a natural filter in improving air quality (Öner et al., 2007).

One of the most important action strategies regarding global warming and climate change in developed countries is the storage of CO_2 within the forest ecosystem (soil, plants and litter). This strategy is defined as carbon sequestration. Urban trees and urban forests have an important role in reducing CO_2 emissions and storing carbon in cities. Therefore, as in developed countries, it is aimed to establish an urban forest in every city or to increase the number of trees in urban areas in our country. Urban afforestation aims to prevent air and noise pollution and improve the urban climate.

Linden species are species that are resistant to wind and air pollution and poor soils within the Fagetum zone (Rajendra, 2009; Pigott, 2012). With these features, they are forest trees that can be tolerant to changing climatic conditions. This study aimed to evaluate the importance and usability of linden used in urban afforestation in terms of carbon storage.

2. GENERAL INFORMATION ABOUT LIDEN (*TILIA sp.*) AND ITS ROLE IN TERMS OF CARBON STORAGE

Linden (*Tilia sp.*), which has 4 species in our country, has around 30 species in the northern hemisphere, including Northeastern America, Europe and Asia (Radoglou et al., 2009). The general distribution of some species of linden tree is as follows: *Tilia platyphyllos* and *Tilia cordata* are common in Europe, *Tilia tomentosa* in the Balkans, *Tilia sibirica* in Siberia and Asia, and *Tilia rubra* in Anatolia, the Caucasus and Northern Iran (Boratynska & Dalatowski, 1991). Linden species growing in Türkiye are *Tilia tomentosa* Moench., *T. plathyphyllos* Scope., *T. rubra* DC. and *Tilia cordata* Mill (Oral, 2013). They are narrow-topped trees that can grow up to 30-40 m and shed their leaves in summer (Oral, 2014). Linden species are not found as pure stands in the forests where they naturally spread, but rather as individual trees or in clusters (Alan et al., 2018).

The flowers of Tilia species (*Tilia cordata* Mill. and *Tilia platyphyllos* Scop.) used for medicinal purposes contain sugar, gum, fixed oil, mucilage and tannin. The ashes of Linden (Tilia) contain manganese, the oil compound in its flowers contains parnesol, and its leaves contain a glycoside called Tiliacin. In addition to being good for diseases such as colds and flu, intestinal diseases, ulcers and constipation, linden also prevents vascular occlusion and hypertension (Tuttu et al., 2017). Its flowers are boiled and consumed as tea (Mamıkoğlu, 2015). It is known that non-wood products are not only leaves and flowers, but also linden tree bark and linden flower water are considered non-wood products. However, it is known that linden flower oil (Parlak et al., 2019) is used for production, and the leaves are also pruned and used as cow feed (Turna, 2001). It is also used in various areas in the furniture industry (URL-2, 2019). Even though it is rarely found in forests, it is preferred as an ornamental tree in parks and gardens.

Urban green spaces have ecosystem characteristics that are fundamental to the provision of ecosystem services, as they retain carbon and nutrients and act as reservoirs for organic matter. While it is known that urban vegetation affects the physico-chemical properties of the soil, it is not known whether ecosystem properties depend on the type of plant used.

Setälä et al. (2016) in the cities of Helsinki and Lahti, they included young parks of different ages (7-15 years), medium parks (about 50 ± 10 years) and old parks (>100 years old, the oldest of which were established more than two centuries ago), 41 city parks and control forests. Three common functional plant groups in parks in terms of their ability to amend soil (evergreen trees; Norway spruce (*Picea abies*), deciduous trees; Linden [*Tilia × vulgaris*] and grass species mostly Poa and Festuca species, with scattered plants such as *Trifolium pratence* and *Plantago major*) and included control forests. In addition, Norway maple (*Acer platanoides* L) was chosen instead of linden in two parks in Lahti and one park in Helsinki, and spruce was chosen instead of Scots pine (*Pinus sylvestris* L) in three parks in Helsinki. The sizes of the parks vary between 0.1 ha and 1 ha. In the city of Lahti, parks of three age groups are randomly distributed throughout the city, while in Helsinki the oldest parks were chosen closer to the urban core than parks of the other two age groups. Five non-grass mature (>60 years old) mixed control forests, several hectares in size, dominated by Norway spruce and small-leaved lime (*Tilia cordata*) near the city of Lahti, were also included in the study. As a result of their study, they showed that the soil has a significant capacity to store N and C even without frequent fertilization and irrigation, that Norway spruce (*Picea abies*) is particularly important in terms of soil properties compared to Linden [*Tilia × vulgaris*] and that Norway spruce (*Picea abies*). They found that old parks which are effective in changing park soil.

In a study examining the inter- and intra-specific variations of carbon in biomass tissues for 10 temperate tree species in Northeast China, it was found that the average amount of carbon for the species varied from 47.1% in the fine roots to 51.4% in the leaves. While the average root carbon amount of 10 species was found to be 49 ± 1.3% (mean ± sd), the average carbon concentration for the species was; Amur cork tree (55.1%) > Amur linden (53.9%) > Korean pine (53.2%) > Manchurian ash (52.9%) > Manchurian walnut (52.4%) > Mongolian oak (47.6%) > Dahurian larch (46.9%) > Mono maple (46.4%) > white birch (46.1%) > aspen (43.7%). Carbon concentration for *Tilia amurensis* Rupr. (Amur linden) species was found to be 55.7% in the leaf, 53.1% in young branches, 53.7% in old branches, 54.3% in stem, 52.7% in thick root, and 50% in thin root. Species weighted average carbon concentration was negatively correlated with average annual biomass increase; found that planting fast-growing tree species for C sequestration in these afforestation and reforestation practices sacrificed some C gain from the increased annual biomass increase due to decreasing C (Zhang et al., 2009).

In their study, Moser et al. (2015) characterized the sizes of two urban tree species (small-leafed lime, *Tilia cordata* Mill. and black carob, *Robinia pseudoacacia* L.) and predicted their future structural sizes based on trunk height diameter and tree age. The data obtained revealed strong relationships for both tree species between crown dimensions (diameter, volume, projection area, height), tree pit and tree height of *T. cordata*. 3 ecosystem properties (cooling, shading, carbon storage) were estimated based on the leaf area index and tree dimensions. As a result of this estimation it was revealed that urban trees significantly improved the city climate. And also a significant relationship was found between carbon storage, shading and cooling of single trees and leaf area index and age of these trees. In the same study, for the *Tilia cordata* Mill. it has been observed that the amount of carbon storage increases in direct proportion to age.

In a study investigating the carbon storage potential of two tree species (*Tilia × vulgaris*, *Alnus glutinosa*) growing in three different growth environments considering urban conditions in Helsinki, measurements were made using an urban land surface model SUEWS (Surface Urban Energy and Water Balance Scheme) and soil to simulate carbon sequestration. The carbon model was evaluated with Yasso15. Yasso 15 measured at temporal scales (daily, monthly and yearly). While SUEWS provides information about the urban microclimate and photosynthesis and respiration of street trees, the amount of soil carbon storage was measured with Yasso 15. Models were used to examine the urban carbon cycle over the expected lifespan of the species (2002-2031). The annual amount of carbon taken per tree for the Tilia region varied between 3.55 and 13.44 kg C, while for the Alnus region it was measured between 2.68 and 10.73 kg C. During the 30-year period, 1.0 and 4.3 kg C per square meter were stored in the leaves of Tilia and Alnus trees, respectively. Cumulatively over a 30-year period, species sequestered 172 and 156 kg C per tree in the Tilia and Alnus regions, respectively (Havu et al., 2022).

Table 1. Amount of carbon in studies conducted.

Researcher	Tree Type	Branch (%)	Leaf (%)	Trunk (%)	Shell (%)
Güner and Makineci (2017)	Quercus L.	49	49	49	48
Ritson and Sochacki (2003)	*Pinus pinaster*	56.6	-	49.7	-
Zhang et al. (2009)	*Tilia amurensis* Rupr.	53.7	55.7	-	-
Kanlı (2022)	Fraxinus L.	52.79	53.28	58.25	63.51

In their study with *Pinus sylvestris* Laiho and Laine (1997) measured the amount of carbon storage as 53.1% in the branch, 53.8% in the leaf, 51.8% in the trunk and 53.2% in the shell.

In their study Güner and Makineci (2017) determined the carbon storage amounts of Quercus L. species as 49% in the branch, 49% in the leaf, 49% in the trunk and 48% in the shell.

Ritson and Sochacki (2003) found carbon storage amounts in *Pinus pinaster* species to be 50.6% live branches and leaves and 48.1% in the roots.

In his study Kanlı (2022) measured the carbon storage amounts of Fraxinus L. species as 52.79% in the branch, 53.28% in the leaf, 58.25% in the trunk and 63.5% in the shell.

3. USE OF LIDEN (*TILIA sp.*) IN URBAN AFFORESTATION

The species to be brought to cities from forests, which are their main habitat, should be resistant to air pollution and pests, have a deep root system, are long-lived and able to grow quickly, and have an aesthetic appearance that do not produce roots and stumps (Alptekin, 1997).

In arid and semi-arid cities, tree species that have developed a mechanism to reduce transpiration, are resistant to drought conditions, are evergreen, contented, have a tap root system, and have visual and functional effects should be preferred. The tree species to be chosen for the afforestation of these cities, in addition to their aesthetic appearance, must have developed a mechanism to absorb water and to minimize the loss of water through transpiration. For example, ash-leaved maple (*Acer negundo* L.) and other maple species, white-flowered false acacia (*Robinia pseudoacacia* L.), linden (*Tilia argentea* Desf.), common ash (*Fraxinus excelsior* L.) provided that it is suitable for the urban habitat conditions, etc. The species are suitable for use in road afforestation (Gezer & Gül, 2009).

It has been determined through research that large and small-leaved linden (*Tilia platyphyllos* Scop., *T. tomentosa*) species provide biological success in many cities with semi-arid climate conditions, especially in the Central and Southeastern Anatolia regions, the Mediterranean and Black Sea regions, where periodic droughts occur (Gezer & Gül, 2009).

Tilia tomentosa Moench is resistant to air pollution, drought, cold and frost and is one of the species used in urban area afforestation such as residential gardens, parks, industrial facilities, squares, hospitals, road afforestation, median pavement (median), urban forest, urban grove and cemeteries (Gezer & Gül, 2009).

The most appropriate size for road trees to reach is; It should be considered according to the width, class and quality of pedestrian and vehicle roads, the density of traffic, and the condition of the structures in the immediate vicinity, and appropriate types should be selected. Medium-crowned broad-leaved silvery linden (*Tilia tomentosa* Moench.) should be preferred for normal-width streets, while large-leaved linden (*Tilia platyphilla* Scop.) should be preferred for very wide streets (Gezer & Gül, 2009).

4. CONCLUSION

Studies on carbon storage due to the development and growth of linden used in urban afforestation over time are limited in Türkiye. As seen in the research, *Tilia sp.* is found in the same population with other species of studies have been conducted on the amount of carbon storage in species. *Tilia sp.* Within the scope of using the species in urban areas in urban forestry studies, it would be appropriate to make sustainable plans in line with the scientific and technical principles and to carry out studies in forests and urban green areas where the linden population is dominant, in order to measure the amount of carbon storage in a healthy way. In urban afforestation areas, species that tend to grow slower in terms of carbon sequestration should be preferred rather than species that grow rapidly. Species that tend to overwinter show lower performance in terms of carbon sequestration. Sustainable management of afforestation areas should be considered and planned from a perspective that supports the tendency of trees in urban living areas to become carbon sinks rather than their overgrowth tendency and their impact on visual quality. In this context, when choosing species, species with a low tendency to overgrowth should be selected or afforestation areas should be arranged at a frequency that eliminates the tendency towards overgrowth.

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