Linden Plantations in the Volga Region and Azerbaijan: (Characteristics of Establishment, Morphology and Utilisation)

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Abstract

This article presents a comparative ecological and silvicultural analysis of linden stands (genus *Tilia L.*) in the Volga region and the mountain forest ecosystems of the Greater Caucasus (Azerbaijan). This paper summarises the characteristics of the spatial distribution, species composition, morphometric parameters, and ecological and biological properties of the small-leaved lime (*Tilia cordata Mill.*) and the Caucasian lime (*Tilia caucasica Rupr.*). This study analyses the multi-purpose resource potential, forestry significance, and environmental functions of the lime tree in lowland and mountain forests.

Keywords: Tilia cordata, Tilia caucasica, the Greater Caucasus, the Volga region, biodiversity, mountain forests, comparative analysis

1.Introduction

1.1. Distribution of linden plantations

The lime tree is one of the valuable broad-leaved tree species that are of great importance to forest ecosystems, forestry, landscaping, and various areas of commercial use. Species of the genus *Tilia* are characterised by their longevity, well-developed crowns, high ornamental value, and the valuable properties of their timber. Furthermore, the lime tree is an important honey plant and plays a significant role in maintaining the biodiversity of forest communities. (Mamadjanov et al., 2019).

Linden trees are widely found in the forests of Eastern Europe, including the Volga region. Here, the small-leaved lime (*Tilia cordata*) is a characteristic component of broad-leaved and mixed forests, particularly oak-lime stands. It is capable of forming a significant proportion of the tree stand and growing successfully alongside oak, maple, ash, elm, and other broad-leaved species (Zykov et al.,2022). (Figure 1)



Figure 1. *A lime tree growing in open countryside.*

In Azerbaijan, the distribution of lime trees is more localised. Natural populations are found predominantly in the mountain forest ecosystems of the Greater Caucasus. The most characteristic species found here is the Caucasian lime (*Tilia caucasica*). Studies carried out in the forests of the Greater Caucasus within Azerbaijan have revealed the presence of the Caucasian lime in the Ismayilli, Sheki and Zakatal districts, as well as its co-occurrence with the small-leaved lime in the Guba and Gusar districts (Efendieva & Novruzov, 2021; Efendieva & Novruzov, 2020).

It is clear from the above that the linden tree has different patterns of distribution in the two regions under consideration. In the Volga region, it is a common component of broad-leaved forests, whereas in Azerbaijan its natural range is predominantly confined to the mountain forests of the Greater Caucasus. At the same time, in both regions, the lime tree is of considerable interest as a forest-forming, ecologically valuable and multi-purpose tree species.

1.2. Characteristics of the establishment of lime tree plantations

The formation of lime tree stands is determined by a combination of climatic, soil, hydrological and topographical conditions. In the Volga region, the lime tree is a common component of broad-leaved forests. Oak-lime forests are particularly characteristic, with lime trees sometimes occupying a significant proportion of the upper or second tree layer. (Seidafarov, 2012; De Jaegere et al., 2016). The Middle Volga region is characterised by forest communities comprising oak, small-leaved lime, maple, ash and elm. The lime tree adapts well to the conditions of the forest community and is capable of surviving for long periods under the canopy of other tree species.

In Azerbaijan, the natural distribution of the lime tree is mainly associated with the forests of the Greater Caucasus. In the Ismailli, Zakatali and Sheki districts, the natural populations consist mainly of Caucasian lime trees. In the Gubinsky and Gusarsky districts, Caucasian lime and small-leaved lime are found growing together. The differences between regions are primarily due to natural conditions. The Volga region is characterised by a predominantly flat and gently undulating landscape and extensive areas of broad-leaved forests. In Azerbaijan, the distribution of lime trees is more closely linked to the mountainous terrain, altitudinal zonation, slope aspect, and the characteristics of the local microclimate. (Martynova et al., 2026; Afandiyeva & Novruzov, 2020).

1.3. Species composition of lime tree plantations

Species composition is of great importance in forestry, as different species of lime tree may differ in their morphological characteristics, ecological requirements, and distribution patterns. In this regard, the extent to which the species composition of lime plantations found in the Volga region and the Greater

Caucasus has been studied is of great importance in determining the current status of these populations (Zykov et al., 2022).

In the Volga region, the main species of the genus *Tilia* is the small-leaved lime (*Tilia cordata*). It is one of the region's characteristic broad-leaved tree species and plays a part in the formation of mixed and structurally complex forest stands.

In Azerbaijan, the main native species is the Caucasian lime (*Tilia caucasica*). It is widespread in the forest ecosystems of the Greater Caucasus and is particularly characteristic of mountainous areas. Small-leaved lime is also found in the northern part of Azerbaijan. (Radoglou et al., 2009; Eaton et al., 2016). In forestry, the lime tree is significant as a companion species in mixed forests. Its presence influences the structure of the forest stand, the formation of storeys and the ecological conditions within the forest community.

1.4. The use of linden resources and linden plantations

The lime tree has a long history of being used for practical purposes. Due to its softness, uniform texture, and ease of working, this wood has long been used to make household items, furniture, interior fittings, and decorative and applied art objects. Linden wood is characterised by its light colour, relatively low density, softness, and uniform texture. It can be easily worked with both hand tools and power tools, which is why it is widely used in situations where a smooth surface or a complex shape is required (Pigott & Huntley, 1978). Linden is used to make furniture and decorative items; artistic woodcarving holds a special place amongst these, as the soft and uniform grain of linden wood is particularly well-suited to this craft.

The bark and the bast of the tree are of particular importance. Traditionally, the bast was used to make ropes, bast fiber, wickerwork, and other items. This use was particularly widespread in traditional agriculture and reflected the versatile nature of the lime tree as a forest resource. The bark and bast also have practical uses. In the past, they were widely used to produce fibrous material. At present, this kind of use is predominantly of a traditional and historical-cultural nature.

The flowers of the lime tree are also of great significance. Thanks to its profuse flowering and the presence of nectar, the lime tree is considered a valuable honey-producing tree species. Its purpose therefore extends far beyond the production of timber. As well as timber, lime tree plantations are valuable for their non-timber resources. The best-known use is in beekeeping. During the flowering season, the lime tree becomes an important source of nectar and pollen for pollinating insects. It is therefore appropriate to regard the linden as a multi-purpose forest species, combining timber, non-timber, ecological and honey-producing functions.

2. Results and Discussion

2.1. The structure of lime trees and lime tree plantations

Linden trees are large deciduous trees with a well-developed trunk and a broad crown. Under favourable conditions, they are capable of reaching considerable sizes and persisting within forest communities for a long time. In the Volga region, the small-leaved lime typically reaches heights of around 25–30 metres, whilst under favourable conditions, individual trees may grow even taller. The Caucasian lime is also a large tree. In the forests of the Greater Caucasus studied, trees were observed to be around 30–35 m tall, with a trunk diameter of around 100–150 cm. The size of individual trees depends on their age, site conditions, their position within the stand, stand density, and the availability of water and nutrients (Rahman et al., 2017).

The trunk and the bark. The trunk of a lime tree is usually straight and well-formed. The bark of young trees is relatively smooth, but as they age, it becomes rougher and develops longitudinal cracks. In mature trees, the trunk can reach a considerable thickness. Particularly large specimens of the Caucasian lime tree

are found in the mature mountain forests of Azerbaijan. The shape and dimensions of the trunk are of silvicultural importance, as they determine the quality of the timber, the stability of the tree and its position within the stand structure.

Crown. The lime tree is characterised by a well-developed crown. In trees growing freely, it can be broad, dense and rounded. In the forest, the shape of the crown varies depending on the density of the stand and the position of the tree (Moser et al., 2015). With high canopy closure, trees tend to grow vertically, and the crown becomes narrower. If there is sufficient space, the lateral branches develop more vigorously, and the crown becomes wider. A well-developed crown provides a large leaf area and plays an important role in photosynthesis and the formation of the forest microclimate.

Leaves. Linden leaves have a distinctive heart-shaped form and long petioles. The small-leaved lime has relatively small leaf blades, usually around 3-8 cm long, with a pointed tip and a serrated margin (Zykov et al., 2022; Mamieva et al., 2022). (Figure 2)



Figure. 2*. The structure of a small-leaved lime leaf*

Leaves are one of the key diagnostic features used to identify a species. Their size and condition can also be used to assess the health of trees. The leaves of the Caucasian lime are also heart-shaped, although their specific dimensions and certain morphological characteristics differ from those of the small-leaved lime (Rahman et al., 2016.

Flowers. Linden flowers are small, yellowish-green, and arranged in inflorescences. Flowering is of great ecological importance, as trees attract large numbers of insects during this period (Martynova et al., 2026; Figure 3).



Figure 3. *The flowering of the small-leaved lime*

Linden flowers produce nectar and provide insects with a food source. The flowering period is therefore significant not only for the biology of the lime tree itself, but also for the functioning of the forest ecosystem (Mamieva et al., 2022).

Fruits and seeds. The fruit of the lime tree is a small nut attached to a distinctive bract. Once ripe, the fruits can be dispersed by the wind (Efendieva & Novruzov, 2020). Linden trees flower during the summer. At this time, the trees become one of the main sources of nectar and pollen for insects.

Fruit set is an important stage in natural reproduction. The presence of seed regeneration enables the lime tree to persist within forest communities, provided that suitable conditions exist for seed germination and the development of young trees.

Characteristics of the structure of lime trees in the study areas. The small-leaved lime and the Caucasian lime share a number of common morphological characteristics. Both are characterised by large trees, a well-developed crown, heart-shaped leaves, small flowers and distinctive fruits (Pigott & Huntley, 1978). At the same time, the Caucasian lime tree can grow to a very large size in the Greater Caucasus. This is particularly noticeable in mature trees growing in favourable conditions. Consequently, whilst they bear an external resemblance, members of the genus *Tilia* exhibit certain differences linked to their species and specific environmental conditions (De Jaegere et al., 2016).

3. The biology and ecology of lime tree plantations

Attitudes towards lighting. The lime tree is one of the tree species that can tolerate shade. This characteristic is of great importance for its survival in mixed forests. Young plants can grow for a while under the canopy of taller trees. In the forests of the Volga region, this characteristic enables the lime tree to persist as part of multi-layered oak-lime stands. In the mountain forests of Azerbaijan, its ability to tolerate shade also contributes to its survival within the complex structure of the forest community. As light levels increase, the growth of young trees may accelerate; however, the optimal conditions depend on the age of the plant and the nature of the forest cover (Mamadjanov et al., 2019).

Soil and moisture requirements. Linden trees thrive best in fairly fertile soils with favourable water and air conditions. It is important for the plant to have an adequate supply of moisture; however, prolonged waterlogging of the soil is detrimental (Saltan et al., 2019). In the Volga region, the lime tree grows in a variety of forest habitats, but the most resilient stands are found in areas with suitable soil and hydrological conditions (Moser et al., 2015). In Azerbaijan, environmental conditions change significantly with altitude. The mountainous terrain gives rise to a wide variety of soils, microclimates, and moisture conditions. Consequently, the condition of lime tree stands can vary considerably even within a single mountainous region.

Growth and development. Linden is one of the long-lived tree species. Under favourable conditions, individual trees may remain part of the stand for a long time. Growth rates depend on age, light levels, soil fertility, moisture availability and competition from neighbouring trees. At a young age, the ability of the root system and the crown to develop is of great importance (Afandiyeva & Novruzov, 2020). In mature forests, lime trees can occupy various positions within the vertical structure of the stand, including the upper and lower storeys.

Natural regeneration. The natural regeneration of lime trees depends on the presence of fruiting trees, seed quality, soil conditions, moisture levels, and light levels. Seed propagation is of great importance for the natural regeneration of lime tree stands. The success of the emergence and development of young trees also depends on the presence of fruiting trees and competition from other plants (Moser et al., 2015). In mixed forests, the light conditions beneath the canopy are particularly important. A forest canopy that is too dense may restrict the growth of young trees, whilst excessive light may increase competition from herbaceous vegetation and other tree species. Therefore, when carrying out a silvicultural assessment, it is

necessary to take into account not only the quantity of young growth, but also its viability, age structure and ability to progress to subsequent age stages (Radoglou et al., 2009).

One of the most important characteristics of the lime tree is its ability to thrive in mixed stands. Oak-lime forests are particularly common in the Volga region, where lime trees grow alongside oaks and other broad-leaved species. The following formulae may be used as illustrative examples of stand composition: 7L3O or 6L2O1B1M. They denote, respectively, 70% lime and 30% oak, or 60% lime, 20% oak, 10% birch and 10% maple. These formulae are provided solely to illustrate the principle of classifying stand composition and do not represent average figures for the entire Volga region. In Azerbaijan, the lime tree forms part of the complex mountain forest communities of the Greater Caucasus, where it coexists with other broad-leaved species. The mixed composition of such forests helps to increase biodiversity and create a variety of ecological niches (Zykov et al., 2022).

Environmental significance. Linden plantations fulfil important ecological functions. They play a part in shaping the forest microclimate, accumulating organic matter, protecting the soil and maintaining biodiversity (Pigott & Huntley, 1978). Linden flowers provide a food source for pollinating insects. The crown and foliage create conditions conducive to the survival of various organisms, whilst fallen leaves contribute to the formation of forest litter and the nutrient cycle. In the mountainous regions of Azerbaijan, forests containing lime trees play an additional role in protecting the soil from erosion and regulating surface runoff.

4. Resources and uses of the lime tree

Wood resources. The main resource of the lime tree is its timber. It is light in colour, relatively soft, uniform in texture, and easy to work with [6]. Compared with heavy and denser types of timber, lime wood is less strong; consequently, its range of applications is determined primarily by its technical properties.

The main advantage is that it is easy to work with. The timber is well suited to manual and machine working, carving and the manufacture of items that do not require high structural strength. Linden wood can be used to make interior fittings. Its light colour and uniform texture enable the creation of smooth and aesthetically pleasing surfaces.

Wood is particularly valued for its ability to be worked relatively easily and to take on various shapes. This broadens the range of ways in which it can be used in interior design. One of the well-known uses of lime wood is the manufacture of materials for baths and saunas. This is due to its relatively low density, low thermal conductivity and ease of processing (Mamieva et al., 2022; Efendieva & Novruzov, 2021). Linden wood can be used to make panelling, interior cladding, shelves and various small items. At the same time, the specific application of timber must take into account the operating conditions and the requirements for the material's strength and durability.

The ability to achieve a smooth surface after treatment is particularly valued. As a result, lime wood is suitable for products where surface quality and the ability to produce complex shapes are important. One of the most characteristic uses of lime wood is artistic carving. The soft, uniform grain of the wood makes it possible to create delicate features and intricate decorative shapes. For this reason, lime wood is traditionally used to make decorative panels, sculptural elements, small decorative items, and other objects.

Bark and bast. Linden bark has historical economic significance. The bast is particularly valuable, as it has traditionally been used to produce a fibrous material. Bast was used to make ropes, bass, wickerwork and other items. At present, this field is of primarily historical, traditional and cultural significance.

Flowers and other non-timber resources. Linden flowers are an important non-timber resource. They are used as a plant-based raw material and are of great importance to beekeeping. During the flowering season, lime tree plantations become a source of nectar and pollen. Therefore, the presence of lime trees in forests can increase their value not only as timber forests but also as honey-producing areas. The seeds and

other parts of the tree are also of biological interest; however, their economic importance is considerably less than that of the timber and floral raw materials.

Significance for honey production. The lime tree is one of the best-known honey-producing tree species. Its flowering is of great importance to bees and other pollinating insects. In the Volga region, the linden tree's importance as a honey plant stems from its widespread presence in broad-leaved and oak-linden forests. In Azerbaijan, this significance is evident locally in areas where the linden tree grows naturally, particularly in the mountain forests of the Greater Caucasus. The honey-producing function is a common characteristic of linden stands in both regions, although the extent to which it manifests itself is determined by the area and structure of the linden forests.

5. A comparative analysis of lime trees and lime tree plantations

A comparison of linden stands in the Volga region and Azerbaijan shows that their current condition and distribution patterns are determined primarily by differences in natural conditions. Despite the general biological similarity among species of the genus *Tilia*, the establishment of stands in these regions takes place under varying forest-vegetation conditions (Mamadjanov et al., 2019; Saltan et al., 2019). In the Volga region, the small-leaved lime (*Tilia cordata*) is a characteristic component of broad-leaved and mixed forests. It is of particular importance in oak-lime tree communities, where it can account for a significant proportion of the tree stand. The flat nature of the terrain and the presence of extensive woodlands create conditions conducive to the wider distribution of lime trees (Mamieva et al., 2022; Seidafarov, 2012).

In Azerbaijan, the natural distribution of lime trees is considerably more localised. The main wild populations are found in the forest ecosystems of the Greater Caucasus. The Caucasian lime (*Tilia caucasica*) is of particular importance here, whilst the small-leaved lime is also found in certain areas of northern Azerbaijan. The distribution of these rock types is closely linked to altitude, topography, slope aspect, soil conditions, and moisture regime (Rahman et al., 2016).

A comparison of morphological characteristics reveals a significant similarity between the species under consideration. They are characterised by large trees, a well-developed crown, heart-shaped leaves, small flowers, and distinctive fruit. At the same time, the size of individual trees can vary considerably depending on the growing conditions. In the mountain forests of Azerbaijan, the Caucasian lime tree can grow to a considerable size, which highlights its role in the structure of mature forest communities.

From an environmental perspective, a common characteristic of linden species is their ability to thrive within mixed stands. The lime tree can tolerate shade, which enables it to thrive beneath the canopy of other tree species. In the Volga region, this contributes to its presence in multi-layered oak-lime forests, whilst in Azerbaijan it is found in complex mountainous broad-leaved communities. A key difference between regions relates to the spatial structure of forests. In the Volga region, the lime tree tends to form extensive forest communities and is a common component of tree stands. In Azerbaijan, its distribution is patchy and localised, and the status of individual populations depends more on the characteristics of the mountainous terrain and local growing conditions.

The linden tree is of multi-purpose value in both regions. Wood is used because of its softness, uniformity and ease of working. It is suitable for use in the manufacture of furniture, household goods, interior fittings and materials for baths and saunas. The lime tree is of particular importance in the field of artistic woodcarving. In addition to woody resources, flowers and other non-woody parts of the plant play an important role. Flowering provides a food source for pollinating insects and determines the value of lime tree plantations as a source of nectar. Historically, bark and bast have been used to produce fibrous materials, ropes and woven goods.

Thus, the main difference between the linden stands of the Volga region and those of Azerbaijan lies not so much in the biological characteristics of the trees themselves as in the extent of their distribution, the composition of the forest communities and the growing conditions. Forest stands in the Volga region are

characterised by a greater prevalence of lime trees in lowland broad-leaved forests, whilst Azerbaijani populations are predominantly mountainous and localised. From a silvicultural perspective, it is necessary in both regions to preserve the mixed composition of the tree stands, to support the natural regeneration of lime trees and to take account of their ecological functions. In this regard, it is particularly important for Azerbaijan to protect the natural populations of lime trees in the mountain forests of the Greater Caucasus, as their distribution is limited by specific natural conditions.

6. Conclusion

The study found that the lime tree stands in the Volga region and Azerbaijan are of high ecological and economic value, but have developed under significantly different natural conditions. In the Volga region, the lime tree is a characteristic component of broad-leaved forests, particularly oak-lime stands. In Azerbaijan, its natural range is predominantly associated with the mountain forests of the Greater Caucasus, where the Caucasian lime plays an important role.

Common to both regions are the linden tree's ability to form part of mixed stands, its ecological role, the value of its timber, and its importance as a source of nectar. At the same time, differences in topography, climate and forest growth conditions determine the varying distribution and structure of lime tree stands. The sustainable use of lime trees must go hand in hand with the conservation of natural populations, the promotion of their regeneration and the protection of valuable forest ecosystems. This is particularly important for the natural lime tree stands of the Greater Caucasus within Azerbaijan.

Overall, the lime tree should be regarded not only as a source of timber, but also as an important component of sustainable forest ecosystems, possessing ecological, protective, honey-producing and resource-related significance.

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