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SUSTAINABILITY OF SOME FOREST SPECIES' ASSOCIATIONS ESTABLISHED ON DEGRADED LANDS FROM THE TRANSYLVANIA PLAIN, IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

This research was carried out based on a wide range of knowledge and research results reported due to previous studies on afforestation of degraded lands and forest species associations, in the southwestern part of the Transylvanian Plain. The existing knowledge made it possible to deepen and analyze different forest management practices, such as forest stand improvement, restoration of degraded lands through afforestation in the context of climate change. Therefore, the main objective of this research was to restore a degraded land in the south-western part of Transylvania. To achieve this goal, different forest plant communities were proposed, established and monitored over 9 years. During the research period, the development of forest plant communities was monitored in a fixed area in Viişoara, in order to determine the influence of soil type and plant community composition on the survival rate of the plants. For this purpose, the survival rates after 3, 5, 7 and 9 years after planting were calculated in relation to forest biometric data such as tree height and crown diameter. The results show that both soil type and forest plant community composition influenced the development of the species. The highest survival rates (96-99.5%) were recorded in Pinus sylvestris, Acer campestre, Hippophaë rhamnoides and Crataegus monogyna preluvosol, erodisol and luvosol. Among the 12 forest species tested, Tilia cordata, Quercus petraea and Acer campestre had the highest biometric values in terms of plant height, which ranged from 357.33 cm (Acer campestre) to 412.42 cm (Tilia cordata) along the diameter of the trunk, which varied from 6.27 cm (Quercus petraea) to 11.65 cm (Tilia cordata).

***Key words**: afforestation; degraded lands; ecosystem; natural hazards; turkey oak; scots pine.*

INTRODUCTION

A lot of previous research has already shown that the restoration of soil is a very slow and long process in comparison to the degradation of soil (Ibrahim, 2008; Bastida et al., 2015; Farrell et al., 2020). Afforestation as a forest management practice can be usefully applied to degraded lands unsuitable for agricultural crops to transform them into productive stands (Reyer et al, 2009; El-Beltagy, 2000). On the one hand, afforestation creates a close-knit forest community that helps restore ecological goods and services. On the other hand, these degraded lands are restored and put back into productive circulation (Duan & Abduwali, 2021).

In addition to afforestation, reforestation is another important tool for improving degraded lands. Previous reports have shown that most agricultural land was covered by forests, but due to global population growth and the transition from extensive to intensive agriculture, forest cover has decreased significantly (Rudel et al., 2005). According to Ritchie et al. (2023), the entire world lost about one-third of the world's forests within a few millennia. It has been observed that when an agricultural land is abandoned or becomes unsuitable for crops, the number of pests, except for the beneficial entomofauna, for certain types of crops (agricultural, meadows and hayfields or plantations) increases exponentially (over several tenfold) in the abandoned areas, leading to real disasters (Visockiene et al., 2019; Bonan, 2008). Within the studied area, an intense activity of the pest *Corythucha arcuata* is observed, a fact that has also been observed in other similar situations (Bălăcenoiu et al., 2021). Unsustainable resource management practices leave degraded lands vulnerable to soil erosion and environmental damage, leading to a decline in biodiversity. This degradation also diminishes the land's capacity to store carbon and retain usable water, further impacting the ecosystem's health and resilience (Alig et al., 1997; Alcamo et al., 2005; Goebel et al., 2005). To effectively combat the negative consequences of land degradation on ecosystems, it's crucial to understand the intricacies and potential impacts of restoration efforts. By implementing targeted ecological restoration activities, we can rehabilitate degraded lands, safeguard biodiversity, and ultimately restore essential ecosystem services that benefit both the environment and human well-being (Govers et al., 2017). While ecological theory provides a valuable framework for restoring degraded land, putting these theories into practice isn't always straightforward. There's a gap between theoretical knowledge and real-world application, and in many cases, restoration efforts require ongoing adaptation, refinement, and persistence to achieve the desired outcomes (Lazar et al., 2017). In general, these areas are found in extreme conditions, the development of species is much more difficult and requires more work, while the range of forest species is broader than in the case of some basic natural forest types (Costandache et al., 2006, Giannini et al., 2017). The importance of reforesting degraded lands is widely recognized and supported by extensive research. Scientists have explored various reforestation methods, but there's no one-size-fits-all solution. Each degraded area presents unique challenges that require careful planning and adaptive management strategies (Pawson et al., 2013). To effectively restore degraded land through afforestation, we need to equip forestry professionals with the right resources, tools, and knowledge. This includes ongoing training and access to the latest research and technology, allowing them to adapt their strategies as needed. Successful afforestation also demands a deep understanding of each site's unique characteristics, including its soil, microclimate, and existing vegetation. This detailed assessment will inform the development of tailored reforestation strategies. While species like pine and white sea buckthorn were once popular choices for land improvement due to their hardiness, a more nuanced approach is now required. However, recent experience and updated best practices show that these species may decline after an initial period of growth, highlighting the need for more nuanced and site-specific approaches to reforestation (Untaru et al., 1993; Ayan et al., 2020). In recent years, the choice of the right species for reforestation of degraded lands has become a major challenge in terms of guidelines and increasing risks or disasters (drought, frozen rains, insect or rodent attacks) that require a longer time for research and understanding of the phenomena (Costandache et al., 2010; Hartanto et al., 2003; Tăut, et al., 2018). In this context, the afforestation of this type of land consists mainly in reducing the intensity of land degradation processes and gradually improving them, under the direct effect of protective forest crops, and mitigating climate change. It also protects human settlements against landslides, wind or snow, provides timber in areas where it is scarce, creates melliferous bases, improves the landscape and, finally, improves the living conditions of the inhabitants of the area (Bowen et al., 2007; Dalling, 2008; Liu et al., 2018; Untaru et al., 2012).

The main function of forest plant species that are established on degraded lands is the mitigation or cessation of land degradation processes and the improvement of environmental conditions. Considering the function of these forest ecosystems, it can be said that forest stands have a temporary role, after fulfilling their role of protection and improvement, they will be replaced, naturally or artificially, by other stands of valuable species’ characteristic of the basic natural type, and their protective function will change, taking its place of production (Schuler et al., 2017).

The main objective of the present research was to increase the knowledge about the planting of forest species on degraded lands unsuitable for agriculture, located in the south-western part of the Transylvanian Plain, with the knowledge of the difficulties encountered due to the physical-geographical conditions (nature of the land, climatic factors and harmful factors), including their vegetation state in the first years after planting. The research aims to specify the circumstances regarding the current state of the plantations, the sustainability of the forest species associations and the interspecific relationships within the plant communities. Another objective is the efficiency of the ecological reconstruction of the land within the perimeters of improvement, and the other is the effect and intensity of the disasters found in these areas.

MATERIALS AND METHODS

To conduct this experiment, several research methods were used. Observation as a research method was used for the recognition of the study area, the description of the land configuration, the characteristics of land degradation, and the soil preparation technology in the establishment of crops. In addition, the viability of the forest seedlings was monitored after several growing seasons. During the growing seasons, their adaptation and vegetation condition were assessed. To determine the biometric characteristics of the forest plants, actual measurements were made. Thus, the associations of forest species established in the Viișoara area were inventoried on soil types and forest compositions, in percentage of success at different intervals since planting (3 years, 5 years, 7 years, 9 years), with the specification that in the 5th, 7th and 9th years, the percentage of filling carried out previously (in the first 3 years after planting) was also taken into account. At the same time, biometric data (tree height and trunk diameter) were measured, and the vegetation status of forest species and the impact of harmful factors and their intensity were determined.

Study area

The study area is located near the village of Urca, which is part of UAT Viisoara, located in the southwestern part of the Transylvanian Plain (Figure 1). The study area consists of a grassland with different degrees of surface and deep erosion, as well as landslides, with different landforms, from steep but short slopes, with slopes of more than 35^{o}, to those with very little inclination, plateaus, as well as numerous ravines and bones. In the usual morphological aspect, the study area is located in the Hilly Plain of Transylvania, consisting of a complex of slow peaks, separated by wide valleys with an altitude between 25 - 640 m. Physically - geographically, the improvement perimeter is located on the southern and western slopes of the hills Vomirul Mare and Vomirul Mic with an altitude between 320 meters and 470 meters.

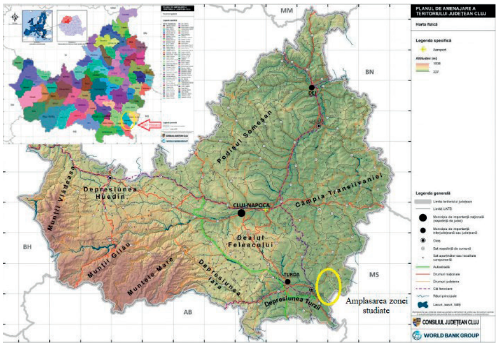

Figure 1. Location of the survey area
(Source: https://www.patjcluj.ro)

It is worth mentioning that out of the total area of 123.37 ha, only 122.15 ha were covered with ecological forest reconstruction works, while the remaining 1.21 ha were non-productive lands, namely a very high slope ravine - 0.81 ha, as well as two bush areas, where the close crop was already formed and where no deforestation and reforestation intervention was appropriate. In this situation, it was intended that the replacement of the current vegetation would take place in time and naturally, the areas being relatively small - 0.4 ha. Prior to the actual reforestation work, a pedostratigraphic mapping of the area was carried out in order to carefully match the reforestation solutions with the soil type and its requirements.

Climate and site conditions

As far as the climatic conditions of the studied area are concerned, Viisoara is situated in the climatic province Dfbx, in the climatic sector Ibp, that is, in the provincial sector with continental-moderate climate, in the country of the hill climate, in the subdivision of the Transylvanian Plain. This land is characterized by a relatively constant higher humidity than in the eastern sector of the country, but also by an uneven distribution of all-weather elements. In this climatic country, the studied area is part of the plain area, which, especially in its southern part, feels the influence of the föhn, which leads to a general increase in air temperature, especially during clear skies, and a decrease in the amount of precipitation (less than 600 mm annually), therefore the studied area is atypical to the general characterization.

The climate of the area is characterized by mild winters, with an annual precipitation of about 550-600 mm, but with an aridity index of about 34, which gives the area a transitional character towards the forest-steppe. Thus, the area under study is one of the driest of the Transylvanian Plain, with atypical climatic conditions. The rainfall regime is characterized by annual average values between 560 and 610 mm per year, but in recent years the average values recorded in the study area did not exceed 580 mm. This area experiences a Mediterranean climate, with rainfall peaking in June (averaging 96.5 mm) and reaching its lowest point in March (averaging 29.1 mm). Winter is the driest season (90-95 mm), while summer brings the most rain (240-250 mm). Although this rainfall level generally supports healthy forest growth, the high temperatures lead to significant evapotranspiration, exceeding precipitation, particularly in July and August. This water deficit can create challenging conditions for vegetation during the summer months. The area around Viisoara is facing increasing challenges due to climate change. Recent years have seen more frequent and severe droughts, particularly on sunny, steep slopes, causing significant damage to existing forest vegetation. While the region lacks natural forests, there is a small, artificially planted stand about 40 years old. Although it initially helped with land improvement, this stand is now insufficient to meet the area's needs for tree cover and does little to influence the local microclimate. Essentially, the area is struggling with a lack of forest cover to mitigate the effects of drought and improve the local environment. The existing forest stand is composed of black pine on the south-facing slopes, with a mix of oak species at the base, along with scattered hawthorn, blackthorn, and black locust trees. However, this stand is showing clear signs of decline due to the increasingly dry conditions. Between 2020 and 2024, a significant portion of the pines have died, and the oaks are also suffering, exhibiting dieback in their crowns and producing stunted shoots because of prolonged water stress. The soil within the study area is diverse and includes preluvosols, luvosols, and alluviosols. Significantly, there are also areas with moderate to severe erosion, classified as erodisols (Figure 2). This variety in soil types is likely influenced by the topography and past land use within the study area.

(A) (B)

Figure 2. Soil types found within the perimeter of Viisoara. (A) – alluviosol; (B) – luvosol. (source: original)

Table 1 provides a helpful guide for matching the right trees to the right soil conditions within the study area. It outlines the different soil types found in the area (preluvosols, luvosols, alluviosols, and erodisols) and identifies suitable site types for various ecological groups of trees. Essentially, it recommends the types of vegetation best suited to thrive in each specific soil type, aiding in successful reforestation efforts.

Table 1. Soil types and forest sites characteristics by ecological groups

Ecological group / Sites group (GE/GS)	Soil Type	Site Type (TS) Proposed afforestation compositions	UA/US	Surface	
				ha	%
GE 56	Preluvosol	TS 1 - GE 56 - Quercus hills site, high edapfic volume 3St(Gi)3Ce(Str)2Te(Ci)2Ci(Ju,Lc)	11, 18A, 3, 9B	12.27	10.0.
GE 57	Preluvosol	TS 2 - GE 57 Hill mixed hardwood forest, medium-large edaphic volume 3Go(Gi)3Ce(Str)2Te(Ci)2Ju(Lc)	14A, 14B, 1A, 24	17.55	14.4.
GS 54	Alluviosol	TS 3 - GS 54 - Slippery land with a moderately kneaded slip mass, with a thickness of over 75 cm, without prolonged excess water 25Str(Ec)25Fr25Te(Ci)25Lc(Ju)	13A, 15B, 15C, 19A, 1C, 22A, 4B, 5, 7B, 8A	38.79	31.8.
GS 9	Luvosol	TS 4 - GS 9 - High slope soil, moderate erosion, 25Pi25Ci(Mj)25Ml(Vi.t)25Pd(Lc)	10, 15A, 15D, 17, 20A, 23A, 23B, 25, 4D, 7A	28.25	23.1.
GS 11	Erodisol	TS 5 - GS 11 - Large slope land with very strong and excessive erosion, clay texture, without rocks 50Pi50Ct(Mj)	12, 13B, 16, 19F, 19G, 20B, 21A, 22B, 22C, 22D, 22E, 22F, 2A, 4A, 4C, 6A, 8B, 8D, 9A	23.17	19.0.
GS 29	Erodisol	TS 6 - GS 29 - Slopes of ravines and gully on erodisoils, without rocks 100Ct(100Sl)	15E, 15F, 18B, 18C, 19E, 21B, 21C, 21D, 21E, 21F, 21G, 2B, 2C, 6C, 7C, 8E, 8F, 8G, 9C, 9D, 9E, 9F, 9G, 9H,	2.12	1.7.

Biometric measurements

In order to achieve these objectives, at the end of the growing seasons in the years indicated in Table 2, 100 m² sample plots were placed homogeneously in the field on the surface of the site units inventoried at each crossing perimeter. Inventories of seedlings were conducted within the sample plots to determine seedling recruitment or failure rate by determining the percentage of success at the end of the growing season. Collar diameter and plant height measurements were also made. Height was measured to the end bud of each seedling using the roulette in centimeters, and when measuring with the roulette became difficult, a graduated pole was used. Collar diameter was measured in centimeters with a caliper. By differentiating the measurements over the years, annual increases in diameter and height were determined.

Statistical analyzes

All recorded data were analyzed using IBM SPSS Statistics 19 (IBM). One-way analysis of variance (ANOVA) was performed at 95% confidence level to determine statistically significant differences between the means of the same species but different soil types and their adaptability to different climatic and site conditions. When the ANOVA null hypothesis was rejected, Duncan's multiple range test was used to determine significant differences between the means.

RESULTS AND DISCUSSIONS

The climatic factors (temperatures, precipitation and potential evapotranspiration), together with the landscape conditions, give the studied area a topo-climate different from the normal representative one. The phenological data of the main species (oak and sessile oak) show that, for them and for other species of the mixture in the mixed hardwood of the hills, the normal climate favors their development, but the typical extreme climate of the area cancels this advantage (Mette et al., 2013; Černý et al., 2024), an aspect that can be observed in the case of the present study (Figure 3).

Although the perimeter was established in 2012-2013, due to the calamities to which it was exposed (prolonged drought and attacks of rodents), in the spring of 2014 it went into full recovery, therefore, the experiments started in 2015, with regular return and consisted in the follow-up of forest crops, determining the growth of trees, the vitality and resistance to disruptive factors. This research will continue until the close crops is achieved, which has not been fully achieved by 2024.

Figure 3. Restoration of the ecosystem through afforestation. Changing the landscape 2012-2016-2024 in the perimeter of Viisoara (Source: original)

Table 2 presents the findings of our measurements, reflecting the factors discussed earlier. The initial success of the seedlings planted in 2013 depended heavily on the weather conditions that year, particularly temperature and rainfall, and the seedlings' ability to adapt to those conditions. While planting was done manually in prepared strips along the slopes, mechanized site preparation could have been more efficient and cost-effective, potentially improving seedling survival rates, as suggested by Wronski & Murphy (1994). After one growing season, with annual monitoring of species regeneration, it was found that the species survival rate was low, so that in the spring of 2014, the reestablishment of the stands took place at a rate of 80%.

Regarding the percentage of success recorded after five years of establishment, it can be observed that for turkey oak (*Quercus cerris*) the percentage of survival varied between 68.5% (u.s. 1A) and 73% (u.s. 7B), a rather low percentage considering that the gaps were filled over three years, this percentage being lower than that recorded for oak (*Quercus robur*) 77.5% and sessile oak (*Quercus petraea*) 81%.

At 9 years after planting, the percentage of survival had the following proportion, with the specification that from the fourth year no filling the gaps have been made, turkey oak (*Quercus cerris*) the percentage of maintenance is between 47.5% (u.s. 11) and 58.75% (u.s. 1A) the percentage being lower than before, this percentage is below the percentage recorded by sessile oak (*Quercus petraea*) 68.5%, with the exception of oak (*Quercus robur*) 58%.

This aspect is somewhat surprising, since the turkey oak (*Quercus cerris*) is a relatively thermophilic and xerophytic species that grows in lowlands and forest-steppe areas with warm climates, tolerating well drought and aridity, and which, due to its strong roots and ability to reduce its sweat, also vegetates well on clay and compact soils with variable humidity, aspects also reported by (De Rigo et al., 2013; Di Filippo et al., 2010). On the one hand, these low survival rates of forest species are mainly due to the attack of biotic pests (invasion of field mice, which gnaw the roots and the collar of the seedlings, and the action of deer, which gnaw the annual growth of the seedlings). On the other hand, the lack of rainfall and the above-average temperatures led to a withered state of the vegetation, which subsequently led to the desiccation of the planted crops (Figure 4). Figure 4 also shows that the vegetation on the southeastern slopes remained much weaker than on the northwestern slopes.

For the mixed species studied, it is noted that the corresponding success is recorded for the common ash (*Fraxinus excelsior*), 81% at 5 years and 75% at 9 years, and European white linden (*Tilia tomentosa*), which is well adapted to the soil and climatic conditions at the base of slopes, achieving a success percentage between 81% and 91% at 5 years, respectively 62.75% and 74.5% at 9 years (Clark et al., 2013; Frischbier et al., 2019).

(A) (B) (C)

Figure 4. Factors leading to low crop success. (A) - Attack of rodents; (B) - Appearance of bush at the sessile oak due to the gnawing of annual growths by the roe deer; (C) - Development of vegetation according to the exhibition of slopes. (source: original)

Among the complementary species of deciduous trees and shrubs, the best survival rates were as follows: bird cherry (*Prunus padus)* with 77.5%, sea buckthorn (*Hippophaë rhamnoides*) with 99% and hawthorn (*Crataegus monogina*) with 99.5%. In the case of coniferous species, Scots pine (*Pinus sylvestris*), showed a higher ecological amplitude (Rehfeldt et al., 2002; Silvestru-Grigore et al., 2018), at least for the moment, have adapted to the pedostasis conditions of the area with a normal development and an optimal survival and development percentage, 96% and 97.5%, respectively, in the ninth year of vegetation.

For seven test areas installed in the Viisoara improvement perimeter, Table 2 summarizes the measurements, and the elements studied.

Appreciation of vegetation status and harmful factors (climatic, biotic and abiotic factors) was made using a symbol scale according to the following specifications:

Abiotic pests

1. Injuries due to climatic factors

a. high temperatures in the growing season;
b. lack of precipitation.

Biotic pests

2. Leaf diseases

a. oak powdery mildew (*Microsphaera abbreviata Peck*);
b. purple staining of cherry leaves (*Coccomyces hiemalis*).

3. Animal pests

a. roe deer (*Capreolus capreolus*);
b. rabbit (*Lepus europaeus*);
c. field mouse (*Microtus arvalis*);
d. oak lace bug (*Corythucha arcuata*).

The intensity of injuries was assessed according to the following scale:

I. very weak (up to 25 %);
II. weak (26-50);
III. medium (51-75%);
IV. strong (over 75%).

For the assessment of the vegetation status of the crops, the notations mentioned in Technical Norms 7/2000 and the best practice guide approved in OM 2357/28.09.2022 were used as follows:

a. very vigorous;
b. vigorous;
c. normal;
d. poor;
e. very weak.

The biometric dimensions of individuals and species are very varied, due to the soil conditions mainly and the climate conditions in secondary. Thus, very varied heights were measured, the average dimensions being in the main deciduous species between 73 cm in the turkey oak (*Quercus cerris*) and 97 cm in the sessile oak (*Qercus petraea*) in year 5 respectively between 43 and 47 cm in the scots pine (*Pinus sylvestris*). At year 9 the measured values recorded 245.33 cm in the turkey oak (*Quercus cerris*) and 362 cm in the sessile oak (*Qercus petraea*), the coniferous being between 120.33 and 137.5 cm (Figures 5 and 6).

Table 2. The centralization of the measurements and elements studied

u.s		Afforestation composition		Succeeded After				Biometric characteristics by				Vegetation status Age 9	Factors of injury Age 9
								Age 5		Age 9			
No.	Soil Type	Species	Proportion %	Age 3 %	Age 5 %	Age 7 %	Age 9 %	Height -cm-	Collar diameter -cm-	Height -cm-	Collar diameter -cm-		
11	preluvosol	St	30	60	77.5	72	58	85	1.5	278	5.8	c-d	1.a.b.2.a.3.a.c.d.III
		Ce	30	58	72	66	47.5	73	1.3	245	5.4	c-d	1.a.b.2.a.3.a.c.d.III
		Te	20	72	81	76.5	62.75	115	2.1	386	11.2	b-c	1.b.3.c.II
		Ci	20	40	63.5	51	32.5	121	2.5	321	8.1	d	1.b.2.b.3.c.III
1A	preluvosol	Go	30	57	81	76.75	68.5	97	1.5	362	6.2	c-d	1.a.b.2.a.3.c.d.II
		Ce	30	52	68.5	65	58.75	75	1.2	276	5.8	c	1.a.b.2.a.3.cIII
		Te	20	83	91	88	73	124	2.3	412	11.7	b-c	1.b.3.c.II
		Ju	20	92	100	98	96	115	1.9	357	7.8	b	1.b.I.
7B	alluviosol	Ce	25	68	73	71	68.75	91	1.2	278	4.9	c-d	1.a.b.3.cIII
		Fr	25	80	81	78	75	78	1.9	319	4.6	b	1.a.b.2.c.3.cII
		Te	25	86.75	89.5	82.75	74.5	71	1.8	357	8.4	b-c	1.b.3.c.II
		Lc	25	90	87.5	86	81	62	0.7	211	2.8	b	1.b.II
15D	luvosol	Pi	25	90	100	99	97.5	47	1.4	121	3.9	b	1.a.b.II
		Ci	25	68	63	57	48.75	89	2.3	235	6.9	c	1.b.2.b.3.c.III
		Ml	25	72	84	79	77.5	104	1.4	297	3.6	b	1.b.II
		Pd	25	98	100	100	99.5	83	0.8	211	2.3	b	1.b.I.
19G	erodisol	Pi	50	91	97	96.5	96	43	1.1	137	3.6	b	1a.II.
		Ct	50	100	99	98	99	86	1.3	201	3.1	b	1.a.b.I
9F	erodisol	Ct	100	98	99.5	99	99	103	1.5	227	3.4	b	1.a.b.I
21C	erodisol	Sl	100	87	89.75	87.5	84	87	1.7	248	3.7	b-c	1.b.I.

- the notations of vegetation status and the action of harmful factors are illustrated in the following paragraph
- the notation of species is: St (oak – *Quercus robur*); Go (sessile oak – *Quercus petraea*); Ce (Turkey oak – *Quercus cerris*); Te (European white lime – *Tilia tomentosa*); Fr (common ash – *Fraxinus excelsior*); Ci (wild cherry – *Prunus avium*); Ju (Field maple – *Acer campestre*) Pi (scots pine – *Pinus sylvestris*); Ml (bird cherry – *Prunus padus*); Lc (privet – *Ligustrum vulgare*); Pd (hawthorn – *Crataegus monogina*); Ct (buckthorn – *Hippophaë rhamnoides*); Sl (oleaster –*Eleagnus angustifolia*);

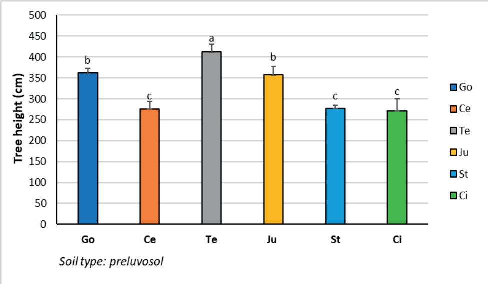

Figure 5. Average tree heights of the investigated species after 9 years of growth. Lowercase letters above the bars indicate significant differences between the species studied according to Duncan's multiple range test at p< 0.05. * Go (sessile oak – *Quercus petraea*); Ce (turkey oak – *Quercus cerris*); Te (european white lime – *Tilia tomentosa*); Ju (field maple – *Acer campestre*); St (oak – *Quercus robur*); Ci (wild cherry – *Prunus avium*).

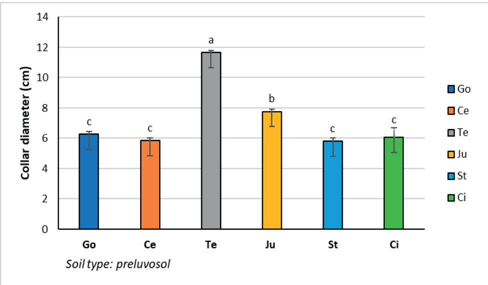

Figure 6. Average collar diameter of the investigated species after 9 years of growth. Lowercase letters above the bars indicate significant differences between the species studied according to Duncan's multiple range test at p< 0.05. Go (sessile oak – *Quercus petraea*); Ce (turkey oak – *Quercus cerris*); Te (european white lime – *Tilia tomentosa*); Ju (field maple – *Acer campestre*); St (oak – *Quercus robur*); Ci (wild cherry – *Prunus avium*).

After nine years, there's a clear difference in height between the tree species planted. *Tilia tomentosa* emerged as the top performer in terms of growth, reaching an average height of 412.42 cm. It was followed by *Quercus petraea* at 361.67 cm and *Acer campestre* at 357.33 cm. These species showed the strongest growth, increasing in size by 69-80% over a 5-year period. Their crown diameters also followed a similar pattern. Based on the results obtained, a positive correlation between tree height and crown diameter was observed in all species studied.

Tilia tomentosa and *Quercus cerris* have been proposed and grown on two different soil type to test their adaptability and survival rate. The results show that the growth parameters recorded in *Quercus cerris* including average tree height and collar diameter were slightly influenced by the soil type, but no statistically significant differences were detected according to Duncan's multiple range test at $p < 0.05$. In this context, it was observed that the maximum average tree height was recorded on aluviosol, while the collar diameter of *Quercus cerris* was larger in trees grown on preluvosol (Figure 7 and Figure 8). On the contrary, the growth of *Tilia tomentosa* species was significantly higher than that of *Quercus cerris*, both in terms of tree height and diameter at breast. The highest mean values for *Tilia tomentosa* were recorded for trees grown on preluvosol (Figure 7 and Figure 8).

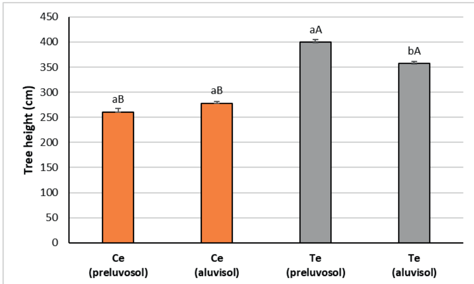

Figure 7. Average tree heights in Ce (turkey oak - *Quercus cerris*) and Te (european white lime - *Tilia tomentosa*) grown on different soil types after 9 years of growth. Lowercase letters above the bars indicate significant differences between soil types within the same species, while capital letters indicate significant differences between tree species grown on the same soil type according to Duncan's multiple range test at $p < 0.05$.

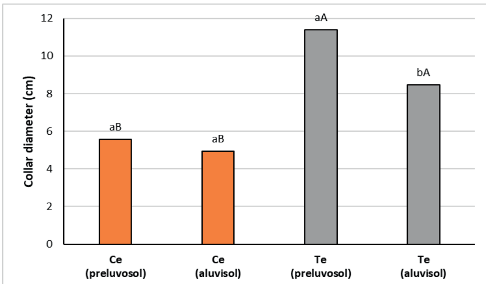

Figure 8. Average collar diameter in Ce (turkey oak - *Quercus cerris*) and Te (European white lime - *Tilia tomentosa*) grown on different soil types after 9 years of growth. Lowercase letters above the bars indicate significant differences between soil types within the same species, while capital letters indicate significant differences between tree species grown on the same soil type according to Duncan's multiple range test at $p < 0.05$.

Besides soil, the mix of tree species planted also affects how well individual species grow (Tănase, 2012). Some species can help or hinder the growth of others. Both *Quercus cerris* and *Tilia tomentosa* grew taller and had thicker trunks when planted alongside *Quercus petraea* (and *Acer campestre*. Specifically, *Quercus cerris* reached an average height of 276.33 cm and a trunk diameter of 5.83 cm, while *Tilia tomentosa* reached an impressive 412.42 cm in height and 11.65 cm in diameter. Lower values of these growth parameters were recorded when *Quercus cerris* and *Tilia tomentosa* were planted in a community with *Quercus robur* L. and *Prunus avium* L. (245.33 cm height; 5.3 cm collar diameter and 386.25 cm height; 11.12 collar diameter).

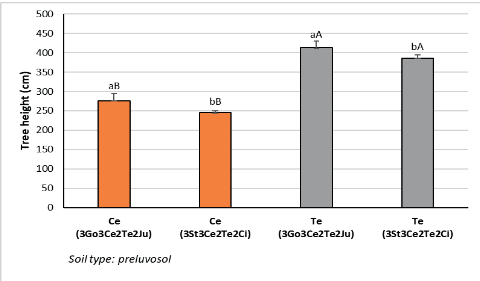

Figure 9. Average tree height in Ce – *Quercus cerris* and Te – *Tilia tomentosa* grown in different plant communities after 9 years of growth. Lowercase letters above the bars indicate significant differences between soil types within the same species, while capital letters indicate significant differences between tree species grown on the same soil type according to Duncan's multiple range test at $p < 0.05$.

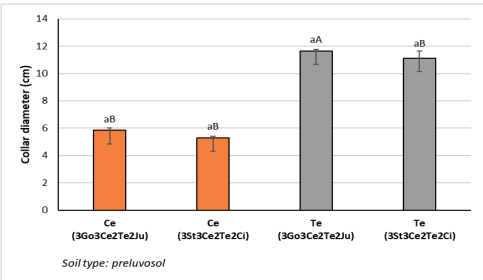

Figure 10. Average collar diameter in Ce – *Quercus cerris* and Te – *Tilia tomentosa* grown in different plant communities after 9 years of growth. Lowercase letters above the bars indicate significant differences between soil types within the same species, while capital letters indicate significant differences between tree species grown on the same soil type according to Duncan's multiple range test at $p < 0.05$.

Other species, such as *Pinus sylvestris*, exhibited different growth rates which appeared to be influenced by the soil type along slope exposure (Vlasin, 2010; Stoll et al., 1994; Ayan et al., 2021). It appears that *Pinus sylvestris* grew better on erodisol, reaching an average height of 137.50 cm, compared to 120.33 cm on luvosol. This difference in growth based on soil type was statistically confirmed and is clearly illustrated in Figure 11.

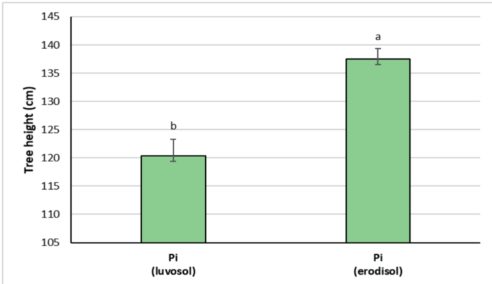

Figure 11. Average tree height of Pi – *Pinus sylvestris* grown on different soil types

In respect to collar diameter of *Pinus sylvestris*, the same growing tendency was observed: erodisol stimulated more collar diameter as well than luvosol (Figure 12).

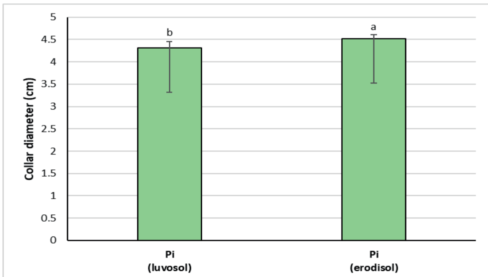

Figure 12. Average collar diameter of Pi – *Pinus sylvestris* grown on different soil types

Hippophaë rhamnoides L. also known as sea buckthorn is an indigenous species with high ecological adaptability. This species is cultivated first, in forest plant communities due to its role in preventing soil erosion, and second, for its fruits which are rich in bioactive compounds and Vitamin C. The roots of this species are rich in root nodules and thus very effective in nitrogen fixation (Chen et al., 2019). In this study, this species has been suggested and planted for pure and mixed plant communities to improve degraded lands by conserving the soil and water for longer time. Therefore, the results show that sea buckthorn reached higher values in terms of plant height when planted and grown in pure communities (227.23 cm) than associated with *Pinus sylvestris* (201.6 cm) as presented in Figure 13.

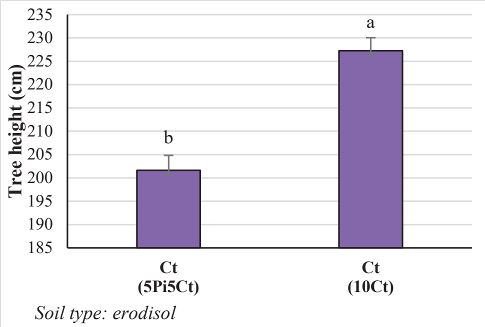

Figure 13. Average plant height of Ct – *Hippophaë rhamnoides* L. grown in different species associations

However, the collar diameter was slightly bigger (3.32 cm) when planted in mixed communities in comparison to pure communities (3.14 cm) as shown in Figure 14.

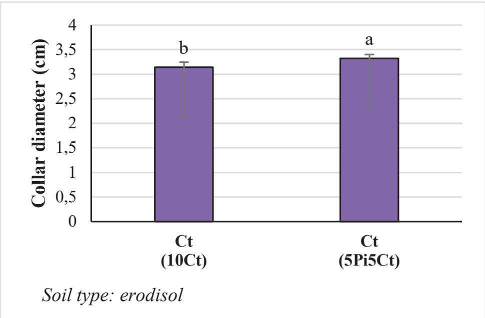

Figure 14. Average collar diameter of Ct – *Hippophaë rhamnoides* L. grown in different species associations

Among the aiding species, the common ash (*Fraxinus excelsior*) reached 319 cm, and the European white lime (*Tilia tomentosa*) reached between 357 and 412 cm in year 9 after planting. The field maple (*Acer campestre*) is a thermophilic species but with certain demands on the soil, vegetating well on the slopes and at the base of the slopes on dry soils and with a higher degree of compaction, a highlighted aspect and by (Zecchin et al., 2016).

From the point of view of the collar diameter, the situation is as follows: the cvercinees recorded values between 1.2 and 1.5 cm and the pine between 1.1 and 1.4 cm in year 5. These differences between values were maintained in year 9 after planting, with the cvercinees between 4.9 and 6.2 cm and the pine between 3.6 and 3.9 cm.

Of the aiding species, common ash (*Fraxinus excelsior*) reached 4.6 cm and European white lime (*Tilia tomentosa*) ranging between 8.4 and 11.7 cm in diameter in year 9 after planting, with the specification that these dimensions were recorded at specimens that developed mainly at the base of the slopes, on the banks of some ravines or on the north-western slopes. As shown in Figure 15 on the southern and south-eastern slopes, the tree vegetation is almost non-existent (except for common ash and pine trees), with only shrub vegetation developing.

Forest crops have developed differently during the research period, depending on the foresting composition of each variant. Differences can thus be observed for each species, which allows some useful conclusions to be drawn for the future, regarding the choice of species associations according to the soil and climatic conditions and the characteristic type of microsite.

Figure 16. Development of forest associations 10 years after planting in the Viișoara improvement perimeter (Source: original)

CONCLUSIONS

Water is the limiting factor in the development of plants, therefore a potential trophicity is distinguished, expressed by the nutrient fund used by plants. In the months with lower humidity compared to the optimal level, the soil trophicity attainment is lower and due to the potential evapotranspiration, namely the lower humidity, the dryness or aridity phenomenon will occur. Linking the ecological requirements of the species to the stationary conditions in the area under consideration, the following species associations were established: oak, sessile oak and turkey oak as the main basic species in the case of deciduous trees, or Scots pine in the case of coniferous trees, used as an association with European white lime and common ash as the main secondary species, field maple, bird cherry and wild cherry as supporting species, and hawthorn, buckthorn and oleaster as shrubby species. The period of adaptation and growth of the forest seedlings is quite long, as the percentages of success and survival during the study period and the measured values show.

Thus, taking into account the soil type, the slope exposure, the composition of the afforestation species, the recorded temperatures and rainfall, it can be said that the forest species planted at the foot of the slopes had an optimal survival percentage and development, similar to those established on the northwestern slopes. However, both in the middle and in the lower third of the slope, optimal values of plant growth were recorded, the survival rate of the species decreased. In addition, on the south-eastern slopes almost, as well as in the upper third of all slopes, the survival rates were lower (in some cases close to zero), and certain species grew inadequately or desolate. Due to the lack of rainfall, the studied area was affected by various disturbing factors (calamities), among which the rodent attack was the most devastating. From November to April, the roots and some of the annual shoots of the trees were gnawed by rodents, while in the spring, the deer came to severely stunt the growth of the young tree, which eventually led to the death of the plant. The turkey oak, a very important forest species with a greater capacity to adapt to extreme conditions, being considered a thermophilic and xerophytic species, did not register a better growth than the sessile oak or the oak. This could be explained by the fact that the turkey oak was used on the slopes, while the other Quercus species were planted in the lower part of the slopes. In addition, Scots pine and sea buckthorn were planted in different species associations on different types of soil, these two had an optimal growth and development, resulting also in a high survival rate. Overall, the results of this research are satisfactory in terms of plant growth and development, but future improvements are still needed to increase their survival rate from 66% to over 90%. In this regard, due to the increasing temperatures in recent years and the increased potential of evapotranspiration, it is recommended to introduce also other species in the studied area, such as black locust (*Robinia pseodoacacia* L.), which can grow and form forest protective curtains for other species such as downy oak (*Quercus pubescens*), sea buckthorn and Scots pine or others, in order to form a forest massif and reach high levels of degraded land improvement.

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