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Review

Paulownia sp. Used as an Energetic Plant, for the Phytoremediation of Soils and in Agroforestry Systems

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Abstract

Paulownia sp. is spread worldwide, being recognized as a 'precious tree' due to its high economic and ecological value. The products obtained from the leaves, skin, branches and flowers of *Paulownia* sp. are used in various forms of therapy both internally and externally, in countries such as China or Japan this plant bearing special significance since ancient times. At present, *Paulownia* sp. bears a particular economic importance, the demand for wood being very high. Its cultivation is highly advantageous in comparison with other crops as it can be used in its entirety, from root to seed. However, few consumers are aware of the real energetic, therapeutic and economic importance of *Paulownia* sp. This is a high productivity crop and the selling price across European markets is highly attractive. In addition, this tree contributes to the preservation of ecological balance and the environment. The paper is a research paper and presents the results of research conducted worldwide on the demands of *Paulownia* sp. crops in regard to the pedoclimatic factors, its uses as an energetic plant and the ecologic benefits of its cultivation, i.e. the phytoremediation of heavy metal polluted soils and salt soils, as well as its use in agroforestry systems. The paper contains data regarding the history and situation of *Paulownia* sp. crops in Romania.

Keywords: *Paulownia sp., energetic plant, phytoremediation, frost, agroforestry system.*

1. Introduction

Paulownia sp. is a decorative tree originating from Asia, where it has been cultivated for approximately 2500 years for wood production purposes, its growth very rapid. The species was introduced in Europe as a garden tree approximately 2000 years ago. Known in Romania as 'the princess' tree', it is characterized by the fastest growth among trees around the world [47, 48].

In Romania, *Paulownia* sp. crops were introduced in 1971. At present, these crops occupy approximately 10000 hectares nationally and 100 hectares across Cluj county. *Paulownia* sp. is mainly used as an energetic plant.

However, its wood can also be used successfully for furniture manufacturing purposes. In fact, *Paulownia* sp. has multiple uses: the skin is used for paint processing, the leaves as fodder, whereas the flowers are used for the preparation of perfumes.

The main issue regarding these crops in our country's conditions is their resistance to low temperatures in winter.

Due to its short fibers, *Paulownia tomentosa* wood is not suitable for paper paste preparation.

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Also, the experiments conducted at the Match Factory in Bucharest indicate that this species is not recommended for the manufacture of matches [36].

The *Paulownia* genus includes 20 species. It originates in southern and eastern Asia, where it occupies an area characterized by a diverse range of zonal climates (from moderate dry mesothermal to moderate wet mesothermal), with minimum temperatures ranging between -19° and +3.9°C. Generally, these trees are highly resistant to stress factors and feature a luxurious globular crown and large opposite cordiform leaves. Some species grow so rapidly, from 3 to 5 meters within one year. They can live for up to 70-100 years, thus exceptional among such rapidly growing trees. According to the Cronquist classification (1981), the *Paulownia* genus belongs to the *Scrophulariaceae* family, whereas according to the APG III phylogenetic classification (2009), it belongs to the *Paulowniaceae* family.

In 1835, the genus was described by Bavarian botanist Philipp Franz von Siebold (1796-1866) and by Joseph Gerhard Zuccarini (1797-1848) [44].

1. The cultivation of *Paulownia* sp. in Romania and worldwide

Paulownia sp. trees were cultivated in China, Laos and Vietnam and on a large scale, in other parts of eastern Asia too, particularly in Japan and Korea. It is estimated that at present, *Paulownia* sp. crops occupy 2.5 million hectares of the agricultural land in China, providing approximately 10 million cube meters of wood every year. Published by Chu in 1049 AD, *A Monography on Paulownia* is one of the major papers of ancient times [7].

Collecting and sorting historical data from the times preceding the Northern Song dynasty, the paper presents the modes of cultivation and uses of *Paulownia* sp. wood.

In addition, the book provides details regarding the taxonomy, morphology and plantation of *Paulownia* sp. trees for forestation purposes, information regarding the breeding, tending and management of *Paulownia* sp. saplings and details regarding the characteristics of *Paulownia* sp. wood, respectively.

Figure 1. *Paulownia tomentosa* flower, China [42]

Paulownia sp. was introduced in Europe in the early 1800’s via Dutch East India. In mid XIXth century, it spreads across the entire Italian and Spanish territories, being recognized for its ornamental qualities and its special wood, its flexibility and density similar to those of aluminum [10].In Romania, *Paulownia* sp. crops were introduced in 1971. Research on *Paulownia tomentosa* cropping was conducted between 1984 and 1986, as part of a complex theme on the introduction and extension of cropping among forest species bearing a special industrial interest and producing wood for special uses. The research aimed to increase our raw stock resources and reduce their import by cropping certain exotic woody plant species that can adapt to our pedoclimatic conditions on limited judiciously selected surfaces [36]. Stefanesti Forest Research and Management Institute (I.C.A.S.) Station have conducted work on the production of *Paulownia* sp. saplings since 1971. In 1973, the thick *Paulownia* sp. crops set up for vegetal biomass production purposes produced increases by 75 cube meters per year per hectare in irrigation conditions and 63 cube meters per year per hectare in non-irrigation conditions. We note that these production levels were reached in the third year of planting, in the context of the sprouts being fully destroyed by frost in the first two years of planting.

Experimental crops containing saplings produced at Stefanesti were also set up at five forestries (i.e. Baia Mare, Tauti-Magherus, Tismana, Simian and Braila). In Tismana, Braila and Tauti-Magherus, the planted saplings froze and disappeared entirely. In the other forestries, the crops endured partially.

Another thick crop was set up for biomass production purposes in Baragan in 1979 to be exploited until 1981.

After four years of planting, the trees reached an average height of 6.15 meters and an average diameter of 7.72 centimeters. The vegetation was inappropriate, presenting drying phenomena due to its sensitivity to low temperatures in winter and limited rainfall in summer [36].

In 1990, approximately 500 *Paulownia* sp. samples were accounted to have survived in the pedoclimatic conditions of the cropped areas across Romania. Most of the trees were less than 30 years old, their height above 15-16 meters only in exceptional conditions, an elongation of the trunks of 6-7 meters and their diameters below 40-58 centimeters. The largest part of the samples presented irregular crowns, fissures and other forms of trunk damage, which reveals their particular sensitivity to low temperatures [36]. Around 2000, *Paulownia* sp. crops began to spread more widely in our country too. At present, these crops occupy approximately 10000 hectares nationally and 100 hectares across Cluj county.

Figure 2. *Paulownia* sp. crop in Samboleni, Cluj County (Original)

In our country, the species presenting the highest adaptability to climate and soil conditions are the following: *Paulownia shang tong*, *Paulownia elongata*, *Paulownia arctic* and *Paulownia cotevisa.*

Paulownia sp. and its hybrid varieties have been in the attention of researchers and specialists over the last years for genetic improvement purposes.

Generally, species such as *Paulownia cotevisa, Paulownia elongata, Paulownia shang tong* or *Paulownia arctic* present a better growth than other species, while also more adaptable to a variety of soils and climates.

Research indicates that the introduction of *Paulownia* sp. forest crops has been accompanied by risks similar to those associated with the species encountered in temperate climates. These crops should be set up within the limits of favorable areas, taking into consideration the local meteorological factors and the nutritional demands of the species. Therefore, ecological zoning and microzoning is required within the territory of Romania.

The main issue these crops raise in our country's conditions is their sensitivity to low temperatures in winter, as well as their high nitrogen demands and their low resistance to dry soils.

As concerns the crops across Romania, the majority of samples present fissures and other forms of trunk damage, which indicate a high sensitivity of this species, particularly to early autumn frost, which usually catches it with the sprouts incompletely lignified. Very frequently, young samples freeze from the ground up, their sprouts however growing vigorously during the following year.

The poor resistance of the non-lignified sprouts to the first autumn frost is another particularity of the species, their stem freezing down to the ground.

In mild winter conditions or if the crops have been covered with leaves or straw, a large part of the roots maintain their vitality and new stems can emerge from the dormant buds in the breast area the following spring.

2. Limiting pedoclimatic factors associated with *Paulownia* sp. crops in Romania

The most significant limiting factors associated with *Paulownia* sp. crops are the temperature, soil and light.

Temperature. Research conducted by Garcia-Morote (2012) in Spain shows us that the resistance of *Paulownia* sp. to low temperatures varies depending on the species. Thus, the most resistant species is *Paulownia arctic*, which can withstand temperatures of approximately -30°C, followed by *Paulownia shang tong* and *Paulownia elongata*, where the temperature can drop down to -20°C and -15°C respectively. *Paulownia fortunei*, *Paulownia australis*, *Paulownia kawakamii* and *Paulownia fargesii* are much more resistant to frost, being able to withstand temperatures ranging between -5°C and -11°C.

The minimum biological threshold of *Paulownia* species is +8°C. In turn, the maximum temperature threshold varies from one species to another. Thus, in some areas of China, growth among *Paulownia tomentosa* samples stops in early September, when the temperatures drop below +20°C. The growth of *Paulownia elongata* stops in early October, when the temperatures drop below +18°C, whereas that of *Paulownia fortunei* may extend to mid-October or even early November.

Rather interesting morphological variations have been observed among the majority of *Paulownia* species.

Thus, inflorescences may emerge outside of the regular blooming period all year round. The formation of buds may begin at the end of summer and continue over autumn and winter, the plant finally blooming at the beginning of the following spring, should the flower buds withstand frost during winter.

Table 1 presents a series of data regarding the ecology and distribution (natural and in crops) of the various *Paulownia* species across China: *Paulownia tomentosa, Paulownia elongata, Paulownia fortunei, Paulownia taiwaniana, Paulownia australis, Paulownia kawakamii.*

Table 1. Ecology and distribution of *Paulownia* sp. across China [3]

Species	Distribution			Temperature			Rainfall		Soil	
	Lat.	Long.	Alt.	Max.	Min.	Mean	Annual (mm)	Dry months	pH	Texture
Paulownia tomentosa	N28-40	E105-128	1500	40°C	-20°C	17-11°C	1500-500	3-9	5-8.5	Light clay-sandy
Paulownia elongata	N28-36	E112-120	1200	40°C	-15°C	17-12°C	1500-600	3-9	5-8.5	Heavy loam-sandy
Paulownia catalpifolia	N32-36	E113-120	800	38°C	-15°C	15-12°C	1300-700	4-8	6-8.0	Light clay-sandy
Paulownia fortunei	N18-30	E105-122	1100	40°C	-10°C	23-15°C	2500-1200	2-3	4.5-7.5	Light clay-sandy
Paulownia taiwaniana	N22-25	E120-122	1000	39°C	2°C	20-23°C	2300-1800	2-3	4.5-7.0	Light clay-sandy
Paulownia albiphloea	N28-30	E100-110	600	41°C	-3°C	18-20°C	900-1400	3-4	4.5-7.5	Medium clay-sandy
Paulownia australis	N22-30	E110-122	700	38°C	-6°C	14-20°C	900-2100	2-3	4.5-7.0	Light clay-sandy
Paulownia kawakamii	N22-30	E110-122	800	38°C	-8°C	14-20°C	1100-2200	2-4	4.5-7.5	Medium clay-sandy
Paulownia fargesii	N23-31	E100-110	2000	34°C	-11°C	13-18°C	1200-1900	1-2	4.5-6.5	Medium clay-sandy

Paulownia sp. crops have been introduced upon ecological zoning, particularly those introduced for agro-forestry intercropping and soil erosion prevention purposes. The altitudes where these crops have been set up vary from 600 meters to 2000 meters. The highest altitudes are withstood by *Pawloana fortunei* (1100 meters), *Paulownia elongata* (1200 meters), *Paulownia tomentosa* (1500 meters) and *Paulownia fargesii* (2000 meters).

According to the table, the temperature ranges withstood by the targeted species are very wide. The ones that stand out from this standpoint are *Paulownia tomentosa* (+60°C), *Paulownia elongata* (+55°C) and *Paulownia catalpifolia* (+53°C), *Paulownia kawakamii* at the other end (+37°C). The maximum temperatures withstood by the studied *Paulownia* species range between +34°C *(Paulownia fargesii)* and +41°C *(Paulownia albiphloea)*. The resistance to low temperatures in winter varies significantly between species. The most resistant from this standpoint are *Paulownia arctic* (-30°C), *Paulownia tomentosa* (-20°C), *Paulownia elongata*, *Paulownia catalpifolia* (-15°C) and *Paulownia fargesii* (-11°C). The following species cannot withstand temperatures below -10°C: *Paulownia kawaianii* (-8°C), *Paulownia australis* (-6°C), *Paulownia albiphloea* (-3°C) and *Paulownia taiwaniana* (+2°C). Insufficiently lignified or poorly developed *Paulownia* sp. saplings present an increased sensitivity to frost, particularly on the sunny side. The root skin presents frost damaged sections. The rot areas are invaded by fungi and the wood is damaged.

The injuries are not necessarily caused by low temperatures, but particularly by the differences between day and night temperatures. The application of soaked lime on the trunk or wrapping it with straw or other vegetal bandages can prove effective in the prevention of front injuries [17].

Rainfall and relative air humidity. *Paulownia* sp. grows both naturally and in crops in areas characterized by rainfall ranging between 500 millimeters and 3000 millimeters. The distribution of rainfall is also significant. Hua et al. (1980) mention that *Paulownia* sp. develops normally in the context of 65% of the annual rainfall being during the massive growth period. In descending order, the *Paulownia* species most resistant to drought are the following: *Paulownia elongata, Paulownia fortunei, Paulownia kawakamii, Paulownia catalpifolia, Paulownia australis* and *Paulownia fargesii.* As regards the relative air humidity, *Paulownia elongata* is the least pretentious.

In the Sha Che province of China, the *Paulownia elongata* crops withstand in conditions of annual rainfall of 41.8 millimeters and a relative air humidity of 52% [41]. The experiments conducted in the Danube Delta by Radu et al. (1977) indicate that the saplings cultivated on low interdunes characterized by excessive ground humidity until June-July disappeared completely since the first year.

Soil. *Paulownia* sp. trees are not sensitive to the edaphic factor and provide good results on sandy and clay-sandy soils, as well as on heavy soils. However, there are certain differences regarding the clay content of the soil, its pH and the depth of the underground water.

The clay content of the soils on which *Paulownia* sp. crops grow varies greatly. *Paulownia arctic* and *Paulownia shang tong* trees grow on soils characterized by a clay content ranging between 16.25% and 23.49%, whereas the trees belonging to the rest of the species can be found on soils characterized by a clay content below 10% [4].

The largest part of *Paulownia* species are characterized by deep roots and well-developed lateral roots. The extension of the root system requires not only suitable hydration and temperature conditions, but also deep moist well-aerated soils. *Paulownia* sp. trees require a total soil porosity above 50%. As regards soils with excess clay content, the species presenting the best behavior in these conditions are *Paulownia fortunei* and *Paulownia tomentosa* [36].

Paulownia sp. trees are sensitive to both the depth of the underground water and the soil salinity. Generally, the depth of the underground water must not exceed 1.5 meters, a water stagnation period longer than 3-4 days potentially proving lethal to the plants. A soil salinity above 1% affects the growth of the trees significantly. The soil pH content and tolerance vary depending on the species, as follows: *Paulownia elongata* and *Paulownia tomentosa* between 5.0 and 8.9 and *Paulownia fargesii, Paulownia albiphloea* between 5.6 and 6.0. *Paulownia fortunei* trees can reach an average diameter growth threshold ranging between 3.6 centimeters and 4.2 centimeters on acid soils, presenting however good growth on soils with a pH content above 8.0 too. *Paulownia elongata* and *Paulownia tomentosa* present good growth on an even greater variety of soils. *Paulownia* sp. trees can absorb calcium and magnesium from the soil selectively [42].

Research conducted in Romania by Radu et al. (1977) demonstrates that *Paulownia tomentosa* is demanding as regards the nitrogen content of the soil, highly demanding as regards its calcium content and little demanding as regards the phosphorus and potassium content. Despite the demands of this species being similar to those of locust trees, *Paulownia* sp. presents the disadvantage of not being able to use nitrogen-fixing bacteria to meet its nitrogen demands.

Light. *Paulownia* sp. trees produce distinct dispersed branches and leaves, allowing light penetration. A slight shade on one of the lateral sides can distort the shape of the tree partially or totally. According to the experiments conducted on *Paulownia* sp. saplings, a 70% shade can affect the plants severely, which confirms the preference of this tree for strong light conditions. Therefore, mixing it with other fast growing trees and the presence of taller trees in its proximity are not recommended.

3. The exploitation of *Paulownia* sp. as an energetic plant

The growing speed of this tree is impressive, a plant purchased from the nursery being able to reach a growth of over 2 meters in the first year. In the following years, the trunk can grow in diameter by approximately 4-5 centimeters yearly. After 10 years, the plant can be considered an adult plant, reaching a height of approximately 10-12 meters. At 25 years of age, the plant reaches its maximum size and shape. In the Kweichan province of China, there are 80-year-old *Paulownia fortunei* samples that measure 49.5 meters in height, 202 centimeters in diameter and produce a timber volume of 34 cube meters [17].

Table 2 points out to *Paulownia elongata* being the species registering the fastest growth over a 10-year period.

Table 2. Growth of various *Paulownia* sp. trees over a 10-year period [4]

Species	Diameter at breast height (cm)		Height (m)		Timber volume	
	Average	Annual increment	Average	Annual increment	Average (cube meters)	Growth index (%) (*Paulownia glabrata* = 100)
Paulownia elongata	39.6	4.0	13.2	1.3	0.6232	306
Paulownia catalpifolia	25.0	2.5	11.5	1.2	0.2996	148
Paulownia tomentosa	28.1	2.8	10.2	1.0	0.2426	120
Paulownia glabrata	27.3	2.7	9.9	1.0	0.2020	100

The wood obtained from *Paulownia* sp. trees is the lightest hardwood, it is very resistant, but aesthetic too (fine texture, no nodes).

It is used industrially for the manufacture of musical instruments, fine furniture, yachts, light planes and surfing crafts, 99.9% biodegradable [2].

According to an assessment performed on *Paulownia* sp. wood, its composition is the following: 14.0% - extractable substances, 50.55% cellulose, 21.36% lignin, 0.49% ash, 13.6% semi-cellulose.

According to research conducted within the Fort Valley State University (FVSU), the amount of *Paulownia elongata* biomass that can be harvested after a period of 30 months (i.e. at the end of three growing seasons) is of approximately 92 kilograms per tree.

In favorable conditions, upon intensive planting of 2000 trees per hectare, the yearly production can reach 150-300 tons of wood after a period of only 5-7 years of planting [24].

Two thirds of the mass of a tree can be used for timber, whereas a third (i.e. waste) can be used as biomass in factories using gasification for green energy production [15]. One kilogram of dry wood material has got an energy value of approximately 4500 kilocalories (18830 kilojoules), thus very high even in comparison with the quality wood types (Table 3).

Tabble 3.The relationship between the energy value of the fuel and the moisture levels in the wood [24]

Wood species	Energy value per kilogram		
	Kcal	KJ	Kilowatts-hour
Paulownia sp.	4500	18830	5.5
Spruce	3900	16250	4.5
Pine	3800	15800	4.4
Birch	3750	15500	4.3
Oak	3600	15100	4.2
Beech	3450	14400	4.0

All the plant organs of *Paulownia* sp. can be used: the stem, mass leaves, branches. *Paulownia* sp. biomass is suitable for silage (therefore, as animal food) and also for numerous other uses, for instance as material for alternative renewable energy sources.

One of the most promising applications is bioethanol, contained in cellulose [20]. In addition, *Paulownia* sp. is cultivated as a biofuel source, thus constituting a significant step toward the resolution of the global energy crisis. Naturally, these trees regenerate from the existing root system, thus earning, and deservedly so, the name of 'Phoenix tree'. Thus, 3-5 rotations of growth wood can be obtained without replanting being necessary. Therefore, *Paulownia* sp. plantations can make a significant contribution to the capture of oxygen from the atmosphere.

To increase biomass production, Lopez et al. (2012) recommend the use of *Paulownia* sp. hybrid varieties. Thus, in the case of the *Paulownia elongata* x *Paulownia fortunei* x *Paulownia tomentosa* trihybrid, obtained by *in vitro* replication, 50 tons of biomass/hectare/year have been obtained, an average length of the fiber of 0.97 millimeters – similar to that of hardwood *(Eucalyptus globulus)*. The same hybrid is characterized by a much lower ash content (8.9 grams/kilogram) and a much higher cellulose content (440 grams/kilogram) than other *Paulownia* species and energetic crops. Also, as compared to the poplar and the willow, the *Paulownia elongata* x *Paulownia fortunei* x *Paulownia tomentosa* trihybrid has got a much lower sulfur and nitrogen content, of 0% and 0.21% respectively. The energy value of the *Paulownia elongata* x *Paulownia fortunei* x *Paulownia tomentosa* wood is of 20.3 macro joules/kilogram, therefore much higher than that of hardwood and slightly higher than that of *Pinus piraster* or softwood [24].

Dominguez et al. (2007) are conducting research on the most effective preliminary autohydrolysis treatments for bioethanol production from *Paulownia tomentosa* wood and demonstrate the feasibility of the biomass of this species as an energetic crop [8].

Paulownia sp. leaves can constitute a potential source of energy in the shape of biogas. Popova et al. (2014) identify differences between the different species and hybrids from this standpoint [32]. Thus, the amount of microorganisms in fresh material is larger in *Paulownia kawakamii* and the *Paulownia* sp. hybrid than in *Paulownia elongata* and *Paulownia shang tong.*

4. The use of *Paulownia* sp. for the phytoremediation of contaminated soils

The use of phytoremediation, both in pilot experiments and in vast experimental fields, has proved to represent a technology of the future, firstly due to its reduced costs, aesthetic advantage and long-term applicability. Phytoremediation is very useful for the decontamination of lands where, practically, no other remediation methods are applicable or feasible from an economic standpoint. In the case of heavy metals, the plants have proved an ability to phytoextract (i.e. absorb and determine contaminants in the above-ground biomass of plants), filter metals in the water via the root system (i.e. rhizofiltration) or stabilize contaminated sites against erosion and water loos through evapotranspiration.

The decontamination of soils using plants involves two main steps: phytostabilization (immobilization of heavy metals in soil or roots) and phytoextraction (absorption and translocation of pollutants from the roots to the above-ground part of the plants) [34].

The experiments conducted by Doumet et al. (2008) in Italy indicate the very high tolerance of *Paulownia* sp. to heavy metal concentrations in hydroponic crops. The authors consider this species to be highly suitable for the phytoremediation of heavy metal contaminated soils. Moreover, it is lucrative commercially as it can be used as biofuel and is characterized by a fast growing speed, a deep root system, large biomass production and stress tolerance. The solubilization of heavy metals in soil can be improved by adding complexing agents (APCA, NTA, EDDS, HEDTA, HEIDA), which improve the translocation of heavy metals from the soil to the plant [18, 6, 25]. However, Doumet et al. (2008) draw attention to the toxicity of these agents to the plants and microorganisms in the soil, therefore recommending the use of natural easily biodegradable less phytotoxic molecules. Specialized literature also mentions other authors who have confirmed the heavy metal resistance of *Paulownia* sp. [11, 12, 38, 40].

Zinc is a heavy metal and plays an essential role in the metabolism of plants. In soil, it can be found in concentrations of 30-150 units per million [31]. On the other hand, in the proximity of zinc pits and retting pits, the concentrations can reach up to 955 units per million.

Di Baccio et al. (2003) and Kramer (2005) demonstrate the negative effects of a high zinc content on the photosynthetic parameters in plants [19, 29]. On the other hand, Azzarello et al. (2012) emphasize the ability of *Paulownia tomentosa* plants to absorb and capture zinc from the soil [3]. Electron microscopy analyses show that the toxic effect of zinc can be reduced by eliminating the heavy metal excess via the exudates found on the leaf stalks and root veins. Apart from their zinc tolerance, *Paulownia* sp. plants also have the advantage of their ability to eliminate pollutants due to their rapid growth. In addition, the roots allow a deep exploration of the soil. Researchers have not yet succeeded in explaining the physiological mechanisms around heavy metal accumulation in plants. Stefanov et al. (2016) noticed the efficient remediation of salt soils by *Paulownia* sp. crops. However, they observed a variable sensitivity to this factor of the different species and hybrids.

Thus, *Paulownia tomentosa* x *Paulownia fortunei* presents a higher soil salinity tolerance than *Paulownia elongata* x *Paulownia elongata*. Excess soil salinity causes the reduction of the chlorophyll and carotenoids content of the plant as a result of osmotic stress. In conclusion, the authors recommend the two lines for the remediation of salt soils. The issue of these soils is extremely important in the context of their occupying 20% of the Earth's cultivated lands [42].

5. The use of *Paulownia* sp. in agroforestry systems

Agroforestry is a method of increasing the amount of carbon fixed through agriculture where trees are planted within or around cultivated lands and grazing lands. The tree species can generate products (fruit, medicinal products, fuel, timber, etc.), benefit agricultural production (by fixing biological nitrogen, protecting crops or animals against wind, etc.), providing ecosystem services (a habitat for natural crop pollenizers, microclimate improvement). The trees or other perennial plants in agroforestry systems capture and store carbon, improving the carbon content of agricultural facilities [28]. *Paulownia* sp. is recommended for agroforestry crop systems, which are increasingly popular due to their benefits to agriculture, the climate and the environment. Muthuri et al. (2005) intercropped maize with *Paulownia fortune* [29]. The trees reached a height of 8 meters in 5 years, competing with the agricultural crop for their water and light demands. Therefore, the authors reached the conclusion that *Paulownia fortunei* can be used in agroforestry maize crops in semidry areas, yet for a maximum period of 3 years. The phenology of trees in relation to that of plants is also important. In China, Newman et al. (1997) obtained very good results upon studying wheat and *Paulownia* sp. in agroforestry systems [30]. The wheat was sown in autumn, after the fall of *Paulownia* sp. leaves. The trees improved the microclimate and protected the annual crops against strong winds. The growing periods of the two species being different, the water and other resources were used more efficiently. In spring, wheat reaches adulthood, whereas other trees begin their vegetation period. Lu et al. (2015) emphasize the multiple benefits of using *Paulownia* sp. in agroforestry systems: timber production, grazing land protection, soil preservation, erosion prevention, agro-climate improvement [22]. Research conducted by Moreno et al. (2007) in Spain indicates that short rotation plantations are the most suitable for biomass production for energy purposes. *Paulownia* sp. is tolerant to various types of soil and climate conditions and is characterized by a short rotation period [41]. The authors recommend the use of forestry biomass waste (bark, ash) as amendment and ground fertilizer. These can constitute a viable alternative to mineral fertilizers and amendments, while protecting the microbial community of the soil. Majedon et al. (2016) recommend *Paulownia fortunei* for the revegetation of polluted soils in the Mediterranean Sea area, as these soils cannot be used for food production purposes [24].

6. The prospects of *Paulownia* sp. cropping in Romania

The setup of *Paulownia* sp. plantations within the territory of Romania constitutes a challenge for farmers due to the unknown factors raised by the absence of a national cultivation program and their superficial training regarding the principles and risks of setting up a *Paulownia* sp. plantation.

The greatest challenge the Romanian agricultural sector is faced with, particularly the forestry and energy sectors, is the absence of specialized literature explaining the cultivation methods, resistance to climatic factors and disease and pest control in Romania's concrete conditions. Despite scientific records of agricultural practices being available globally, the absence of a coherent program on the cultivation of *Paulownia* sp. trees is noted. Such a tool would be of real help to specialists and farmers operating in this field. Also, a compendium on the cultivation of *Paulownia* sp. in Romania would add value to the academic agricultural world.

4. Conclusions

Paulownia sp. is a woody species of the *Scrophulariaceae* family, which includes 20 species, and originates from southern and eastern Asia; historical research demonstrates that *Paulownia* sp. timber is approximately 2600 years old.

The *Paulownia* genus has its origins in China, is greatly diversified genetically and specifically, reproduces both vegetatively and generatively and grows fast, thus being recommended for forestry planting.

Paulownia sp. is the fastest growing tree in the world, its ecological plasticity is very high, its uses extremely diverse and its benefits to the environment and human health remarkable: energetic plant, agroforestry intercropping, rapid forestation, rehabilitation of tailing ponds, climate improvement, use of its flowers and inflorescences as fodder and fertilizer due to the high nitrogen content, manufacture of furniture and musical instruments, use of its inflorescences and leaves as medicinal plants, production of honey from the very rich flowers of the tree.

In Romania, the first *Paulownia* sp. plantations were introduced in 1971; in 1990, five hundred samples were taken account of within the entire territory of Romania; at present, the surface cultivated with *Paulownia* sp. Reaches 10.000 hectares.

The energy value of *Paulownia* sp. wood is of 18.83 macro joules/kilogram, much superior to that of other woody species or even to low-rank coals (peat: 6.28-14.65 macro joules/kilogram; lignite: 5.02-10.47 macro joules/kilogram).

Paulownia sp. can be used successfully for the phytoremediation of heavy metal contaminated soils and salt soils.

Paulownia sp. is recommended for agroforestry crops in semidry areas.Farmers' research and experience indicate that frost constitutes the main limiting ecological factor associated with *Paulownia* sp. in Romania; thus, ecological zoning of *Paulownia* sp. species is required in Romania in order to prevent losses caused by this factor.

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