

Black locust stand structure on the sterile dump in the middle basin of Jiu River (Romania)

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ARTICLE INFO

Citation:

Buzatu-Goanță C, Corneanu M, Nețoiu C, Buzatu A, Lăcătușu A-R, Cojocaru L (2020) Black locust stand structure on the sterile dump in the middle basin of Jiu River (Romania). Reforesta 9:9-18. DOI:<https://dx.doi.org/10.21750/REFOR.9.02.76>

Editor: Jovana Devetaković, Serbia

Received: 2019-30-06

Accepted: 2020-03-05

Published: 2020-06-30



Abstract

Introduced in 1750 as an ornamental tree and then in 1852 as a forest tree species, black locust occupied nowadays 250,000 ha in Romania. The tree species is important for its wood (lumber, poles, firewood, etc.), its honey-related production as well as its environmental role (afforestation of sand dunes and sterile dumps).

One of the most important activities in the middle basin of Jiu River is coal mining. After 1956 this activity has developed very quickly and two power plants were built in Rovinari and Turceni. As a result, sterile dumps and coal ash dumps have established so it was necessary to restore the area by afforestation. This activity started with the sterile dump Viaduct Rovinari, using Austrian pine and black locust, and continued with others such as Cocoreni and Moi. The most used tree species for ecological restoration was black locust. In order to express the stand structure, diameter at breast height (DBH), total height (H) and crown diameter were measured. The soil analysis were performed and showed differences in the content of heavy metals and radionuclides for both location. The study revealed positive correlations between DBH and H, a stronger one for Moi plantation. Our research highlights the capacity of black locust to establish and grow under very difficult site conditions.

Keywords

Black locust; Restoration; Stand structure sterile dump

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1 Introduction

Black locust (*Robinia pseudoacacia* L.) is one of the most important non-native tree species, not only for its ornamental role but also for its wood (used for lumber, poles, firewood etc.), its honey-related production as well as its environmental role (especially afforestation of sand dunes and sterile dumps).

The species was introduced in Romania in 1750 as an ornamental tree and first black locust plantation was established on sand dunes, at Băilesti (Oltenia Region – south-west of the country), in 1852 (Stănescu 1979). As a consequence of good results under those initial conditions, an important black locust nursery was established in Piscu-Tunari and Ciuperceni, in 1884 (Cârnu-Munteanu 1888). Even in its native range, black locust grows in a humid climate, in Romania, black locust is very drought tolerant (Roșu 1996). Black locust grows best on deep, nutrient-rich soil but tolerates dry and nutrient poor soils (Hararlamb 1967) The species was used on different site conditions because their assumed low ecological requirements and initial fast growth (Haralamb 1967).

The area occupied by black locust stands in Romania has increased from 28.000 ha in 1922 to 90,000 ha in 1960; nowadays the species covers over 250,000 ha (ca. 4% of Romanian forestland), (Șofletea and Curtu 2007; Enescu and Dănescu 2015). Black locust has been used mostly for sandy soil and sterile dump afforestation. In this respect, a good example is the afforestation work carried out on the sterile dumps (very heterogeneous, with no humus but a small amount of clay and organic material) from the middle basin of Jiu River. In that area, the exploitation of coal (lignite) started after 1960, with multiple economic, social, cultural but especially ecological changes. The use of agricultural and forest land has been changed, villages and routes have been relocated, water courses were diverted and new economic, social and cultural objectives were built throughout the area (Huidu and Ianc 2002).

The forest cover in Rovinari and Motru Basin was originally covered by oak and beech stands, specific to the hilly area of Oltenia. There are eight forest management units in the middle basin of Jiu River, covering an area over 13,000 ha. 5,000 ha of these forests provide ecosystem services such as water regulation, erosion and pollution control and also have an important scientific role (Nețoiu et al. 2011).

Although it represents a small amount (5%), plantations established on degraded lands in the area are very important for reforesting some of the areas lost as a result of coal mining activities (Nețoiu et al 2011). First plantation was established on sterile dump Viaduct-Rovinari in 1979, using Austrian pine (*Pinus nigra* Arn.) and black locust (*Robinia pseudoacacia* L.). In the first three growing seasons, dead seedlings were replaced with other tree species such as sessile oak (*Quercus petraea* (Matt. Liebl.), Turkey oak (*Quercus cerris* L), common ash (*Fraxinus excelsior* L.), wild cherry (*Prunus avium* L.), crab apple (*Malus sylvestris* Mill.), wild pear (*Pyrus pyraster* (L.) Burgsd.), honey locust (*Gleditsia triacanthos* L.).

The planting technology was the classical one: shallow soil preparation (80 x 60 x 15 cm area), followed by planting bare root seedlings in 30 x 30 x 30 cm pits dug manually. In that way, more than 1,000 ha of black locust stands have been established on different sterile dumps: Moi, Cororeni, Fârtățești, etc.

The stands established artificially on sterile dump have only one or two tree species in their species composition. A good example is the sterile dumps afforested in the area of forest districts Târgu-Jiu, Peșteana, Motru, Hurezani and Cărbunești,

between 1979 and 2002; in here black locust was used almost exclusively (over 90 % of species composition), (Naiche et al. 2002).

Taking into account this situation, the aim of our study is to highlight the restoration potential of black locust in the middle basin of Jiu River, an area with large-scale coal mining activities.

2 Materials and methods

2.1 Study area and stand characteristics

Two areas on sterile dumps have been considered in this study: Cocoreni and Moi, where black locust plantations were established. They are both composed of a non-uniform mixture of vegetal soil, gravel, coarse sand, clay, and coal that developed a microrelief with wide variety. There are differences regarding the constitutive nature of these dumps. In Cocoreni location prevail gravel (60 -70%), coarse sand (10-20%), clay (under 10%), while in Moi there is a balanced mixture of sand, gravel and clay with coal waste (Rosu et al, 2002), with a higher capacity for water retention than Cocoreni. In these circumstances there is a difference between the two locations, in terms of favourability for productive potential of forest species.

The sterile dump Cocoreni is located at 44°48'26" N lat, 23°18'31" E long and 164 m elevation. Source of air pollution are: in North, between villages Olari and Cocoreni a coal deposit and in South and active coal surface exploitation. The sterile dump Moi is located at 44°54'29"N lat, 23°10'37" E long and 211 m elevation. Source of air pollution are: in North an active coal exploitation and an active ash pit, as well as a closed one and in East ThermoElectric Power Plant (TEPP) Rovinari (Figure 1).

The climate, according to Köppen's classification system, is C.f.b.x., (temperate oceanic climate; coldest month averaging above 0 °C, all months with average temperatures below 22 °C, and at least four months averaging above 10 °C. Maximum of precipitation at the beginning of the summer and the minimum at the end of the winter) with a mean annual temperature of 10.2°C, maximum absolute temperature at soil level of 65.7°C, and minimum absolute temperature at soil level of - 33.5°C. Mean annual rainfall is 762 mm and the growing season comprises 160–180 days (Management Plan of Forest District Peșteana, 2000).

The fieldwork was carried out in two black locust plantations, 14 years old (Cocoreni) and 17 years old (Moi). They are both artificially regenerated using root bare seedlings with a 2 x 1 m spacing (5,000 seedlings ha⁻¹). Immediately after planting, all seedlings were cut 1-2 cm above the soil level in order to reduce transpiration and improve root to stem ratio. Only mowing around the seedling were made in the first two growing seasons. No other management operations were applied.

2.2 Soil analysis

Soil samples (3 for each location) were collected from top soil (0-20 cm). The heavy metals analysis was performed in National Research and Development Institute for Soil Science, Agrochemistry and Environment Protection Bucharest, Romania. The amount of heavy metals in soil (expressed in mg x kg soil⁻¹) was determined using flame atomic mass spectrometry method (Lăcătușu et al. 2011). Radionuclides activity

was performed in Radioactivity Monitoring Station, Environment Protection Agency Craiova, Dolj, Romania. Radionuclides activity was determined by the Duggan method (Duggan 1988); IAEA TECDOC 1092 directives), with a gamma spectrometry system, analyzer SPECTRUM-MASTER-ADCAM, model 92X. Analysis was also performed for ash and coal dust.



Figure 1. Geographical location of sterile dumps Cocoreni (above) and Moi (below).

2.3 Fieldwork and statistical analyses

Structural characteristics of the stand were analysed in a 20 x 20 m plot (Cocoreni) and 20 x 26 m plot (Moi) where a full inventory was conducted. Plot dimensions were chosen according with the stand shape. Several measurements were performed: (i) horizontal location (x, y- orthogonal method) of each tree, using measuring tape, the seedlings were planting on a 2 x 1 m design; (ii) diameter at breast height using Haglöf Sweden AB aluminium tree callipers with a precision of 1 mm; (iii) total height using Suunto hypsometer with a precision of 0.5 m; (iv) crown diameter with a tape ruler with a precision of 0.5 m.

The gamma distribution was used for the diameter at breast height and total height, and their values were estimated. Fit tests, the chi-square, Kolmogorov-Smirnov and Lilliefors tests, were used (Sheykholeslami 2011). SilvaStat programme were used for the statistical analyses.

3 Results and discussion

Due to the constitutive differentiation of the two waste dumps, the analyses revealed differences in the content of heavy metals (Table 1) and radionuclides (Table 2). Normal soil contents (Anonymous 1997) were exceeded for Cu, Ni, Pb, Cd. Values close to the minimum alert threshold were recorded for Pb only. The highest values were recorded in the Cocoreni samples. Heavy metals, in small quantities, stimulate the metabolic activity of living cells, acting as catalysts. Over certain limits, heavy metals, that penetrate the cells, induce toxic effects: inhibit the activity of the most enzymes, affect the mineral nutrition and water balance, induce changes in phytohormones activity, affect the membrane structure, a.o. (Seregin et al. 2004; Yakhin et al. 2009; Corneanu et al. 2009), ultimately inducing plant debilitation.

Table 1. The amount of heavy metals in topsoil (0-20 cm level) and bottom ash (mg kg⁻¹ soil) (with bold, the values over normal content in soil in Romania).

Heavy metal	Cocoreni waste dump	Moi waste dump	Normal soil content	Alert limits	Bottom ash
Zn	148.0±10.1	72.9±6.1	100	300 – 700	63.0±5.9
Cu	23.3±1.9	23.3±2.2	20	100 – 250	19.0±1.7
Fe	23,719±2.192	31,801±2.934	NA	*	25,004±2.325
Mn	341±32.4	587±56.3	900	1500 – 2000	252±22.6
Pb	47.6±4.5	42.2±4.1	20	50 – 250	2.53±0.2
Ni	20.3±1.8	34.9±3.2	20	75 – 200	50.0±4.8
Cr	14.9±1.3	20.5±1.9	30	100 – 300	20.0±1.9
Co	14.7±1.3	10.36±1.1	NA	*	7.38±0.8
Cd	1.38±0.1	1.60±0.1	1.0	3.0 – 5.0	0.154±0.01

The coal, as any ore, containing a discrete amount of primordial radionuclides, naturally occurring, such as K-40, U-238, U-235, Th-232, Ra-226. By surface coal exploitation, there is a redistribution of natural radionuclides concentration and a change in environmental radioactivity (Lăcătușu et al. 2011).

Radionuclides determined in soil samples are part of the natural series, K-40 and Cs-137, of Chernobyl origin. The result of the analysis of the radionuclides activity revealed value far above normal levels in sterile samples collected from Cocoreni. In case of Moi samples, there were exceedances of the limits only for U-238, Pb-210 and U-235.

Table 2. Radionuclides activity in topsoil (0-20 cm level), bottom ash and coal dust (Bq*kg⁻¹ dry mass) (with bold, the values over the limit for Romania).

Radionuclide	Cocoreni sterile dump	Moi sterile dump	Limits for Romania	Ash Pit Rovinari	Coal dust
U-238/Th-234	55.1± 6.25	28.4± 3.35	25.0	163.6± 17.50	< 10.5
Ra-226	40.1± 1.69	20.1 ±1.70	10 – 90	229.5± 5.1	19.1 ± 1.75
Pb-210	82.3± 5.00	44.4±1.29	20 – 40	151.1± 8.42	0
Bi-214	72.4 ± 5.0	17.2±1.71	20 – 40	117.1± 4.00	23.5 ± 1.91
Pb-214	43.3± 1.70	23.6±1.56	20 – 40	142.0± 5.35	14.8 ± 1.28
U-235	4.79± 1.90	2.77±1.3	2.0	8.99± 1.73	2.18 ± 1.83
Ac-228/Th232	37.2± 2.63	25.4±2.06	13 – 65	88.4±5.14	19.10 ± 1.72
Pb-212	148.9± 1.61	26.6±0.93	20 – 50	137.8± 4.86	0
K-40	585.6± 36.9	347.4± 20.5	330 – 800	519.2± 40.9	< 43.0
Cs-137	93.4± 4.00	< 1.9	0	77.5± 3.5	< 1.9

The results suggest that one of the main causes of the status of the Cocoreni stands is the high load in the radionuclide of the sterile, from which the dump is formed, as well as the vicinity of the coal deposit and active coal exploitation (sources of coal dust).

The study of the trees biometrical and stand structural characteristics of the two previously established plantations showed the existence of a spatial relationship between trees.

The comparison of biometrical characteristics (Table 3) with the values from Romanian yield tables (Table 4) show, for both plantation, a mean height close to yield table III and a quadratic mean diameter (QMD) close to yield class II value but a lower basal area, probably because of the low stocking. For plantation Moi, the value of QMD is found between yield classes III and IV, with a higher basal area in accordance with the higher stocking.

Table 3. Biometrical characteristics in the two plantations.

Sterile dump	Age (years)	No. of trees per ha	Mean height (m)	Quadratic mean diameter (cm)	Basal area (m ² ha ⁻¹)
Cocoreni	14	1,150	13.68	13.24	15.83
Moi	17	1,885	14.92	11.65	20.07

The value of mean height is quite similar with dimension registered in reforestation made on spoil bank in Poland (Pajak et al. 2004).

In absence of any management operation, the number of trees in Cocoreni plantation is a result of a lower survival rate in difficult environmental condition.

Black locust plantation established on sterile dump Cocoreni showed a small variation in terms of diameter at breast height and total height (Table 5).

The average diameter at breast height was 13.01 cm, with a 19.08% coefficient of variation for Cocoreni population, and 11.91 cm, with a 31.67% coefficient of variation, for Moi population. These differences are explained by the wider space between trees and an unclosed canopy in the first case and a much closer one in the second one (Figure 2). In terms of tree height, the results are quite similar.

Table 4. Biometrical characteristics for black locust plantations – mean values (Giurgiu and Drăghiciu 2004).

Yield class	Age (years)	No. of trees per ha	Mean height (m)	Quadratic mean diameter (cm)	Basal area (m ² ha ⁻¹)
I	14	1,222	18.7	16.1	24.8
	17	1,015	21.2	19.5	28.4
II	14	1,447	15.6	13.5	20.8
	17	1,222	17.8	15.8	23.8
III	14	1,736	12.6	11.0	16.4
	17	1,478	14.5	12.8	19.2
IV	14	NA	9.6	8.4	12.1
	17	NA	11.1	10.0	14.2
V	14	NA	6.6	5.9	8.0
	17	NA	7.8	7.0	9.5

Table 5. Statistical parameters of biometric characteristics of black locust populations from sterile dumps Cocoreni and Moi.

Statistical parameters	Cocoreni		Moi	
	Diameter at breast height (cm)	Total height (m)	Diameter at breast height (cm)	Total height (m)
Minimum	9.6	11	4.1	5
Maximum	19.7	18	20.7	20
Amplitude	10.1	7	16.6	15
Sample Average	13,01	13.68	11.91	14.92
Sample Variance	6.16	2.44	14.23	19.79
Sample Standard deviation	2.48	1.56	3.77	4.44
Sample Coefficient of variation (%)	19.08	11.4	31.67	29.80
Standard error of the mean	0.36	0.23	0.38	0.44
skewness coefficient (A)	0.37	0.28	0.12	-0.89
kurtosis coefficient (E)	-0.61	0.11	-0.42	-0.57

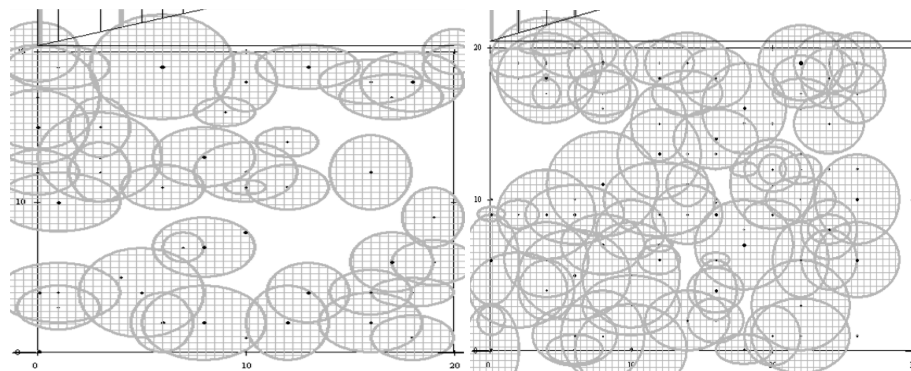


Figure 2. Horizontal projection of trees in plantations Cocoreni (left) and Moi (right).

Plantation Cocoreni presents a positive left asymmetry for both characteristics, diameter and height whereas Moi plantation shows a positive asymmetry for diameter at breast height and a negative one for total height, specific for even-aged stand.

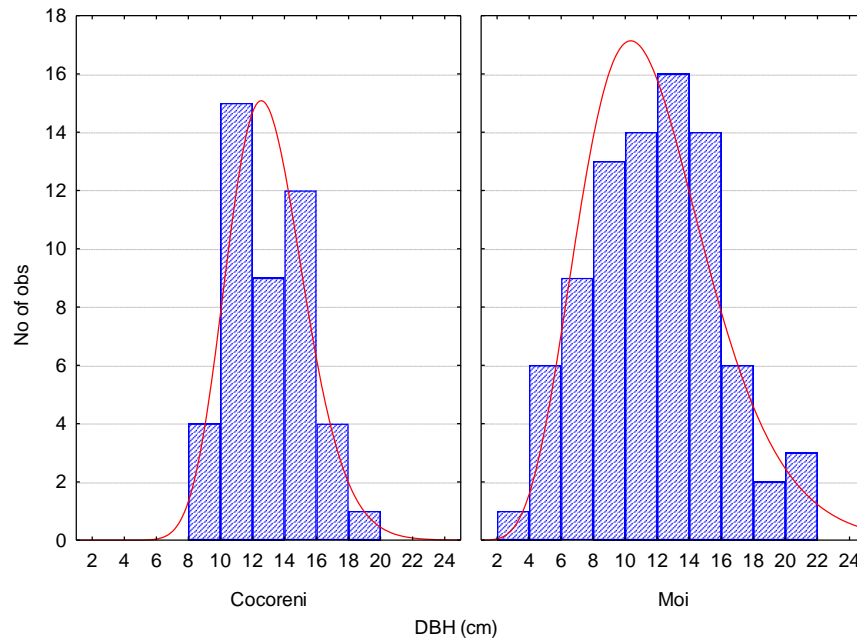


Figure 3. Experimental and theoretical gamma distribution in plantations Cocoreni and Moi.

In order to express the tree distribution according with diameter at breast height and total height, gamma distribution was used (Figure 3). The Fit tests showed that this distribution fits very well the experimental one (Table 6).

Table 6. Results of Fit tests of experimental distribution of diameter at breast height and height using the theoretical distribution gamma.

	Diameter at breast height		Height	
	Experimental value	Theoretical value (p=0,05)	Experimental value	Theoretical value (p=0,05)
Cocoreni plantation				
Chi2	0.981	9.488	1.752	7.815
Kolmogorov -Smirnov	0.080	0.567	0.066	0.516
Lilliefors	0.080	0.343	0.066	0.317
Moi plantation				
Chi2	1.485	14.067	9.319	14.067
Kolmogorov -Smirnov	0.053	0.405	0.094	0.405
Lilliefors	0.053	0.260	0.094	0.260

In terms of DBH and H relationship, the results are showed in fig. 4.

The correlation between DBH and H (r-values) are significant at p 0.05 for both plantations, higher in Moi than Cocoreni plantation. The same trend is observed for coefficient of determination which is lower for Cocoreni plantations ($R^2=0.405$) than for Moi plantation ($R^2=0.79$).

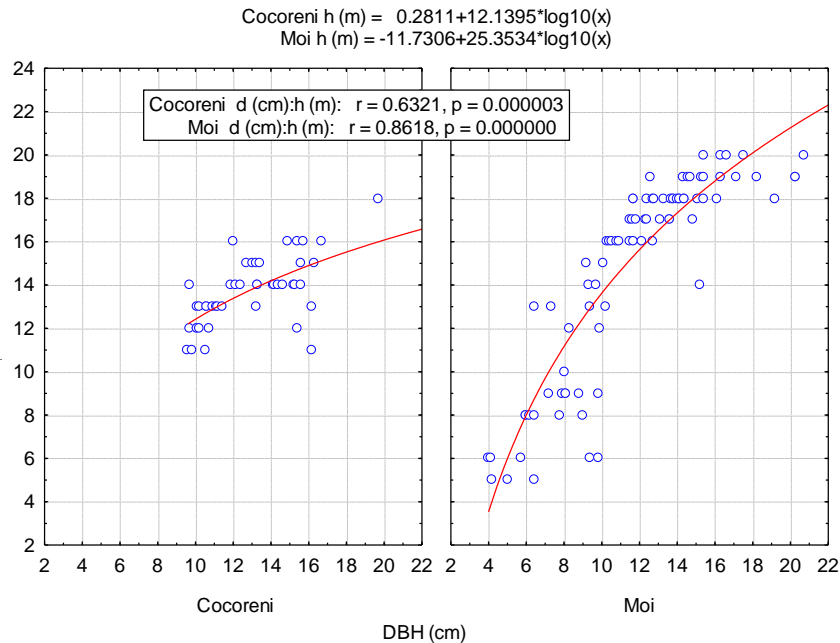


Figure 4. Relationship between DBH and H in plantation Cocoreni (left) and Moi (right).

4 Conclusions

The development of black locust plantation taken in the study is directly dependent on soil quality. Significant quantities of heavy metals and radionuclides reach the surface of the soil, due to the mining and energy industries based on fossil fuels (coal). The sterile dumps and ash deposits of TEPP are permanent pollution sources for air, water and soil. Analyzes of sterile pollutants (heavy metals and radionuclides) as well as additional sources of pollution (ash, coal dust) were interpreted by comparing the values recorded with the values in the literature (normal content, alert thresholds, thresholds intervention).

Both plantations established on sterile dumps presented different statistical parameters. In the case of Cocoreni plantation, the DBH is higher than in Moi plantation, even the age and stocking are lower. Regarding plantation Moi, the left DBH asymmetry and right H asymmetry as well as a much better correlation between these two characteristics showed that this plantation has a structure closed to the normal stand.

However, it is important to consider that these plantations have not been established especially for wood production but have a major ecological role to stop dump degradation and to create a better landscape.

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