Regeneration and early tending of black locust (*Robinia pseudoacacia* L.) stands in the north-west of Romania

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Early silviculture of black locust in the north-west of Romania

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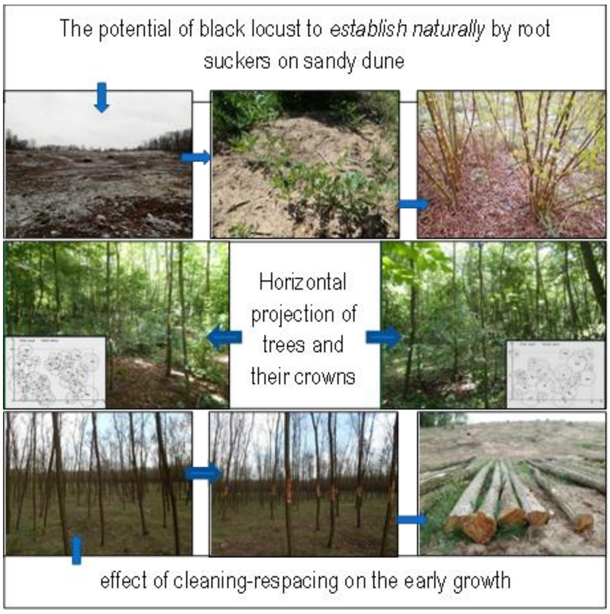
Abstract

Aim: The aim of this study is to highlight the importance of black locust (*Robinia pseudoacacia* L.) on extreme site condition like sand dunes. Aspects of natural regeneration and early results of tending operation in terms of quality, growth and yield of young black locust stand are presented.

Methodology: A Research and Development project was carried out in Carei-Valea lui Mihai Plain (north-west of the country) since 2016. Three management units were selected: pure natural regeneration by root suckers of black locust at different ages (management units 3B and 52A%) and a mixed black locust-black cherry stand (management unit 23D). Biometrical measurements and analyses as well as biomass estimations were performed.

Results: (1) Black locust was established naturally by root suckers and the stocking of newly established stands can be as high as 50,000 suckers ha^{-1}; (2) The initial growth of black locust regeneration is quick and the young regeneration can close the canopy in 1-2 years, resulting in an appropriate dune fixation and wind erosion control; (3) The young pure or mixed black locust-dominated stands are left untended until the first cleaning-respacing (mean diameter 5-6 cm), when the stand shows high stocking/density and a wide variation in tree size. This intervention is *from below*, *heavy* (intensity over 25% by number of trees or basal area) and of *negative selection* type, removing mostly low Kraft class, dead or dying, and defective trees.

Interpretation: The potential of black locust to *establish naturally* by root suckers and their fast initial growth, despite the unfavourable conditions in the case study area, resulted in effective dune stabilization and wind erosion control. The effect of cleaning-respacing on the early growth of this species in pure or mixed stands was outlined.



Keywords black locust, cleaning-respacing, initial growth, regeneration, release cutting

Introduction

Black locust in the world, in Europe and in Romania

Black locust (*Robinia pseudoacacia* L.) originates from the eastern half of the United States, where it is found in two areas, eastern (Pennsylvania, Ohio, Alabama, Georgia and South Carolina states) and western (Missouri, Arkansas, and Oklahoma states) (Huntley, 1990).

Globally black locust has been introduced and became naturalized in all sub-Mediterranean and temperate regions: Asia (i.e. South Korea - over 1.2 million ha; China - over 1 million ha; India, Pakistan, Japan), Australia, New Zealand, Africa (north and south), South America (Argentina, Chile) (Keresztesi, 1988; Luna, 1996; Demené and Merzeau 2007; Șofletea and Curtu 2007; Tu et al. 2007; Cierjacks *et al.*, 2013). Black locust is now rivaling poplar as the second most planted broadleaved tree species in the world, after the eucalypts (Savill, 2013; Rédei, 2013b; Wojda *et al.*, 2015). This expansion worldwide is due to the fact that black locust is an *economically important multipurpose tree*, as wood producer (e.g. firewood, pulpwood, flooring, railway sleepers, boat building, fences, construction, barrel staves, veneer, solid furniture), fodder producer, honey producer, as a source of bio-oil, for biomass production and carbon sequestration, soil stabilization, erosion control, re-vegetation of landfills, mining areas and wastelands, in biotherapy, landscape architecture (Poskin, 1926; Negulescu and Săvulescu 1957; Haralamb, 1967; McAlister, 1971; Stănescu, 1979; Harlow *et al.*, 1986; Gilman and Watson 1994; Luna, 1996; CRPF, 2007; Dini-Papanastasi *et al.*, 2012; Cierjacks *et al.*, 2013; Enescu and Dănescu 2013; Sitzia *et al.*, 2016; Pedrol *et al.*, 2017).

Black locust was the first North American forest tree species to be imported in *Europe* at the beginning of the 17th century (1601) (Negulescu and Săvulescu, 1957; Haralamb, 1967; Bîrlănescu and Belu, 1968; Stănescu *et al.*, 1997; CRPF, 2007). Currently, black locust is naturalized in thirty-two European countries (Pyšek *et al.*, 2009, in Sitzia *et al.*, 2016), covers a total area of 2,306,607 ha (Brus, 2016), and is the most used non-native broadleaved tree species on the continent. The areas in Europe where black locust has expanded most are in Hungary (460,000 ha - Rédei *et al.*, 2014), Ukraine (422,525 ha - Lavnyy and Savchyn, 2016), Italy (377,186 ha – Monteverdi *et al.*, 2016), France (191,000 ha ± 23,000 ha – Orazio and Bastien, 2016), Serbia (169,153 ha – Andrašev *et al.*, 2016), and Bulgaria (150,590 ha – Petkova *et al.*, 2016).

In *Romania*, black locust was introduced as a park tree around 1750, probably from Turkey, in the southern and eastern provinces (Wallachia and Moldova) as well as through Serbia and Austro-Hungary in Transylvania (centre) and Banat (south-west) provinces (Drăcea, 1919). The first forest plantation with black locust was established in the south-west of Romania (Oltenia Plain) in 1852, in order to stabilize the mobile sand dunes (Crăciunescu, 1904; Drăcea, 1919). After 1883, it was widely introduced throughout the country for the same purpose, as sand dune systems extend to about 266,000 ha in Romania (about 1% of national territory - Ciortuz and Păcurar, 2004; Târziu, 2008) of Oltenia Plain (ca. 140,000 ha), Carei-Valea lui Mihai Plain (ca. 32,000 ha), Tecuci Plain–Hanul Conachi, and Danube Delta (Negulescu and Săvulescu, 1957; Stănescu, 1979; Stănescu *et al.*, 1997).

The area covered by black locust in 1922 was only 28,000 ha (Drăcea, 1928), expanding to ca. 100,000 ha by the mid-1950s (Negulescu and Săvulescu, 1957) and further to approx. 250,000 ha at the present time. 4% of this is on national forest land, mostly in the south of the country, on sand dunes and areas with heavy soils in the forest steppe zone (Enescu and Dănescu, 2013; Nicolescu *et al.*, 2018).

Regeneration and early growth of black locust

In different parts of the world, black locust is regenerated by one of three methods:

a. *Planting* in spring using 1-year-old seedlings, normally bare-rooted, 0.5-1.0 (or even 2) m tall, produced in conventional nurseries (Olson, 1974; Luna, 1996; Redei, 2013a). The initial stocking rate of black locust plantations in Europe is very variable: 1,100-1,900 seedlings ha^{-1} in France (Bourgogne) (Borde, 2011), 1,200-1,700 seedlings ha^{-1} (4 m x 2 m, or 3 m x 2 m) in France (Aquitaine and Poitou-Charentes) (Carbonnière *et al.*, 2007; CRPF, 2007), 2,000-2,500 seedlings ha^{-1} (2.5 x 2.0 m, or 2.5 x 1.6 m) in Poland (Wojda *et al.*, 2015) to 4,000-

5,000 seedlings ha^{-1} (2.0 m x 1.25 m, or 2.0 x 1.0 m in Romania; 2.4 m x 0.7-0.8 m, or 2.4 m x 1.0 m in Hungary) (MAPPM, 2000a; Rédei *et al.*, 2008; Redei *et al.*, 2011; Rédei, 2013a).

b. *Naturally by seed*. This is rare, as the hard and impermeable seed coat limits germination in the forest/natural environment. However, there are some examples of natural regeneration in the literature (Negulescu and Săvulescu, 1957; Stănescu, 1979), this process being facilitated by seed wounding with heavy machinery, or natural thermal shock (Stănescu *et al.*, 1997; Șofletea and Curtu, 2007).

c. *Naturally by vegetative regeneration* from stool shoots and root suckers. As black locust coppices freely this is considered *the most cost-effective management system for the species* (Bîrlănescu and Belu, 1968; Sitzia *et al.*, 2016). The method is cheap, efficient and allows local people to collect the stem wood, highly valued as firewood. Root suckers live longer and are healthier (i.e. show less rot at the same age) than stool shoots, however the latter grow quicker up to 12-15 years of age than root suckers (Negulescu and Săvulescu, 1957; Haralamb, 1967; Stănescu, 1979). The most common rejuvenation method is by root suckers as black locust develops horizontal, shallow and wide-spreading roots which can extend 15-20 m from the parent tree (Negulescu and Săvulescu, 1957; Stănescu, 1979; Luna, 1996).

Early management of black locust stands

The application of early management operations, such as release cutting and cleaning-respacing, in black locust stands varies according to the regeneration method as follows: No release cutting is needed in *plantations* but it is necessary in coppice stands to reduce the number of shoots per stool to 1 or 2 and to protect root suckers from stool shoot competition (Haralamb, 1967; Debenne, 1988).

a. In *plantations* with up to 5,000 seedlings ha^{-1} there is no need for any release cutting (MAPPM, 2000b; CRPF, 2007; Wojda *et al.*, 2015). In such stands cleaning-respacing begins after canopy closure, at 4-5 years and the stocking should be reduced to about 2,500 trees ha^{-1} (Wojda *et al.*, 2015). The second cleaning follows 2-3 years later, with a further reduction to ca 1,700 trees ha^{-1} (Wojda *et al.*, 2015).

b*. In black locust coppice stands* regenerated from stool shoots and root suckers, release cutting is necessary to reduce the number of shoots per stool to 1 or 2 and to protect root suckers from stool shoot competition (Haralamb, 1967; Debenne, 1988). Normally two release cuttings are performed, the first one in the first or second year, followed by another 1-3 years subsequently (Costea *et al.*, 1969; MAPPM, 2000b). In Romania, two cleaning-respacing operations are performed in years 3-4 and 6-7, reducing the canopy cover to 80-85%.

In both black locust plantations and coppice stands cleaning-respacing is considered "*the basis for all good management in black locust stands*" (Halupa and Rédei, 1988). These authors aimed to heavily reduce the number of stems, allowing the potential final crop trees sufficient space to grow. If this intervention is too late or too light, the remaining trees were found not to develop their crowns normally (they are deformed or very small) as this is a strong light demanding species and is *intolerant of shade/competition* (Negulescu and Săvulescu, 1957; McAlister,1971; Harlow *et al.*, 1986). They do not recover no matter how much light is subsequently supplied (Haralamb, 1967; MAPPM, 2000b). The cleaning-respacing is based on *negative selections* (particularly in the first intervention) removing defective trees, for example those that are forked (this species is sensitive to early frosts, leading to forking – Haralamb, 1967; Constantinescu, 1976), badly formed, wounded, bent-over (the effect of strong phototropism) combined with *positive selections* where even well-formed and healthy individuals are removed to provide additional growing space to those selected to remain (Constantinescu, 1976). Halupa and Rédei (1988) highlighted the importance of cleaning-respacing to produce regular spacing of the remaining trees.

In the context of these characteristics of black locust stands and silviculture in the early stages, a Research and Development (R&D) project was launched in 2016, in order to evaluate the regeneration and early tending of black locust stands in the north-west of Romania. The objectives of this project are (1) to assess the regeneration potential of black locust by root suckers, (2) to assess the early growth of root sucker stems and (3) to follow and evaluate the early results of these interventions in terms of quality, growth and yield of young black locust stands.

Materials and methods

Study sites

In order to achieve the objectives set out above, fieldwork was undertaken in black locust stands managed by the Săcueni Forest District, part of Bihor County Branch, National Forest Administration ROMSILVA. These stands are located in the north-west of Romania (Carei-Valea lui Mihai Plain), and comprise three management units (46º58' N, 22º16' E) part of the IV Valea lui Mihai Working Unit. The study area had the following main characteristics:

Landform: *continental sand dunes*, of river and wind origin, formed in the Holocene, with a SW-NE and NW-SE orientation and an elevation between 140 and 160 m (Spîrchez *et al*, 1962). Two types of sand dunes are found: *main* (5-15 m height, 1-1.5 km length, 100-350 m width; distance between these dunes: 500-3,000 m), and *secondary* (1-6 m height, 100-1,000 m length; distance between such dunes: 100-500 m).

According to Spîrchez *et al.* (1962) and Târziu and Spârchez (2013), the local **soils** are part of the Psamments suborder, Entisols order (sandy soils), with the following characteristics: (i) very deep but poor, with a low fertility and low nutrient (N, P, and K) content; (ii) light s*oil texture* (85-90% sand, mostly fine); (iii) moderately acid to neutral (5 to 7) pH; (iv) m*aximum fraction of humus* is 1% in the upper 25 cm of soil; (v) presence of a hard and poorly drained *ortstein (ironpan) horizon,* Al, Fe, Mn, and humus compounds-rich from the overlying shallow O horizon. The ironpan is sand-cemented and developed on the dune top and along the dune slopes from 55 cm deep downwards (Spîrchez *et al.*, 1962). This horizon restricts water infiltration during the driest summer periods, when the sand gets very warm at the surface and to a considerable depth, providing an important water supply for the forest vegetation.

The local **climate** is classified as *temperate-continental* (*C.f.b.x.* type according to Köppen - ICAS 2008), compared to a *humid* climate in the native range of black locust (Huntley, 1990).

Mean annual temperature: 10.3 Cº; maximum monthly temperatures in July (20.7 Cº), minimum in January (-1.6 Cº). *Mean annual total precipitation*: 573.3 mm, and this value is much lower than the one found in the U.S.A., ranging between 1020 and 1830 mm (Huntley, 1990). The maximum monthly precipitations is in June (83 mm), the minimum in March (30 mm).

Potential mean annual total evapotranspiration is around 600 mm, similar to the mean annual total precipitation. *Maximum wind speed* is 4.0 m/s (South), so no wind damage to forest vegetation normally occurs (the black locust stands have deep vertical roots to depths of 2-3 m or more - Spîrchez *et al.*, 1962). The only exception was the event in this area on August 3, 1988, when the wind speed reached 18 m/s and the volume of black locust damaged reached 1,087 cu.m (3,599 trees) (Rițiu *et al.*, 1988). *Mean length of frost-free period* is 270 days, much longer than in the native range, where it is between 150 and-210 days (Huntley, 1990). The *mean annual aridity (de Martonne) index* is 28.2, so the area is considered to be located in the *transition zone between the plain forest zone, moderately humid, and the forest steppe zone.*

Forest vegetation

The first black locust plantations (200 ha, 2 x 2 m initial spacing) on the sandy soils in the Carei-Valea lui Mihai Plain were established in 1892 (Spîrchez *et al.*, 1962; ICAS, 2008). Until 1933 only small-scale plantations including Scots pine (*Pinus sylvestris*), black pine (*Pinus nigra*), pedunculate oak (*Quercus robur*), northern red oak (*Q. rubra*), pin oak (*Q. palustris*), and black cherry (*Prunus serotina*) were established on about 18 ha. Further plantations were established between 1933 and 1940 (792 ha), 1946-1959 (1,958 ha), and 1960-1980 (450 ha), with the majority on low fertility former agricultural land (Spîrchez *et al.*, 1962). Currently forest vegetation covers about 12% of the total area of the Carei-Valea lui Mihai Plain, with black locust the main tree species covering over 80% of the total forest area (ca 3,000 ha). Other tree species, found on a much smaller scale in the same area, are black cherry, Canadian poplars (*Populus x euramericana*), oaks (e.g., pedunculate, northern red, pin), and pines (black, Scots).

In the Carei-Valea lui Mihai Plain, black locust has been used since 1892 on (i) low-fertility former agricultural land or (ii) for replacing low-productive tree species such as *Quercus robur, Tilia cordata, Acer campestre,* and *Ulmus campestris*, in order to prevent wind erosion and sand dune movement and to produce firewood. Subsequently, black locust stands were treated as simple (low) coppice, usually on a rotation of 20-30, but up to 35 years, similar to the timescales found in the U.S.A. (McAlister, 1971), India (Luna, 1996), France (Carbonnière *et al.*, 2007; Borde, 2011) and Hungary (Rédei *et al*., 2011; Rédei, 2013c), depending on yield class.

Experimental material

In this context, three management units - 3B, 23D and 52A% - were selected for the R&D project. The main characteristics of these stands are: (1) Management unit 3B - pure natural regeneration by root suckers of black locust, 1-year-old, following simple coppice cut (winter 2015-2016) and removal of stumps; (2) Management unit 52A% - pure natural regeneration by root suckers of black locust, 2-years old, following simple coppice cut (winter 2013-2014) and removal of stumps; (3) Management unit 23D - mixed black locust-black cherry stand, 12-year-old, originating from root suckers after a simple coppice cut (2004) and removal of stumps. No silvicultural interventions had been performed since establishment.

Experimental design

In order to carry out the fieldwork, different experimental plots were designed: (1) Management unit 3B - six plots of 25 sq.m (5 x 5 m) each, established in April 2017 (Fig. 1); (2) Management unit 52A% - two plots of 25 sq.m (5 x 5 m) each established in June 2016; (3) Management unit 23D - two plots of 150 sq.m (15 x 10 m) established in July 2016.

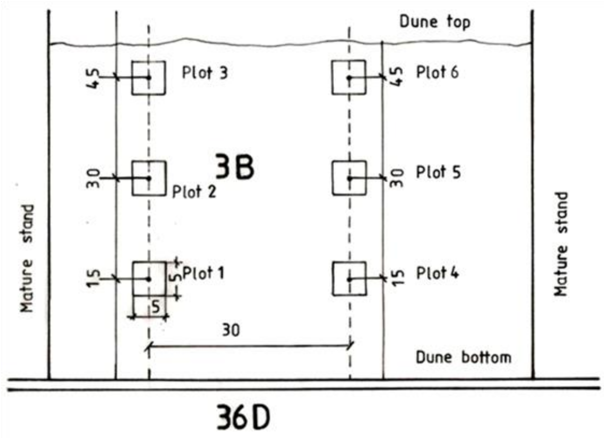


Fig. 1 Location of plots 1-6 within the management unit 3B

Root suckers/Trees measurements

Root collar diameter and total height were measured for all initial and remaining root suckers, after the release cutting carried out in all plots from management units 3B and 52A%. Diameter at breast height (DBH) and total height for all initial and remaining trees after the cleaning-respacing were measured in management unit 23D. The location (x-y) of each remaining tree as well as four perpendicular crown radii for such trees were also measured.

Biomass estimation

The suckers cut during the release intervention (management unit 3B) were bundled in each plot and transported to the laboratory. The dry matter content was determined by drying material at 105^{0}C, until constant weight. To assess biomass production, an allometric relationship between W and stem diameter was used: $W = bD^c$, where W - biomass, D – root collar diameter, b and c – constant parameters.

Silvicultural, biometrical and statistical analysis

Using the data collected in the field the following calculations were performed: stocking (no. of trees/ha) before and after release cutting and cleaning-respacing, in order to determine the intensity of the interventions; density (sq.m ha^{-1}) before and after cleaning-respacing, with the same purpose; mean collar diameter in release cutting, DBH in cleaning-respacing, of initial, extracted and remaining trees and their standard deviations; mean height (in both release cutting and cleaning-respacing) of initial, extracted and remaining trees and their standard deviations; dry biomass of extracted, remaining and initial suckers in management unit 3B; coefficients of variation of diameters and heights (initial, extracted and remaining suckers or trees); significant differences beetwen means were tested using ANOVA and Duncan post hoc test (Statistica 7, Statsoft Inc, USA); differences between means were analysed using ANOVA and the significant effects were tested with Duncan post hoc test.

Results and discussions

(A) Regeneration of black locust stands

In the two management units analyzed with respect to the ***natural regeneration*** of black locust by root suckers, the most relevant results are as follows:

(i) 1 year old natural regeneration (management unit 3B)

The potential for natural regeneration of black locust from root suckers was very high and the initial stocking after one growing season ranged between 15,200 and 67,600 suckers ha^{-1} (50,800 on average). The initial stocking was higher than that found in the study made in France, which recorded over 40,000 suckers ha^{-1} using this regeneration method (Pagès, 1985, cited in Carbonnière *et al.*, 2007). This very high stocking allowed for *very heavy* interventions (over 25% of the number of trees – MAPPM, 2000b) with release cutting (from 68.42% to 91.89%, over 80% in the majority of plots), reducing the stocking per ha to between 4,800 suckers and 9,200 suckers (7,200 suckers on average) (Table 1).

Table 1 Stocking in the six plots locate in 1 year old regeneration and intensity of release cutting

Plot no.	Number of root suckers per plot/ha						Intensity of intervention, %
	Initial		Extracted		Remaining		
	plot	ha	plot	ha	plot	ha	
1	156	62,400	135	54,000	21	8,400	86.54
2	148	59,200	136	54,400	12	4,800	91.89
3	119	47,600	101	40,400	18	7,200	84.87
4	38	15,200	26	10,400	12	4,800	68.42
5	169	67,600	146	58,400	23	9,200	86.39
6	130	52,000	109	43,600	21	8,400	83.85
Average no.	127	50,800	109	43,600	18	7,200	85.83
Range		15,200-67,600		10,400-58,400		4,800-9,200	

Significant differences (F=4.735, p=0,0003) were registered in terms of root collar diameter for root suckers located on the dune top, in the middle of the slope and the bottom of the dune at the beginning of the experiment. The same pattern was observed for the removed root suckers (F=4.942, p=0.0002).

The suckers removed by release cutting were the smallest (or thinnest) ones. Consequently, the arithmetic mean collar diameter of black locust suckers increased from 7.36±3.91-9.81±5.32 mm to 11.67±4.12-14.72±6.76 mm, the coefficients of variation of diameters being the lowest in the remaining root suckers. No significant differences were registrated for the remaining root suckers (F=1.010, p=0.416) (Table 2).

Table 2 Arithmetic mean collar diameters (mean), arithmetic mean height (mean), standard deviations (SD) and coefficients of variation (CV) of black locust root suckers (initial, extracted, and remaining) in the 1 year old regeneration

Plot no...	Initial root suckers			Extracted root suckers			Remaining root suckers		
	Mean	± SD	CV	Mean	± SD	CV	Mean	± SD	CV
Collar diameter (mm)									
1	7.36[b]	± 3.91	53.15	6.58[b]	± 3.35	50.92	12.38	± 3.57	28.84
2	7.87[b]	± 4.84	61.44	7.30[b]	± 4.38	60.04	14.33	± 5.21	36.35
3	9.81[a]	± 5.32	54.22	8.93[a]	± 4.53	50.66	14.72	± 6,76	45.94
4	7.71[b]	± 4.01	52.02	5.89[b]	± 2.32	39.40	11.67	± 4.12	35.31
5	7.71[b]	± 4.45	57.65	7.04[b]	± 3.98	56.57	11.96	± 4.95	41.40
6	8.90[ab]	± 5.85	65.76	8.07[ab]	± 5.61	69.56	13.24	± 5.24	39.61
All plots	8.20	± 4.87	59.43	7.42	± 4.37	58.88	12.99	± 5.08	39.12
Height (cm)									
1	89.08	± 47.64	53.48	78.62	± 40.67	51.73	156.33	± 31.94	20.43
2	91.61	± 51.15	55.83	84.20	± 44.74	53.13	175.67	± 44.88	25.55
3	95.58	± 52.88	55.32	84.91	± 45.51	53.60	155.44	± 52.46	33.75
4	87.79	± 40.18	45.77	70.00	± 28.40	40.57	126.33	± 35.06	27.75
5	96.81	± 53.91	55.68	86.66	± 46.81	54.01	161.22	± 52.25	32.41
6	100.18	± 63.29	63.18	89.19	± 59.32	66.51	157.19	± 52.55	33.43
All plots	*94.14*	*± 53.14*	*56.45*	*83.98*	*± 46.83*	*55.77*	*156.21*	*± 46.99*	*30.08*

Note: Within columns, means with the same letter are not significantly different (*p-level* = 0.05)

The suckers extracted through this intervention were also the shortest, so the arithmetic mean height of black locust suckers increased from 87.79±40.18-100.18±63.29 cm to between 126.33±35.06 and 175.67±44.88 cm, the coefficients of variation of heights being also the smallest in the remaining root suckers. In terms of root sucker height, the analysis of variance showed no significant differences: F=0.896, p=0.483 for initial root suckers, F=1.193, p=0.311 for removed root suckers and F=1.469, p=0.207 for the remaining ones.

The *aboveground dry biomass* of initial, extracted, and remaining black locust root suckers in the six plots was calculated using the allometric formula $W = 0.0652D^{2.582}$, R^2=0.9426.

The initial above ground dry biomass in all plots, except plot no. 4, exceeded 1.1 t ha^{-1} (1.384 t ha^{-1} on average), the maximum being measured in plots 3 (1.875 t ha^{-1}) and 6 (1.939 t ha^{-1}) (Table 3), which were both located close to the dune top.

Table 3 Dry biomass of root suckers in the 1 year old regeneration

Plot no.	Dry biomass (t ha^{-1})		
	Extracted	Remaining	Initial
1	0.721	0.422	**1.143**
2	1.129	0.379	**1.508**
3	1.176	0.699	**1.875**
4	0.087	0.219	**0.306**
5	1.044	0.488	**1.532**
6	1.374	0.565	**1.939**
Mean	*0.922*	*0.462*	*1.384*
Range	*0.087-1.374*	*0.219-0.699*	*0.306-1.939*

As the release cutting intervention had a very heavy intensity, the remaining above ground biomass was less than 0.5 t ha^{-1}, with the exception of plots 3 (0.699 t ha^{-1}) and 6 (0.565 t ha^{-1}), with a mean of 0.462 t ha^{-1}.

(ii) 2 years old natural regeneration (management unit 52A%)

This stand was regenerated identically to management unit 3B and is located in very similar ecological conditions. In the two plots the very strong competition between the suckers started immediately after the canopy closure of the newly established regeneration, i.e. at the end of first growing season, producing an abrupt reduction in stocking of this 2-year-old stand (12,000 suckers ha^{-1} in plot 1 and 22,000 suckers ha^{-1} in plot 2) (Table 4).

Table 4 Main characteristics of plots 1 and 2 in 2 years old regeneration

		Plot 1(7)	Plot 2(8)	Overall
Number of individuals ha^{-1}		12,000	22,000	**17,000**
Basal area (sq.m ha^{-1})		0.53	0.93	**0.73**
Collar	Arithmetic mean	**6.9**	**6.7**	**6.8**
diameter	Maximum	14.4	15.1	**15.1**
(mm)	Minimum	3.0	2.8	**2.8**
Height (cm)	Arithmetic mean	**162**	**155**	**158**
	Maximum	257	264	**264**
	Minimum	60	50	**50**

The mean collar diameters (6.9 mm and 6.7 mm respectively) and mean height (162 cm and 155 cm respectively) are similar in the two plots. The ranges in both these parameters are similar and no significant statistical differences occurred (F=0.132, p=0.717 for collar diameter and F=0.372, p=0.543 for height) between the collar diameter and height of suckers in these two plots (Table 4).

(B) Cleaning-respacing of young mixed black locust-dominated stands

This intervention was carried out in management unit 23D, which showed the following main characteristics:

The stand initial stocking was very high (5,467 trees ha^{-1}) in plot 1, and lower (3,533 trees ha^{-1}), in plot 2. These trees had a similar basal area (14.30 sq.m ha^{-1} in plot 1 and 13.87 sq.m ha^{-1} in plot 2). This made possible a *very heavy* intervention, with removal of over 25%, reducing the stocking to 2,333 trees ha^{-1} and the basal area to 9.33 sq.m ha^{-1} (plot 1) and 1,733 trees ha^{-1} and 9.10 sq.m ha^{-1} (plot 2) (Table 5**).**

Table 5 Main characteristics of stand and of cleaning-respacing carried out in the 12 years old natural regeneration

		Black locust BL	Black cherry BC	Overall	Species composition, %
Number of trees ha^{-1}					
Plot 1	Initial	4,867	600	*5.467*	89BL11BC
	Extracted	2,933	200	3.133	94BL6BC
	Remaining	1,933	400	2.333	83BL17BC
	Intensity of intervention, %	60.3	33.3	*57.3*	
Plot 2	Initial	2,400	1,133	*3,533*	68BL32BC
	Extracted	1,267	533	1,800	70BL30BC
	Remaining	1,133	600	1,733	65BL35BC
	Intensity of intervention, %	52.8	47.1	*50.9*	
Basal area sq.m ha^{-1}					
Plot 1	Initial	10.87	3.43	*14.30*	76BL24BC
	Extracted	4.25	0.72	4.87	87BL13BC
	Remaining	6.62	2.71	9.33	71BL29BC
	Intensity of intervention, %	39.1	21.0	*34.1*	
Plot 2	Initial	5.61	8.26	*13.87*	40BL60BC
	Extracted	1.82	2.95	4.77	38BL62BC
	Remaining	3.79	5.31	9.10	42BL58BC
	Intensity of intervention, %	32.4	35.8	*34.4*	

As the intensity by number of trees (57.3% in plot 1, and 50.9% in plot 2) was much higher than by basal area (34.1% in plot 1 and 34.4 in plot 2), the intervention was *from below* in both plots, removing mostly trees from the lower diameter classes.

As the intervention removed mostly the smallest (thinnest and shortest) trees, the arithmetic mean diameter and arithmetic mean height increased in both black locust and black cherry, particularly in the former species (Table 6**).**

Table 6 Biometrical characteristics of 12 years old natural regenerated black locust and black cherry before and after intervention

		Black locust	Black cherry
Arithmetic mean diameter ± standard deviation (cm)			
Initial	Plot 1	5.3 ± 1.82	8.0 ± 3.50
	Plot 2	5.4 ± 1.67	9.5 ± 2.88
Extracted	Plot 1	4.0 ± 1.44	6.7 ± 1.15
	Plot 2	4.4 ± 1.00	8.1 ± 2.21
Remaining	Plot 1	*6.5* ± 1.44	*8.5* ± 4.17
	Plot 2	*6.5* ± 1.52	*10.7* ± 2.95
Arithmetic mean height ± standard deviation (m)			
Initial	Plot 1	8.6 ± 2.51	8.6 ± 3.00
	Plot 2	9.5 ± 2.88	10.3 ± 1.77
Extracted	Plot 1	7.0 ± 1.99	8.1 ± 1.79
	Plot 2	7.9 ± 1.62	9.5 ± 1.73
Remaining	Plot 1	*10.6* ± 1.38	*8.9* ± 3.60
	Plot 2	*10.0* ± 1.33	*11.0* ± 1.58

Even black locust and black cherry have similar heights (F=3.781, p=0.054), significant differences were found for diameter (F=67.051, p=0.000).

The intervention produced gaps in the canopy cover, which shows a value after cleaning-respacing of circa. 80% in plot 1, and 75% in plot 2, so that some trees have additional space at canopy level to develop their crowns and consequently increase DBH.

Conclusions

The R&D project, which began in 2016, focusing on pure and mixed black locust-dominated stands has led the following conclusions on regeneration and the early management of such stands:

- The potential of black locust to *establish naturally* by root suckers after a low coppice cut and stump removal is very high and the stocking of such newly established stands can exceed 50,000 suckers ha^{-1}.
- Despite the unfavourable conditions in the case study area, the *initial growth of regenerated black locust* is fast and the newly established stand can close the canopy in 1-2 years, resulting in effective dune stabilization and wind erosion control.
- There are significant biometric differences, for example in collar diameter and height, between the young shoots, leading to a high level of natural mortality after canopy closure.
- Economic factors, such as lack of markets and/or workforce, results in young pure or mixed black locust-dominated stands usually being untended in the early stages. The first commercial intervention (cleaning-respacing) occurs when the stand has reached the thicket stage (minimum mean diameter 5-6 cm) and exhibits high stocking and density as well as wide dimensional (DBH and ht) variation. Consequently, the first cleaning-respacing intervention is *from below*, of *high intensity* and *negative selection* type, removing mostly low Kraft class (intermediate/suppressed), dead or dying, and defective (for example forked, wounded, or bent-over) trees.

However, these are only preliminary results and at the next intervention, different measurements (e.g. collar diameters and heights - stands for release cutting; diameters, heights and crown radii - stands for cleaning-respacing) will be taken. These will provide an assessment of natural dieback in young, naturally regenerated, black locust stands, and the effects of the two silvicultural interventions on the early growth of this species in pure or mixed stands.

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