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Early growth of *Pinus nigra* and *Robina pseudoacacia* stands: contributions to soil genesis and landscape improvement on lignite spoils in Ptolemaida

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Abstract

Two forest species planted on spoil heaps in Ptolemaida, *Pinus nigra* and *Robinia pseudoacacia*, were studied. The productivity of both species was high. The majority of trees in the pine stand were vigorous and had good quality trunks, while most *Robinia* trees suffered from strong competition from neighbouring trees and were forked in many branches. The addition of fly ash to spoil materials produced generally better growing conditions.

Fourteen years after their establishment, the two stands had improved soil properties significantly more than had natural revegetation. Distinct surface, A_1 and C horizons formed under both stands. The contribution to landscape aesthetic improvement by the evergreen *Pinus nigra* was greater than that by the deciduous Robinia, also a desirable species because of its initial fast growth, intense sprouting and rapid nitrogen-enriching properties. The study suggests that afforestation with mixed stands of evergreen pine species and nitrogen-fixing trees is probably the best solution for successful rehabilitation.

Keywords: Afforestation; Growth; Soil genesis

1. Introduction

Much of the world's wealth is derived from mining, but land surfaces are inevitably disturbed. In Greece, mining continues without planning for subsequent rehabilitation, and the Greek landscape is changing significantly through lignite surface mining. Recently, in the lignite mining areas of Ptolemaida, the National Electricity Company (NEC), which is responsible for the area, began to afforestate spoil heaps which will probably not be removed for future mining.

This afforestation has not been adequately planned. Some of the species selected were inappropriate for the climate and soil, and irrigation, fertilisation and additional topsoil were not provided. Many afforestation trials failed through inappropriate afforestation techniques and adverse ecological conditions in some microenvironments. Ashby and Kolar (1985) have pointed out that climate, type of rooting medium, drainage and herbaceous competition may limit reclamation success with trees.

Afforestation in Ptolemaida valley is necessary because forests can provide many advantages to an area with minimum forest cover and heavy air pollution. In addition to afforestation, the NEC has attempted to turn some areas of the

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spoils to agricultural use. Small numbers of fruit trees have been established and serial species have been cultivated successfully. However, the transference of toxic and radioactive materials along food-chains to man (Francis et al., 1985; Hatzistathis, 1989) and the long-term effects that tree plantations have had on the Ptolemaida spoil soils has not been studied.

This study examines the productivity of 14-year-old *Pinus nigra* and *Robinia pseudoacacia* stands on the lignite spoils of Ptolemaida and their influence on soil properties and landscape improvement, and examines the effects of the addition of lignite ash to the spoil heaps.

2. Description of the study area

Lignite mines are located in the west area of Macedonia near the city of Ptolemaida (Fig. 1), in a valley between the Vermio and Siniatsiko mountains, at 22° latitude and 40°30′ longitude, with a mean average altitude of 667.5 m. The valley is rich in lignite, with six active lignite mines in the area. Until recently, only 400 ha had been rehabilitated of the 7500 affected by mining; by the year 2025, it is estimated that the area affected by mining will be 18 000 ha.

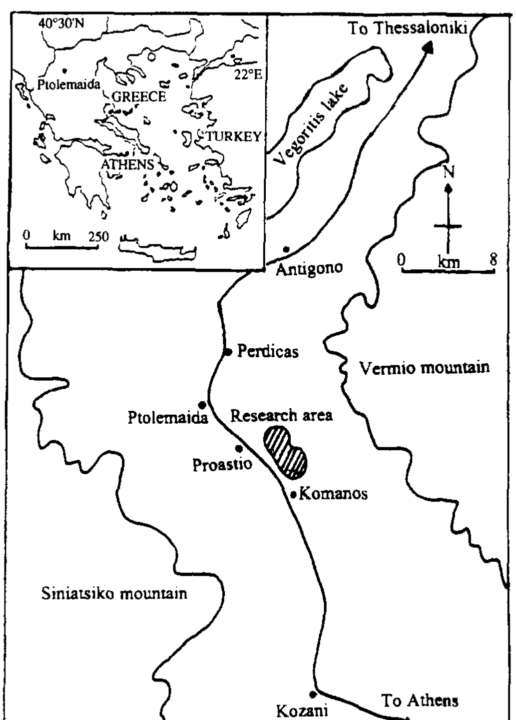

Fig. 1. Location of the study area.

Mining started in 1957 with no planning for subsequent rehabilitation, and until 1970 the NEC, which is responsible for the area, did nothing to return the land to its original state. From 1970 to 1980, the NEC afforested some areas on the spoil heaps. This work was also unplanned and carried out without the use of topsoil, irrigation or fertilisation. The species selected for the afforestation were *Pinus nigra* and *Robinia pseudoacacia*. Two stands from this period, one of each species, were selected for examination in this study.

The climate of the area is subhumid Mediterranean with a cool winter. Average annual precipitation is 550.76 mm (Ptolemaida meteorological station, 35 years of record) with a maximum monthly average in November (68.19 mm) and a lesser peak in May (54.47 mm). The average annual air temperature is 12.26°C. The dry period is relatively short, with a more even distribution of precipitation than other regions of Greece (winter 123.02 mm; autumn 167.9 mm; spring 157.19 mm; summer 108.65 mm), producing good moisture conditions for vegetation. During winter, snow and early and late frosts are common; there are approximately 150 days of frost risk each year. Average annual relative humidity is 62.5%, with average monthly values varying between 48 and 76%.

The overburden that covers the lignite layers in the valley consists of marls, sediments, redsoils, alluvials, peatmould, peat, fossils, and others. After the extraction of lignite, overburden layers are mixed together with bad quality lignite and lignite ashes. The new soils that arise from this mixture are heterogeneous, unstable and unconsolidated, with a high pH and low compaction; also they have large amounts of carbonate in them. In many cases, unburned lignite is exposed on the surface of the spoils and many self-igniting fires have destroyed newly established stands.

The main forest species in the area are *Pinus nigra* and *Quercus macedonica*, and wheat, sugarbeet and livestock forage are grown by farmers. Species composition on the spoils depends on the age of the spoil. Chenopodiacea species predominate on newly established spoils (2 years old) while Compositae species are more common on older spoils; leguminous species are generally on younger and herbaceous species on older spoils (Diamandopoulos, 1985).

3. Materials and methods

3.1. Productivity measurements

Two stands 14 years old, one of each species, were selected for examination in this study. In both stands, an area of 0.05 ha was selected at random for estimation of growth rate, vitality, and trunk quality. Growth estimates were made on trees of more than 4 cm breast height diameter, while other measurements were made on all trees. Stems coming from the same root and forked before 130 cm high were measured as separate trees. In the construction of the structural profile, trunks growing from the same root were treated as one tree with one canopy.

Kraft's tree classification was used and tree vigour and trunk quality were also measured. Kraft's classification has five classes (Daniel et al., 1979) applied to even-aged stands, but because in the stands there had been also natural regeneration by sprouting and some species invasion in the area, a tree class 'natural revegetation' is also included. For tree vigour three classes were used, as in the International Union of Forestry Research Organisation (IUFRO) tree classification (Dafis, 1986), which were: high, normal and low. For trunk quality, three classes were used: good, normal and poor depending on wood quality, the number of branches on the lower part of the trunk and whether the trunk was straight or warped and forked to subtrunks.

3.2. Soil

The selection of sample sites to examine soil development under the tree canopy was difficult because the plantation was not continuous over the spoil heaps. Locations were selected from continuous dense stands; both stands had the same aspects and inclinations. The control area was located between the two sample sites, at the top of the spoil heap. It was selected because it was close to both sites and had been treated similarly; as Chambers et al. (1987) note, in cases of greatly similar soil and vegetation characteristics, naturally revegetated areas may be better standards of reclamation success than native undisturbed reference areas.

Five random samples were collected from each of the three sites at depths of 10, 20 and 30 cm. After the removal of litter, sections from each depth were mixed and rocks larger than 5 cm in diameter were discarded. The remaining soil and coarse fragments were mixed thoroughly and then quartered. One quarter was used for analysis (Vimmerstedt et al., 1989). One sample of lignite gasification ash was also taken for analysis. The samples were packed in polythene bags and transferred to the laboratory.

The mixture of soil and coarse fragments was air-dried, weighed and carefully sieved through a 2 mm screen without breaking up fragile fragments. The fine earth fraction was analysed for the following: particle size by sieve and pipette method; pH by glass electrode pH meter in 1:1 slurry of soil and distilled water; available water content by pressure membrane extraction of saturated soil at 0.33 bar and 15 bar (Peters, 1965); organic matter (OM) by weight loss on ignition at 350°C for 20 h (Ball, 1964); calcium carbonate ($CaCO_3$) by a manometric method with hydrochloric acid (Papamichos and Alifragis, 1988); available phosphorus (P) by the Olsen method (Homer and Pratt, 1961); total nitrogen (N) by the Kjeldahl digestion method (<0.1 mm ground material) (Bremmer, 1960); electrical conductivity by glass electrode in 1:1 slurry of soil and distilled water (Bower and Wilcox, 1965); exchangeable calcium (Ca), magnesium (Mg) and potassium (K) by ammonium acetate extraction at pH 9, individual cations determined by atomic absorption (Bower et al., 1952).

Two-way analysis of variance (ANOVA) was used to determine differences ($P=0.05$) in physical and chemical properties between sites (*Robinia* site, *Pinus* site and naturally revegetated control site) and differences in site types at the same depths. Comparisons of all means were examined with Fisher's protected least significant differences (LSD). Significant differences at $P=0.01$ were noted separately.

4. Results and discussion

4.1. Productivity

In a 0.05 ha area, 43 trees of 14-year-old *Pinus nigra*, planted in a 3 m×3 m space, were recorded. They had an average height of 4.74 m (0.34 m per year) and an average diameter of 10.28 cm (0.73 cm per year). These growth rates were slower than the growth rates of the exotic *Pinus nigra* var. *corsicana*: 0.50 m in height and 0.81–0.96 cm in diameter per year. The average height of the *Pinus* stand would have been higher, with fewer branches, if the stand had been planted more densely.

More than 54% of the trees had high vigour and 49% good trunk quality (Table 1), and only a few (six) had died. Four broadleaved species had invaded the space left by dead trees: *Pyrus communis*, *Salix alba*, *Prunus coromilia* and *Rubus tomentosus*, their heights varying from 2 to 6 m, all very vigorous. Natural revegetation as a self-greening process is mentioned by other authors (Gene and Samuel, 1979; Wade, 1989; Rosiere et al., 1989). The absence of Leguminosae species as natural colonisers and the presence of salt-resistant species from the early stages of the natural establishment of revegetation is mentioned by Diamandopoulos (1985).

In the 13-year-old *Robinia* stand, 85 trunks were recorded; 31 were forked below 130 cm in height and were treated as separate trees. Average height was 9.92 m (0.76 m per year) and average diameter 8.94 cm (0.68 cm per year). Comparing the productivity of *Robinia* stands in Ptolemaida with other areas, it is evident that there are no problems of productivity for this species. *Robinia* stands on good quality sites with cultivation can attain 32 cm in diameter in 40 years (Papanastasi, 1991); 9-year-old black locust trees established on coal spoil heaps in Ukraine were 8 m high and 6.4 cm in diameter (Kaleberta, 1978).

The trees were planted at a 2 m×3 m spacing and all had many forked branches. The stand had not been cultivated, which accounts for the large number of trees with poor trunk quality (more than 48%) and low middle-storey vigour (Table 2). Nineteen trees were dead; 25 trees were naturally regenerated under the dead trees and they were highly vigorous trees.

The *Robinia* stand was dense, resulting in the suppression of the codominant and intermediate trees, which suffered from competition from the dominant trees. Most dead trees were 6–7 m high and were randomly spread in all the area, indicating that they probably died after suppression—the self-thinning process. The cutting of some stems was necessary to reduce competition for light, water and nutrients and to increase natural revegetation by sprouting.

Ashby and Kolar (1985) state that conifers

Table 1
Vigour and trunk quality of the *P. nigra* stand

	N ha^{-1}	Vigour (%)			Trunk quality (%)		
		High	Normal	Low	Good	Normal	Poor
Ovst.	680	66	31	3	53	28	19
Midst.	260	35	38	27	46	32	22
Undst.	200	40	10	50	40	10	50
Total	1140	54	29	17	49	26	25

Ovst., overstorey (>4 m); midst., middle-storey (2–4 m); undst., understorey (<2 m). N, number of trees.

Table 2
Vigour and trunk quality of the *R. pseudoacacia* stand

	N ha^{-1}	Vigour (%)			Trunk quality (%)		
		High	Normal	Low	Good	Normal	Poor
Ovst.	1020	43	32	25	19	39	42
Midst.	760	19	36	43	8	26	66
Undst.	600	55	28	17	21	42	37
Total	2380	38	32	30	16	36	48

Ovst., overstorey (> 8 m); midst., middle-storey (4–8 m); undst., understorey (< 4 m). N, number of trees.

have generally not grown well outside their native range, but the *Pinus* species planted on the spoils had fast growth rates. The exotic *Pinus corsicana*, largely used on the spoils of Ptolemaida in recent years, had much faster growth rates than the native *Pinus nigra* var. *grevena*, which also grows well. The only problem for the exotic species was the attacks by the caterpillar *Thaumetopoea pityocampa* from the early stages of their establishment. For most species, areas of good site quality are also areas where growth rates are high (Clutter et al., 1983), indicating that the sites in the study area were good quality sites.

4.2. Soil characteristics

4.2.1. Physical properties

Colour is the most obvious and easily determined soil property and is usually one of the first properties to be noted in a field description. Generally, the colour of the spoils in Ptolemaida was light grey to dark black, depending on water content, $CaCO_3$, the percentage of unburned lignite and ash mixed with overburden and the presence of OM. The significance of soil colour, however, is mainly its use as an indirect measure of other important soil characteristics and also in making many important inferences regarding soil genesis and land use (Kaleberta, 1978).

In the *Robinia* and *Pinus* stands, a black surface O horizon, 3–5 cm deep, had developed—an indicator of accumulated humus. Under the humus layer, a greyish-brown A_1 horizon extended to 10–15 cm, influenced by accumulated humus and parent material (spoil material). The A_1 horizon boundaries were clear and wavy. Below 10–15 cm, a light grey C horizon extended to more than 100 cm. This horizon was influenced by parent material—a mixture of surface soil, marl, sand, limestone, peatmould and lignite ash.

The structure of the soil was moderately granular in the O horizon, weak blocky in the A_1 horizon and massive in the C horizon. Roots were noticeable on the face of all profiles. The naturally revegetated site was light grey, structureless and with undefined horizons.

Pinus and *Robinia* pedons were described as O–A_1–C profiles. Similar horizon development is also mentioned by other authors: A–B horizon development was noted by Kaleberta (1978) 8–10 years after the establishment of vegetation on lignite spoil heaps; Roberts et al. (1988) state that A–C profiles developed in Southwest Virginia coal mines; Gonzalez-Sangregorio et al. (1991) note that in 3 years of pedogenesis some of the biochemical properties of the lignite mine soils of northwest Spain became similar to those found in the native soils of the area.

Particle size composition of the soils on the spoil heaps varied (Table 3), primarily because of the composition of the soil mixtures on which soil forms; generally, they are characterised as medium-textured loamy. The ash sample had a sand-loamy texture. The clay content in the humus horizon increased, although insignificantly, under the forest vegetation, increasing by 5% in the 0–10 cm layer under both species (also noted by Kaleberta, 1978).

Table 3 shows that the soils under forest vegetation retained greater amounts of available water than soil on the naturally revegetated site. Available water in the *Robinia* stand was significantly

Table 3
Soil texture, coarse fragments and soil water relationships of lignite soils under *R. pseudoacacia* (Rob), *P. nigra* (Pin.), naturally revegetated (Nat.) sites and fly ash

Site	Depth (cm)	Coarse fragments >2 mm (%)	Texture (%)			Hygroscopic water 15 bar (%)	Field capcity 0.33 bar (%)	Available water (%)
			Clay	Silt	Sand			
Rob.	10	33.87	20.3	39.9	39.8	23.68	50.61	26.93
Rob.	20	41.99	19.3	41.4	39.4	21.22	47.37	26.15
Rob.	30	44.48	15.1	45.8	39.1	20.62	44.98	24.36
Pin.	10	34.57	20.9	40.9	38.2	20.66	48.52	27.86
Pin.	20	44.12	20.0	41.9	38.1	19.27	43.35	24.08
Pin.	30	46.61	18.8	46.0	35.2	17.46	39.17	21.71
Nat.	10	38.28	15.2	46.8	36.0	24.63	49.38	24.75
Nat.	20	41.68	18.5	36.0	45.5	19.81	43.57	23.76
Nat.	30	36.68	14.5	34.9	50.6	18.72	40.88	22.16
Ash		0.00	13.1	17.0	69.9	34.68	59.07	24.39

greater than on the naturally revegetated stand, and on the *Pinus* stand at 10 and 20 cm was highly significant ($P=0.01$). Available water depends mostly on soil texture, structure and soil OM. The ability of the spoil soils to retain greater amounts of water available to the plants than similarly textured soils was probably due to the high OM content.

Hygroscopic water content was high—from 17.46% under pine, 24.63% on the naturally revegetated site and 34.68% on the ash sample—resulting in large amounts of water not available to the plants. Field capacity was also great, resulting in soil aeration problems during winter when the soil is saturated. However, in dry years, soil moisture deficits during summer may be a more important determinant of tree survival and growth than short-term winter waterlogging (Moffat and Roberts, 1989).

4.2.2. Chemical properties

There were no significant differences in $CaCO_3$ content, available P and exchangeable Ca between the artificially and naturally revegetated sites; pH was significantly higher on the naturally revegetated site. The ash sample had a higher pH and had less $CaCO_3$ than the other sites. As a result of the high $CaCO_3$ content and the high pH of fly ash, the overall pH was above 7 in all cases, but for most pine and mycorrhizal fungi it should be less.

Available P varied between sites and depths and was generally low (5.7–14.9 p.p.m.) in all samples (Table 4). Most forest species need 50 p.p.m. available P and frugal species need at least 15 p.p.m. to grow well (Wilde, 1958). Palmer and Iverson (1985) note that the effect of phosphate, together with climatic factors, particularly the amount of rainfall and the associated soil moisture, are important factors governing N fixation, so the success of the N-fixing *Robinia* in enriching the soil with N depends on available P.

Table 4 and Fig. 2 show that there were large differences in available N between sites at the same depth; the *Pinus* site at 10 cm had 42% more N than the naturally revegetated site, and the *Robinia* site 64% more ($P=0.01$). Both sample stands had 63% more available N at 20 cm than the naturally revegetated site ($P=0.01$). At 30 cm depth, there were no significant differences between sites. The soil 10 cm under *Robinia*, a N-fixing legume, had 15% more N than under the *Pinus* stand ($P=0.01$), but there were no significant differences between the two forest species in the averages of all depths.

Rhizobial N-fixation was probably the main factor in increasing fertility on mine soils (Palmer and Iverson, 1985). N is a limiting factor in tree growth. Available N in soil at 0.2% is satisfactory (Wilde, 1958), so that the N content in the examined spoils of Ptolemaida, 14 years from the establishment of vegetation, was satisfactory

Table 4
Chemical properties of lignite soils under *R. pseudoacacia* (Rob.), *P. nigra* (Pin.), naturally revegetated (Nat.) sites and fly ash

Site	Depth (cm)	$CaCO_3$ (%)	pH	OM (%)	N (%)	C:N	P (p.p.m.)
Rob.	10	46.40	7.0	21.74	0.388	32.50	7.2
Rob.	20	47.28	7.0	15.36	0.251	35.49	9.2
Rob.	30	63.28	7.2	8.50	0.153	32.22	5.7
Pin.	10	54.32	7.1	21.58	0.336	37.26	14.9
Pin.	20	54.32	7.2	13.67	0.258	30.73	9.5
Pin.	30	55.20	7.3	7.60	0.167	26.41	10.2
Nat.	10	55.28	7.5	12.68	0.237	31.05	14.4
Nat.	20	53.44	7.4	5.45	0.157	20.12	6.9
Nat.	30	56.60	7.5	8.26	0.149	32.14	6.9
Ash		6.16	9.2	5.17	0.145	36.68	12.3

OM, organic matter.

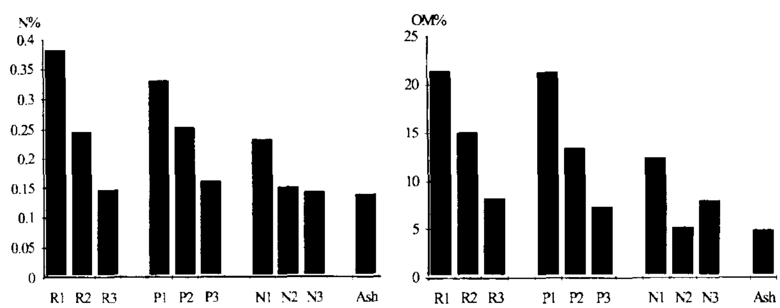

Fig. 2. Available nitrogen (N%) and organic matter (OM%) on lignite soils under *R. pseudoacacia* (R), *P. nigra* (P), naturally revegetated (N) sites and ash. (The numbers 1, 2, 3 indicate 10, 20, 30 cm depth.)

under both forest species, but not on the naturally revegetated site.

There were large differences in the amounts of OM between artificially and naturally revegetated sites. It was 75% greater under both forest species at 10 cm and 163% higher at 20 cm (Fig. 2). At 30 cm, there were significant differences only between *Pinus* and the naturally revegetated site ($P=0.01$). The generally high percentage of OM was probably due to the presence of peatmould and unburned lignite in the spoils, which usually retain large amounts of carbon but in a form not available to plants.

The amounts of OM and available N were directly related. The C:N ratio is an important factor, influencing both the rate of decomposition and nutrient cycling, with low ratios favouring more rapid decomposition (Vimmerstedt et al., 1989). C:N ratios were high in all samples (>20:1), indicating slow decomposition, so that the availability of N may have been limited on all sites. Alexander (1989) stated that where the C:N ratio exceeds 15–17:1 then the availability of N in particular may be limiting.

Large differences in electric conductivity (EC) were also found (Table 5, Fig. 3). Total soil EC was significantly lower under both forest species ($P=0.01$), 52% lower at 10 cm in both stands than on the naturally revegetated site, and 67% lower under pine at 20 cm. The decrease in EC in the surface horizons was probably due to leaching and the effect of vegetation. The ash sample had a high EC (3.42 dS m^{-1}).

Exchangeable Ca was also high and this perhaps results in deficiencies in barium and K (Wilde, 1958). Although exchangeable Mg and

Table 5
Exchangeable cations and salinity of lignite soils under *R. pseudoacacia* (Rob.), *P. nigra* (Pin.), naturally revegetated (Nat.) sites and fly ash

Site	Depth (cm)	Exchangeable cations (meq per 100 g)			Electric conductivity ($dS\ m^{-1}$)
		Ca	Mg	K	
Rob.	10	38.54	3.26	1.27	0.685
Rob.	20	29.44	2.95	0.76	1.301
Rob.	30	19.34	2.24	0.63	1.184
Pin.	10	38.91	2.85	0.76	0.621
Pin.	20	33.06	2.35	0.52	0.779
Pin.	30	28.44	2.24	0.39	2.174
Nat.	10	39.31	1.93	0.57	1.441
Nat.	20	35.30	1.43	0.38	2.418
Nat.	30	31.04	1.25	0.31	2.134
Ash		57.41	0.84	0.63	3.419

K increased significantly under both forest species (Fig. 3), their concentrations were low and the plants may have been deficient in both elements. K is available to plants as K_2O and frugal species such as pines need at least 36 p.p.m. K_2O (Wilde, 1958). K in the spoils of Ptolemaida was low (0.31–1.27 meq per 100 g or 5–20 p.p.m.). Polyzopoulos (1976) noted that when K/CEC is <0.02, there is deficiency of K. In the Ptolemaida spoils, the soil under *Robinia* was very close to the limit of deficiency (K/CEC = 0.025–0.028) and on the other sites much less. Exchangeable Mg must range from 20 to 33% of the exchangeable Ca (Wilde, 1958), but in the lignite spoils of Ptolemaida it was less than 10%, indicating Mg deficiency.

4.3. Aesthetic improvement of the landscape

Greeks today are more aware of their ecological heritage, and wish to preserve the land or restore disturbances for greater aesthetic appeal. Ancient Greeks believed that straight lines were not beautiful, as they never occur in nature, but this was not followed in the plantations on the lignite spoils of Ptolemaida. The Ptolemaida spoils are generally unattractive sites dominated by undesirable man-made features such as large terraces, plantations in straight lines, garbage,

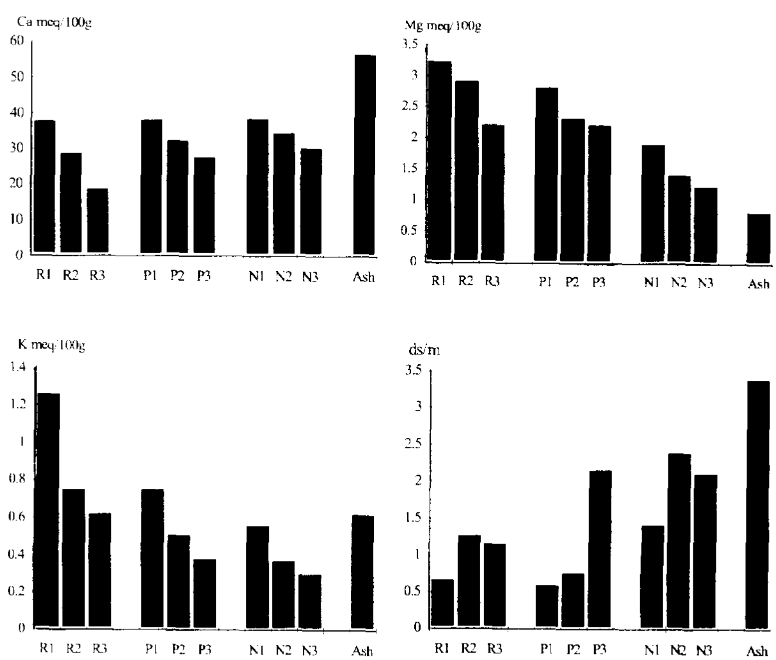

Fig. 3. Exchangeable Ca, exchangeable Mg, exchangeable K and EC of lignite soils under *R. pseudoacacia* (R), *P. nigra* (P), naturally revegetated sites (N) and fly ash. (The numbers 1, 2, 3 indicate 10, 20, 30 cm depth.)

Fig. 4. The lignite spoil heap at Ptolemaida from which data were collected for this study. In December, in winter only the evergreen *Pinus nigra* adds colour to the landscape.

and a concentration of other waste and litter. The main aesthetic consequences of the extraction of lignite in the Ptolemaida valley were the destruction of the physical and visual characteristics of the landscape and the appearance of new man-made characteristics, with intense colours, geometrical lines and different hues and reliefs than the surrounding areas. The artificial stands were planted in lines, with trees at fixed intervals, making the stands readily visible from a great distance and obviously covering lignite spoils.

These aesthetic effects are worse during autumn and winter (Fig. 4) because *Robinia* has leaves only from May to November, but as it is a fast-growing species and because of the intense sprouting and growth of many stems from the same root, the landscape is rapidly becoming green. With the help of *Robinia*, soil restoration and aesthetic improvement could be achieved more quickly and more safely. Another advantage of establishing *Robinia* on the spoils is that when other, more site-sensitive species, planted in the area, they will grow much better when planted under black locust (Ashby and Kolar, 1977). *Pinus nigra* stands grow more slowly but provide cover throughout the year, contributing more to landscape improvement as they age. Optimal rehabilitation of the area will be achieved if plantations are established as 60:40 mixtures of pine and N-fixing species.

5. Conclusions

The rehabilitation of the environment in Ptolemaida requires afforestation of the spoils by suitably adapted plants. *Robinia pseudoacacia* has a broad range of tolerance to commonly encountered reclamation conditions. Of the two forest species that have been largely used on the spoil heaps of Ptolemaida, *Robinia* has greater survival rates (not including the self-thinning process) and the greater heights and diameters. The productivity of both species was high. The majority of trees in the *Pinus nigra* stand were vigorous and in the future will give high quality wood; in the *Robinia* stand, most trees were forked, because they were cut when young to resprout and make the landscape greener, and many of them suffered due to lack of cultivation.

Significant changes in physicochemical properties of soil mixtures in spoil heaps occurred under the 14-year-old forest stands. Kaleberta (1978) mention that only 8–10 years were probably needed to manifest this changes morphologically. Generally, afforestation has improved soil texture and structure, increased available water and improved most chemical properties. The addition of lignite leftovers and lignite fly ash to the spoils positively influences the growth of vegetation. The clay content of humus horizon increased, although insignificantly, under forest vegetation, and these soils held greater amounts of available water than the naturally revegetated site. There were no significant differences in $CaCO_3$ content, available P, exchangeable Ca and CEC between artificially and naturally revegetated sites. pH was significantly higher on the naturally revegetated site. N increased on all sites but mostly under the leguminous *Robinia*. Although *Robinia* is a N-fixing species, there was no significant difference in available N under the two forest species. There were great differences in OM and EC between artificially and naturally revegetated sites; OM was significantly higher and EC was significantly lower under both forest species. Exchangeable Mg and K increased significantly under both forest species but were low in concentration and the plants were probably deficient in both elements; they may also have been deficient in available P on all sites.

Aesthetic considerations are important when rehabilitating; permanent rehabilitation requires the presence of many species. Mixed stands with deciduous and evergreen species are preferable. The slow-growing, deep-rooted evergreen *Pinus* species and the fast-growing, shallow-rooted N-fixing *Robinia* planted in mixed stands can be more productive and lead to faster soil genesis and greater landscape improvement.

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