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Original Research

Effect of Forest Plantations on Erodibility of Reclaimed Lignite Mine Soils

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Abstract

The effect of different forest monocultures on mine soil properties that determine the soil's capacity to resist erosion agents was researched. The following properties were analyzed: content of total organic matter, water permeability, structure, and particle size distribution. The reclaimed lignite mine soils were researched in the Kolubarski Basin in central Serbia in four monocultures of each silver lime (*Tilia tomentosa* Moench), black alder (*Alnus glutunosa* L.), Japanese larch (*Larix leptolepis* (Siebold et Zucc.) Gord.), and Austrian pine (*Pinus nigra* Arn.). The sample plots differed in plantation age and also in the initial characteristics of recently deposited mine waste. The dead organic residues and the products of their decomposition in all forest plantations improved the mine soil properties indicative of soil erodibility. After the effect of forest plantations, mine soil erodibility was lower compared to the recently deposited mine waste. The higher capacity of mine soils to resist erosion agents in all forest plantations was mostly caused by an increase in the content of total organic matter in the top 10 cm of topsoil. The effect of plantations on mine soil properties indicative of soil erodibility depended on tree species and the characteristics of recently deposited mine waste, its textural and mineralogical composition. The effect on soil properties that decrease soil erodibility was the highest in silver lime plantations, and the lowest in black alder plantations.

Keywords: erodibility, forest plantations, mine soils, soil properties

Introduction

Recently deposited mine waste from opencast lignite mines is the cause of both aeolian and water sediments, especially in the absence of selective overburden removal. For this reason, mine soil afforestation is designated as protective afforestation. The establishment of artificial forest ecosystems on uncovered soils mitigates the impacts of erosion agents.

Forest plantations of different tree species affect and change the soil properties by the production of dead organic matter [1-4]. Some of the soil properties that are affected by organic matter of the specific chemistry are the properties by which the soil resists erosion agents.

The main soil properties that determine its resistance to erosion agents are: organic matter content (OM), soil texture (M), sizes of structural aggregates (S) and soil permeability (P) [5]. Mine soils exhibit soil profile characteristics, physical, chemical, and biological conditions that reflect anthropogenic perturbations rather than natural soil-forming processes [6].

Mine soils formed by the deposition of mine waste from opencast lignite mines in the Kolubarski Basin have a deep solum. By the method of deposition, they are mosaics of

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different lithological layers, of different texture and mineralogical composition. Physical and chemical, and also microbiological properties of these mine soils were researched by many authors [7-15]. All of them report that the main problems are the unfavourable chemical properties of the formed anthropogenic soils, primarily the complete absence of humus and organic matter. Field water capacity and available water capacity differ and depend on soil texture, but are mainly high in all mine soils in this region The geological layers above the lignite coal beds generating the study mine soils consist of loose (incohesive) sandy, loamy, and clayey sediments with almost completely absent rock fragments. Simultaneously, the forest tree rooting depth is not limited. This enables rather high water holding capacity, even in the recently deposited waste materials that do not contain organic matter. The study objective was the research of the effects of different forest plantations on the soil properties that determine the soil capacity to resist erosion agents.

Material and Methods

The study area is in central Serbia, about 60 km south of Belgrade. Sample plots range at altitudes from 141 m to 226 m and, in a geographical sense, from 20º20’45” to 20º24’10” East longitude and from 44º24’11” to 44º27’04” North latitude. Natural potential vegetation of the study area is the climatogenic forest *Quercetum frainetto cerris* Rud.

To determine the effect of different forest plantations on soil erodibility, 16 sample plots were established under 4 forest plantations, so that each plantation was subject to 4 replicates. The study plantations were: silver lime (*Tilia tomentosa* Moench), black alder (*Alnus glutinosa* L.), Japanese larch (*Larix leptolepis* (Siebold et Zucc. Gord.), and Austrian pine (*Pinus nigra* Arn.).

On each sample plot, soil erodibility factor (in further text KO – Observed) was calculated by the equation used for the soil loss calculation by USLE model [5].

$$100 \cdot K = 2.713 \cdot 10^{-4}(12-OM) \cdot M^{1.14} + 3.25 \cdot (S-2) + 2.5 \cdot (P-3)$$

...where:

OM – organic matter content in 10 cm of topsoil
S – soil structure code for 10 cm of topsoil
P – permeability class of the profile
M – texture characteristic in 10 cm of topsoil

$$M = (\text{silt} + \text{fine sand}) \cdot (100-\text{clay})$$

The parameters for the calculation of erodibility factors after Wischmeier et al. [5] were determined by the following methods:

- Soil texture of fine earth was determined by international pipette-B method using sodium pyrophosphate as a peptizing agent.
- Content of organic matter was determined by Turin method, by wet combustion in the mixture of K_2CrO_7 and H_2SO_4.
- Soil structure was determined in the field during profile description and sampling, and coded after Wischmeier et al. [5].
- Soil permeability was determined in cylinders after Kopecky (steel rings volume 50 cm^3) on Litvinov’s apparatus. Determination was carried out both in the surface 0-10 cm soil layers and in deeper layers. The permeability class for the whole profile was obtained based on the hydraulic conductivity value of the least permeable layer.

The soil erodibility observed after the effect of forest plantations was under a significant effect of the initial properties of minesoils formed from the recently deposited mine waste. For this reason, it was necessary to estimate the value of minesoil erodibility factor before afforestation (in further text KI – initial erodibility factor) on each sample plot.

The estimated value of the initial erodibility factor (KI) was calculated by the same equation as the erodibility factor (KO). The input parameters for the calculation of KI were estimated based on the topsoil properties of organic matter and soil texture, predicted before afforestation. In the recently deposited spoil banks, organic matter was completely absent, and the soil texture could not have been affected by the plantations within a short-period of time.

The structural aggregates for KI calculation were coded based on the sizes of the structural aggregates formed in the deepest mine soil layers (100 cm deep), because the properties of recently deposited mine waste were best retained in the deeper layers of minesoils. The permeability class of the entire profile is defined by the least permeable layer, and they were mainly the deeper layers of the solum in which the changes, compared to the recently deposited mine waste, were the smallest. For this reason, the same permeability class that was measured in the determination of KO was also applied in the calculation of KI. The value of erodibility factor of thus-calculated KI was not the same, but it was very close to the value of erodibility factor of the recently deposited mine waste before afforestation.

Taking the observed erodibility factor on tested locations (KO) as a dependent variable, and the initial erodibility factor of the recently deposited mine waste (KI) and the duration of impact of plantation on the soil (Age) as the independent variables, the analysis of multiple linear regression produced the regression equation, which may be used as a means for calculating the predicted erodibility factor following the impact of plantations (KP), if the initial erodibility factor (KI) is a known quantity.

The analysis of residual values showed the deviations of KO from KP under each individual forest plantation.

Results

The texture of the study soils varied from sandy loam to clay (Table 1). The high spatial variability in particle size composition resulted in great differences in the value of texture characteristic (M), which is the input parameter

Table 1. Soil erodibility factor and parameters for its calculation.

Plantation	Age	Sample plot	Fine sand	Silt	Clay	(M)	(OM)	(S)		(P)	KI	KO
	years		%	%	%		%	0-10 cm	100 cm			
Tilia tomentosa	16	1	40.55	16.52	24.62	4302.01	3.59	2	3	2	0.4269	0.3242
	15	2	36.49	25.88	21.52	4894.88	2.88	2	3	2	0.4985	0.4054
	25	3	40.29	19.21	22.82	4591.82	3.21	2	3	2	0.4617	0.3639
	24	4	39.92	19.22	23.25	4539.07	3.31	2	3	2	0.4554	0.3553
Pinus nigra	18	5	14.28	22.91	55.31	1662.02	1.91	4	4	3	0.2178	0.1935
	18	6	19.99	18.35	50.85	1884.17	1.86	4	4	3	0.2413	0.2140
	24	7	17.51	20.85	53.18	1795.87	1.73	4	4	3	0.2319	0.2079
	24	8	19.05	23.18	46.98	2239.25	1.73	4	4	3	0.2797	0.2487
Alnus glutinosa	15	9	47.10	10.61	21.67	4520.66	1.42	2	3	2	0.4532	0.4291
	16	10	51.04	11.09	15.68	5239.14	0.84	2	3	2	0.5407	0.5336
	11	11	33.03	13.71	26.70	3425.75	1.70	2	2	2	0.3235	0.2742
	24	12	49.94	10.61	21.67	4743.00	1.50	2	3	2	0.4801	0.4494
Larix leptolepis	17	13	52.46	8.45	16.35	5094.95	1.08	2	2	2	0.5230	0.4737
	18	14	36.06	20.94	27.07	4157.30	1.19	2	2	2	0.4096	0.3665
	18	15	44.99	19.00	16.07	5370.60	1.08	2	2	2	0.5569	0.5045
	26	16	49.91	10.21	16.42	5024.83	2.29	2	2	2	0.5144	0.4115

Table 2. Regression summary for dependent variable: (KO).

	Beta	Std. Err.	B	Std. Err.	t(13)	p-level
Intercept			0.0288	0.0478	0.6023	0.5574
Age	-0.0760	0.0774	-0.0018	0.0019	-0.9822	0.3439
KI	0.9551	0.0774	0.8854	0.0717	12.3454	0.0000

$R=0.9603$ $R^2=0.9223$ Adjusted $R^2=0.9103$
$F(2,13)=77.1070$ $p<0.0000$ Std. Error of estimate: 0.03233

in Wischmeier's equation. The different textural composition and, simultaneously, the different mineralogical compositions caused greater differences in the sizes of structural aggregates (S) and soil permeability (P) between different locations. Great differences in all input parameters for the calculation of erodibility factor resulted in great differences in the initial erodibility factor (KI) of recently deposited mine waste. The approximate value of erodibility factor before afforestation (KI) ranged from 0.2178 to 0.5569.

In all forest plantations, organic matter production led to an increase in organic matter content in topsoil layers. As a result, the observed erodibility factor (KO) in all plantations was lower than the initial (KI) factor before afforestation, i.e. before the effect of forest plantations. The higher presence of organic matter in topsoil layers of reclaimed minesoils was also reflected on soil structure in all profiles. However, it was only in the soils under broadleaf plantations that the differences in the sizes of structural aggregates between topsoil and deeper soil layers were sufficiently great to be coded differently.

The analysis of multiple regression resulted in the equation for the calculation of predicted erodibility factor (KP) depending on initial erodibility (KI) prior to afforestation and the duration of forest plantation effect on the soil (age):

$$KP=0.0288-0.0018\cdot(Age)+0.8854\cdot(KI)$$

The results of multiple regression (Table 2) indicated that minesoil erodibility, after the effect of forest plantations and soil enrichment with organic matter, was significantly affected by the initial properties of recently deposited mine waste, which determine the initial erodibility of the recently formed minesoils (KI). The other independent variable – plantation age, i.e. the duration of the plantation effect on the soil, was not statistically significant.

Table 3. Predicted and residual values (dependent variable: KO).

Plantation	Sample plot	Observed value (KO)	Predicted value (KP)	Residual	Standard residual value
Tilia tomentosa	1	0.3242	0.3776	-0.0535	-1.6536
	2	0.4054	0.4429	-0.0375	-1.1606
	3	0.3639	0.3922	-0.0283	-0.8748
	4	0.3553	0.3883	-0.0330	-1.0222
Pinus nigra	5	0.1935	0.1889	0.0046	0.1417
	6	0.2140	0.2097	0.0043	0.1321
	7	0.2079	0.1905	0.0174	0.5371
	8	0.2487	0.2328	0.0160	0.4935
Alnus glutinosa	9	0.4291	0.4027	0.0263	0.8150
	10	0.5336	0.4784	0.0552	1.7070
	11	0.2742	0.2952	-0.0211	-0.6520
	12	0.4494	0.4102	0.0392	1.2138
Larix leptolepis	13	0.4737	0.4609	0.0127	0.3943
	14	0.3665	0.3587	0.0078	0.2410
	15	0.5045	0.4891	0.0154	0.4764
	16	0.4115	0.4370	-0.0255	-0.7887
Minimum		0.1935	0.1889	-0.0535	-1.6536
Maximum		0.5336	0.4891	0.0552	1.7070
Mean		0.3597	0.3597	0.0000	0.0000
Median		0.3652	0.3902	0.0062	0.1914

In all silver lime plantations, the observed erodibility factor (KO) was lower than the predicted factor (KP), based on the multiple regression equation. Of the four plots under silver lime plantation, on three plots standardised residual values were greater than one standard deviation (Table 3 and Fig. 1).

In all four sample plots under Austrian pine plantations, KO was higher than KP, however standardised residual values were lower than one standard deviation, i.e. KO values were close to the values predicted by multiple regression equation.

In black alder plantations, KO was lower than KP only on one sample plot in which the standardised residual value was lower than one standard deviation. KO was higher than KP on three plots under black alder plantations, of which on two plots standardised residual value exceeded one standard deviation, i.e. exceeded the confidence level of 95% (Fig. 1).

On three plots under Japanese larch plantations, the observed erodibility factor (KO) was higher than predicted (KP) by the multiple regression equation, and it was lower on one sample plot. The standardised residual value under larch plantations did not exceed one standard deviation in any of the localities.

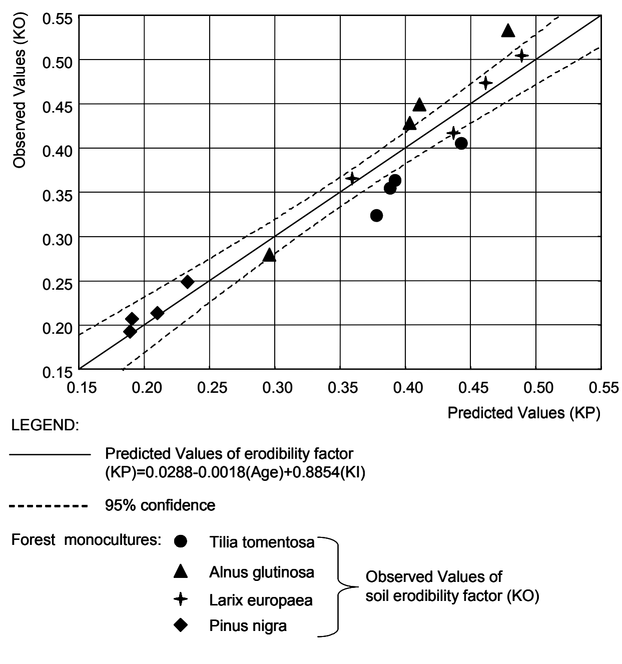

Fig. 1. Observed and predicted values of erodibility factor.

Discussion

In all study sample plots under the effect of forest plantations, the soil erodibility factor decreased more or less significantly compared to KI in recently deposited mine waste. Forest tree species affect soil functions in various ways and at various rates, and particularly by the changes in organic carbon and nitrogen cycles [4]. Accordingly, the plantations of different tree species produced different effects on the decrease in soil erodibility factor in the reclaimed minesoils.

The greatest effect on the decrease in soil erodibility factor on sample plots was that of the higher organic matter content in the soil. Organic matter content in the soil results from the dynamic balance of its input to the soil and its decomposition to the final products of mineralization.

Litterfall represents the most important source of organic carbon inputs to the forest floor [16], and this signifies the most important input of total organic matter. The rates of litter decomposition in terrestrial ecosystems depend on geographic factors, climatic factors and litter quality factors [17]. Plant species affected decomposition through both direct and indirect effects. Direct effects were mediated through leaf litter quality, while indirect effects were related to unique conditions that the plant species created in the surrounding environment [18].

Chemical characteristics of litterfall, and the micro-site conditions established by forest plantations causing the decomposition of organic matter, are not the same in the plantations of different tree species. Simultaneously, different forest tree species also provide the input of different quantities of dead organic residue to the soil surface. Total input of organic matter quantity to soil surface, in addition to tree species in the plantation, depends also on plantation age. The amount of litterfall increases with plant growth, but our investigations did not show a statistically significant effect of plantation age on the soil erodibility factor. This probably resulted from the fact that our research did not include juvenile plantations characterized by a still an unformed stand canopy and an unbalanced annual input of organic matter.

The presence of organic matter in the soil is also reflected on soil structure, which is also a factor of soil resistance to erosion agents. Soil organic matter binds mineral particles into aggregates and ensures their stability [19-22]. Binding of organic and mineral components in the soil depends on the mineralogical and textural composition, chemical characteristics of the soil solution and cation composition of the adsorption complex [23-25].

There were also some differences between the sizes of structural aggregates in the top 10 cm of topsoil and the sizes of structural aggregates leached to the deepest layers of the soil profiles. But under coniferous species, the differences within the same soil profile were not so great to be coded by other codes.

In our study, silver lime (*Tilia tomentosa* Moench) made the most positive effects on the soil properties that determine soil erodibility. The weakest effect was attained by black alder. This species is capable of using nitrogen by symbiotic nitrogen fixation [26]. Consequently, black alder produces leaf litter of narrow carbon/nitrogen (C/N) ratio. The C/N ratio is one of the most effective indices of the decomposition and humification of organic matter [27]. The narrow C/N ratio is a precondition for the fast decomposition of organic matter. For this reason, the storage of organic matter under black alder monoculture was not great, and this was also reflected on the reclaimed soil erodibility factor.

Austrian pine is an acidifying species, which acidifies the soil by its leaf litter and products of its decomposition [1]. Although the effect of Austrian pine on soil productivity is unfavourable, the soil erodibility factor of the studied minesoils decreased under its effect compared to recently deposited mine waste. In the study plots, the effect of Austrian pine on the erodibility factor decrease was better than that of black alder, and worse than that of silver lime.

The effect of Japanese larch on erodibility of reclaimed minesoils was different at different localities. Larch is a heliophilous species, with thin crown and transparent stands. This enables the spontaneous invasion of native species to larch plantations, especially in the ground flora layer. The diverse floristic composition of larch plantations contributed to the more diverse organic matter than that in other plantations.

Conclusions

It can be concluded that the same site factors that cause organic matter storage in the soil also affect the extent of plantation effects on soil erodibility. In our study, at the site condition of the climatogenic forest *Quercetum frainetto-cerris* Rud., silver lime (*Tilia tomentosa* Moench) made the most positive effects on the soil properties that determine soil erodibility. In silver lime plantations, the observed erodibility factors were lower than predicted in all sample plots and the residuals exceeded a confidence level of 95%. Rather weaker effects on the soil properties that determine soil erodibility were achieved by Austrian pine (*Pinus nigra* Arn.) and Japanese larch (*Larix leptolepis* (Siebold et Zucc. Gord.), which showed no significant differences between the observed and predicted erodibility factors in any of the observed sample plots. The weakest effect was attained by black alder. In black alder plantations, on two sample plots, the observed erodibility factor was higher than predicted, while the residuals exceeded the confidence level of 95% and on two sample plots there were no significant differences between the observed and the predicted erodibility factors

References

1. KNEŽEVIĆ M. Soil Changes afected by Austrian pine, spruce and Scots pine plantations on different sites in Serbia Ph.D. Thesis, Faculty of Forestry, Belgrade, **1992** [In Serbian].
2. HOWARD P.J.A., HOWARD D.M., LOWE L.E. Effects of tree species and soil physico-chemical conditions on the

nature of soil organic matter. Soil Biol. Biochem. **30**, 285, **1998**.

3. CHEN C. R., XU Z. H., MATHERSA, N. J. Soil Carbon Pools in Adjacent Natural and Plantation Forests of Subtropical Australia Soil Sci. Soc. Am. J. **68**, (1), 282, **2004**.
4. MOUKOUMI J., MUNIER-LAMY C., BERTHELIN J., RANGER, J. Effect of tree species substitution on organic matter biodegradability and mineral nutrient availability in a temperate topsoil. Ann. For. Sci. **63**, 763, **2006**.
5. WISCHMEIER W.H., JOHNSON C.B., CROSS B.V. A soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation **26**, 189, **1971**.
6. McSWEETNEY K., JANSEN I.J. Soil structure and associated rooting behavior in minesoil. Soil Sci. Soc. Am. J. **48**, 607, **1984**.
7. STOJANOVIĆ D., MARTINOVIĆ B., VUČKOVIĆ S., SIMIĆ S., FILIPOVIĆ R. Chemical composition of soils disturbed by mining. Soil and Plant. **26**, (2). **1977**.
8. ANTONOVIĆ G. NIKODIJEVIĆ V., ŽIVANOVIĆ Ž. Characteristics of disturbed soils of the mines in the basins of Kolubara and Kostolac. Soil and Plant. **27**, (1-2), **1978** [In Serbian].
9. ANTONOVIĆ G., MOSKOVLJEVIĆ S., PROTIĆ N. Characteristics of minesoils as substrates in the region of Kolubara. Soil and Plant. **33**, (1), **1984** [In Serbian].
10. VESELINOVIĆ N., MARKOVIĆ D., PENO M., VULETIĆ D. Analysis of Austrian pine (*Pinus nigra* Arn.) plantation development on sandy minespoil banks of the opencast mine REIK "Kolubara". Soil and Plant. **33**, (1), **1984**.
11. RASULIĆ N. Heterotrophic microflora of the sands on the barren soil deposits of the open-cast mines, of electrical industry of Serbia. Master of Sciences Thesis, Faculty of Agriculture, Belgrade. **1997** [In Serbian].
12. ŠMIT S., VESELINOVIĆ N. Recultivation by Afforestation of Minespoil Banks of Opencast Lignite Mine "Kolubara", Special Editions of the Institute of Forestry, Belgrade. **1997**.
13. DRAŽIĆ D. Research of the state and function of spoil-banks recultivated by afforestation of Kolubara Basin aiming at better quality environmental and its use for recreation, Ph.D. Thesis, Faculty of Forestry, Belgrade. **1997** [In Serbian].
14. MILETIĆ Z. Soil development on REIK "Kolubara" mine-spoil banks under the effect of forest plantations. Ph.D. Thesis, Faculty of Forestry, Belgrade. **2004** [In Serbian].
15. MILETIĆ Z., RADULOVIĆ Z. Biogeneity of the organic litter of different forest plantations on minesoils of REIK "Kolubara". Forestry **4**, 11, **2005** [In Serbian].
16. NORDÉN U. Leaf litterfall concentrations and fluxes of elements in deciduous tree species, Scandinavian Journal of Forest Research. **9**, (1), 9, **1994**.
17. ZHANG D., HUI D., LUO Y., ZHOU G. Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors, Journal of Plant Ecology **1**, (2), 85, **2008**.
18. VIVANCO L., AUSTIN A.T. Tree species identity alters forest litter decomposition through long-term plant and soil interactions in Patagonia, Argentina. Journal of Ecology. **96**, (4), 727, **2008**.
19. TISDALL J. M. OADES J. M. Organic matter and water-stable aggregates in soils. European Journal of Soil Science. **33**, (2), 141, **1982**.
20. CARAVACA F., LAX A., ALBALADEJO J. Soil aggregate stability and organic matter in clay and fine silt fractions in urban refuse-amended semiarid soils. Soil Sci Soc Am. J. **65**, (4), 1235, **2001**.
21. SIX J., ELLIOTT E.T., PAUSTIAN K. Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems. Soil Sci Soc Am. J. **63**, 1350, **1999**.
22. SIX J., PAUSTIAN K., ELLIOTT E.T., COMBRIK C. Soil Structure and Organic Matter: I. Distribution of Aggregate-Size Classes and Aggregate-Associated Carbon. Soil Sci Soc Am. J. **64**, 681, **2000**.
23. GREENLAND D. J. Interactions between Humic and Fulvic Acids and Clays, Soil Science. **111** (1), 34, **1971**.
24. BOSATTA E., ÅGREN I. G. Theoretical analyses of soil texture effecst on organic matter dynamics. Soil Biol. Biochem. **29**, (11-12), 1633, **1997**.
25. ARROUAYS D., SABY N., WALTER C., LEMERCIER B., SCHVARTZ C. Relationships between particle-size distribution and organic carbon in French arable topsoils. Soil Use and Management. **22**, (1), 48, **2006**.
26. BLOM J., ROELOFSEN W., AKKERMANS A.D.L. Assimilation of Nitrogen in Root Nodules of Alder (*Alnus glutinosa*). New Phytologist. **89**, (2), 321, **1981**.
27. OHTA S., KUMADA K. Studies on the humus forms of forest soils. VI. Mineralisation of nitrogen in brown forest soils. Soils Sc. Plant Nutrition. **24**, (1), 41, **1978**.