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ASSESSMENT OF ACRISOLS SOIL FERTILITY ON THE TERRITORY OF PETROHAN TRAINING AND EXPERIMENTAL FOREST RANGE, BULGARIA

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Abstract

The soil fertility of Acrisols on the territory of ‘Petrohan’ Training and Experimental Forest Range was assessed by applying the National Classification System developed for soils in forest territories, according to which the following 4 indicators were used – soil depth, org. C stock, total N stock and available soil moisture. In accordance with it Acrisols were characterized from low to moderately fertile. The growth of tree species was also assessed and it was determined as very good for *Fagus sylvatica* L., *Quercus petraea* (Matt.) Liebl. and *Betula pendula* L. For *Pinus sylvestris* L. and *Carpinus betulus* L. was established low growth. The good growth of tree stands did not correspond to the soil fertility assessments. They were different regarding the different indicators. It is assumed that the static examination of nutrient stock should be replaced by studies on the balance of their use and recovery in soils through the biological nutrient cycling.

Key words: available soil moisture, forest soil, org. C stock, total N stock, tree growth.

Introduction

Different indicators for assessment of soil fertility are mentioned in scientific literature. They can be divided into chemical (nutrients), physical (soil depth) and biological (soil organisms). The most frequently used indicators are pH_{H2O}, humus quantity, total amounts of nitrogen, phosphorus and potassium, as well as available forms of nitrogen, phosphorus, potassium, copper, zinc, boron, iron, etc. (Deng et al. 2016). The ratio of nutrients in soil is also significant (Ingestad 1987). Particular attention is given to the ratio org. C/N (Lukina et al. 2011), which is an indicator of nitrogen nutrition. According to Deng et al. (2016) the high soil fertility in forest territories is characterized by the high nitrogen content, low phosphorus and moderate potassium content. According to Legout et al. (2014) soil fertility is high if the pH_{H2O}, exchange basic cations and available phosphorus are in high quantities or the ratio C/N in soil is low. Fungal communities are also an important indicator. Their interrelation with soil fertility is very strong at the levels of species, genera/orders and functional groups (Sterkenburg et al. 2015).

Ponette et al. (2014) studied indicators such as climate, water balance, availability of nutrients, etc., taking into account that at certain moment the fertility indicators could have an opposite effect – disturbance of water balance, delayed organic matter decomposition, changes in the duration of vegetation period, etc.

The deficiency of plant nutrients in soil is important in agricultural lands. Such an approach is often applied to naturally growing species but this creates a number of difficulties, especially regarding the plant communities (Chapin et al. 1986). For example, significant differences in nutrient content were determined in tree layer and forest floor. The ratio between org. C and nutrient amount is higher in the forest floor (Vesterdal and Raulund-Rasmussen 1998). For practical purposes the soil 'chemical fertility' in a given forest is usually determined by a group of nutrients which content is compared to the requirements of the different tree species. This approach is inherited from agronomy and is often unreliable when applied in forest ecosystems. Sometimes these soils are poor in main macroelements such as Ca, Mg, K and are still characterized by high fertility (Legout et al. 2014). Practice showed that the highest species richness often occurred in poor growing conditions (Huston 1980). However, in some cases gradients of changes in plant communities, depending on soil pH_{H2O} and amount of available nitrogen, were determined (Sterkenburg et al. 2015).

Contemporary approaches for assessment of soil fertility include a number of complex relations in forest ecosystems, connected with the nutrient cycling. The recovery of elements in soil is assessed. The main method is associated with decomposition of organic matter deposited on the surface of forest litterfall (Ponette et al. 2014). Significant relations between the adsorption processes occurring on the fine roots of tree species and leaf biomass were determined (Shun 2018, Meng et al. 2018).

Finding the sensitive indicators in forest ecosystems, which could evolve under the influence of the carried out silvicultural practices and global environmental changes, is a challenge to contemporary science (Ponette et al. 2014).

The aim of the present study was to assess the soil fertility of Acrisols on the territory of 'Petrohan' Training and Experimental Forest Range.

Material and Methods

The studied soils occupy an altitude from 692 m to 754 m on the northern slope of the Balkan Mountains, on the territory of 'Petrohan' Training and Experimental Forest Range. They are formed on acidic magma and metamorphic rocks, mainly granite, gneiss granite, diorite, gabro, etc., which are the result of basic magma fractionation and its mixing with acidic one (Tacheva et al. 2006, 2007). The relief is typically mountainous, with steep slopes, deep-cut river valleys, and steep secondary ridges (Ninov 2002). The continental nature of the climate in this area is highly pronounced. The absolute air temperature minimums reach -28.0 °C. Temperatures in July are from 19.6 °C to 20.2 °C, reaching 26.0–27.0 °C. The amount of precipitations is within the range of 450–500 mm (Koleva-Lizama 2006). The main tree specimen, taking part in the soil-forming process, is the Common beech (*Fagus sylvatica* L.). Other deciduous tree species also occur – Common hornbeam (*Carpinus betulus* L.), Turkey oak (*Quercus cerris* L.), Sessile oak (*Quercus petraea* (Matt.) Liebl.), etc. The distribution of coniferous tree species is limited, mainly stands of Scots pine (*Pinus sylvestris* L.), Austrian pine (*Pinus nigra* Arn.), etc.

Acrisols is a new soil unit for Bulgaria, described for first time in 2019 on the territory of ‘Petrohan’ Training and Experimental Forest Range (Malinova and Petrova 2019). In accordance with the WRB requirements (2006–2007) they were determined as Vetic Acrisols.

The National Classification System, developed for soils in forest territories, was applied to assess the fertility of this soil type (Donov 1976, Donov and Yordanov 1988, Raikov et al. 2011). Four indicators – soil depth, org. C stock, total N stock and available soil moisture, determined for the soil profile depth, were used. Soils, having the following characteristics, are assessed as fertile: deep soils (>150 cm), with a high humus stock (>150 $t \cdot ha^{-1}$) and high nitrogen stock (>10 $t \cdot ha^{-1}$), and high values of available soil moisture (>400 mm). Low fertile soils are shallow ones (<100 cm), with low humus (<100 $t \cdot ha^{-1}$) and low nitrogen stock (<5 $t \cdot ha^{-1}$), as well as with low values of available soil moisture (<200 mm). Moderately fertile soils are characterized by intermediate indicators.

The content of soil organic matter was determined by the modified Turin method – 120 °C, 45 min and Ag_2SO_4 as a catalyst (Kononova 1963, Filcheva and Tsadilas 2002); total nitrogen – using Kjeldal’s method with Kjeltec Auto 1030 Analyzer; total water capacity, field capacity, wilting point and available soil moisture – Kachinskii method (Kachinskii 1963) and bulk density – ISO 11272.

The forest mensuration methods were determined according the stands’ age. A tabular method was used for the young stands (up to 20 years); older stands were assessed by applying a mathematical and statistical method. Sample plots with dimensions from 30×50 m to 40×70 m were used. The height and DBH (diameter at breast height) of all trees on the plots were measured. The following indicators were determined: stand composition and origin; average age, average height, average DBH and growing stock by tree species; site index by tree species and relative stocking. The age of stands was determined using increment borer.

Results

In the National Scale for Assessment of Soil Fertility in forest territories it is assumed that the increase of soil depth will also increase root soil layer and also the area from which the tree roots take nutrients and water (Donov 1976, Donov and Yordanov 1988). Previous studies demonstrated that org. C stock, total N stock and available soil moisture can be limiting factors to the tree growth, but the increase of their values resulted in improved growth. The assessment is actual over time although in the recent past nitrogen depositions were too high for the territory of the continent. In some regions they affected the soils in forest ecosystems which resulted in changes of the org. C/N ratio, eutrophication, etc. Their reduction began shortly – after 2015 (EEA 2015). According to some authors, soils in forest ecosystems are not easily saturated with nitrogen (Robert et al. 2012), even when the amounts of nitrogen depositions exceed the needs of vegetation on a given territory. No changes of the ratio org. C/N, caused by increased nitrogen depositions, was determined for the soils on forest territories of Bulgaria for the period 1998–2015 (Tsvetkova et al. 2016), which allowed the use of the assessment scale developed by Donov and Yordanov (1988) in the respective part for total N stock.

The results, necessary for assessment of soil fertility, are presented in Table 1. Acrisols refer to the shallow soils.

Table 1. Acrisols location, composition parameters and available soil moisture (ASM).

Soil profile, No	Coordinates	Elevation, m	Soil horizons	Soil depth, cm	Humus, t·ha^{-1}	Total N, t·ha^{-1}	Bulk density, g·cm^{-3}	ASM, mm
1	43°11'08.5" N 23°07'52.3" E	754	A	0-27	159	105	1.4	77
		754	Bt1	27-52	46	51	1.5	77
		754	Bt2	52-82	36	59	1.6	74
2	43°11'21.5" N 23°07'58.2" E	717	A	0-5	29	8	1.2	22
		717	Bt	5-47	126	51	1.1	189
3	43°11'21.04" N 23°07'59.9" E	694	A	0-13	72	34	1.2	53
		694	Bt	13-42	148	91	1.6	74
4	43°11'35.2" N 23°08'13.3" E	649	A	0-15	45	29	1.2	52
		649	B	15-55	52	65	1.5	115
		649	Bt	55-102	8	50	1.7	113
5	43°10'29.9" N 23°09'12.1" E	692	A	0-7	32	12	1.3	27
		692	B	7-23	39	15	1.4	40
		692	Bt	23-105	111	57	1.6	288

Their profile was less than 100 cm. The boundary between shallow and medium deep soils (100 cm) was slightly exceeded from 2 to 5 cm in only two of the profiles – No 4 and 5. The results showed a different degree of erosion processes occurring in the past. In the predominant case *A* horizon had a depth from 5 to 15 cm. An exception was determined in profile No 1 where the humus horizon reached 27 cm. According to a study, carried out by Ilieva and Petrova (2019), the terrain and climatic conditions on the territory of the Forest Range are a prerequisite for the high erosion potential. The absence of modern intensive processes of sheet and gully water soil erosion is due to the high soil-protecting efficiency of the stands on 92.6 % of the territory.

Humus stocks in the studied soil profiles were different (Table 1). Profiles No 1, 3 and 5 were referred to the high stock category (over 150 t·ha^{-1}). Profile No 2 can be referred to the same category, although the excess over 150 t·ha^{-1} was only 5 t·ha^{-1}. The high stock is due to their higher soil depth.

The high humus content, illustrated for profile No 1 on Figure 1, is also important. Profile No 3 was characterized by the high humus content also in the *argic* diagnostic horizon (Fig. 2). The *argic* horizon itself is enriched with clay that contributes for the active use of humic substances with it. It can be assumed that in this case the soil texture shows a greater influence on the ASM than on the soil depth. Profile No 4 was different – the stock was medium.

The assessment of the total nitrogen stock did not fully coincide with that of the humus. It was high in profiles No 1, 3 and 4, and medium in profiles No 2 and 5.

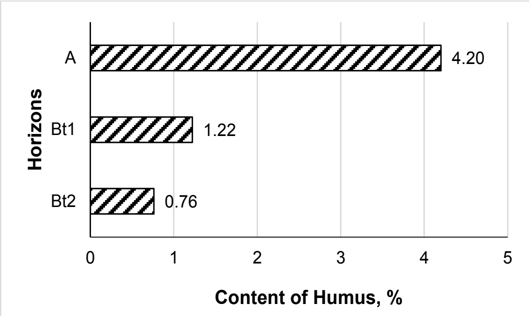

Fig. 1. Humus in soil profile No 1.

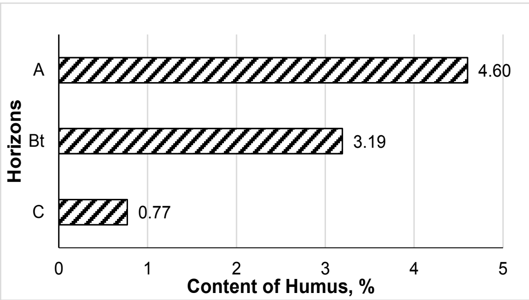

Fig. 2. Humus in soil profile No 2.

The values of the available soil moisture were assessed as low in only one of the profiles – No 3. It was shallow and the values of the available soil moisture in the surface and *argic* horizons were 126 mm. In the other profiles the values ranged from 210 mm to 355 mm and can be assessed as medium.

The assessments regarding the 4 criteria applied to the studied soil profiles are presented in Table 2.

The assessments differed regarding the individual indicators in the same profile. Similar results were also obtained from other authors (Legout et al. 2014), which confirmed the complexity of the overall assessment of soil fertility. In summary, according to the applied assessment scale (Donov and Yordanov 1988) the fertility of Acrisols was low in the shallow soils (profiles No 1, 2 and 3). In these soils the root layer was a limiting factor. The other two profiles (No 4 and 5) were characterized by moderate fertility.

In studies, carried out by Malinova and Petrova (2019), the 'chemical' fertility was assessed as very low. Acrisols were characterized by an oxide composition in the fine earth. It contained mainly quartz (45–49 %), microcline (17–25 %) and albite (10–19 %). Clay minerals were absent or difficult to determine due to their low content. This explains the very low cation exchange capacity – lower than 6 cmol (+)·kg^{-1}, which is enough to assess the soil as very poor.

The growth of tree species, however, was very good. They are of natural origin. The predominant tree species on the Forest Range territory is *Fagus sylvatica*. On the territory, where Acrisols were determined, it was presented in 2 stands – pure Beech (profile No 2) and mixed with other deciduous species (profile No 4) of

Table 2. Results from the assessment of soil profiles.

Soil profile, No	Soil depth	Humus stock	Total N stock	Available soil moisture
1	shallow	high	high	high
2	shallow	high	moderately high	high
3	shallow	high	high	low
4	moderately deep	moderately high	high	high
5	moderately deep	high	moderately high	high

similar age. The site index was high – I for the mixed stand and II for the pure stand. The high site index of the Sessile oak – I class, should be noted. Unlike the Common beech and Sessile oak, the Common hornbeam was characterized by much worse growth. In the studied pure Common hornbeam stand (profile No 5), the site index fell to IV class.

Good growth on Acrisols demonstrated the young stands of Silver birch and Scots pine, which are less demanding. They are also of natural origin. Their dendrometric indicators (Table 3) allowed to refer both tree species to I yield class. Scots pine had the highest yield class – I^A.

The spring-summer aspect of grass species showed great variety. The largest number of species was determined in the Silver birch stand. Its crown was not dense and allowed the passage of enough light and heat to the soil surface for development of grass and shrub species. The presence of the following species was determined in the stand: *Pteridium aqulinum* (L.) Kuhn, *Aethusa cynapium* L., *Rubus Idaeus* L., *Rubus fruticosus* L., *Campanula persicifolia* L., *Fragaria vesca* L., *Galium* sp., *Euphorbia cyparissias* L., *Ajuga reptans* L., *Potentilla recta* L., *Leucanthemum vulgare* Lam., *Filipendula vulgaris* Moench, *Clinopodium vulgare* L., *Crataegus monogyna* Jacq., *Festuca* sp., *Melica uniflora* Retz., *Anthriscus cerefolium* L. Participation of grass species in the other sites was limited. In addition to the aforementioned species there were also single or small groups of *Rumex acetosella* L., *Taraxacum officinale* (L.) Weber, *Viola odorata* L., *Viola sylvatica* Fr., *Galium* sp., *Athyrium filix-femina* (L.) Roth, *Polygonatum multiflorum* (L.) All., etc.

The good growth of tree stands did not correspond to the soil fertility assessments. They were different regarding the different indicators.

The assessments themselves are different for each indicator and this should also be taken into account in practice, for example when determining forest sites. In this case, the studied sites fall into the same site (Raikov et al. 2011). In it, they should be homogeneous in terms of both abiotic factors and growth of tree species.

Other authors also had similar difficulties when performing a complex assessment of soil fertility in forest ecosystems (Chapin et al. 1986, Ponette et al. 2014, Legout et al. 2014, Vesterdal and Raulund-Rasmussen 1998). According to Legout et al. (2014) enough nutrients for the good growth of stands are present in soils when the geochemical component of circulation of substances in the system 'soil – plant' prevails over the biological one. The main source of nutrients in this case is the weathering process occurring in the mineral part of soil. Atmospheric depositions and rise of water in a capillary way from the deeper soil layers also contribute to them. In contrast, small amount of nutrients in soil is observed in the cases of dominating biological or chemical circulation. The importance of biological circulation for plant nutrition is well described in the literature based on the example fast-growing eucalyptus forests. It was determined that the nutrient content in the aboveground biomass is directly dependent on the presence of slash – aboveground organic residues such as leaves, branches, bark, etc. The slope contains immobilized nutrients which in the process of mineralization pass into available for plants form (Nzila et al. 2002, Laclau et al. 2003).

The circulation of nutrients in the examined forest ecosystems with presence of Acrisols has not been studied yet. The results of the analysis of their cation ex-

Table 3. Stands' characteristics.

Soil profile No	Tree species	Tree partici-pation	Origin	Average age, years	Relative stocking	Average height, m	Average DBH, cm	Site in-dex	Growing stock, $m^3 \cdot ha^{-1}$
1	*Pinus sylvestris* L. Single trees: *Betula pendula* L., *Acer pseudo-platanus* L., *Pyrus pyraster* L., *Prunus avium* L., *Prunus cerasifera* Ehrh.	10	Seed natural origin	15	1.0	7.5	10	I^a	84
2	*Fagus sylvatica* L. Single trees: *Prunus avium* L., *Quercus petraea* (Matt.) Liebl.	10	Seed natural origin	86	0.97	23.6	29.6	II	403
3	*Betula pendula* L.	9	Seed natural origin	20	1.02	10.7	11.9	I	86
	Pinus sylvestris L. Single trees: *Carpinus betulus* L., *Acer pseudo-platanus* L., *Populus tremula* L., *Fagus sylvatica* L.	1	Seed natural origin	20		11.3	11.0	I^a	11
4	*Fagus sylvatica* L.	7	Seed natural origin	84	0.72	27.4	30.9	I	227
	Quercus petraea (Matt.) Liebl.	2	Seed natural origin	78		27.2	31.8	I	58
	Carpinus betulus L.	1	Seed natural origin	80		21.8	19.7	III	31
5	*Carpinus betulus* L. Single trees: *Fagus sylvatica* L.	10	Seed natural origin	105	0.79	22.3	28.0	IV	230

change properties showed that in the conditions of very high to high soil acidity (pH_{H2O} in the A horizon from 4.7 to 5.4), forest litter was saturated with bases (96–97 %) (Malinova and Petrova 2019). This means that litter is an important nutrient depot in the circulation of substances. Good growth of stands revealed that its decomposition released enough amounts of nutrients which were easily-absorbable by the roots of tree species. The ratios org. C/N in the litter (from 18 to 27) and in the surface soil horizon (from 9 to 20) were low and showed a relatively fast release of mineral nitrogen, i.e. the factors which determine the good growth of stands were available.

Conclusions

The assessment of soil fertility of Acrisols through chemical and physical indicators is insufficient to interpret the good growth of stands on very poor soils on the territory of the 'Petrohan' Training and Experimental Forest Range. The static examination of nutrient stock should be substituted with studies on the dynamics of their depletion and recovery. The nutrient stock in the forest litter was low and concentrated. For now, it can be assumed that the biological circulation of substances is the main source of mineral nutrition of plants and its balance should be studied and maintained in the long term.

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