SILVA BALCANICA

Silva Balcanica 24(2): 91-100 (2023)
doi: 10.3897/silvabalcanica.24.e104591

RESEARCH ARTICLE

Canopy influence on soil properties in Austrian pine artificial stands

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Academic editor: Georgi Georgiev | Received 5 April 2023 | Accepted 30 October 2023 | Published 21 November 2023

Citation: Glogov P., Bogdanov S., Gyudorova S. 2023. Canopy influence on soil properties in Austrian pine artificial stands. Silva Balcanica 24(2): 91-100. https://doi.org/10.3897/silvabalcanica.24.e104591

Abstract

The aim of the present study is to track changes in the canopy (cover-abundance of the tree layer) of vegetation and cover of the forest litter, and the relationship between them and the dynamics of soil parameters in Austrian pine (*Pinus nigra* Arn.) plantations. The objects of study are 50-80-year-old artificial plantations of Austrian pine located in the xerothermic oak belt of five mountains in the area of Sofia. In each mountain, three test plots (SPs) were laid out, each measuring 400 m² (Table 1). The main reason for choosing PP is the cover abundance of the first layer. Within each SP, the following metrics are measured: cover-abundance (%) of vegetation in each layer; the cover of plant litter (%). From all SPs, soil samples were taken from three depths: 0-10 cm, 10-20 cm and 20 -30 cm. An analysis of the content of soil organic matter was carried out, including: total nitrogen (N), the C/N ratio – calculation method, the reaction of the soil solution (pH) in the aqueous extract and the mechanical composition of the soil.

The results show that the properties of the studied soils change to a significant extent in accordance with the cover abundance, especially in the first floor of the vegetation. Soil organic matter content, C/N ratio and mechanical composition are the indicators that most clearly reflect the relationship between the canopy and the cover of plant litter on the one hand, and soil properties. The proven, statistically significant differences in the values of these indicators emphasize the role of vegetation in soil-forming processes, the formation and change of soil fertility.

Keywords

cover-abundance, coniferous plantations, *Pinus nigra*, soil properties, Rendzinas

Introduction

Studies on the structure of phytomass and changes in soil properties are extremely important in facilitating an understanding of the soil–vegetation link mechanism (Rahmonov et al., 2021). Analyzing the interactions between soil and vegetation determines the possibilities for restoration, conservation and improvement of soil fertility and vegetation development as a condition for biodiversity conservation, increasing the productivity of plant communities and rational use of natural resources. (van der Putten et al., 2013, Huang et al., 2015)

In forest ecology, "canopy"" refers to the upper layer or habitat zone, formed by mature tree crowns and includes other biological organisms (epiphytes, lianas, arboreal animals, etc.) Parker, Geoffrey (1995). In phytocoenology, a close analogue of canopy is "cover-abundance" of the first (tree) layer in the forest community (Pavlov, 1995).

Cavard et. al. (2011) examine the effect of forest canopy composition on soil nutrients and dynamics of the understorey in mixture stands of *Pinus maritima* Lam., *Populus tremuloides* Michx.. and *Pinus banksiana* Lamb.. The authors found that higher aspen presence, linked to greater nutrient availability in the forest floor, was generally associated with higher vascular biomass and production in the understory.

A study by Wichmann et al. (2022) on changes in vegetation, the soil seed bank, and soil nutrients in oak forest bait sites situated in Mátra Landscape Protection Area (Hungary), shows that the amount of soil nutrients was significantly (more than 10 times) higher in the clearings and this, along with their greater openness, may be responsible for the higher number of weed species in their seed banks.

The study of the effects of canopy on soil erosion and carbon sequestration in a pure Pedunculate oak (*Quercus robur* L. subsp. *robur* L.) coppice stands during the conversion process into high forest. In other words, the decrease of canopy density increases soil losses and decreases carbon stocks, and in turn if the canopy gets reduced during the conversion process, C stocks are at risk (Yücesan et al., 2019).

Currently, most of the coniferous plantations in Bulgaria are over 40-50 years old and due to their low resistance, they are affected by an intensive thin out and degradation processes, and on the other side intensive succession processes aimed at the restoration of the natural vegetation, have begun (Popov et al., 2018). For this reason, it is important to follow the influence of artificial stands on the environmental conditions in view of the prerequisites for future shifts in vegetation composition. The same authors point to afforestation patterns as one of the reasons for subsequent early drying of coniferous stands. Stand density turned out subsequently to be one of the main factors in their mechanical and biological instability. Raev et al. 1991 found that in rich but dry soils, their nutrient supply could not be digested by conifers and they became unstable, vulnerable to calamites and drying.

The aim of the present study was to trace changes in canopy (cover-abundance) of vegetation and dead forest litter and the relationship between them and the dynamics of soil indicators in Austrian pine (*Pinus nigra* Arn.) artificial stands.

Materials and methods

The study was conducted in 2020. The objects of study are 50-80 year old artificial plantations of Austrian pine located in the xerothermic oak belt of five mountains in Sofia region. In each mountain, 400 m²- sample plots (SPs) were set up (Table 1). The main reason for choosing the location of the SP is the canopy (the cover-abundance of the first (tree) layer is used for the purposes of the study). Within each SP, the following are measured: cover-abundance (%) of vegetation in each layer; the cover of plant litter (%) (Pavlova et al., 2021).

Table 1. Geographic data for SP

Object	SP No	Geographical coordinates	Altitude (m a.s.l.)	Exposition	Slope (°)
Plana Mt.	1	N 42°35'22.0; E 23°24'15.0	730	SE	33
	2	N 42°35'23.0 E 23°24'15.0	740	SE	21
	3	N 42°35'22.0 E 23°24'21.0	709	SE	25
Vitosha Mt.	1	N 42°38'55.0 E 23°14'10.0	810	N	26
	2	N 42°38'57.0 E 23°14'12.0	800	NW	12
	3	N 42°39'02.0 E 23°14'14.0	775	N	19
Lyulin Mt.	1	N 42°39'51.0 E 23°12'57.0	800	SE	18
	2	N 42°39'49.0 E 23°12'56.0	850	E	11
	3	N 42°39'47.0 E 23°12'42.0	850	SE	7
Lozenska Mt.	1	N 42°34'55.0 E 23°25'53.0	780	SE	41
	2	N 42°34'53.0 E 23°25'51.0	774	SE	21
	3	N 42°34'52.0 E 23°25'45.0	700	SE	19
Stara planina Mt	1	N 42°47'15.0 E23°30'48.0	751	SE	17
	2	N 42°47'14.0 E 23°30'45.0	743	SE	20
	3	N 42°47'14.0 E 23°30'45.0	742	SE	20

The soils in all SPs are humus-carbonate, also known as Rendzinas. In the classification of soils in Bulgaria (Penkov et al., 1992) and in the International Reference Base for Soil Resources (IUSS Working Group WRB, 2014), they are defined as primitive soils (Leptosols), developed on carbonate-rich rocks under different climatic conditions. A primary qualifier for the Rendzina at a lower taxonomic level in the same qualification scheme is Rendzic.

Soil samples have been taken from three SPs in each object from the layers 0–10 cm 10-20 cm and 20–30 cm. The following methods were used to analyze the soil samples.

- Soil organic matter (SOM, %) by the Turin method;
- Total N (%) content, with a modified version of the classic Kjeldahl method;
- C:N ratio – calculation method;
- Soil acidity (pH in water extraction) – measured potentiometrically;
- Soil texture by the Kachinski method.

The results of the soil properties study were statistically analyzed using SPSS programs. LSD Post-Hoc analysis (IBM SPSS 26.0 for Mac) was applied to prove statistically significant differences between indicators in individual sample areas. A significance level of $p < 0,05$ was chosen.

Results and discussion

The cover-abundance of the tree floor varies between each of the SPs from 55% to 75%, in the shrub floor it varies from 5% to 90%, in the grass floor – from 10% to 70%, the moss floor – from 0% up to 5% (Table 2). The cover of plant litter is between 75% and 95%.

Table 2. Data on vegetation cover-abundance and the cover of plant litter in SPs

Object	**Plana Mt.**			**Vitosha Mt.**			**Lyulin Mt.**			**Lozenska Mt.**			**Stara planina Mt.**		
SpNo	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Cover- abundance of layer I (%)	65	70	55	60	75	65	55	65	75	70	65	60	60	65	75
Cover- abundance of layer II (%)	70	50	65	45	90	40	85	80	30	20	60	85	70	30	5
Cover- abundance of layer III (%)	50	40	50	45	70	40	35	55	40	40	50	70	60	30	10
Cover- abundance of layer IV (%)			3		5		2			5	2	5	5	5	2
Cover of plant liter (%)	90	95	90	80	85	85	85	80	80	90	80	80	75	85	95

In the first layer of all SPs there is a predominant cover-abundance of *Pinus nigra*, in places with a single presence of *Quercus dalechampii* Ten.. and *Carpinus betulus* L. The second layer is occupied by representatives of autochthonic tree and shrub vegetation – *Q. dalechampii*, *Q. frainetto* Ten., Q. cerris L., *Acer campestre* L., *Pyrus pyraster* (L.) Burgsd. , *Sorbus aria* (L.) Crantz, *Fraxinus ornus* L., *Carpinus orientalis* Mill., *Lygustrum vulgare* L., *Syringa vulgaris* L., *Crataegus monogyna* Jacq., *Cornus mas* L., *Rosa canina* L. , etc., of which with a higher cover-abundance (over 15%) in individual PPs are: *F. ornus, S. vulgaris* and *C. orinetalis* and *Q. dalechampii*. The third layer includes part of the above-mentioned tree and shrub species understory, as well as grasses characteristic of oak communities such as *Buglossoides purpurocaerulea* (L.) I.M.Johnst, *Clinopodium vulgare* L., *Teucrium chamaedrys* L., *Campanula persicifolia* L., *Festuca heterophylla* Lam., *Galium sylvaticum* L., etc. There are no grass species with cover-abundance more than 3-5%. The abundance of Austrian pine in the second and third layers in the different SPs is low (1-2%), which is due to the weak regeneration of the species and the competition of autochthonic tree and shrub species. *Hypnum cupressiformae* Hadw. is most often found in the layer of mosses. Single individuals of the invasive alien species *Laburnum anagyroides* Medik., which at this stage do not pose a danger to the native vegetation, were found in two of the SPs on the territory of Lozenska Mt.

The soils in all SPs have a similar structure, which is characteristic of Rendzina formed on hard carbonate rocks (Bogdanov, 2022). The soil profile is composed of a humus-accumulative A horizon of varying thickness (30-40 cm), located on hard soil-forming rocks of limestones and marls. As a result of the vital activity of the plant communities, a soft-type plant litter was formed with a small thickness – between 2 and 4 cm.

The results of the laboratory tests are presented in Table. 3. The obtained data show differences in the properties of the soil depending on the characteristics of the vegetation cover-abundance, especially in relation to the cover-abundance of its first layer.

The soils are relatively well-stocked with humus, with its content ranging from 4.06 to 7.02 % in the 0-10 cm layer, between 2.95 and 5.23 % in the 10-20 cm layer, and from 0.89 to 3.74 % in the 20-30 cm layer. Soil organic matter is a major source of nutrients for plants. In accordance with this, in all SPs, the first floor cover-abundance of the vegetation increases in accordance with the humus content, and this is most clearly expressed in the soil layers closer to the surface (Table 3)

Similar to changes in the humus content, the amount of total nitrogen (N) also decreases with depth in the soil profile. In the uppermost (0-10 cm) layer it is from 0.158 to 0.234 %, in the middle (10-20 cm) soil layer – between 0.114 and 0.182 %, and between 0.035 and 0.104 % in the 20-30 cm layer (Table 3). Despite the fact that the content of humus and total nitrogen, which is its component, are to a certain extent related, the analysis of the data from most of the SPs shows an opposite trend in the quantitative changes of nitrogen depending on the cover-abundance of the first plant floor. With increasing cover-abundance, the content of total nitrogen decreased in the 0-10 cm and 10-20 cm soil layers in almost all sample areas (Table 3). This can be explained by the more intensive absorption of ammonium and nitrate forms of nitrogen, which young plants use for their development and growth. An exception to this trend is the data from SP1 on the territory of Lyulin Mountain, in which a lower total nitrogen content was found with a weaker coverage of the first floor. Probably, in this case, the greater age of the plantation in the SP has a determining influence.

The ratio of the amount of total C to the amount of total nitrogen (C/N) expresses the degree of decomposition of organic matter and helps to clarify the nature of processes in the soil. The values of this indicator vary widely – from 10 to 28, growing with the increase in depth (Table 3), which shows that in the lower (20-30 cm) soil layer, mineralization proceeds more slowly, and at the same time – that the humus there is poorer in nitrogen. The faster the decomposition of organic matter, the lower the amount of total carbon, and the greater the amount of total nitrogen. And conversely, the slower the decomposition of organic matter, the more carbon and the less the amount of nitrogen released during decomposition. This determines the established correspondence between the C/N ratio and the cover of the dead forest floor (Table 3), which is less at lower values of this indicator, reflecting the higher intensity of mineralization of organic matter.

At the same time, the characteristics of plant communities influence the microclimate and the vital activity of soil microorganisms, which are factors of essential importance for the intensity of the transformation of organic substances. This is confirmed by the correspondence between lower values of the C/N ratio and less cover of the first vegetation floor.

The reaction of the studied soils is from neutral to slightly alkaline, with pH values between 6.6 and 7.4 (Table 3). In most cases, they increase in depth as they approach the carbonate bedrock, which is a major factor in pH variations in humus-carbonate soils and the formation of this soil type.

The mechanical composition of the soils in the studied sites is from sandy to slightly sandy loamy. The results show that the projective cover of the first plant floor is different depending on the clay content. Similar to the correspondence with humus content, the projective coverage of the first floor is greater on clay soils, which is a natural result of their better nutrient availability and plant-available soil moisture.

The statistical analysis of the research results shows statistically significant differences between the cover-abundance of the first plant layer, on the one hand, and the humus content (Fig. 1) and the mechanical composition (Fig. 2) on the other, as well as between the cover of the dead forest litter and the values of the C/N ratio (Fig. 3). These are the indicators that most closely reflect the relationship between vegetation development and soil properties. No clear correlation was found between the changes in the cover-abundance of the second and third layers and the soil indicators. The probable reasons for this are: the seasonal nature of the vegetation in the second and third layers and the predominance of broad-leaved deciduous species in the understory element, as well as the relatively young age of the species in the second layer.

The proven statistically significant differences of these indicators underlines the importance of vegetation as the main factor of soil formation.

The lack of statistical significance in the changes in the values of soil acidity (pH) in the individual sample areas confirms the leading role of the main scale in the changes in the reaction of the soil solution, as well as in the formation of Rendzina as a soil type.

Table 3. Soil properties

Object	Sample plot	Depth cm	Soil organic matter %	Total N %	C/N	pH	Soil texture	
							Sand %	Clay %
Plana Mt.	1	0-10 10-20 20-30	6.04 4.00 1.53	0.205 0.121 0.052	17 19 17	7.2 7.3 7.4	79 81 84	21 19 16
	2	0-10 10-20 20-30	7.02 4.24 3.33	0.187 0.114 0.068	22 22 28	7.0 7.0 7.1	74 77 82	26 23 18
	3	0-10 10-20 20-30	4.42 3.33 1.48	0.217 0.126 0.050	12 15 17	7.2 7.2 7.4	81 82 85	19 18 15
Vitosha Mt.	1	0-10 10-20 20-30	4.06 2.95 0.89	0.200 0.167 0.044	12 10 12	6.8 7.0 7.1	73 73 77	27 27 23
	2	0-10 10-20 20-30	5.27 4.90 2.06	0.188 0.155 0.055	16 20 22	6.6 6.7 6.8	61 62 66	39 38 34
	3	0-10 10-20 20-30	4.88 3.48 1.21	0.192 0.160 0.035	15 13 20	6.9 7.1 7.3	68 73 76	32 27 24
Lyulin Mt.	1	0-10 10-20 20-30	5.69 4.88 2.41	0.180 0.142 0.060	18 20 23	7.3 7.2 7.2	78 80 84	22 20 16
	2	0-10 10-20 20-30	6.00 4.97 2.85	0.234 0.182 0.104	15 16 16	7.0 7.1 7.1	72 74 79	28 26 21
	3	0-10 10-20 20-30	6.59 5.23 3.74	0.226 0.177 0.093	17 17 23	6.7 6.9 6.8	69 69 72	31 31 28
Lozenska Mt.	1	0-10 10-20 20-30	5.08 4.11 2.67	0.178 0.140 0.069	17 17 22	7.1 7.2 7.4	82 85 88	18 15 12
	2	0-10 10-20 20-30	4.65 3.96 2.03	0.204 0.163 0.084	13 14 14	7.0 7.1 7.2	87 89 90	13 11 10
	3	0-10 10-20 20-30	4.29 3.62 1.49	0.220 0.174 0.053	11 12 16	7.1 7.1 7.2	92 92 93	8 8 7
Stara planina Mt.	1	0-10 10-20 20-30	4.07 3.21 1.31	0.208 0.170 0.065	11 11 12	6.8 7.0 7.4	69 71 75	31 29 25
	2	0-10 10-20 20-30	4.00 3.76 2.01	0.172 0.135 0.070	13 16 17	6.8 6.8 7.0	65 68 70	35 32 30
	3	0-10 10-20 20-30	4.87 4.35 2.82	0.158 0.119 0.071	18 21 23	6.8 6.9 7.0	61 61 63	39 39 37

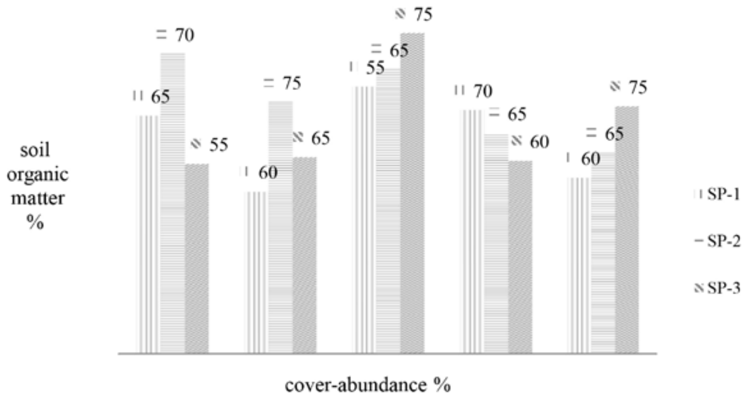

Figure 1. Statistically significant differences (p = 0.035 < 0.05) in the content of soil organic matter in accordance with cover-abundance

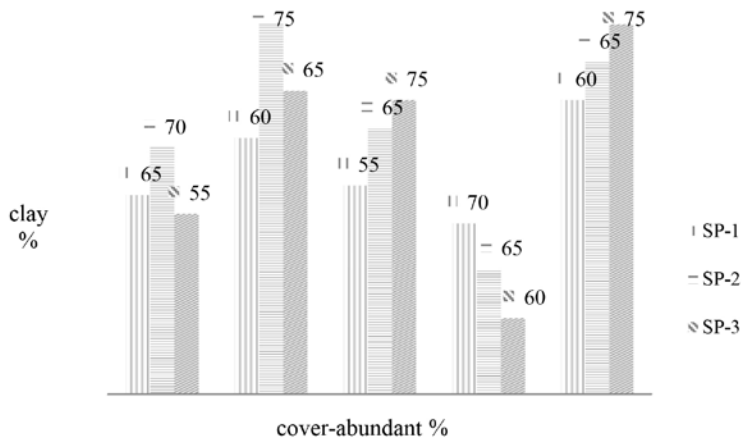

Figure 2. Statistically significant differences (p = 0.032 < 0.05) in soil texture in accordance with cover-abundance

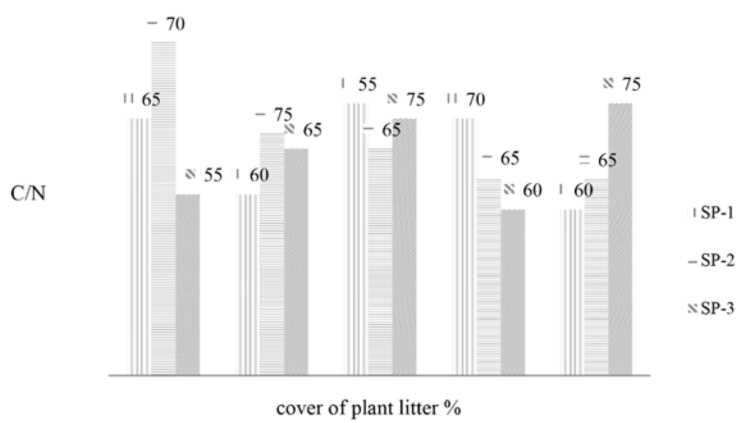

Figure 3. Statistically significant differences (p = 0.032 < 0.05) in C/N value in accordance with cover of plant litter

Conclusions

The cover-abundance of the first layer of vegetation (canopy) increases in accordance with the humus content, and this is most clearly expressed in the soil layers closer to the surface.

Soils with a higher clay content provide plants with a greater amount of nutrients and available soil moisture, which is reflected in a greater canopy.

More intensive absorption of ammonium and nitrate forms of nitrogen, which young plants use for their development and growth, determines the lower content of total N in the SPs with greater canopy.

No clear correlation was found between the changes in the cover-abundance of the second and third layers and the soil indicators.

Plant communities influence the microclimate and the vital activity of soil microorganisms, which are factors of essential importance for the intensity of the transformation of organic substances. This is confirmed by the correspondence between lower values of the C/N ratio, which express more intense mineralization of organic matter, and less cover of dead forest litter.

Statistically significant differences in soil organic matter content, C/N ratio and mechanical composition, according to vegetation cover and dead forest litter, highlight the importance of plant communities as a major factor in soil formation.

The lack of statistical significance in the changes in the values of soil acidity (pH) in the individual sample areas shows that the influence of vegetation development on this indicator is weaker compared to other factors, among which the main rock plays a leading role.

Acknowledgments

This work has been carried out in the framework of the National Science Program “Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters”, approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01-271/039.12.2022).

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