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VARIATION OF THE ACID-BASE PROPERTIES OF FOREST SOIL AND LITTER UNDER DIFFERENT TREE SPECIES AFFECTED BY FOREST FIRES IN SOUTH-EASTERN BULGARIA

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Abstract

Acid-base properties in cinnamonic forest soils (Chromic Luvisols) and forest litter under different fire-affected stands of tree species have been studied. The samples were taken immediately after fire, 1 month, 3 months and 1 year after it from affected and from unaffected (control) areas. The depth at which soil sampling was performed was from 0 cm to 5 cm and from 5 cm to 20 cm. Soil and litter acidity (pH) was measured potentiometrically in an aqueous extract. The most pronounced changes in pH values in comparison with the control variants was established in soil samples, taken from influenced by a surface fire broadleaf stand of *Quercus pubescens* Willd. The pH changes in the samples from forest litter were more pronounced than the changes registered in soil samples. A trend of a soil acidity increase was established till one year after fire influence for Austrian pine plantations and oak stands.

Key words: cinnamonic forest soil, forest litter, soil acidity, *Pinus nigra* Arn., *Pinus sylvestris* L., *Quercus pubescens* Willd.

Introduction

Fire is a dynamic process that influences composition, structure, and patterns of a vegetation community and soil (Boerner 1982). Soil properties could be influenced by short-term, long-term or permanent fire-induced changes, depending primarily on types, severity and frequency of fires, and post-fire climatic conditions. Fire could cause alterations of soil biogeochemical cycles, destroying/burning soil organic matter that increased soil pH for short duration, and change availability of nutrients in soil (Prieto-Fernandez et al. 1993, González-Pérez et al. 2004, Neill et al. 2007, Nguyen 2011).

Soil pH is one of the most important index, influencing directly and indirectly availability of soil nutrients (DeBano et al. 1998, Úbeda et al. 2005). According to Pritchett and Fisher (1987) the magnitude and duration of soil pH changes depends on the amount of ash formed, and also on the soil texture and pre-fire content of soil organic matter. Nutrient cations – Ca, Mg, and K, released by combustion of organic matter tend to move downward into the soil's profile, and result in elevation of sub-surface soil pH (Dikici and Yilmax 2006, Murphy et al. 2006). In many studies was found that the soil pH increases immediately after forest fire (Kutiel and Shaviv 1990, Velizarova et al. 2001, Velizarova et al. 2002, Boerner et al. 2009, Tufekcioglu et al. 2010, Aref et al. 2011, Bogdanov 2013, Pereira et al. 2014). The results of pH changes in fire influenced soils under Austrian pine plantations show that its increasing depends on fire intensity (Velizarova et al. 2010). According to Kutiel and Naveh (1987) the pH values showed significant increase immediately after the fire and then decreased rapidly to the levels of unburned soil. This trend is presumably due to the increase of soluble cations from the formed ash (DeBano et al. 1977). Khanna et al. (1994) assessed that capacity of ash to neutralize soil acidity was well correlated with sum of concentrations of K, Ca, and Mg in ash itself. Forest fires lead to quick increase in soil pH, resulting from combustions of soil organic matter (SOM) and plant residues, and denaturation of organic acids in soils. The numerous authors suppose that increment of pH only occurs when temperature during fire is greater than 450° and organic matter is absolutely burned, and ash is formed (Macadam 1987, Arocena and Opio 2003, Qian et al. 2009). Kutiel et al. (1990) found that soil pH decreased to pre-fire conditions eight months after a low intensity fire in a pine forest in Israel, while following a high intensity fire was found that soil pH values remained significantly higher in burned plots for at least two years (Litton and Santelices 2003). Higher soil acidity (lower pH values) in fire influenced soil in comparison with not affected was established five years after fire occurrence in deciduous forests (Ilinkin et al. 2013). Increasing of the soluble forms of calcium, magnesium, potassium and sodium are the reason for soil acidity decrease immediately after forest fire (Bogdanov 2014). Ulery et al. (1993) found that the topsoil pH could increase as much as 3 units immediately after fire. This rise was essentially due to formation of K and Na oxides, hydroxides, and carbonates in result of fire. In contrast, the fire-induced changes of soil pH are negligible in calcareous soils which have a high buffer capacity (Motavalli et al. 1995). All reviewed data show that the impact of forest fire on soil and forest litter pH depends on tree species composition, type and intensity of fire, buffer capacity of soils and require detail studies for separate area, affected by forest fire.

The purpose of the study was to establish the time-dependence changes in pH of cinnamonic forest soils (Chromic Luvisols) and forest litter under different tree species form South-eastern part of Bulgaria.

Material and Methods

The sampling was performed in Cinnamonic forest soils – Chromic Luvisols (LVha) (WRBSR 2014) impacted by crown and surface forest fires occurred in summer 2013 in South-eastern part of Bulgaria (Fig. 1).

Object 1 was representative for crown and surface fire affected area in Mineralni bani Municipality region. The main tree species is Austrian pine (*Pinus nigra* Arn.) plantation assigned as '*PN*' impacted by crown and surface fire occurred in August 2013. Soil samples were collected in three replications from fire-influenced soil, assigned as C1, C2, C3 (crown fire) and from undisturbed soil – U1, U2 and U3 (control variants) (Fig. 1, Table 1).

Within Svilengrad Municipality region two objects have been established. The studied area is located in southern part of Sakar Mountain referring to Southern edge of border of forest vegetation region (Zahariev et al. 1979). In Object 2 the mixed coppice stand with dominant tree species Downy oak (*Quercus pubescens* Willd.) assigned as follows – S1, S2, S3 was affected by surface fire. In Object 3, the main tree species, affected by surface fire in August 2013 was Scots pine plantation (*Pinus sylvestris* L.) – '*PS*'. Sampling plots were assigned as S4, S5 and S6 respectively. Close to the affected area undisturbed sites for control plots were established – U4, U5, U6, U7, U8 and U9 (Table 1).

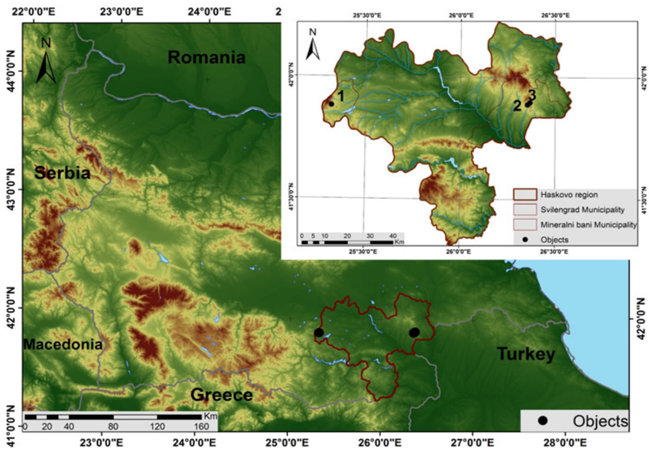

Fig. 1. Location of the studied area: Object 1 – Mineralni bani Municipality region; Object 2 and Object 3 – Svilengrad Municipality region.

Table 1. Study area characteristics.

Studied objects	Variants	Fire type	Dominant tree species	Altitude, m	Stand age	Area, ha	Geographic coordinates
			Mineralni bani Municipality				
	C1						41°52'54.9" N 25°19'8.1" E
	C2	Crown and surface fire					41°52'55.5" N 25°19'9.6" E
1	C3		*Pinus nigra* (*PN*)	473	40	7.0	41°52'55.3" N 25°19'9.9" E
	U1						41°52'57.6" N 25°19'5.9" E
	U2	Undisturbed					41°52'57.3" N 25°19'5.8" E
	U3						41°52'57.5" N 25°19'5.9" E
			Svilengrad Municipality				
	S1						41°53'18.9"N 26°21'15.1"E
	S2	Surface fire			50	5.8	41°53'18.7"N 26°21'15.1"E
2	S3		*Quercus pubescens* (*Q*)	462			41°53'18.9"N 26°21'15.5"E
	U4						41°53'18.9"N 26°21'14.2"E
	U5	Undisturbed			35	6.7	41°53'19.2"N 26°21'13.9"E
	U6						41°53'18.7"N 26°21'13.6"E
	S4						41°53'50.8"N 26°22'4.2"E
	S5	Surface fire		378			41°53'50.6"N 26°22'4.3"E
3	S6		*Pinus sylvestris* (*PS*)		45	1.2	41°53'50.6"N 26°22'4.0"E
	U7						41°53'51.5"N 26°22'4.4"E
	U8	Undisturbed		377			41°53'51.3"N 26°22'4.7"E
	U9						41°53'51.6"N 26°22'5.1"E

The changes in soil pH were studied in dynamic. For this purpose, the sampling was performed immediately after fire, 1 month, 3 months and one year after fire marked as I, II, III and IV (sampling) respectively. The soil samples for analysis were taken in 3 replications from a depth: 0–5 cm and 5–20 cm. Sampling was performed from forest litter at each variant for soil sampling. Forest litter samples were collected using sampling frame with size 25 × 25 cm. Forest litter samples were analysed for pH, using a 1:2 ratio (mass forest litter /volume H_2O) solution. Soil pH was determined in suspension soil to water in ratio 1:5. Measurement was performed potentiometrically by pH meter (HANNA HI 2211).

Results and Discussion

In Fig. 2, the results of pH values of forest litter from different tree species, affected by forest fire in studied periods are presented.

A considerable increase of pH in forest litter, collected from *PN* plantation affected by fire was observed, as the highest value 7.9 was recorded for the period immediately after the fire occurrence. During next three periods of investigation a decrease of pH was observed (Fig. 2). The similar trend was observed for two other tree species affected by forest fire in Object 2 and Object 3. However the most pronounced changes of pH between control variants and fire affected forest litter were observed for *PN* and *PS*, which is most probably in result of the organic acids denaturation (Certini 2005) and due to increase of soluble cations from the formed ash (DeBano et al. 1977).

Parzych and Sobisz (2012) established that in the needles of *Pinus nigra* a notably higher accumulation of P, K, Ca, Mg and Mn was observed than that in the needles of *Pinus sylvestris* which could be the reason for higher differences in pH of *PN* forest litter between control and fire affected samples. Less increase in pH values for all studied periods in the forest litter under coppice oak stand (*Q*) influenced by surface fire was found as results of investigations. The highest values were recorded in the period immediately after the fire – pH = 8.2.

The trend in pH changes through the next studied periods was slightly downward (Fig. 2, Object 2). The results of forest litter pH from the *PS* sampling sites show the highest values of the pH – 8.3 immediately after fire occurrence. The difference in pH of the fire affected forest litter and control one is the highest immediately after forest fire and decreased to values from the control sampling sites one year after forest fire. The pH increment is with about 3 units, while in ash formed as a result of the fire affected oak litter, it is with about 1.5 units. Pereira et al. (2011) also found higher pH in ash of conifers species in comparison with broadleaf (oak) species and explain the increasing of pH in ash with formation of more $CaCO_3$. Similar results were obtained by Pereira et al. (2014) and Blank and Zamudio (1998), who found that pH values were higher in ash extracted from fire affected forest litter under *Pinus pinaster* Ait. and *Salix scouleriana* Barratt ex Hook. respectively than from unburned one. Our results for time-relation changes of pH in forest litter after fire are in agreement with that established by Smith (1969) who found that the pH values of fire influenced L-H sub-horizons remained higher than ones of uninfluenced litter for a year after the fire occurrence. One year after fire, due to the felling of Austrian pine forest stands no ash on the surface of mineral soil was found (Fig. 2, Object 1).

Additionally, the newly formed needle fall was found just before the second period of sampling, which could also provoke slightly underestimation of forest litter pH (Fig. 2, Object 3). In Fig. 3 the results of pH values in both soil layers are presented. Soil pH in layer from 0 to 5 cm under *PN* affected by surface and crown fire show negligible changes in comparison with control variants during all studied periods (Fig. 3).

However slightly increased pH could be mentioned at the end of the period – about one year after forest fire. The combustion of forest litter, in result of which sum of concentrations of K, Ca, and Mg in ash itself increase reduced fire intensity and heat transfer to the mineral soil.

On the other hand, the dissolution of this ash and subsequent effects upon surface soil chemistry depends, to a great extent, on the nutrient status of the soil prior to fire and the mass of ash-derived nutrients that are added as a consequence of fire (Boerner 1982). Similar trend was observed for Chromic Luvisols under *PN* plantations, affected by surface and crown fire 20 months after it (Velizarova et al. 2011). In studies of Glogov and Bogdanov (2003) and Bogdanov (2013) in Chromic Luvisols under coniferous forests affected by surface and crown fire also observed increasing of pH values one year after it.

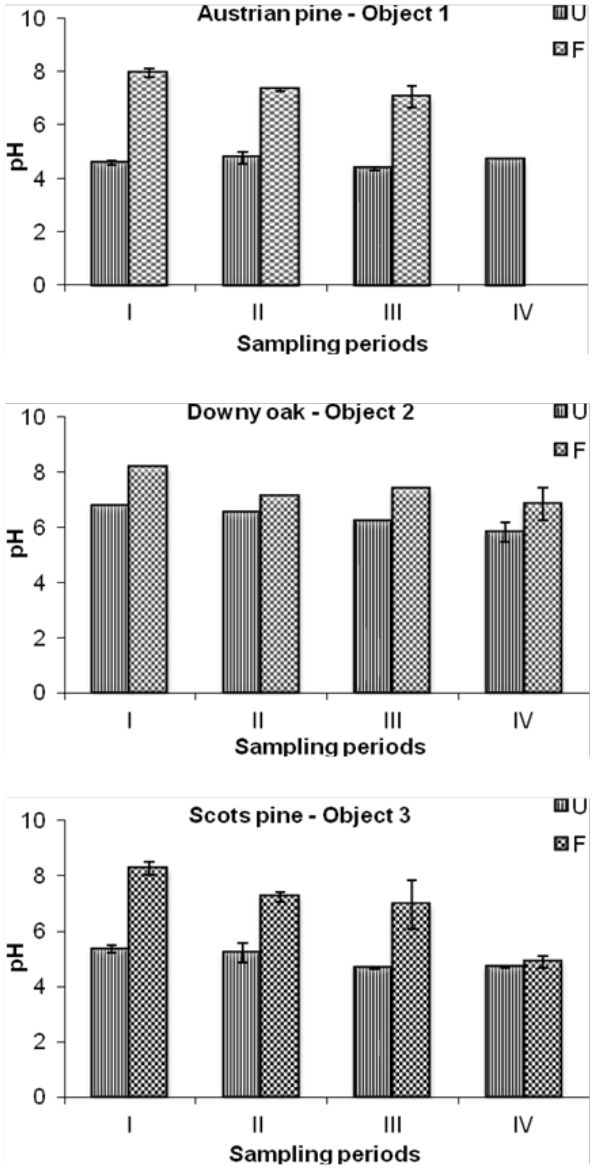

Fig. 2. Time-related changes of pH (mean ±SD) in the forest litter under Austrian pine plantation – Object 1, Downy oak stand – Object 2 and Scots pine plantation – Object 3.

Note: U – unburned sampling sites; F – fire affected sampling sites.

Soil pH in variant with *PS* plantation affected by surface fire, was changed

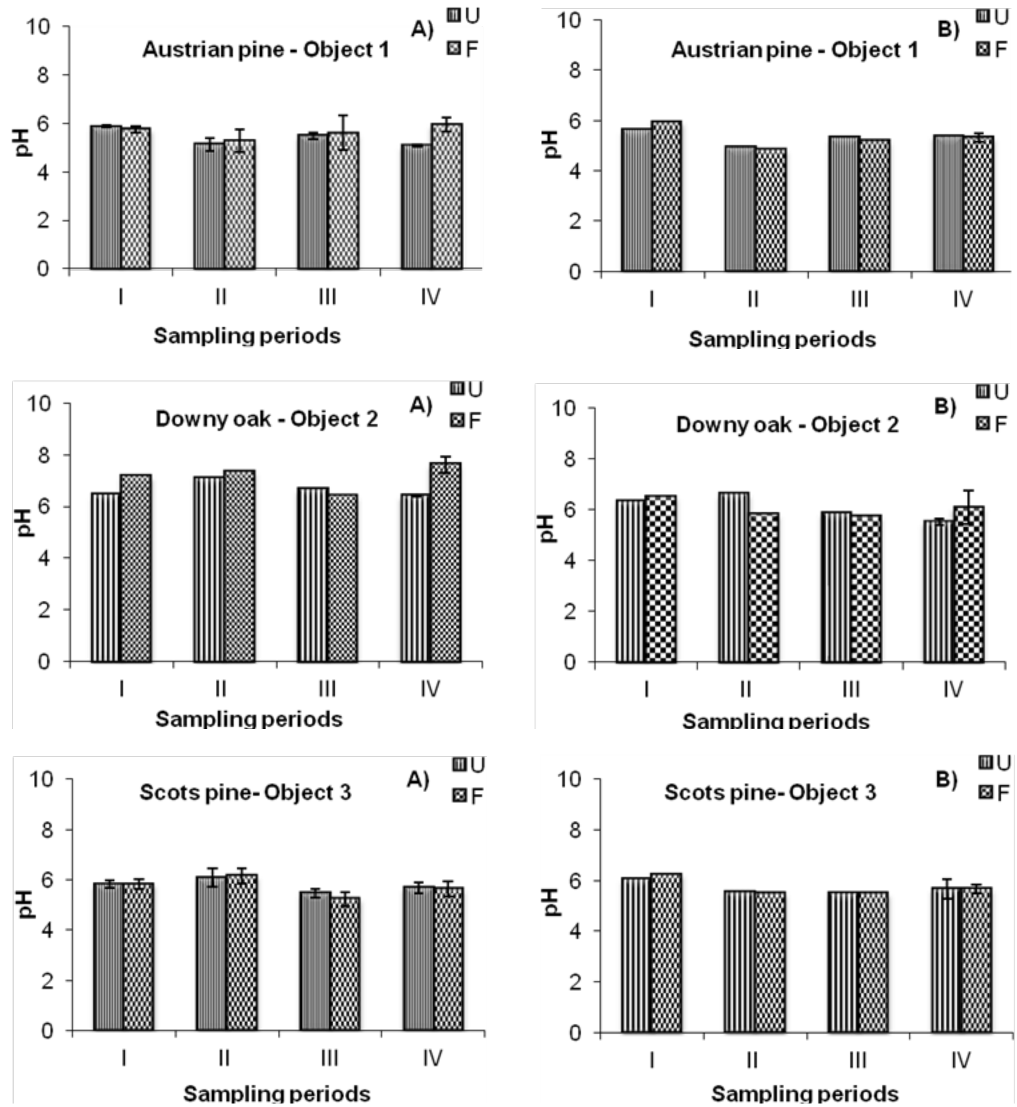

Fig. 3. Time-related changes of soil pH (mean ±SD) under *P. nigra* plantation – Object 1, *Q. pubescens* stand – Object 2 and *P. sylvestris* plantation – Object 3.
Note: A) 0–5 cm soil layer; B) 5–20 cm soil layer, U – unburned sampling sites, F – fire affected sampling sites.

negligibly for both layers for all studied periods. The increase in soil pH, however, is usually temporarily and depends on the initial soil pH, amount of ash released, chemical composition of the ash, and wetness of the climate (Wells et al. 1979). Also, the fire has different effect on soil pH depending on a reached temperature. The decrease in soil pH at lower temperature was established as well as increasing of soil pH at the higher temperature (Fernandez et al. 1997).

The increasing of pH in soil a year after fire in variants *Q* and *PN* is presumably due to leaching of soluble components from surface mineral soil layer to soil depths (Grier 1975). The same increasing of the pH values in cinnamonic forest soils under Austrian pine plantation a year after forest fire occurrence was also established (Bogdanov 2013). Tryon (1948) found that the hardwood ash is more effective in increasing of pH values of the soil than the conifer ash. Our results show that soil pH increases more pronouncedly in the surface 0–5 cm of soil affected by fire under oak stand. If we take into account the statement that magnitude and duration of pH changes in mineral soil depends on the amount of ash formed due to forest litter burning, the relatively high pH values in forest litter (formed ash) after fire occurrence could be the reason for this results (Tryon 1948). Knighton (1977) studied the burning effects on an oak-hickory forest and found that the availability of Ca and Mg were considerably higher in the soil solution from the burned sites than the control, but with no indication of a cumulative effect over time. Soil pH in the layer of 0 to 5 cm in the variant of oak stand affected by fire is increased immediately after it. The soil pH under oak stand changed negligibly in result of fire influence in the next two periods, but at the end of the studied period increase in comparison with control variants is mentioned (Fig. 3, Object 2).

The data for pH of soil layer from 5 to 20 cm also are presented in Fig. 3 (B). Our results show that changes were negligible in all studied variants, except in case of the stands of oak, influenced by forest fire (Object 2). The difference between pH of fire influenced soil for all studied periods in surface soil layer of oak stand (Object 2) is higher in comparison with pH of surface soil layer under *PS* and *PN*. This affect is long-term, as high pH values were kept during all studied period (Fig. 3, Fig. 4). According to the results obtained by Ulery et al. (1993), Henig-Sever et al. (2001) and

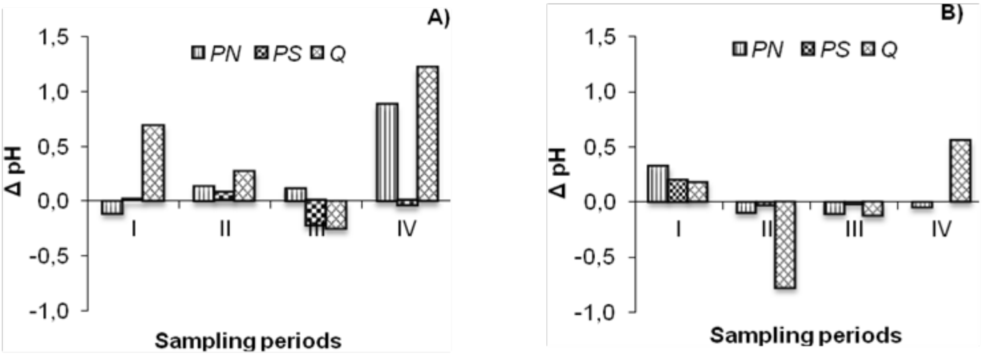

Fig. 4. Time-related soil pH differences (Δ pH) in soil layers: A) from 0 to 5 cm; B) from 5 to 20 cm of studied variants and time periods.

Note: *PN – Pinus nigra*; *PS – Pinus sylvestris* and *Q – Quercus pubescens*.

Fig. 5. Studied sampling sites immediately after fire occurrence:
A) Object 1 – *P. nigra* plantation, influenced by crown and surface fire, the forest litter after fire is black coloured;
B) Object 2 – *Q. pubescens* stand, influenced by surface fire, the forest litter after fire is grey-white coloured;
C) Object 3 – *P. sylvestris* plantation, influenced by surface fire, the forest litter after fire is black coloured.

Goforth et al. (2005) the pH values of the ash, sampled after forest fire increased with fire severity increase. Neary et al. (1999) and Dūdaitė et al. (2011) found that during high intensity fires (~500ºC) a light grey or white ash is produced, composed mainly of alkaline (Ca, K, Mg). The elements such as Ca, K, Mg were the most abundant in white ashes, produced from combusted leaf litter (Goforth et al. 2005) which over time, could increase pH of the soil. Most probably, the newly formed light-grey coloured ash layer, on the soil surface under downy oak stand, is the reason for more sizable changes of the soil pH values than in *PN* and in *PS* plantations. At the end of the studied period ∆ pH = 1.22 in the 0–5 cm soil layer (Fig. 4, A). Only in the variant with *PS* significant changes in soil pH have not been registered as immediately after fire and one year after. Similar results were obtained by Velizarova and Tashev (2008) studied changes in soil pH one year after fire influenced mixed plantations of *Pinus sylvestris* and *Pinus nigra*.

Conclusions

The values of pH increased significantly in fire affected forest litter of *Pinus nigra*, *Quercus pubescens* and *Pinus sylvestris* immediately after forest fire occurrence. In long-term scale – one year after fire these values are still higher than control variants.

The results for soil pH changes showed more pronounced increases in the surface 0–5 cm of soil affected by surface fire under oak stand. This trend was kept for the layer below. Slightly increase in soil pH was observed at the first year of observations.

During all studied periods, the results show negligible changes in soils affected by surface and crown fires under *Pinus nigra* in both layers compared to control variants. At the end of the period, the pH increase of fire-influenced soil in the surface 0–5 cm soil layer was observed.

Soil pH changes for both soil layers in variant with *Pinus sylvestris* plantation are negligible for all researched periods.

References

Aref I., Atta H., Ghamade A. 2011. Effect of forest fires on tree diversity and some soil properties. International Journal of Agriculture and Biology 13: 659–664.

Arocena J., Opio C. 2003. Prescribed fire-induced changes in properties of sub-boreal forest soils. Geoderma 113: 1–16.

Blank R., Zamudio D. 1998. The influence of wildfire on aqueous extractable soil solutes in forested and wet meadow ecosystems along Eastern front of the Sierra-Nevada range, California. International Journal of Wildland Fire 8: 79–85 DOI: 10.1071/WF9980079.

Boerner R. 1982. Fire and nutrient cycling in temperate ecosystems. BioScience 32: 187–192.

Boerner R., Hart S., Huang J. 2009. Impacts of Fire and Fire Surrogate treatments. Ecological Applications 19(2): 338–358.

Bogdanov S. 2013. Soil acidity changes in soils of class Luvisols influenced by forest fires. Ecological engineering and environment protection 2: 61–67 (in Bulgarian).

Bogdanov S. 2014. Changes in meadow soils of high mountain forest belt after fire. Ecological engineering and environment protection 2: 61–67 (in Bulgarian)

Certini G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143: 1–10.

DeBano L., Dunn P., Conrad C. 1977. Fire effect on physical and chemical properties of chaparral soils. In: Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service General Technical Report 3: 65–74.

DeBano L., Neary D. Folliott P. 1998. Fire's effects on ecosystems. John Wiley & Sons, Inc. 352 p.

Dikici H., Yilmaz C. 2006. Peat fire effects on some properties of an artificially drained peatland. Journal of Environmental Quality 35: 866–870.

Dūdaitė J., Baltrėnaitė E., Pereira P., Úbeda X. 2011. Temperature effects on the ash colour of forest litter. Environmental Protection Engineering, ISSN 2029-2252 online, 3(5): 18–23.

Fernandez I., Cabaneiro A., Carballas T. 1997. Organic matter changes immediately after a wildfire in an Atlantic forest soil and comparison with soil heating. Soil Biology and Biochemistry 29: 1–11.

Glogov P., Bogdanov S. 2003. Changes in some soil indices and their relationship with the species composition of vegetation on destroyed by fire forest territories. Nauka za gorata 1: 71–81 (in Bulgarian).

Goforth B., Graham R., Hubbert K., Zanner C., Minnich R. 2005. Spatial distribution and properties of ash and thermally altered soils after high-severity forest fire, southern California. International journal of wildland fire 14: 343–354.

González-Pérez J., González-Vila F., Almendros G., Knicker H. 2004. The effect of fire on soil organic matter – a review. Environment International 30: 855–870.

Grier C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian Journal of Forest Research 5: 599–607.

Henig-Sever N., Poliakov D., Broza M. 2001. A novel method for estimation of wild fire intensity based on ash pH and soil microarthropod community. Pedobiologia 45(2): 98–106.

Ilinkin V., Bogdanov S., Petrova R. 2013. Soil characteristics changes in gray forest soils (Gray Luvisols) influenced by forest fire in deciduous forests. XXII international scientific conference 'Management and quality' for young scientists. 17–19 October 2013 – Yundola Training and Experimental Forest Range: 5–18 (in Bulgarian).

Khanna P., Raison R., Falkiner R. 1994. Chemical properties of ash derived from Eucalyptus floor and its effects on forest soils. Forest Ecology and Management 66: 107–125.

Knighton M. 1977. Hydrologic response and nutrient concentrations following spring burns in an oakhickory forest. Soil Science Society of America Journal 41: 627–632.

Kutiel P., Naveh Z. 1987. The effect of fire on nutrients in a pine forest soil. Lowdermilk Faculty of Agricultural Engineering, Technion. Plant and Soil 104: 269–274.

Kutiel P., Naveh Z., Kutiel H. 1990. The effect of a wildfire on soil nutrients and vegetation in an Aleppo pine forest on Mount Carmel, Israel. In: Goldammer J.G. & M.J. Jenkins (Eds.) Fire in ecosystem dynamics: Mediterranean and northern perspectives: 85–94. SPB Academic Publishing, The Hague, The Netherlands.

Kutiel P., Shaviv A. 1990. Effects of soil types, plant composition and leaching processes on soil nutrients following a simulated forest fire. In: Proceedings of International Conference of Forest Fire Research, 19–22 November, Coimbra, Portugal, C.03.1-C.03. 12 p.

Litton C., Santelices R. 2003. Effect of wildfire on soil physical and chemical properties in a *Nothofagus glauca* forest, Chile. Revista Chilena de Historia Natural 76: 529–542.

Macadam A. 1987. Effects of broadcast slash burning on fuels and soil chemical properties in the sub-boreal spruce zone of Central British Columbia. Canadian Journal of Forest Research 17: 1577–1584.

Motavalli P., Palm C., Parton W., Elliott E., Frey S. 1995. Soil pH and organic C dynamics in tropical forest soils: evidence from laboratory and simulation studies. Soil Biology and Biochemistry 27: 1589–1599.

Murphy J., Johnson D., Miller W., Walker R., Blank R. 2006. Prescribed fire effects on forest floor and soil nutrients in Sierra Nevada Forest. Soil Science 171: 181–199.

Neary D., Klopatek C., DeBano L., Ffolliott P. 1999. Fire effects on belowground sustainability: a review and synthesis, Forest Ecology and Management 122: 51–71.

Neill C., Patterson W., Crary D. 2007. Responses of soil carbon, nitrogen and cations to the frequency and seasonality of prescribed burning in a Cape Cod Oak-pine forest. Forest Ecology and Management 250: 234–243.

Nguyen C. 2011. Effects of a prescribed fire on soil nutrient pools in the pine rockland forest ecosystem. PhD thesis. University of Florida. 288 p.

Parzych A., Sobisz Z. 2012. The macro- and microelemental content of *Pinus sylvestris* L. and *Pinus nigra* Arn. needles in Cladonio-Pinetum habitat of the Słowiński National Park. Forest Research Papers 73(4): 295–303.

Pereira P., Úbeda X., Martin D. 2011. Heavy metals released from leaf litter exposed to different fire temperatures. A laboratory experiment. Darnus Vystymosi Strategia ir Pratica 1: 137–154.

Pereira P., Ubeda X., Martin D., Mataix-Solera J., Cerda A., Burguet M. 2014. Wildfire effects on extractable elements in ash from a *Pinus pinaster* forest in Portugal. Hydrological Processes 28: 3681–3690. Available: http://digitalcommons.unl.edu/usgsstaffpub/839.

Prieto-Fernandez A., Villar M., Carballas M., Carballas T. 1993. Short-term effects of a wildfire on the nitrogen status and its mineralization kinetics in an Atlantic forest soil. Soil Biology and Biochemistry 25: 1657–1664.

Pritchett W., Fisher R. 1987. Properties and management of forest soil. Second edition. John Wiley and Sons, Inc., New York, New York, USA. 494 p.

Qian Y., Miao S., Gu B., Li Y. 2009. Estimation of post fire nutrient loss in the Florida Everglades. Journal of Environmental Quality 38: 1812–1820.

Smith D. 1969. Concentration of soil nutrients before and after fire. Department of Botany, University of Guelph, Guelph, Ontario. Canadian journal of soil science 50: 17–29.

Tryon E. 1948. Effect of charcoal on certain physical, chemical, and biological properties of forest soils. Ecological monographs 18 No 1: 81–115. Published by: Ecological Society of America Stable URL: http://www.jstor.org/stable/1948629.

Tufekcioglu A, Kucuk M, Saglam B., Bilgili E., Altun L. 2010. Soil properties and root biomass responses to prescribed burning in young Corsican pine (*Pinus nigra* Arn.) stands. Journal of Environmental Biology 31: 369–373.

Úbeda X., Lorca M., Outeiro L., Bernia S., Castellnou M. 2005. Effects of prescribed fire on soil quality in Mediterranean grassland (Prades Mountains, North-East Spain). International Journal of Wildland Fire 14: 379–384.

Ulery A., Graham R., Amrhein C. 1993. Wood-ash composition and soil pH following intense burning. Soil Science 156(5): 358–364.

Velizarova E. Tashev A., Topalova-Rzerzycha L., Atanassova I. 2011. Dynamics of soil organic matter after surface and crown fire depending on the forest tree species variability. Ecology and Future. Journal of Agricultural Science and Forest Science 10(3): 25–29.

Velizarova E., Jorova K., Tashev A. 2001. Investigations on some characteristics of forest soils influenced by fire in plantations of Black pine (*P. nigra* L.) II. Chemical characteristics. Nauka za gorata 1–2: 34–43 (in Bulgarian).

Velizarova E., Marinov I., Liubenov T., Konstantinov Vl., Mihajlova M. 2010. Forest fires impact on erodibility of soils of Plana and Sredna Gora mountains, Bulgaria. In: Viegas D.X. (Ed.) VI International Conference on Forest Fire Research: 1–7.

Velizarova E., Tashev A. 2008. Changes in some soil properties of coniferous stands influenced by fire in the Osogovo mountain (Bulgaria). In: Cvetcov P.A. (Ed.). Fires in forest ecosystems of Siberia. Proceedings of the All-Russian Conference with international participation – Krasnoyarsk, N. Sukachev Institute of Forest, Siberian Br., Russian Academy of Sciences Krasnoyarsk, Russia: 198–200.

Velizarova E., Tashev A., Jorova K. 2002. Trends and peculiarities in the changes of some properties and indexes of forest soils affected by fires. Forestry ideas 3–4: 3–22 (in Bulgarian).

Wells C., Campbell R., DeBano L., Lewis C., Fredrickson R., Franklin E., Froelich R., Dunn P. 1979. Effects of fire on soil: a state-of-the-knowledge review. General Technical Report WO7. Washington, DC: U.S. Department of Agriculture, Forest Service. 34 p.

WRBSR 2014. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. Soil Resources Reports No. 106. FAO, Rome. 119 p.

Zahariev B., Donov V., Petrunov K., Masarov S. 1979. Forest vegetation zoning of Bulgaria. Zemizdat. 199 p. (in Bulgarian).