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EVALUATION OF IMPACT OF FERTILIZATION ON SOIL SOLUTION CHEMISTRY IN DOMINATED FOREST SITE TYPES IN LATVIA

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Enhanced forest growth may respond to the increasing demand for wood resources. Moreover, the forest is considered to be carbon storage, thus contributing to climate change mitigation. The forest soil fertilization, as well as forest drainage, thinning and regeneration may be an effective measure in increasing harvest rates. In the context of bio-economy, wood ash needs to be managed and can be utilized as an equivalent to potassium and phosphorus containing fertilizer. Ammonium nitrate can be used as fertilizer in forests on mineral soil since nitrogen is considered to be a tree growth limiting element in boreal forests. However, environmental aspects like leaching of the fertilizer should be taken into account. The aim of this research is to evaluate the impact of wood ash, ammonium nitrate and combined wood ash and nitrogen fertilizer impact on the chemical properties of soil water in dominated forest site types in Latvia. The trials were conducted in total in 16 forest stands. The fertilizers were spread in treatment plots, but the control plots were left untreated. The soil water samples were collected for two seasons. The pH, potassium, calcium, magnesium, phosphate and total nitrogen were determined in the soil water samples. Ammonium nitrate had an impact on the elevated concentration of total nitrogen in all experimental objects; although the significant differences between the control plot and treated plot were detected only in a part of experimental objects. The elevated concentrations of total nitrogen decreased after two months and remained above the control level. Interestingly, we observed a trend of both – increased and decreased concentrations of potassium, calcium, magnesium and phosphate. Nevertheless, only a part of the differences was statistically significant. The impact of wood ash on chemical properties of soil water was less pronounced in comparison to ammonium nitrate.

Keywords: *ammonium nitrate, lysimeter, nutrient leaching, wood ash*

INTRODUCTION

The forest soil enrichment with fertilizers is acknowledged as an effective measure of improvement of forest growth conditions (Jacobson, 2003; Jansons et al., 2016). There are usually limited K and P in forest stands on drained organic soil. The shortage of the elements can be compensated with wood ash (Ring et al., 2011). Stabilized wood ash dissolve easily in water. It has been reported on significant increase in the concentrations of K and Ca (Ring et al., 2011). Whereas untreated wood ash can possibly initiate a rapid increase of pH of the soil (Aronsson and Ekelund, 2004). It has been also reported on increased concentration of K in soil water samples two years after the wood ash application in pine stand on drained organic soil. If wood ash is spread in forest stand where the tree growth limiting element is N the enhanced leached rate of NO_3^- can be observed (Kahl et al., 1996). Still wood ash can be used as fertilizer in stands on podzols if the N is non-limiting element (Pitman, 2006). N do not ensure the additional radial increment of trees drained oligotrophic peatland stands, but wood ash or K in combination with P increases growth of trees (Sikström et al., 2010). Forest soil enrichment with N or combined wood ash and N fertilizer enhances the tree growth on mineral soil (Jacobson, 2003). Forest soil enrichment with N containing mineral fertilizer induces temporarily elevated inorganic N concentrations in soil water, whereas the pH is reduced by fertilization. Repeated nitrogen addition in small dosages causes a significant leaching of NO_3^- in soil water (Pregitzer et al., 2004). The assumption is that forest soil fertilization with both wood ash and N contributes to the tree growth. The wood ash can be used as an equivalent P and K fertilizer to enhance the tree growth on the drained organic soil (Sikström et al., 2010). Initially used combined N, P, K fertilizer improve the growth of the Norway Spruce (Jansons et al., 2016). Most available data on the effects of forest fertilization on water quality originate from Fennoscandia (Ring et al. 2011; Sikström et al., 2010), but due to dissimilar soil and hydrological conditions, results and conclusions obtained there may not necessarily be applicable in Latvian conditions (Libiete et al., 2017). The aim of this study was to evaluate the impact of the forest fertilization with wood ash and N containing fertilizer on soil water chemical properties in dominated forest site types in Latvia.

MATERIALS AND METHODS

The study sites. In the period 2014 – 2018 experimental objects were established at coniferous and deciduous stands, including different forest site types – stands on dry mineral soil, wet mineral soil, drained organic soil and drained mineral soil. The study was conducted in 16 forest stands in total. The experimental plots were established in the forest sites managed by the Research forest station and Joint Stock Company 'Latvia's State Forests' (Table 1). In the first experimental group forest soil was enriched with wood ash, in the second – with ammonium nitrate. In the third experimental group forest soil was treated first with wood ash and the after a period of time with ammonium nitrate. The fertilizers were spread in the experimental plots, but the control plots were left untreated. Each of the object has one control plot and one treated plot, except the Scots pine (Pinus sylvestris L.) stand on drained organic soil with a single treated plot.

Table 1.Description of experimental objects and treatment with fertilizers

Forest stand	Forest type	Dominant tree species	Stand age	Fertilizer	Dose of fertilizer, t ha^{-1}	Date of fertilization	Coordinates	
							Lat:	Lon:
301-209-13	*Oxalidosa turf. mel.*/ drained organic soil	Norway spruce (*Picea abies (L.) H.Karst.*)	53	WA	2	11.2014	56.39569	25.65087
301-231-12	*Oxalidosa turf. mel.*/ drained organic soil	Norway spruce (*Picea abies (L.) H.Karst.*)	48	WA	2	11.2014	56.36349	25.60691
301-228-5	*Hylocomiosa*/ dry mineral soil	Norway spruce (*Picea abies (L.) H.Karst.*)	53	WA	2	11.2014	56.37363	25.63310
301-221-17	*Hylocomiosa*/ dry mineral soil	Norway spruce (*Picea abies (L.) H.Karst.)*	53	WA	2	11.2014	56.37316	25.60170
405-421-3	*Myrtillosa turf. mel./* drained organic soil	Scots pine (*Pinus sylvestris L.*)	93	WA	3	02.2018	57.39860	24.59336
21-49-14	*Myrtilloso-sphagnosa*/ Wet mineral soil	birch (*Betula ssp.*)	22	N	0.44	05.2017	56.70964	23.75585
11-18-5	*Hylocomiosa*/ dry mineral soil	Norway Spruce (*Picea abies (L.) H.Karst.*)	43	N	0.44	07.2017	56.73717	25.87868
11-210-5	*Myrtillosa*/ dry mineral soil	Scots pine (*Pinus sylvestris L.*)	74	N	0.44	07.2017	56.68098	25.99050
21-10-4	*Hylocomiosa*/ dry mineral soil	Scots pine (*Pinus sylvestris L.*)	29	N	0.44	06.2017	56.73703	23.71972
580-231-25	*Myrtillosa*/ dry mineral soil	Scots pine (*Pinus sylvestris L.*)	60	N	0.44	07.2017	56.66734	24.51863
609-34-24	*Myrtillosa mel.*/ drained mineral soil	birch (*Betula ssp.*)	33	WA + N	3 + 0.44	02.2017 + 07.2017	56.83235	23.64299
11-187-16	*Oxalidosa turf. mel.*/ drained organic soil	Norway spruce (*Picea abies (L.) H.Karst.*)	53	WA + N	3 + 0.44	10.2016 + 07.2017	56.67334	25.89532
21-32-13	*Myrtillosa mel.*/ drained mineral soil	birch (*Betula ssp.*)	36	WA + N	3 + 0.44	10.2016 + 06.2017	56.72086	23.74566
609-29-33	*Myrtillosa mel.*/ drained mineral soil	Norway spruce (*Picea abies (L.) H.Karst.*)	37	WA + N	3 + 0.44	02.2017 + 07.2017	56.84812	23.70357
608-29-4	*Vacciniosa mel.*/ drained mineral soil	Scots pine (*Pinus sylvestris L.*)	64	WA + N	3 + 0.44	02.2017 + 07.2017	56.80118	23.48938
608-19-21	*Vacciniosa turf. mel./* drained organic soil	Scots pine (*Pinus sylvestris L.*)	58	WA + N	3 + 0.44	02.2017 + 07.2017	56.80424	23.48279

WA - wood ash; N - ammonium nitrate; WA + N - combined wood ash and ammonium nitrate

Soil water monitoring. Vacuum lysimeters were installed in the soil at the fixed depths of 30 cm and 60 cm to collect soil water. Three pairs of vacuum lysimeters were installed according to ICP Forests guidelines (Convention on…, 2010) in all plots, ensuring three replicates of the particular depth for each of the plot. Soil water samples were collected in the period 2017 – 2018. The period of fieldwork was restricted by average daily temperature and lasted from May till September or October. The soil water samples were collected once per month. The parameters determined in the collected soil water samples were: pH, K (mg L^{-1}), Ca (mg L^{-1}), Mg (mg L^{-1}), PO_4^{3-} (mg L^{-1}) and N_{TOT} (mg L^{-1}).

Data analysis. To identify the short-term effect of forest soil fertilization on soil water quality, descriptive statistics and non-parametrical statistical tests were used. First, the data range of each of the parameters was compared between the soil water samples collected from the depths of 30 cm and 60 cm at the individual research object level. The data were collected according to the same schedule, therefore the Wilcoxon signed-rank test with continuity correction was used. If there was no statistically significant difference, the two data sets (30 cm and 60 cm) of one parameter were merged. Next, Wilcoxon rank sum test with continuity correction was used to analyse differences between the control plot and the treated plot at the individual research object level. Finally, the differences among forest site types were compared at the level of the experimental group, determined by the type of the utilized fertilizer – wood ash, ammonium nitrate or combined wood ash and nitrogen fertilizer, respectively. The tests were conducted at a 95 % confidence level. The statistical tests were performed in program R (R Core…, 2018).

RESULTS

Impact of wood ash on soil water quality. The soil water monitoring was conducted in the third and the fourth year after the forest soil enrichment with wood ash. The observed differences between the control and the fertilized plots were quite the opposite (Table 2).

Table 2. Chemistry of soil water samples collected from wood ash treated and control plots during 2017-2018

Forest stand/ forest type	cm	pH		K		Ca		Mg		PO_4^{3-}		$N_{TOT.}$	
		C	T	C	T	C	T	C	T	C	T	C	T
301-209-13[1] drained organic soil	30	7.24 ±0.08	7.2 ±0.1	0.37 ±0.04	0.5 ±0.1	33 ±2	36 ±3	7.7 ±0.6	6.8 ±0.8	0.03 ±0.01	0.015 ±0.003	3.4 ±0.6	6.5 ±0.9
	60	*7.24 ±0.09	*6.87 ±0.09			44 ±3	38 ±2	11.5 ±0.9	8.2 ±0.4			*3.4 ±0.6	*4.4 ±0.2
301-231-12[1] drained organic soil	30	7.25 ±0.05	7.07 ±0.07	0.29 ±0.02	0.25 ±0.02	36 ±2	45 ±2	9.8 ±0.7	9.0 ±0.4	0.015 ±0.001	0.034 ±0.006	8.6 ±0.7	12 ±1
	60	7.41 ±0.06	7.15 ±0.07			46 ±1	48 ±2	15.4 ±0.4	11.7 ±0.3			5.5 ±0.7	9 ±1
301-228-5[1] dry mineral soil	30	7.71 ±0.04	7.84 ±0.09	2.7 ±0.2	2.1 ±0.5	*36 ±3	*26 ±2	4.1 ±0.2	4.1 ±0.4	0.13 ±0.01	0.10 ±0.02	2.6 ±0.3	1.8 ±0.6
	60	7.80 ±0.06	7.94 ±0.07										
301-221-17[1] dry mineral soil	30	*6.90 ±0.09	*7.26 ±0.03	*4.7 ±0.4	*2.3 ±0.2	4.0 ±0.4	9 ±3	2.6 ±0.2	3.1 ±0.4	0.03 ±0.01	0.06 ±0.01	*1.3 ±0.1	*0.87 ±0.6
	60	*7.01 ±0.09	*7.4 ±0.1									1.08 ±0.7	1.1 ±0.1
405-421-3[2] drained organic soil	30	ND	7.6 ±0.1	ND	0.84 ±0.09	ND	44 ±5	ND	6.1 ±0.5	ND	0.011 ±0.002	ND	1.6 ±0.2
	60	ND	7.2 ±0.1	ND	0.35 ±0.03	ND	39 ±2	ND	6.9 ±0.4	ND	0.03 ±0.01	ND	1.42 ±0.09

[1] fertilized in 2014
[2] fertilized in 2018
*significant difference between the control and the treated plot ($p<0.05$)
C – control plot; T – treated plot; NS – no soil water sample available; ND – no data, because the plot was not established

The significant differences between control and treated plots were observed for pH at certain stands. Wood ash is alkaline and stabilizing fertilizer (Pitman, 2006). As we expected, there was a significant increase in the pH in both depths in the soil water samples collected from the Norway spruce stand on dry mineral soil (301-221-17); although there was also a trend of an increased pH in other *Hylocomiosa* stand (Fransman and Nihlgård, 1995). On the contrary, there was a decrease in the pH in the samples collected from the Norway spruce stands on drained organic soil. It has been reported also on decreasing pH 4-5 years after a forest soil (podzol) enrichment with wood ash (Saarsalmi et al., 2005). Wood ash are rich in K, Ca, Mg and P; however, the wood ash used in these trial plots contained less concentrations of the elements. compared to the wood ash used in the trial with N fertilizer (Okmanis et al., 2017). We detected a significant decrease of K and Ca in Norway spruce stand on dry mineral soils. The observed differences may be explained with the fact that soil water monitoring in most of these experimental objects was commenced 3 years after soil treatment. While the observed tendency of increased Ca (Fransman and Nihlgård, 1995) and Mg concentrations in the samples from the treated stands on mineral soil support the conclusions of Saarsalmi et al. (2005). We have observed the tendency of higher N_{TOT} concentrations in the soil water from the treated plots, while other authors report on N leaching (Kahl et al.,1996) in form of NO_3^- (Högbom et al., 2001; Fransman and Nihlgård, 1995). The wood ash were spread in stand 405-421-3 in February, 2018; however, we could estimate only the average concentrations of the elements from the one treated plot. Still, we observed a higher pH, as well as higher concentrations of Ca and PO_4^{3-} at the upper level – 30 cm, respectively (Stuanes et al., 1995). This might be explained with the gradual leaching of wood ash.

Impact of ammonium nitrate on soil water quality. Generally, the chemical analyses indicated reduced pH and elevated N_{TOT} concentrations in soil samples collected from the treated plots (Table 3).

There was a significant decrease in the pH of the soil water collected from the Scots pine stand on dry mineral soil (*Myrtillosa*), although the tendency was observed in other stands. And on the contrary, a significant increase in the pH was observed in the other Scots pine stand (*Myrtillosa*) (Aber et al., 1989). As it was expected, elevated N_{TOT} concentrations were observed in all research objects (Karklina and Stola, 2019), although only at certain plots the differences were statistically significant. It is possible that in certain treated plots N could be accumulated in the soil organic matter in already N limited ecosystem (Houle and Moore, 2019). The higher leaching rate of N was detected in 30 cm rather than 60 cm depth, thus supporting the conclusions of Stuanes et al. 1995. There were also significant differences in the concentrations of K, Ca, Mg and PO_4^{3-}.

Table 3.Chemistry of soil water samples collected from N mineral fertilizer treated and control plots during 2017-2018

Forest stand/ forest type	cm	pH		K		Ca		Mg		PO_4^{3-}		$N_{TOT.}$	
		C	T	C	T	C	T	C	T	C	T	C	T
21-49-14[1] wet mineral soil	30	7.65 ±0.07	7.63 ±0.06	*0.24 ±0.04	*0.40 ±0.05	*35 ±5	*53 ±2	5.3 ±5	4.6 ±0.3	0.016 ±0.002	0.04 ±0.01	*1.8 ±0.3	*7.3 ±0.9
	60			0.23 ±0.03	0.23 ±0.02	89 ±25	52 ±2	7 ±1	6.9 ±0.3	0.026 ±0.007	0.027 ±0.006	*2.1 ±0.3	*5.9 ±0.5
11-18-5[1] dry mineral soil	30	7.10 ±0.08	7.1 ±0.1	*1.8 ±0.2	*3.5 ±0.5	*1.0 ±0.2	*2.8 ±0.8	0.7 ±0.1	1.6 ±0.4	0.05 ±0.01	0.023 ±0.007	0.9 ±0.2	3 ±2
	60	6.93 ±0.08	7.1 ±0.1	0.9 ±0.2	4	1.1 ±0.2	2	0.68 ±0.07	NS	0.004 ±0.004	0.017 ±0.002	0.38 ±0.06	2
11-210-5[1] dry mineral soil	30	*6.95 ±0.04	*6.68 ±0.09	*1.9 ±0.4	*1.5 ±0.4	1.1 ±0.1	2.4 ±0.7	0.8 ±0.1	1.3 ±0.3	*0.06 ±0.03	*0.008 ±0.002	1.3 ±0.4	6 ±3
21-10-4[1] dry mineral soil	30	*5.8 ±0.2	*7.46 ±0.08	1.9 ±0.3	3.2 ±0.3	*1.5 ±0.2	*59 ±3	1.0 ±0.2	5.0 ±0.4	*0.032 ±0.005	*0.012 ±0.003	*2.5 ±0.5	*20 ±4
	60			1.6 ±0.3	1.0 ±0.2			*0.94 ±0.09	*3.9 ±0.4			2.1 ±0.4	5 ±2
580-231-25[1] dry mineral soil	30	7.1 ±0.2	6.7 ±0.1	2.6 ±0.2	3.2 ±0.3	2.1 ±0.3	1.43 ±0.07	1.1 ±0.1	1.1 ±0.2	0.022 ±0.007	0.035 ±0.006	1.2 ±0.1	3.7 ±0.7
	60	7.0 ±0.2	7.1 ±0.1										

[1] fertilized in 2017

* significant difference between the control and the treated plot ($p<0.05$)

C – control plot; T – treated ploy; NS – no soil water sample available

Impact of wood ash and ammonium nitrate on soil water quality. Likewise, the chemical analyses indicated also declined pH and increased N_{TOT} concentrations in soil samples collected from the treated plots (Table 4).

Table 4. Chemistry of soil water samples collected from combined fertilizer treated and control plots during 2017-2018

Forest stand/ forest type	cm	pH		K		Ca		Mg		PO_4^{3-}		N_{TOT}	
		C	T	C	T	C	T	C	T	C	T	C	T
609-34-24[1] drained mineral soil	30	*6.84 ±0.09	*7.2 ±0.1	1.0 ±0.2	0.7 ±0.3	*10 ±1	*27 ±4	*1.9 ±0.2	*35 ±17	0.013 ±0.003	0.022 ±0.004	2.3 ±0.2	8 ±4
	60	*6.9 ±0.2	*7.63 ±0.04	*1.0 ±0.2	*0.3 ±0.1								
11-187-16[2] drained organic soil	30	6.67 ±0.06	6.53 ±0.06	0.7 ±0.3	1.0 ±0.5	20 ±2	29 ±6	3.7 ±0.3	5 ±1	0.03 ±0.01	0.027 ±0.003	4.3 ±0.4	19 ±8
	60			0.4 ±0.1	0.31 ±0.08	24 ±2	26 ±3	4.6 ±0.3	4.9 ±0.7			3.4 ±0.2	8 ±3
21-32-13[2] drained mineral soil	30	7.76 ±0.06	7.69 ±0.08	1.1 ±0.3	1.0 ±0.2	*43 ±2	*38 ±3	4 ±0.3	4.5 ±0.4	*0.10 ±0.03	*0.04 ±0.01	*1.7 ±0.2	*8 ±3
	60			*0.31 ±0.02	*0.22 ±0.02			5 ±0.6	4.1 ±0.4	0.012 ±0.003	0.02 ±0.02		
609-29-33[1] drained mineral soil	30	6.24 ±0.08	6.3 ±0.2	0.98 ±0.13	3.03	18 ±4	25	3.5 ±0.9	NS	0.015 ±0.004	NS	1.3 ±0.2	31
	60	*6.51 ±0.05	*6.17 ±0.05	*0.29 ±0.02	*0.73 ±0.08	41 ±8	76 ±15	*7 ±1	*3.2 ±0.6	*0.04 ±0.02	*0.013 ±0.006	*1.8 ±0.1	*27 ±10
608-29-4[1] drained mineral soil	30	*5.2 ±0.2	*6.3 ±0.2	*1.04 ±0.09	*4.4 ±0.8	*0.6 ±0.3	*1.5 ±0.4	*0.39 ±0.3	*4 ±1	0.042 ±0.008	0.10 ±0.02	*0.76 ±0.03	*18 ±8
	60	*4.9 ±0.2	*4.5 ±0.2										
608-19-21[1] drained organic soil	30	*5.9 ±0.2	*4.8 ±0.2	2.3 ±0.4	3.1 ±0.5	0.8 ±0.2	1.5 ±0.4	0.7 ±0.1	2.6 ±0.7	*0.035 ±0.005	*0.13 ±0.02	*0.7 ±0.2	*22 ±8
	60												

[1] fertilized in 2017

[2] fertilized in 2016 and 2017

*significant difference between the control and the treated plot ($p<0.05$)

C – control plot; T – treated plot; NS – no soil water sample available

We observed both – increasing and decreasing mean pH values in treated plots, but the main tendency of this experimental group is diminished pH values in soil water samples from fertilized plots. The diminished pH occurred due to forest soil fertilization with ammonium nitrate that was accomplished at the beginning of soil water monitoring (Pregitzer et al., 2004). As foreseen, there were higher N_{TOT} concentrations in the samples collected from the treated plots; however, the elevated concentrations diminished within two months and stayed above the control level (Karklina and Stola, 2019). We observed, for the most part, elevated concentrations of Ca and Mg, which could be related to the impact of wood ash. Although, the PO_4^{3-} at certain stands and at certain depths declined significantly.

Comparison of soil water chemistry among different forest types. The average concentrations of K, PO_4^{3-} and N_{TOT} in the water samples compared among different forest types elucidate the differences of the utilized fertilizer impact on the soil water chemistry (Figure 1).

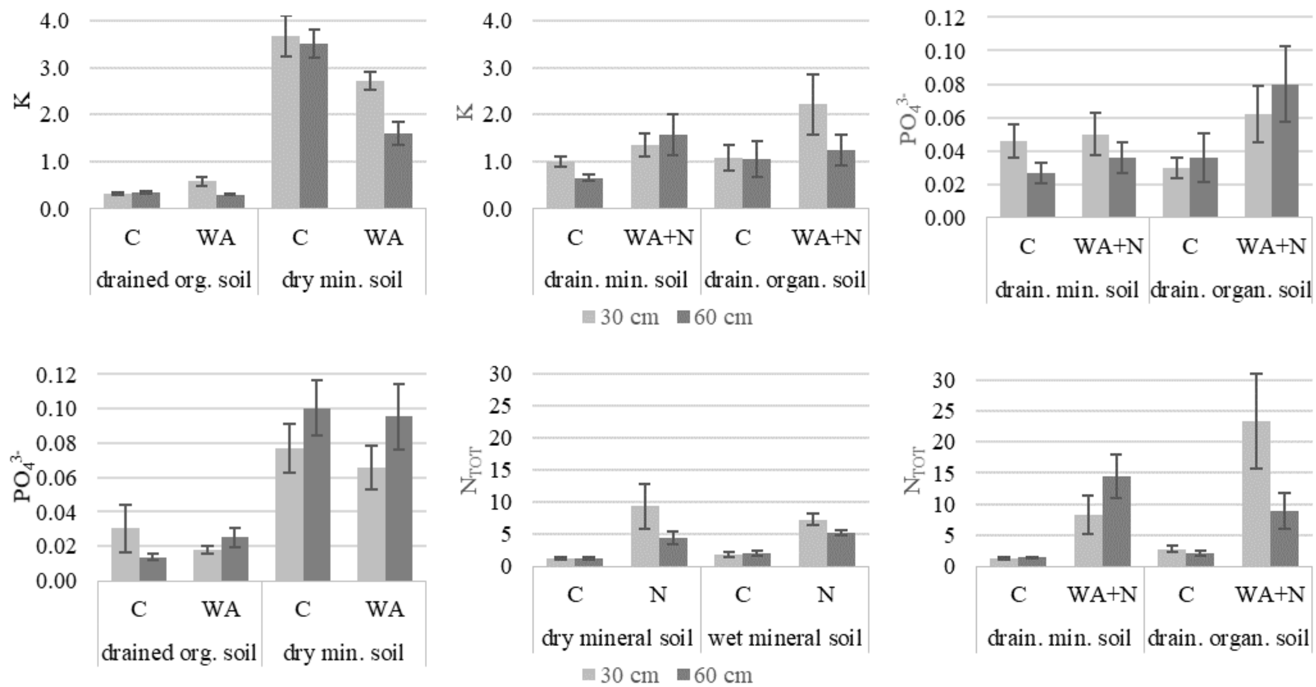

Figure 1.Comparison of K, PO_4^{3-} and N_{TOT} in soil water among different forest types (C – control plots; WA – wood ash treated plots; WA+N – wood ash and N fertilizer treated plots; N – nitrogen fertilizer treated plots)

There were higher concentrations of K in the water samples of the treated plots collected from the forest stands on drained organic soil and stands on drained mineral soil. While the average K concentration in the samples from stands on dry mineral soil was relatively higher, thereby assuming that these particular ecosystems are more K sufficient. The concentrations of PO_4^{3-} were higher in the wood ash and N fertilizer treated plots. The usage of N containing fertilizer elevated N_{TOT} concentrations in all forest types of the established experimental objects. There was an increase in N_{TOT} concentrations, whereas in fertilization was used only the ammonium nitrate or wood ash combined with ammonium nitrate.

CONCLUSIONS

1. Generally the impact of wood ash on soil water chemistry was not distinguishable among the control plots and the treated plots in the third and the fourth year after the forest soil enrichment. Although we observed both increased and decreased trend of the concentrations of K, Ca Mg, PO_4^{3-} and pH level, the detected changes were significant only in certain research objects – in forest stands on dry mineral soil and in one forest stand on drained organic soil.
2. Forest soil fertilization with N containing mineral fertilizer tends to elevate N_{TOT} concentrations in the soil water samples, nevertheless the elevated concentrations decreased within two months after forest soil fertilization and remained slightly higher comparing to the control level.
3. The K concentrations were relatively higher in the soil water samples, collected from the wood ash or combined wood ash and nitrogen containing fertilizer treated forest stands on drained organic or drained mineral soil.
4. The N_{TOT} concentrations in soil water samples were relatively higher in all forest types of the established experimental objects, whereas the plots were fertilized with N mineral fertilizer or combined wood ash an N mineral fertilizer.
5. The following research will involve the results forest soil monitoring to improve the understanding of the movement of the nutrients brought into the forest stand with wood ash and ammonium nitrate.

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REFERENCES

1. Aber J.D., Nadelhoffer K.J., Steudler P., Melillo J.M. 1989. Nitrogen Saturation in Northern Forest Ecosystems. *BioScience,* Vol. 39, pp. 378–286. https://doi.org/10.2307/1311067
2. Aronsson K. A., Ekelund N. G. A. 2004. Biological Effects of Wood Ash Application to Forest and Aquatic Ecosystems. *Journal of Environment Quality,* Vol. 33, 1595. https://doi.org/10.2134/jeq2004.1595
3. Convention on Long Range Transboundary Air Pollution (ed.) 2010. *I*CP forests manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests: international co-operative programme on assessment and monitoring of air pollution effects on forests (ICP forests). Hamburg: Johann Heinrich von Thünen Inst., Inst. for World Forestry.
4. Fransman B., Nihlgård B. 1995. Water chemistry in forested catchments after topsoil treatment with liming agents in South Sweden. *Water, Air, and Soil Pollution,* Vol. 85, pp. 895–900. https://doi.org/10.1007/BF00476943.
5. Houle D., Moore J.-D. 2019. Soil solution, foliar concentrations and tree growth response to 8 years of ammonium-nitrate additions in two boreal forests of Quebec, Canada. *Forest Ecology and Management,* Vol. 437, pp. 263–271. https://doi.org/10.1016/j.foreco.2019.01.024.
6. Jacobson S. 2003. Addition of Stabilized Wood Ashes to Swedish Coniferous Stands on Mineral Soils – Effects on Stem Growth and Needle Nutrient Concentrations. *Silva Fennica,* Vol. 37, pp. 437–450. https://doi.org/10.14214/sf.483
7. Jansons Ā., Matisons R., Krišāns O., Džeriņa B., Zeps M. 2016. Effect of initial fertilization on 34-year increment and wood properties of Norway spruce in Latvia. *Silva Fennica,* Vol. 50. https://doi.org/10.14214/sf.1346.
8. Kahl J. S., Fernandez I. J., Rustad L. E., Peckenham J. 1996. Threshold Application Rates of Wood Ash to an Acidic Forest Soil. *Journal of Environment Quality,* Vol. 25, pp. 220. https://doi.org/10.2134/jeq1996.00472425002500020003x.
9. Karklina I., Stola J. 2019. Impact of forest soil enrichment with nitrogen fertilizer on throughfall and soil water chemical properties. *Proceeding of 25th Annual International Scientific Conference "Research for Rural Development 2019"*, In press.
10. Libiete Z., Bardule A., Murniece S., Lupikis S. 2017. Impact of clearfelling on dissolved nitrogen content in soil-, ground-, and surface waters: initial results from a study in Latvia. *Agronomy Research,* Vol. 15, pp. 767–787.
11. Okmanis M., Petaja G., Lupiķis, A. 2017. Productivity of mechanized wood ash application in forest. "*Research for rural development 2017*", Vol. 1, pp. 62–68. https://di.org/10.22616/rrd.23.2017.009.
12. Pitman R. M. 2006. Wood ash use in forestry - a review of the environmental impacts. *Forestry,* Vol. 79, pp. 563–588. https://doi.org/10.1093/forestry/cpl041.
13. Pregitzer K.S., Zak D.R., Burton A.J., Ashby J.A., MacDonald N.W. 2004. Chronic nitrate additions dramatically increase the export of carbon and nitrogen from northern hardwood ecosystems. *Biogeochemistry,* Vol. 68, pp. 179–197. https://doi.org/10.1023/B:BIOG.0000025737.29546.fd.
14. R Core Team, 2018. *R: A language and environment for statistical computing*, Vienna, Austria: R Foundation for Statistical Computing.
15. Ring E., Brömssen C. von Losjö K., Sikström U. 2011. Water chemistry following wood-ash application to a Scots pine stand on a drained peatland in Sweden. *Forestry Studies,* Vol. 54, pp. 54–70. https://doi.org/10.2478/v10132-011-0096-4.
16. Saarsalmi A., Derome J., Levule T. 2005. Effect of wood ash fertilisation on stand growth, soil, water and needle chemistry, and berry yields of lingonberry (Vaccinium vitis-idaea L.) in a Scots pine stand in Finland. *Forestry Studies,* Vol. 42, pp. 13–33.
17. Sikström U., Almqvist C., Jansson G. 2010. Growth of Pinus sylvestris after the Application of Wood Ash or P and K Fertilizer to a Peatland in Southern Sweden. *Silva Fennica,* Vol. 44, pp. 411–425. https://doi.org/10.14214/sf.139
18. Stuanes A. O., Kjønaas O. J., van Miegroet H. 1995. Soil solution response to experimental addition of nitrogen to a forested catchment at Gårdsjön, Sweden. *Forest Ecology and Management,* Vol. 71, pp. 99–110. https://doi.org/10.1016/0378-1127(94)06087-Y.