IMPACT OF WOOD ASH AND POTASSIUM SULPHATE FERTILIZATION ON GROWTH OF NORWAY SPRUCE STAND ON ORGANIC SOIL

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Abstract
Wood based ash can be used as a liming material and fertilizer in forest, thus providing a solution for utilization of wood ash and formation of additional increment of trees, especially on organic soils, where lack of potassium and phosphorus is a well known factor limiting the growth of trees. Yet, many studies have been made with adverse results mostly because of different soil types and species investigated. However, by now the best results on fertilization with wood ash have been found on drained peatlands, where some nutrient deficiencies have emerged. The aim of this study was to find out the growth response of Norway spruce on drained organic soils after spreading of potassium sulphate (K_2SO_4) and wood ash (WA). The experiment was carried out in three middle aged Norway spruce (*Picea abies*) stands on drained mineral and peat soil. Experiment consisted of three replications of each treatment in each stand including WA, K_2SO_4 and the control on 400 m^2 sub-sample plots each. The diameter and height of trees were measured. The samples of increment cores were collected 4 years after fertilization to determine the additional volume increment, which varied from 8.5 m^3 ha^{-1} to 19.2 m^3 ha^{-1} in WA plots and from 9.7 m^3 ha^{-1} to 17.2 m^3 ha^{-1} on K_2SO_4 plots. Both - the wood ash and potassium application - significantly increased the increment of Norway spruce on drained mineral and peat soil, although no significant differences were found between the treatments ($p = 0.82$, $\alpha = 0.05$).
Key words: forest fertilization, additional increment, wood ash.

Introduction

One of the aims of forest policy in Latvia is to maintain and increase the productivity of forests. Fertilization is considered as one of the tools to increase forest value (Lībiete, 2012; Bergh & Hedwall, 2013). Necessity and impact of fertilization depend on many factors - stand age, soil type, species etc., and all of them should be considered before application of the measure. Studies have revealed that nitrogen (N) addition to oligotrophic upland sites can bring a positive result of tree increment, but application of potassium (K) and phosphorus (P) containing fertilizers alone has no significant effect on tree growth on upland sites (Jacobson, 2003; Moilanen *et al.*, 2013) or can have even negative effect (Brais, Bélanger, & Guillemette, 2015), while Hytönen (2003), Sikström, Almqvist, & Jansson (2010) and Moilanen *et al*. (2013) have found P deficiency in drained peat lands and positive tree growth response after application of P containing fertilizer on these sites. Drained forest lands are highly distributed in Latvia. In total, about 32% of forest lands are drained and 16% of these stands are covered with Norway spruce, which is the third highly distributed tree species in Latvia (about 18.3% of forest land cover, VMD, 2016).

Spruce is relatively fast-growing species, especially at a young and middle age when it is also the most productive tree species in Latvia (Zviedris, 1960; Bisenieks, 1997). Zālītis & Lībiete (2004) have found sharp productivity decrease in 40-year-old spruce stands on drained peatlands. In 2010 dieback of Norway spruce stands was observed on drained organic and drained mineral soils. Mostly the middle aged stands were affected (Lazdiņš, Miezīte, & Bārdule, 2011; Miezite, Okmanis, & Indriksons, 2013; Klavina *et al*., 2016a) and correlation between the tree foliage damages and the K content in soil was found (Bardule *et al*., 2012). Moilanen *et al*. (2013) conclude that fertilization with wood ash shows the best results in stands with visual symptoms of P deficiency on N rich drained peat soils. In Latvia peatlands, including drained lands, are the richest with nitrogen forest soils (Bārdule *et al*., 2009).

Selection of fertilizers is essential depending on the deficiency of certain nutrients. Several fertilizers in the form of sulphates, nitrates and chlorides are known as sources of K. The last group (KCl) can cause soil pollution with chlorine if exceeding dosages are applied. Instead of manufactured mineral fertilizers, which usually consist of several elements and require investment to buy the fertilizer, wood ash could be used at no cost and considering balanced amount of macro and micro-nutrients except N. The latest tendencies in energy sector (Būmanis *et al*., 2014) will lead to increase of ash production in future. Already now industrial applications and households use 7.7 mill. m^3 of woody biomass (CSP, 2015), which means about 150 thousand tonnes of wood ash production annually. The question of utilization of wood ash should be solved in near future. Numerous studies have been made by now in relation to the use of wood ash as soil amendment. Wood ash contains numerous elements which can improve soil fertility (Demeyer, Voundi Nkana, & Verloo, 2001; Saarsalmi, Mälkönen, & Piirainen, 2001; Moilanen, Silfverberg,

Table 1

Treated stand location and parameters by 2011

Stand	Age, years	Latitude	Altitude	Treatment	DBH, cm	H, m	G, m^2 ha^{-1}	M, m^3 ha^{-1}
Ks47*	47	56º 51' 25''	23º 40' 45''	C	22.1	18.2	13.1	117.0
				K_2SO_4	23.1	18.5	21.3	190.8
				WA	21.9	18.0	19.0	171.5
Ks43*	43	56º 51' 32''	23º 41' 23''	C	26.0	19.3	22.9	205.9
				K_2SO_4	25.9	19.3	21.2	191.0
				WA	25.6	19.2	23.7	213.1
As36**	36	23º 27' 35''	23º 27' 35''	C	21.5	18.0	17.0	154.4
				K_2SO_4	21.4	18.2	14.2	128.0
				WA	22.2	18.4	19.3	174.5

*Forest type - *Myrtillosa turf. mel;* **Forest type - *Myrtillosa mel.*
DBH – mean diameter at breast height; H – mean height; G – basal area; M – stock volume.

& Hokkanen, 2002; Ozolinčius *et al*., 2007; Brais, Bélanger, & Guillemette, 2015; Okmanis, Lazdiņa, & Lazdiņš, 2015). The application of wood ash has other advantages, for example, Ozolinčius *et al*. (2007) state that wood ash increases denitrifying and ammonifying microorganisms and cellulose decomposers. Klemedtsson *et al*. (2010) have found that fertilization with ash reduces greenhouse gas emissions from soil; Klavina *et al*. (2015) concluded that a high dose of wood ash application had increased the diversity and richness of ectomycorrhizal fungi in a long term. Considering that the content of phosphorus in wood ash is low, Hytönen (2003) concluded that K content is predominantly responsible for a positive impact of the wood ash applied as a fertilizer. The aim of this study was to find out the growth response of Norway spruce on drained soils after application of potassium sulphate containing mineral fertilizer and wood biomass ash.

Materials and Methods

Experiment was carried out in 3 middle aged Norway spruce stands on mesotrophic drained peat soil (*Myrtillosa turf. mel*.) and drained mineral soil (*Myrtillosa mel*.). Characteristics of stands are provided in Table 1. Nine systematically located square (400 m^2, 20×20 m) sample sub-plots were set in each stand in summer of 2011 with 11 m long buffer zone between them. The diameter of every tree was measured at 1.3 m height to an accuracy of 1 mm in every sub-plot. The heights of 10 trees in every sub-plot were measured to an accuracy of 0.1 m using a hypsometer.

In June 2011, wood ash (WA, 2.5 t ha^{-1}) was applied in 3 sub-plots of each stand and 145 kg ha^{-1} of potassium sulphate (K_2SO_4) containing mineral fertilizer was applied in another set of 3 sub-plots and the remaining sub-plots were left untreated as control (C).

The amount of K applied to soil was approximately 65 kg ha^{-1} for WA and 62 kg ha^{-1} for K_2SO_4, respectively. WA contained a considerable amount of other macro and micro-nutrients (Table 2). Chemical content of K_2SO_4 was provided by manufacturer. Potassium (K), calcium (Ca), magnesium (Mg) and manganese (Mn) in WA were determined using an atom absorption spectrophotometer (ISO 11466:1005). Phosphates (P) were determined with colorimetry in aqua regia (LVS 298 (2002), LVS ISO 11466: 1995, LVS EN 14672 (2006)). Total sulphur (S) was determined using ELTRA CS-530 method, oxidizing S to SO_2 at 1340 □ (ELTRA CS 530 methodology). Every set of 3 sub-plots in each stand was combined into one sample plot (1200 m^2) for determination of dendrometric parameters within a treatment. The basal area, mean tree height, diameter and stem volume were calculated for each plot. The stem volume (including bark) was calculated using empirical functions provided by Liepa (1996).

Table 2

Chemical content of applied fertilizers, g kg^{-1}

Element	P	K	Ca	Mg	Mn	S
WA	10.9	26	224.8	30.9	3.1	-
K_2SO_4	-	430	-	-	-	180

In November 2015, the increment cores of all trees from all sample plots were collected at 1.3 m height with the Pressler borer. In total 423 cores were collected and analysed during the study. Cores were glued on desks, then the surface of cores was grinded so that every increment ring can be visually identified. The prepared cores were scanned with the high resolution scanner Epson Expression 10000 XL and following measurements of width of the annual increment rings were made with WinDENDRO software, which provides 0.001 mm accuracy. The average annual radial increments of the last 16 years (12 years of retrospection period and 4 years for the evaluation of fertilization effect) were calculated for each stand and the treatment. The additional volume increment was calculated according to I. Liepa (1996). Regression analysis of retrospective period was done to calculate prognostic annual radial increments in the last four years. The first factorial variable was natural logarithm of radial increments of the average tree in the control plots and resulting variable – natural logarithm of the radial increments of average tree from fertilized plots. Significance and conformity of hypothesis were estimated after the evaluation of regression and the following power regression (Formula 1) was set:

$$i'_j = \beta_0 + {i'_{k;j}}^{\beta_1}, \quad (1)$$

where i'_j – prognostic annual radial increment, $i'_{k;j}$ – annual radial increment of the control plots, β_0 and β_1 – coefficients of power function.

Statistical significance of the difference of the addition volume increment per unit of stand basal area between treatments within the experiment was evaluated using analysis of variance (ANOVA).

Results and Discussion

Previous studies have been made on distribution of fine root in fertilized plots and it was found that biomass of fine roots is significantly reduced during the first year after the application of fertilizers (Kļaviņa *et al.*, 2016b), despite the fact that positive tree growth response was observed already 1 year after the fertilization (Figure 1).

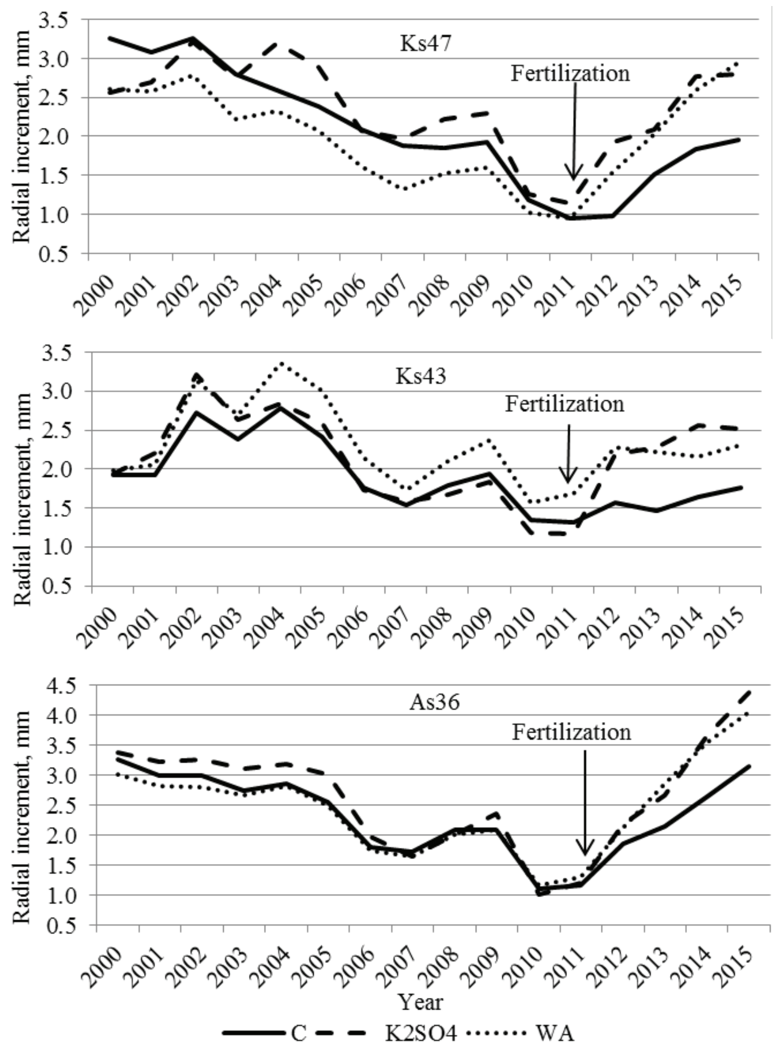

Figure 1. Average values for radial increment of Norway spruce in the control and fertilized plots.

Table 3

Results of regression analysis

Stand	Regression	R^2	p-value	Lower β_1	Upper β_1	Equation
Ks47	C-K_2SO_4	0.868	1.05×10^{-5}	0.58	1.02	$y = 1.2252x^{0.8014}$
	C-WA	0.953	6.01×10^{-8}	0.77	1.06	$y = 0.8897x^{0.9141}$
Ks43	C-K_2SO_4	0.961	2.23×10^{-8}	1.10	1.47	$y = 0.8359x^{1.287}$
	C-WA	0.939	2.10×10^{-7}	0.81	1.16	$y = 1.1784x^{0.9831}$
As36	C-K_2SO_4	0.976	2.14×10^{-9}	1.01	1.27	$y = 0.951x^{1.1388}$
	C-WA	0.991	1.23×10^{-11}	0.83	0.95	$y = 1.0699x^{0.8883}$

Fertilization improved the radial growth of trees so that in older stands (Ks47 and Ks43) it almost reached the highest increment values during the analysed period, but in younger stand (As36) even overreached the previous radial increments. It is important to note that the radial increment increased the most rapidly in the youngest stand. This could be related to the conclusion made by Lībiete, Jansons, & Zālītis (2009) conclusion that spruce stands reach the productivity peak at the agerange of 21 to 40 years. Visible tendencies of the growth difference points to the continuous effect of fertilization. Both, K_2SO_4 and WA applications express similar growth response, which approve hypothesis of potassium deficiency in Norway spruce stands on drained soils, as both treatments include similar doses of K.

The average increments of the control trees used to compare both fertilization cases statistically significantly differ in the retrospection period. Therefore, the regression analysis was done by comparison of the control and each of the fertilized plots so that the additional increment can be calculated for each case separately. Equations provided in Table 3 were elaborated with high coefficient of determination values as a result of the analysis. P-values of all equations are smaller than significance level ($p < \alpha = 0.05$) and hypothetical value of $\beta1$ ($\beta1 = 0$) is out of the 95% confidence interval (Arhipova & Bāliņa, 2006). All equations are statistically significant.

The highest increase of radial growth in the last year of observation according to prognostic values was observed in Ks47-WA plot (80 %) and the lowest in Ks43-WA plot (13%).

The tendencies of dynamics of the increase of stock volume in Figure 2 demonstrate that the effect of fertilization is continuous and future investigations should be done to recognize the total cumulative additional volume increase so that the economic analysis can be done. Many studies reveal that wood ash has a long term influence on tree increments. Jansons *et al*. (2016) concluded that the duration of effect of the NPK fertilizers applied to planting spot of Norway spruce is 15 years effect resulting in 17 % higher stem volume compared to the unfertilized plots. Saarsalmi *et al*. (2014) reported that fertilization of upland site induced up to 71 % higher increase of stem volume during 5 years after the application of nitrogen combined with wood ash. In the same study, a significant difference between the increment in treated and control plots was found only 6 years after the application of stabilized wood ash on peatland; although during the following 10 years stem volume increment in the ash-treated plots was 25 % higher than in the control plots (Saarsalmi *et al*., 2014). Sikström, Almqvist, & Jansson, (2010) concluded that signs of the wood ash fertilization can be recognized even 26 years after the application in elemental composition of the Scots pine needles and as an additional annual volume increment varying from 1.2 to 1.4 m^3 ha^{-1} yr^{-1}. In Sweden even 30 years after the fertilization some evidence of additional growth and chemical content of needles can be found when ash in combination with N is applied (Saarsalmi *et al*., 2012). Similarly, the study in Finland on drained mire identified that wood ash causes additional increment even 50 years after the application (Moilanen, Silfverberg, & Hokkanen, 2002).

The difference between the stock volume in fertilized plots (m) and the prognostic stock volume (mt) appears as the cumulative additional stock volume increment in Figure 2. By the year 2015, the highest value of the cumulative additional stock volume increment was observed in Ks47-WA plot (19.2 m^3 ha^{-1}) and the lowest value was in the WA plot in the stand Ks43 (8.5 m^3 ha^{-1}). In the Ks43-WA plot the basal area was much lower than in other plots (Table 1). Bergh *et al*. (2014) concluded that in a non-thinned pine stand the cumulative volume increment was higher than in thinned stands. It is significant to ensure optimal stand density before fertilization to obtain a better result. At the same time, it is important to consider the dimension of trees and to improve the growth of large dimension trees. In the K_2SO_4 fertilized plots values of the cumulative additional stock volume varied from 9.7 m^3 ha^{-1} (As36) to 17.2 m^3 ha^{-1} (Ks43).

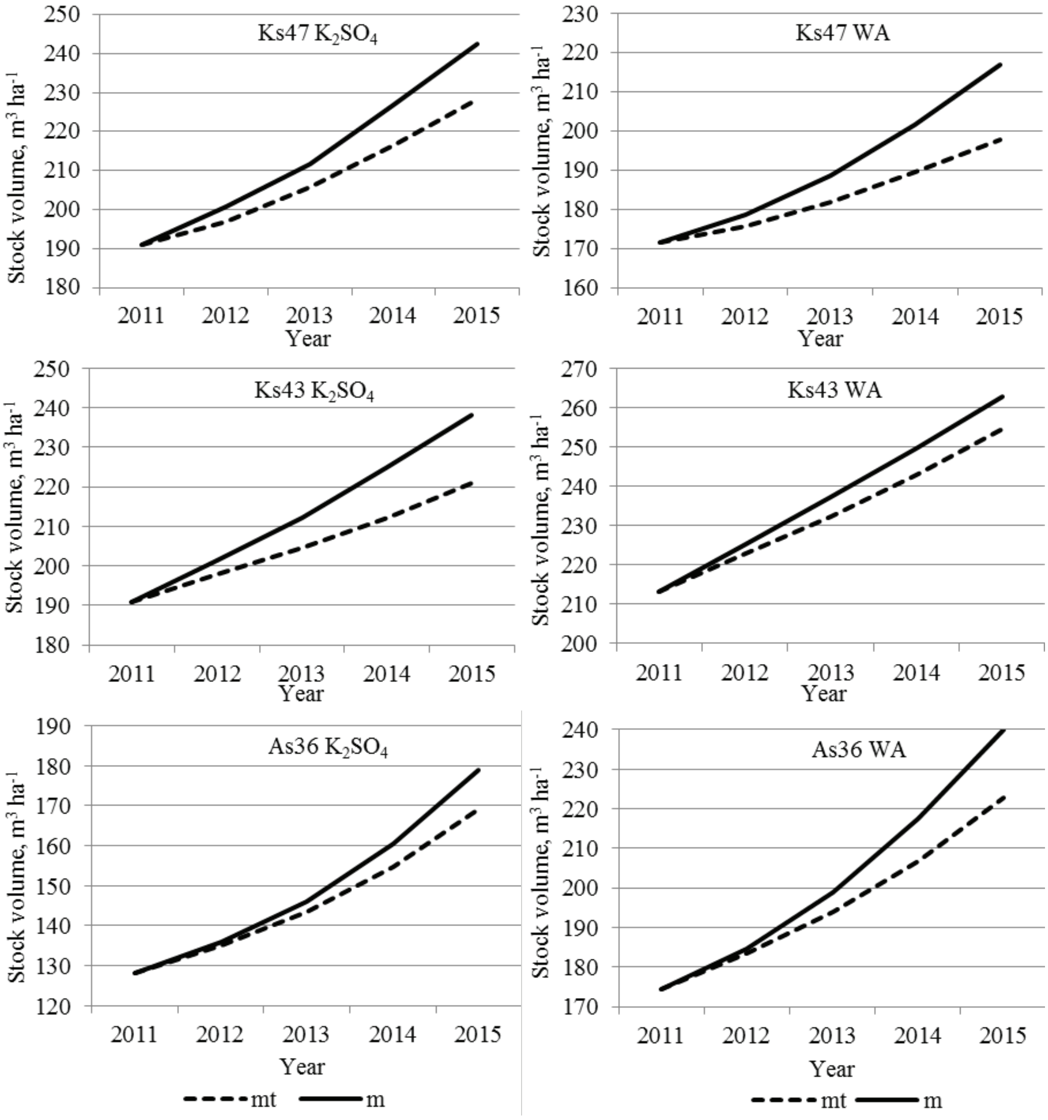

Figure 2. Dynamics of stock volume after fertilization (m) compared to prognostic stock volume (mt).

Increase of the volume increment per unit of the stand basal area can be used for a better comparison of effect of the fertilization between treatments (Table 4, Liepa, 1996).

ANOVA two factor analysis (the first factor as treatment and the second factor as year of observation) with replications (3 stands) demonstrates that there are no significant (95% probability) differences between fertilization with wood ash and K containing mineral fertilizer ($p = 0.82$, $\alpha = 0.05$). It can be concluded that a similar effect could be acquired with similar doses of potassium irrelevant to the type of fertilizers; however, complex fertilizers, like wood ash, can act longer according to the research data (Moilanen, Silfverberg,

Table 4

Increase of volume increment per unit of stand basal area in each plot

Year	Increase of volume increment per unit of stand basal area, $m^3\ m^{-2}\ yr^{-1}$					
	Ks47-K_2SO_4	Ks47-WA	Ks43- K_2SO_4	Ks43-WA	As36- K_2SO_4	As36-WA
2012	0.17	0.16	0.15	0.10	0.07	0.07
2013	0.09	0.18	0.19	0.11	0.10	0.18
2014	0.18	0.26	0.21	0.06	0.21	0.26
2015	0.18	0.32	0.18	0.06	0.24	0.29

& Hokkanen, 2002; Sikström, Almqvist, & Jansson, 2010; Saarsalmi *et al*., 2012).

Conclusions

1. The potassium containing mineral fertilizer and wood ash improve the growth of Norway spruce on drained mineral and organic soils already after the first year of application.
2. The impact of the fertilizers continuously increases during 4 years after the application of wood ash or potassium sulphate. The stem volume increment of trees in fertilized plots has increased significantly; further investigations are necessary to evaluate the duration of the impact and economic assessment should be made.
3. Four years after the application of fertilizers, the cumulative additional stock volume increment varied from 8.5 m^3 ha^{-1} to 19.2 m^3 ha^{-1} in wood ash treated plots and from 9.7 m^3 ha^{-1} to 17.2 m^3 ha^{-1} in potassium sulphate treated plots; however, no statistically significant differences between treatments were found.

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