

The utilization of wood ash as fertilizer in Slovak forestry

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Abstract – Main reason for wood ash research has been increasing of biomass utilization in Slovakia and concerned production. Application of wood ash as a fertilizer is allowed only for research purposes in Slovakia, because in some cases content of heavy metals exceed limit values by relevant legislation. The short-term effects of wood ash fertilization on chemistry of soil and leaves were investigated in 4-year-old beech stand (*Fagus sylvatica* L.) on acid soil in Kysuce. Three plots – the control plot and two plots with different ash treatments were established. Only bottom ash was used. The content of heavy metals was under the limit according to legislative regulation for fertilizers. The basic biometric measurements were performed on all the monitored beech seedlings before the first application (2007) and 3 years later (2010). Beech trees were statistically significantly higher (10 %) and had greater diameters (9,2 %) after applying higher dose of wood ash around plants.

Keywords: Wood ash, fertilization, Fagus sylvatica.

INTRODUCTION

Wood ash is alkalic, calcareous-potassic material containing a number of elements necessary for plant nutrition. It arises as a strong alkalic waste product after using the dendromass for energy purposes. According to the SR legislation, ash produced from unpolluted, chemically untreated wood does not possess the properties of dangerous waste and is classified within the group of "Other waste". Under the SR legislation and strategic documents, it is convenient and demanded to prefer its value increasing and utilizing to its dumping in the land. Ash contains a lot of macronutrients and micronutrients, which are important to plant nutrition and growth. Depending on the type of combusted biomass and combustion conditions, ash also contains various amounts of heavy metals (e.g. Pb, Cd, Cr, Hg, Ni, Cu, Zn, Se, Mo), which are appraised to be risk substances from the point of their following use as a fertilizer, or as a mineral amendment to the compost. It is necessary to follow the SR acts on waste, fertilisers and their corresponding executive regulations when searching for possibilities of the mentioned waste type recovery and of using its expected manurial properties. Only fertilizers recorded in a Register of fertilizers can be used, with the exception of tested materials for research purposes, what is also a matter of wood ash. In comparison with natural materials (e.g. milled limestone) used in the SR forests in past to eliminate the acidification, the content of potassium in ash may be the most significant difference resulting in improving plant resistance to drought, frost and in relative harmonising of microelements representation. Potassium content in ash and also the overall optimization of forest tree species nutrition can be important factors, which will contribute in successful forest stands establishment after spruce monoculture.

Legislation sets the limits of maximum allowable concentrations of risk elements in fertilizers applied into the soil. It is necessary to follow the SR acts on waste, fertilizers and their corresponding executive regulations when searching for possibilities of the mentioned waste type recovery and of using its expected manurial properties. Except for materials tested for research purposes, only fertilizers recorded in the Register of fertilizers can be used in Slovakia. Only research institution dealing with research in plant nutrition can apply unregistered fertilizers into soil only in inevitable amount. Limits on risk element contents are defined for fertilizers and also for other materials originating in different economy spheres and of which application into the soil is possible on certain conditions. Materials such as sediments from sewage treatment plants and bottom sediments from water basins which are produced in large amounts (Tab. 1) are included here.

Tab. 1 Limit values of risk elements in fertilizers [mg.kg⁻¹]

Risk element	Slovak Republic				Sweden	Finland
	Mineral fertilizer ¹⁾	Soil auxiliary substance ²⁾	Raw material for composting ³⁾	Sewage and bottom sediments ⁴⁾	Wood ash ⁵⁾	Wood ash ⁶⁾
Hg	0,5	1	10	10	3	2
Cd	1,5	2	13	10	30	3
Pb	30	100	500	750	300	150
Cr	50	100	1000	1000	100	-
As	10	10	50	20	30	50
Cu	-	200	1200	1000	400	-
Mo	-		25	-	-	600
Ni	-	50	200	300	70	100
Zn	-	400	3000	2500	7000	1500
Se	-	5	-	-	-	-

1) Limit values of risk elements for mineral calcareous and magnesium-calcareous fertilizers according to the SR regulation issued by the Ministry of Agriculture on 15 December 2000 by which the types of fertilizers, risk elements contents, sampling conditions and testing methods of fertilizers are defined, Collection of laws No. 26 / 2001, Appendix 2.

2) Limit values of risk elements for soil auxiliary substances contained in waste material according to the Appendix 3, Tab. 4 of the SR regulation issued by the Ministry of Agriculture on 23 May 2005 which defines types of fertilizers, composition, their packaging and labelling, analytical testing methods of fertilizers, risk elements, their limit values for individual groups of fertilizers, acceptable deviations and limit values of commercial fertilizers, Collection of laws No. 575 / 2005.

3) Limit values of risk elements occurring in the raw material for composting according to STN 46 5735 Industrial composts.

4) Marginal limits of concentration of risk substances in sewage and bottom sediments in accordance with Act No. 188/2003 on application of sewage and bottom sediments into the soil.

5) Limit values of risk elements in wood ash designed for application in the forest following the Recommendations for the extraction of forest fuel and compensation fertilizing, National board of forestry, Sweden, 2002 [1].

6) Limit values of risk elements for wood ash application in Finland [8].

Direct application of wood ash into the soil is now and most probably will be the most suitable method in view of economic reasons. This is exactly the case when strict limits on heavy metal contents in any random sample of wood ash have to be adhered, although the SR Ministry of Agriculture Regulation No. 26/2001 which specified the contents of risk elements was substituted for a follow-up one (575/2005) which increases the maximum limits for some risk substances (Tab. 1).

Properties of wood ash and rather large variability in heavy metals contents which are considered to be so called risk elements and thus strictly limited, do not allow asking for a certification of ash produced directly from the source (the biomass heating plant).

If the heating plant is combusting only unpolluted, chemically untreated wood, then ash contains concentrated elements which were originally found in dendromass. If this dendromass was left in the forest, after decay elements would return into the forest soil again.

Samples of wood ash were taken for the first time directly from the wood burning operations within the project "*Energy use of biomass in agriculture*". Upon the analyses and literary knowledge, it was stated that this ash possesses with different chemical properties than ash from plant biomass produced at laboratory temperature of (550°C). Harmonic composition of nutrients in wood ash and positive experience from Scandinavian countries, with long tradition of using wood ash as a fertilizer in forests, also motivated a start of field experiments in Slovakia, on the area of Nálepkovo municipal forests.

After finishing financing of the mentioned project, in 2002 co-operation with wood ash producers (biomass heating plants, pulp mill) and potential purchasers of wood ash fertilizer (State enterprise Forests of the SR, municipal forests) was established. Interest of practice in investigating the wood ash use in a broader scale than only for research purpose enabled to continue in long-term research on assessment of its effects.

Current projects "Wood ash use in the forest management" (Operational Programme Research and Development) and "Use of wood ash fertilising potential for growing of energy plants as a renewable source of energy" (Slovak Research and Development Agency) originated on the basis of increased interest in renewable energy sources and its relating growing production of only one solid waste after wood burning – wood ash. Using of wood ash as a fertilizer will bring several positive effects into the economic practice, namely in the form of decreasing the amount of existing ash on landfills and its returning into the natural cycle of substances, mainly at forest regeneration and silviculture processes.

The platform for effective co-operation between forest research organisations and following transfer of knowledge into the practice was formed. Research activities can be carried out only on the ground of good co-operation practice with the state enterprise Forests of the SR, Nálepkovo municipal forests and Propopulo Poprad company, on whose long-time field experiments are taking place, and also with operators of biomass heating plants, who are providing the samples of wood ash for following analyses and its field application.

Bottom ash from unpolluted, chemically untreated wood was manually applied on all experimental plots. Except those applications, on 14 November 2011 the first aerial application of wood ash was executed in Slovakia, with the dose of 1 – 3 tons per hectare on the area of PROPOPULO company forests, near the Spišská Teplica village.

Tradition of using the wood ash in the forest for fertilizing purposes is the most common in Sweden and Finland. Thus the most extensive degree of knowledge is in the field of ash effect on older coniferous stands, forests and peatlands. Contribution of research activities in Slovakia consists in widening the knowledge on wood ash application impacts in broadleaved tree species planting as well as in initiating the intense co-operation with practice.

In the era of climate changes, when spruce monocultures are dying and probably will have to be substituted by broadleaved tree species, wood ash can represent suitable and economically available fertilizer in the forest management.

An aim of current research activities in Slovakia consists in preparation of the similar provision which will define cumulative limits for entering of risk elements into the soil when fertilizing and will simplify wood ash use at adhering to safety. Only reliable data on wood ash properties and its effect, achieved by proper research in Slovakia, as well as intense co-operation among Slovak experts on practice, science, research, strategists and politicians can lead to the change of legislation. Whether the provision will be in a form of regulation or act (as it exists for sewage and bottom sediments application) depends on law experts' appraisal.

METHODOLOGY

In 2007 the Forest Management Unit Čadca (region Kysuce), on the area of the SR Forest state enterprise, was selected for an experimental application of wood ash. An exposure of the 131b compartment, where research and long-term observation of wood ash effect takes place, is NE with the average slope of 35 %. The total stand area is 10,57 ha, the age of an initial stand was 90 years with its stand density of 8. Spruce tree species represented originally 100 %, with mean height of 32 m, diameter of 36 cm and mean tree volume of 1,34 m³. Regeneration felling with the precedence rating of 2 was prescribed at the total volume of 2 500 m³. A rotation period of the stand is 100 years and a regeneration period is 30 years. Tree species such as spruce, fir, beech were prescribed for afforestation.

Incidental felling caused by bark beetles calamity was carried out in the stand. The first rotation incidental felling was carried out in 1999 and the last one in 2006. Experimental plots intended for wood ash application and observation of its effects (K, P1, P2) were afforested with beech plants in 2006 (i.e. an year before wood ash applying). Seedlings of the beech, spruce, fir, birch and mountain ash tree species are also represented on these plots.

Before wood ash applying, the soil on these plots was extremely acid with low amount of accessible nutrients. In 2007 wood ash was applied into the soil in the spring and autumn. Three plots, each with the size of 40 x 12 m and with the outside protective zone of 2 m, were measured and stabilised on the plot where incidental felling of the spruce monoculture was carried out and this was later afforested with beech plants. In spring 2007, so at the beginning of the experiment, heights and diameters of beech plants were measured on the control plot and on the P1 plot. There were 318 plants on the K control plot and 343 plants on the plot P1. Biometrical measurements on the plot P2 were conducted during the autumn, when wood ash was applied. There were 332 plants. One plot was left as a control plot, where no ash was applied. With the aim to achieve the most accurate distribution of ash, ash was applied manually on the soil surface on other plots. When applying, ash was softly applied onto the top-soil layer on the area of 0,5 m x 0,5 m to eliminate its loss and relocation by wind. Periods and a method of application are given in Tab. 2.

Tab. 2 A list of experimental plots, the period and method of wood ash application

Plot	Period of application	Method of application	Ash dose
K (control)	-	Without intervention	-
P1	Spring 2007	Around the plant 0.5x0.5 m	1 t.ha ⁻¹
P2	Autumn 2007	Around the plant 0.5x0.5 m	3 t.ha ⁻¹

On the basis of results obtained from chemical analyses of wood ashes available in 2007, ash coming from burnt bark of chemically untreated wood, taken from the MONDI SCP Ružomberok operation, was selected for the direct application into the soil. Ash was taken only from the bottom of the boiler because the risk of an increased level of heavy metal concentrations is lower here than by fly ashes [6]. Concentration of heavy metals in used ash met the limits for mineral fertilizers existing in valid legislative regulations in the SR, only the concentration of arsenic and cadmium was slightly higher. At the same time, ash met the limits for applying wood ash, i.e. with regulations in Sweden [1].

Research into wood ash properties and consequences of its application into the forest soil is demanding on proper sampling and precise chemical analysis of the large number of samples. Our long-term experience in forest health condition monitoring has been used for taking the partial samples, producing the cumulative samples and carrying out chemical analyses. Analytical works were conducted by the Central Forestry Laboratory of the NFC. This laboratory has been operating with the AQA system – Analytical Quality Assurance (a system for ensuring the reliability of the analyses results produced and interpreted for “Forests” partial monitoring system purposes) which has been operating for the government department of agriculture since 1994. Quality of works is secured by internal and external quality control which is in accordance with principles of correct laboratory practice. Analytical procedures for risk elements content in samples of wood ash and fuel were defined in the SR Ministry of Agriculture Regulation No. 26/2001. After mineralisation of the sample is done using the mixture of nitric acid and hydrochloric acid, risk elements which are required will be fixed by means of AAS or AES – ICP method from the obtained mineralisat.

On the plots where wood ash was applied, soil around the plants was taken from the 2 cm topsoil layer and from a depth of 20 cm within the species root system. In autumn 2007, partial soil samples were being taken from ten sites of each plot and cumulative samples were made for individual depths of sampling. All analyses were conducted in compliance with internationally valid manual for monitoring of air pollution effects on forests, a part for soil [7].

Two growth parameters were measured on sample and the control plots with the aim to observe growth processes of tree species. Species height, or the length of above-ground parts, was measured from the root neck right to a top of the leader. A root neck diameter was measured at the place of its contact with the ground. At the beginning of this experiment, i.e in spring 2007 and later in autumn 2007, these parameters were measured on all plants on the plots with applied wood ash and on the control plot in order to control the growth processes. Biometrical measurements were repeated after three years, in spring 2010, before new vegetation period began. These measurements were conducted only on 50 % of the original area of experimental plots because of the natural regeneration on all the plots. Thus we eliminated new seedlings, which were not treated with wood ash in 2007.

RESULTS

Before wood ash applying, the soil was extremely acid ($\text{pH}_{\text{H}_2\text{O}}$ 3.74 and pH_{KCl} 2.83 in a depth of 20 cm) with low amounts of accessible nutrients. In the depth of 20 cm, concentration of calcium was 341 mg.kg^{-1} , of potassium 74 mg.kg^{-1} and of magnesium 51 mg.kg^{-1} , which resulted in insufficient tree species nutrition. A ratio between carbon and nitrogen was lower than 25, the amount of total nitrogen was good. Soil was strongly sorptively unsaturated (V value lower than 15). A beneficial effect of alkalic wood ash application on chemical changes in soil already appeared five months from application. Sorption saturation, values of active and exchange soil reactions and also a reserve of accessible nutrients notably increased. Results are given in Table 3 and 4. Regarding heavy metals, we have discovered moderate increase in cadmium content in 2 cm top-soil layer, but also in the depth of 20 cm (Tab. 5).

Tab. 3 Change of soil properties after wood ash applying – active and exchange soil reaction, amount of the total carbon and nitrogen [%], C/N ratio and V values

Plot	Sampling depth	$\text{pH}_{\text{H}_2\text{O}}$	pH_{KCl}	N_T	C_T	C/N	V
				[%]			
K	0-2	3.8	2.8	0.989	24.7	24.97	10.10
P1	0-2	4.9	4.0	1.800	32.2	29.81	32.52
K	20	3.7	2.8	0.621	14.4	23.19	6.59
P1	20	3.9	3.0	0.957	22.1	23.09	73.83

Tab. 4 Change of soil properties after wood ash applying – amount of accessible nutrients of Ca, Mg, K, P [mg.kg^{-1}]

Plot	Sampling depth	Ca_M	Mg_M	K_M	P_M
		[mg.kg^{-1}]			
K	0-2	720	106.5	114	19.3
P1	0-2	2204	316.5	312	71.1
K	20	341	51.3	74	5.6
P1	20	601	101.5	111	18.5

Tab. 5 Change of heavy metals content in the soil after wood ash applying in the 2 cm top-soil layer and in the depth of 20 cm [mg.kg⁻¹]

Plot	Sampling depth	Pb	Cd	As	Cr	Hg
		[mg.kg ⁻¹]				
K	0-2	73.05	0.38	15.56	30.3	0.289
P1	0-2	64.83	0.53	5.03	25.4	0.258
K	20	71.38	0.22	26.35	39.9	0.294
P1	20	67.50	0.36	18.55	35.8	0.298

Observation of tree species growth processes belongs to the most frequent methods of evaluation of tree species reaction on fertilizer material application. Biomass production of tree species is a complex response to a change, i.e. to nutrients supply, but also a supply of potentially risk elements into the soil environment. When wood ash applying, optimization of nutrition with the alkaline nutrients and following improvement of a forest stand vitality is expected to current scientific knowledge [2, 3, 4]. Increased biomass production is possible in certain site conditions. As mentioned authors state, primarily on the basis of growth changes observation of tree species after ash applying in Scandinavia, positive growth effect can be expected on plots with sufficient reserve of nitrogen, where C/N ratio is lower than 25. Before wood ash applying, initial ratio of C/N was lower than 20 on experimental plots in the Kysuce region.

Application of wood ash into the soil was carried out in two periods, in spring and autumn 2007, so it is approximately one year after planting and this ought to be a sufficiently long period for rootlets and soil environment merging together. The method of wood ash fertilizing is a determining factor in a possible damage of plants. Precise manual application of wood ash around each plant (*Fagus sylvatica* L.) separately, on the area of 0.5 m x 0.5 m, was carried out on plots P1 and P2. There was almost no contact between the plant and applied material by this method. The risk of plant tissue damage on above-ground parts with alkaline material was minimal. Before fertilizing in spring and autumn 2007, we carried out the basic biometrical measurements of plants on all the observed individuals.

Biometrical measurements were repeated after three years, in spring 2010, before the beginning of new vegetation period. These measurements were carried out only on 50 % of the original area of experimental plots because we wanted to eliminate new seedlings from measurements which were not treated with wood ash in 2007. Two growth parameters were measured on experimental plots and control plot in order to observe the growth processes of tree species. Tree species height, or above-ground parts length, was measured from the root neck right to the top of the leader. A root neck diameter was measured at the place of its contact with the ground. Statistical characteristics are given in Table 6 (heights) and in Table 7 (tree species diameter).

Relative changes in mean height and diameter of plants in comparison to the control plot, when wood ash applied in 2007 and 2010, are shown in Picture 1.

Results already obtained in a 5-month short period after wood ash application in 2007 indicated the positive effect of wood ash mainly on plants diameter, which was bigger on the plot P1 by 13.6 % than on the control plot.

After applying wood ash in the spring in a dose of 1 t.ha⁻¹, mean height of plants was bigger by 3.5 % than on the control plot. In 2010, i.e. three years after application, the plants were higher by about 10 % after two doses of ash. A higher dose positively affected the plants diameter, too. Mean diameter was higher by 9.2 % on the plot P2 with the application of 3t/ha than on the control plot and on the plot with the dose of 1t/ha it was higher by 6.5 %.

On the control plot where no wood ash was added, plants grew by 33 cm at average from the beginning of the experiment. It was by 39 cm on the plot with spring dose of 1 t/ha and on the plot with most intense dose (3 t/ha) it was by 41 cm.

Statistically significant difference in plants growth was confirmed between the plot with the higher dose of ash (3 t.ha⁻¹) and the control plot (Anova test, significance level $\epsilon=0,005$). P value for height difference was 0,04 and for diameters P=0,0002.

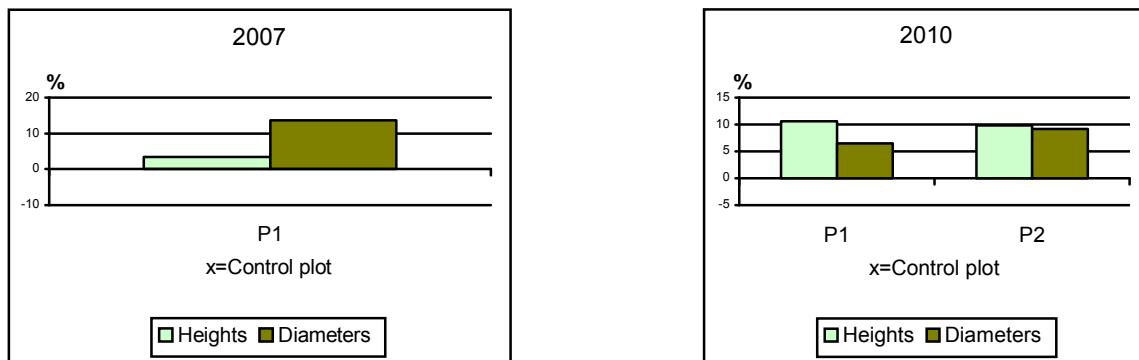
To our former experiments with wood ash application into forest soil on Nálepkovo municipal forests, statistically significant difference in plants growth was confirmed between the plot with the higher dose of ash (5 t.ha⁻¹) and the control plot (Anova test, significance level $\alpha=0,005$). P value for height difference was 0,03 and for diameters P=0,0001. When wood ash of higher dose was applied around the plants, the beeches grew higher and wider after four years from application [5, 6].

Tab. 6 Height of beech plants (*Fagus sylvatica* L.) in 2007 and 2010 – statistical characteristics

Autumn 2007	K (control - without ash)	P1 (1t/ha in spring)	P2 (3t/ha in autumn)
Number of plants	306	331	332
Arithmetic mean	34.15	35.43	32.61
Median	33.50	34.00	31.80
Standard deviation	8.29	9.35	7.94
Spring 2010			
Number of plants	163	144	200
Arithmetic mean	67.43	74.58	74.05
Median	65.00	72.25	72.50
Standard deviation	21.24	24.58	22.10

Tab. 7 Diameter of beech plants in 2007 and 2010 – statistical characteristics

Autumn 2007	K (control - without ash)	P1 (1t/ha in spring)	P2 (3t/ha in autumn)
Number of plants	306	331	332
Arithmetic means	0.59	0.67	0.57
Median	0.60	0.60	0.60
Standard deviation	0.16	0.20	0.13
Spring 2010			
Number of plants	163	144	200
Arithmetic mean	11.94	13.90	13.03
Median	12	13	13
Standard deviation	2.54	3.86	2.84



Pic. 1 Increase of mean height and diameter of beech plants on the plots with wood ash application after five months (2007) and three years (2010) later

K- a control plot, P1 – application to plants in the dose of 1 t.ha⁻¹ in the spring, P2 – application to plants in the dose of 3 t.ha⁻¹ in the autumn

SUMMARY AND CONCLUSION

The experiment with wood ash application into the forest soil while planting beech plants (*Fagus sylvatica* L.) began in spring 2007, on the area of Čadca forest district where calamity felling was carried out. Manual fertilizing around the plant, in a scheme mentioned in the methodology part of this work, was applied after the selecting and fixing of three plots (K- the control plot, P1 – plot with ash application in spring with the dose of 1 t.ha⁻¹, P2 – the plot with ash application in autumn with the dose of 3 t.ha⁻¹). Applied wood ash was obtained from bark burning of unpolluted, chemically untreated wood coming from MONDI Ružomberok operation.

Wood ash contains all important nutrition elements, except the nitrogen, which were originally present in dendromass. Combustion of biomass in new types of boilers is operated at higher temperatures and this causes concentration, or reduction of certain elements. In comparison with natural materials (e.g. milled limestone), which were used in the forests of Slovakia in the past, content of potassium in wood ash could be the most notable difference. Wood ash used in Kysuce region contained 4.7 % of potassium, the macroelement which improves plant resistance to drought, but also to frost. It was also remarkable with relatively harmonic composition of other macroelements and microelements important for plant nutrition. In context of expected climatic changes, potassium and the optimization of forest plant nutrition can be the significant factors determining the successful establishment of forest stands after calamity fellings on spruce monoculture areas in Kysuce region.

In the course of 2007, preliminary samples of assimilatory organs and soil were being taken and analysed and measuring of plant heights and diameters was carried out on all the plots. In 2008, samples of assimilatory organs were being taken and analysed in order to identify long-term effects of wood ash on tree species nutrition. In 2009, monitoring continued with sampling and analysing the assimilatory organs and in 2010 it was supplemented with biometrical measurements and soil sampling. A database of analytical results represents valuable data necessary for long-term assessment of wood ash effects on the forest ecosystem.

Discovered increase in contents of macroelements and microelements in assimilatory organs as well as the total optimization of nutrition may be appraised beneficially in regard to long-standing problems with tree species nutrition on the control plot. Already assessment of biometrical data taken in 2007 have indicated favourable effect on tree species growth processes and measurements from 2010 confirmed more intense growth of beech plants on plots with wood ash.

Statistically significant difference in plants growth was confirmed between the plot with the higher dose of ash (3 t.ha⁻¹) and the control plot (Anova test, significance level $\alpha=0,005$). P value for height difference was 0,04 and for diameters P=0,0002. When wood ash of higher dose was applied around the plants, the beeches grew higher and wider after 3 years from application.

To conclude, it is important to mention that only a long-term assessment of ecological effects of wood ash can change the legislation in the SR and a consequent possibility of applied use in the forestry as it is material rich in nutrients.

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