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Effects of Wood Ash on the Chemical Properties of Soil and Crop Vitality in Small Plot Experiments

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Abstract – Wood-burning power plants and heating plants produce a great amount of wood ash as a by-product of the combustion process. In 2009 we launched an experiment in which we examined the composition of ash, the nutrient supplying capacity of soil mixed with ash, and the availability of its constituents. In the spring of 2010, we conducted small plot experiments using wood ash applications equivalent to 0; 1; 2.5; 5 and 10 t of wood ash/ha, on slightly acidic clay loam soil using white mustard and rye grass as the test plants. The pH value of the soil rose in a statistically verifiable way as a result of the ash treatments. After the application of ash, the P_2O_5 and K_2O-content of the soil rose significantly; the treatments also increased the magnesium and sulphur content of the arable soil as well as the level of Zinc among the microelements. However, none of the wood ash applications caused verifiable changes in the number of shoots, in the green mass, or in the height of test plants. The increased nutrient supply of the soil through the treatments was not reflected in the nutrient content of the plants during the first year.

wood ash load / small plot experiment / nutrient supply / heavy metal content

Kivonat – Fahamu hatása a talaj kémiai jellemzőire és a termény vitalitására egy kisparcellás kísérletben. A fatüzelésű erőművekben és fűtőművekben az égetés melléktermékeként nagy mennyiségben keletkezik fahamu. 2009-ben indított kísérletsorozatunkban vizsgáltuk a hamu összetételét, a hamuval kevert talaj tápanyag-szolgáltató képességét, alkotórészeinek felvehetőségét. 2010 tavaszán szabadföldi kisparcellás kísérletet állítottunk be 0, 1, 2,5, 5, 10 t fahamu/ha-nak megfelelő dózissal fehér mustár és angol perje tesztnövényekkel, gyengén savanyú, agyagos vályogtalajon. A talaj vizes szuszpenzióban mért pH-értéke statisztikailag igazolhatóan növekedett a kezelések hatására. A hamu kijuttatásakor jelentősen emelkedett a talaj P_2O_5- és a K_2O-tartalma. A kezelések növelték a termőtalaj magnézium- és kéntartalmát, valamint a mikroelemek közül a cink mennyiségét. A tesztnövények kelésszámában, zöldtömegében és magasságában egyik fahamu dózis sem okozott igazolható változást. A kezelések hatására a talajban megnövekedő tápelem kínálatot a növények tápanyagtartalma az első évben nem mutatta.

fahamu-kijuttatás / kisparcellás kísérlet / tápelem-ellátottság / nehézfémtartalom

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1 INTRODUCTION

Interest in using biomass for energy has grown recently because of the reduced availability of fossil fuels. In recent years, a partial or complete switch to biomass heating solutions has happened in Hungary, both in regular households and in many coal-fired power plants such as the ones in Pécs and Ajka. (Tóth et al. 2011). For fuel, these power plants use firewood or sawdust and scrap wood from forestry and the wood industry.

The by-product of wood combustion is ash. The amount of combusted firewood is growing every year, which is consequently reflected in the increasing amount of wood ash. The annual estimated mass of wood ash in Hungary is 30 thousand tonnes; its volume is 50 thousand m^3 (Tóth et al. 2011). Currently, wood ash is treated as waste and is most often used for filling former mine-shafts or it is simply landfilled. The growing expenses associated with landfilling and the reluctance to open new waste landfill sites have brought about increasing interest in alternative methods of disposal. Among these is the use of wood ash for the purposes of soil amelioration and soil refill in agriculture, horticulture, and forestry (Demeyer et al. 2001; Steenari – Lindqvist 1997; Zimmermann et al. 2010).

A variety of factors can influence the composition of wood ash. The quality of the combusted wood – whether it was scrap wood or of higher quality – can play a role as can the combustion technology used. (Campbell 1990). Which parts of trees are combusted can also influence the ash significantly; the nutrient content of roots and branches is much higher than the nutrient content of logs, for example. The difference between species can have significant effects, in many cases even within the same genus. In certain species the chemical compound of ash is normally influenced by the soil properties and the climate (Werkelin el al. 2005). The differences in the chemical composition of identical wood species from different stocks with acidic or calcareous soil may be bigger than in different wood species from stocks with identical soil qualities (Ulrich 1990). In addition to nutrients, ash might contain other elements such as heavy metals. Consequently, the data in literature concerning the chemical composition of wood ash is considerably diverse (Demeyer et al. 2001).

The application of wood ash can cause rapid changes in the chemical properties of the soil, especially in the top layer. The treatment can enhance the pH of the top layer by 0.3–2.4 units in a load of 1–7 t/ha (Mandre et al. 2006; Ozolincius et al. 2007; Perucci et al. 2008). In the deeper layers, the neutralizing effects are far more moderate, or they do not appear at all (Arvidsson et al. 2002). Oxides, hydroxides, hydrogen carbonates and carbonates are responsible for the rapid change in the pH level. The rate of hydroxide/hydrogen carbonates/carbonates ions can vary to a great extent, and consequently the alkalinisation effects of different ashes can also be diverse (Etiegni – Campbell 1991).

Ash contains all the components of wood in a concentrated form, except for carbon, hydrogen and nitrogen which evaporate during the firing of wood. The mean concentration of major nutrients in wood ash is as follows: 0.06% N, 0.42% P, 18% Ca, 0.97% Mg. Also, 2.27% of K for wood-fired boiler ashes (Vance 1996) and 1.57% P, 18.5% Ca, 2.86% Mg and 3.52% K for bark ashes have been reported (Someswhar 1996). During its application in soil, wood ash behaves like fertilizers with a low nitrogen content (NPK: 1:10:50) (Park et al. 2004). Its K-content perfectly dissolves in water, which explains its sensitivity to leaching (Demeyer et al. 2001; Odlare – Pell 2005). The greatest part of potassium gets bound in the soil both physically and chemically, and only 20 to 40% of potassium is available (Naylor – Schmidt 1989) when the potassium content in the soil is low. The calcium-oxide content of soil turns into calcium-hydroxide in the presence of water. Calcium-hydroxide reacts with the carbon-dioxide in the air, which results in the formation of calcium-carbonate. As a result, wood-ash enhances the lime content of the soil (Steenari et al. 1999).

The microelement concentration of wood ash is diverse. According to prior research, the heavy metal content of wood ash is typically low (Someshwar 1996). The increased pH-level in the soil will cause a further decrease in the mobilization of certain heavy metals. Despite the low concentration and the differences in mobility, heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Zn) may cause changes in the soil, vegetation and consequently in the composition of ground water (Ozolincius et al. 2007). Repeated spillage of ash may cause an accumulation of heavy metals. By lowering the soil pH, the mobilization of heavy metals will increase, which is a potential threat for the environment. However, wood ash has just the opposite effect on soil because it reduces the mobility of heavy metals (Vance 1996; Campbell 1990). According to the latest surveys, the toxic trace element load of the ash can fluctuate, so its Cd-content can reach a concentration of 20 mg/kg (Omil et al. 2007), like when the wood used comes from the soil of a spoil bank with high cadmium content and high acidity, for instance. In cases other than that, the accumulation of cadmium to such an extent is rare. Nevertheless, ash still needs to be used carefully in order to prevent heavy metal contamination or its incidental negative effects on terrestrial and aquatic ecosystems (Narodoslawsky – Obernberger 1996).

Application of ash on soil can be performed in several ways, and each way impacts the environment differently. Raw ash (as a strong alkaline) is difficult to manage as its particulates tend to dissolve easily. The particulate size of stabilized ash is larger, and as its pH-value is about 10.5, it is easier to manage, but at the same time – as it has a tendency to carbonation – the dissolution of nutrients is slow (Steenari – Lindqvist 1997). The pH of ash granules is lower, about 9, and its elements dissolve slowly due to the bigger particulate size (Callesen et al. 2007). Extruded, pelleted wood ash is also easy to manage thanks to its size, however, the dissolution of the elements is limited (Emilsson 2006; Csiha et al. 2007).

Wood ash is regarded as non-hazardous waste of non-agricultural origin, thus its use for agricultural purposes is an activity subject to prior authorisation. According to Act CXXIX of 2007, an application for an authorisation certificate must be submitted to the Directorate for Plant and Soil Protection of the relevant government office of a given county.

To examine the effect of wood ash on soil and vegetation we conducted a small plot experiment launched in May 2010. Within this framework we have been examining the composition of wood ash, the mobilization of its constituents, and its nutrient-supplying capacity. We have been studying the changes in the chemical properties of the soil as a result of the treatment, as well as the effect of the ash on the number of shoots, the growth and the element content in the test plants.

2 MATERIALS AND METHODS

The wood ash used in the experiment was collected in March 2010 from the ADA Hungária Bútorgyár Kft [ADA Hungária Furniture Factory Ltd.] in Körmend where scrap wood is disposed of through burning. Before the experiment was launched, the wood ash was stored in sealed plastic bags. We chose a slightly acidic soil for the experiment due to the alkalizing effect of wood ash. The agricultural plot selected for the experiment had an area of 100 m^2 and was located in Tanakajd, in Vas County. The designated land was divided into forty plots (1 m x 1 m / plot) to allow for the investigation of the effects of different loads of wood ash on ryegrass (*Lolium perenne*) and white mustard (*Sinapis alba*). The treatment groups were composed of a treatment-free control group and groups based on 1, 2.5, 5 and 10 tonnes of wood ash/ha with four replications for each treatment for both plant species (i.e. four replications per treatment per plant species). The treatment plots were arranged according to the laws of a randomized block design (Sváb 1981).

Of the two test plants, ryegrass responds intensely to changes in nutrient quantity, with rapid initial growth and strong germination. Ryegrass is commonly used for the testing of fertilizing effects for this reason. Seeds of white mustard show a rapid and nearly 100 per cent germination, which is why it can be used for testing anti-sprouting and germination inhibiting effects.

The preparation of each plot was followed by the application of the required amount of ash load, with the ash evenly mixed into the upper 10 cm layer of the soil. The test plants were seeded in May 2010. White mustard seeds were seeded on the 1 m^2 small plots, with 200 germinative seeds/m^2 and 25 cm spacing between each line, at a depth of 2–3 cm. Ryegrass seeds were dispersed on the 1 m^2 small plots, (40 grams of germinative seeds/m^2) onto the surface of the soil, and subsequently worked into the soil to a depth of 1–2 cm. Rainy weather assured the water needs of the plants and no additional watering was required.

On the seventh day after planting, the number of sprouted white mustard plants was recorded for each plot. The white mustard and ryegrass plants were harvested in August (95 days after planting), at which point the number of plants per plot was recorded. In addition, the average height of the white mustard plants was determined based on the height of five randomly chosen plants. In the case of the ryegrass, we measured the average height of the plants. After the plants were cut off at the base, the above-ground biomass was measured per each plot, and subsequent to the harvest, we took samples of the white mustard test plants. Average samples from the replications were created for laboratory testing per treatment. Soil sampling also took place during the harvest. The samples were taken from depth of 0–10 cm, and consequently one average sample per treatment and replication was created. The laboratory-based analyses on wood ash, soil and plant samples were performed at the accredited soil protection laboratory of the Directorate for Plant and Soil Protection of the Vas County Government Office. The „total" element content of the wood ash, of the soil and of the white mustard test plants was determined following cc. HNO_3 + cc. H_2O_2 destruction, using Inductively Coupled Plasma. The soluble nutrient content of the soil was detected based on the method of Hungarian Standard MSZ 20135:1999.

Determination of easily soluble nitrogen fractions was made by means of extraction solvent 0.01M $CaCl_2$, while determination of soluble potassium and phosphorus fractions was performed by ammonium lactate solution (AL). For the extraction of the copper, manganese and zinc content ethylenediaminetetraacetic acid was used.

The statistical analysis was performed using software StatSoft, Inc. (2012), STATISTICA (data analysis software system), version 11. To explore the differences in the treatment effects, a one-way analysis of variance (ANOVA) was performed.

3 RESULTS

The ash mixed during the experiment is strongly alkaline, with a pH of 13.0. Its phosphorus content is 0.37%, calcium content is 23.29%, magnesium content is 2.68% and potassium content is 5.42% by weight. The iron content of the ash is significant too, 13.46 g/kg *(Table 1).* According to the test results it can be stated that the phosphorus content of the ash is lower than the values given in the literature (Etiégni – Campbell 1991), and the toxic heavy metal load did not exceed the values in the literature, with the exception of chromium.

The mechanical composition of the soil mixed for the experiment had the physical consistency of clayey loam, with slightly acidic pH, with no soda lime content, with nearly 27.3 per cent of clay-content (< 0.002 mm), and over 60 per cent of mud sediments in it (< 0.002 mm). According to its physical properties, the hydraulic conductivity of the soil is average, while its water holding capacity is good and its air metabolism is satisfactory. Its nutrient content, based on its humus concentration, is good too.

Table 1. Characteristics and content of nutrients and heavy metals of wood ash.

Tested parameters	Units	Results	Results given in the literature (Etiégni – Campbell 1991)
pH (H_2O)		13.0	13.1 – 13.3
dry matter	% w/w	99.9	–
volume/mass	kg/dm^3	0.926	–
P	g/kg d.m.*	3.7	14.0
K	g/kg d.m.	54	41.3
Ca	g/kg d.m.	233	317
Mg	g/kg d.m.	27	22.5
Na	g/kg d.m.	5.8	3.4
Al	g/kg d.m.	18	23.65
Fe	mg/kg d.m.	13.5	19.5
Cd	mg/kg d.m.	6.5	21
Cr	mg/kg d.m.	182	86
Cu	mg/kg d.m.	110	145
Hg	mg/kg d.m.	< 0.5	–
Ni	mg/kg d.m.	58.9	–
Pb	mg/kg d.m.	85.0	130
Zn	mg/kg d.m.	496	700

Note: d.m. - dry matter*

The soil pH is favourable for the exposure to nutrients and thus for the nutrient uptake of plants, as this is a suitable pH-range for active biological life, with no extreme chemical conditions in the soil that would significantly lower the mineralization of any type of organic substances, macro- or micro-nutrients.

Due to the sum of the exchangeable cations in the soil, the overall cation exchange capacity of the soil (T-value) is good, 23.2 meq/100 g of soil. The good adsorption properties are formed as a result of the clay content and the humus content of the soil *(Table 2).* It is the colloids of the soil that are responsible for the water and nutrient absorption, as the amount of water stored in soil and available for uptake depends on the quantity and quality of colloids.

Table 2. Major characteristics of the soil used in the green-house experiments

Parameters	Results
pH (H_2O)	6.6
pH (KCl)	5.6
Plasticity index according to Arany (K_A)	43
Percentage of humus	2.6%
Percentage of carbonated lime	< 0.1%
Cation exchange capacity (T-value) (meq/100 g of soil)	23.2

In the case of the white mustard test plants, the treatments didn't cause a significant difference either in the number of all the emerged plants recorded on the seventh day, or in the number of plants per plot at the end of the trial period *(Table 3).*

Table 3. Effect of wood ash treatment on test plants.

Wood ash treatment (t/ha of soil)					Significant difference (5%)	Average
0	1	2.5	5	10		
White mustard, number of shoots (pc)						
182	181	184	180	179	10	181
White mustard, number of stocks (pc)						
180	179	186	183	183	7	182
White mustard, height (cm)						
120	121	122	120	121	8	121
White mustard, green mass (g)						
2543	2705	2430	2713	2663	919	2611
Ryegrass, height (cm)						
27	27	28	28	27	1.94	28
Ryegrass, green mass (g)						
802	830	821	848	864	107	833

According to the weight measurement of the different plots, the ash treatments provided a higher weight of organic material in both plant species on all plots, with the exception of one. There was no difference between the average growth in height within a species: white mustard reached an average height of 120–122 cm in each plot, while ryegrass reached 27–28 cm. The positive effects of wood ash treatment were manifested in the organic material content of the above-ground parts. When the white mustard was compared to the control group, the treatment of 1 t/ha caused 6.3% increase in weight, the treatment of 5 t/ha caused 6.7% increase, while the 10 t/ha treatment caused a growth of 4.7%. In the 2.5 t/ha treatment the green mass was lower than that of the control. A very similar tendency occurred with the ryegrass, too: when compared to the control, the 1 t/ha treatment resulted in a growth of 3.5%, the 2.5 t/ha treatment in a growth of 2.4%, the 5 t/ha treatment in a growth of 5.7%, while the 10 t/ha treatment caused an 8% growth in the above-ground organic matter. No significant change in the height and green mass of the test plants could be detected in any of the cases.

The ash treatment enhanced the soil pH measured in aqueous suspension. The pH value of the average soil-sample taken from an identically treated soil rose for both white mustard and ryegrass; after the application of a 10 t/ha dose, the pH level rose to 7.6, compared to the pH 6.4 level of the control. The values measured in the 1 mole KCl-suspension followed the pH-changes of water. No statistically verifiable differences in the pH-changes of the soil were uncovered for the two test plants: the pH values measured both in aqueous suspension and in suspension of potassium chloride seem to form a saturation curve (*Figure 1*).

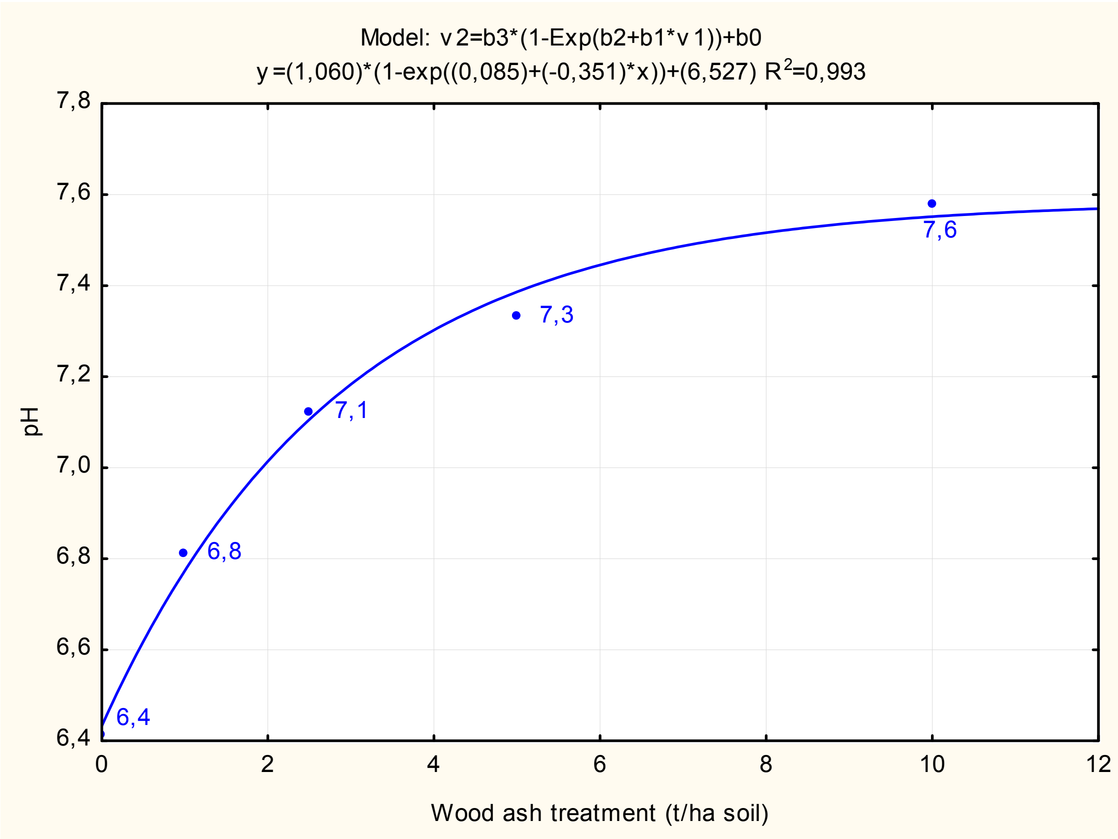

Figure 1. The pH-change in the soil of white mustard caused by the wood ash treatment

The ash treatment increased the carbonated lime content of the soil as well as the amount of potassium, phosphorus, magnesium and zinc, among the other nutrients. The carbonated lime content of the lime-defective soil rose to 0.8 mass% during the treatment of 10 t/ha. The treatment did not affect the amount of nitrogen, as this substance essentially evaporates during wood combustion.

The potassium content of the wood ash used in the experiment is equivalent to 653 kg of K_2O active substance per hectare. The AL-soluble K_2O content compared to the value of 301 mg/kg of the control increased up to 792 mg/kg, in the case of the highest dose in the 0-10 cm layer, so the potassium content of the originally well-supplied soil showed a further increase (limit value: 301–500 mg/kg).

The amount of phosphorus applied together with wood ash is equivalent to 85 kg P_2O_5 of active substance per hectare. The treatment caused a change in the P_2O_5 content from the value of 760 mg/kg to 1144 mg/kg in the 0–10 cm layer, thus the amount of phosphorus continued to increase in the especially well-supplied soil (limit value: 161–360).

The dosage of 10 t/ha enhanced the sulphate content of the top layer; its value changed to 35.6 mg/kg from the control's 11.9 value.

As a result of the ash treatment, the amount of magnesium in the soil with optimum magnesium supply (limit value: 100 <) increased to 398 mg/kg, from the initial 141 mg/kg (Buzás 1983). The EDTA-soluble zinc content of the control soil changed from the value of 5.3 mg/kg to 10.5 mg/kg after the wood ash treatment. In the case of copper and manganese no increase in concentration could be detected, while the amount of AL-soluble sodium content significantly rose after the wood ash treatment, reaching the value of 127 mg/kg, compared to the 36.0 mg/kg of the control. As to heavy metals, an increase in the amount of cadmium could be detected, with a change from 0.3 mg/kg to 0.5 mg/kg in the soil *(Table 4)*.

Table 4. Effects of the wood ash treatment on the lime-, nutrient- and heavy metal-content in average soil samples

Parameters	Units	Doses of ash (t/ha)				
		0	1	2.5	5	10
$CaCO_3$	% w/w	0.0	0.0	0.3	0.3	0.8
$NO_3^-+NO_2^-$-N	mg/kg	8.2	8.4	11.6	11.6	11.6
P_2O_5	mg/kg	760	888	906	999	1144
K_2O	mg/kg	301	383	468	579	792
Na	mg/kg	36.0	56.0	71.0	95.0	127
Mg	mg/kg	141	148	237	305	398
SO_4^{2-}-S	mg/kg	11.9	13.4	19.7	22.6	35.6
Ca	mg/kg d.m.	4648	5115	6187	6696	7435
Cd	mg/kg d.m.	0.3	0.4	0.4	0.5	0.5
Cr	mg/kg d.m.	37.2	38.5	38.2	38.2	40.1
Cu	mg/kg d.m.	21.5	22.5	22.8	23.3	23.3
Hg	mg/kg d.m.	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
Ni	mg/kg d.m.	25.7	27.1	26.5	25.8	27.3
Pb	mg/kg d.m.	28.9	30.4	30.7	30.8	31.8
Zn	mg/kg d.m.	82.7	87.5	89.0	90.6	93.3

The particulate content of white mustard test plants did not change significantly, which proves that the amount of nutrients in the untreated soil was initially suitable for the development of the plants. The amount of heavy metals in test plants did not change following the treatment *(Table 5)*.

Table 5. Effects of the wood ash treatment on the average element content of the white mustard test plants.

Parameters	Units	Doses of ash (t/ha)				
		0	1	2.5	5	10
N	% w/w d.m.	2.6	1.9	2.3	1.6	1.5
P	% w/w d.m.	0.3	0.2	0.3	0.2	0.2
K	% w/w d.m.	2.1	2.1	2.0	1.9	1.6
S	% w/w d.m.	0.9	0.8	1.0	0.6	0.5
Cd	mg/kg d.m.	0.2	0.4	0.3	0.2	0.2
Cr	mg/kg d.m.	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
Cu	mg/kg d.m.	3.4	2.7	2.7	2.0	2.1
Hg	mg/kg d.m.	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Ni	mg/kg d.m.	< 7.5	< 7.5	< 7.5	< 7.5	< 7.5
Pb	mg/kg d.m.	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0
Zn	mg/kg d.m.	31.8	36.1	34.1	24.9	21.0

4 EVALUATION OF RESULTS AND CONCLUSION

During our research we examined the properties and chemical composition of wood ash. We studied its effect on the chemical condition and nutrient supplying properties of soil. Using white mustard and perennial ryegrass as test plants, we examined the effect of wood ash on the growth of test plants.

The laboratory tests revealed that wood ash has fairly high potassium, phosphorus and magnesium content, and its pH is highly alkaline. With one exception, the toxic heavy metal content of wood ash did not exceed the average values cited in literature (Etiégni – Campbell 1991). Wood ash has apparent effects on the soil. In the case of both test plants the dose of 10 t/ha raised the soil pH by approximately 1 unit. Regarding the nutrients, the nitrogen content of the soil did not change; however its potassium, phosphorus, sulphur, magnesium, calcium and zinc content increased following the ash treatment, as well as the lime content of the lime deficient soil. Among heavy metals, a slight increase in the cadmium amount could be detected, while the raised sodium content of the soil calls for further research.

The raised Na-content is unfavourable for cultivated plants, and its value exceeding 60 mg/kg is a sign of unfavourable salinization.

The treatment did not cause any statistically verifiable differences in the number of shoots and stocks or in the height and in the green mass of the test plants. Despite the fact that the above-ground organic matter grown on the different plots could not be detected with 95% level of significance, their amount increased by 3–8%, which means the plants were able to produce a greater amount of organic material from the excess amount of nutrients during a representative period of time. The plants experienced no toxic effects even with a maximum amount of ash-dose applied. The nutrient supply enhanced by the wood ash treatment was not reflected in the nutrient content of the plants. The test plants must have had an optimum nutrient supply at the time of the control, which would explain why the treatments did not cause significant differences. No significant change could be detected in the heavy metal content of the plants as a result of the wood-ash treatment.

Based on the conducted trials it can be stated that wood ash can effectively be used for agricultural purposes of amelioration of acidic soils instead of liming in order to reduce the acidification of soils with characteristics similar to those examined in the experiment. The experiments have proved that wood ash can successfully be used for purposes of nutrient supply. The ash must be applied and evenly mixed with the upper level of the soil before sowing; the recommended wood ash dose is 1 to 5 t/ha. With higher doses the P_2O_5 and K_2O-values measured in the soil would exceed the optimum values, which would cause the applied nutrients to be washed out of the topsoil in default of the needed colloid-content. In nitrogen-deficient soils, it is recommended to combine the application of wood-ash with N-fertilization.

Moreover, the agricultural application of wood ash has significant economic importance too. Application of ash on arable lands may lower the expenses of landfilling ash as waste. Utilization of wood ash, which is available in huge amounts, may partially replace expensive soil conditioners and fertilizers.

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