

# Leachates from wood ash – environmental effects of storage on soil

*Inger Valeur<sup>1</sup> & Gunnar Thelin<sup>2</sup>*

<sup>1</sup>PhD systemekologi, [inger.valeur@ekobalans.se](mailto:inger.valeur@ekobalans.se)

<sup>2</sup>PhD Plant ecology, [gunnar.thelin@ekobalans.se](mailto:gunnar.thelin@ekobalans.se)

**Abstract** – In general three leaching patterns were observed when monitoring leachate from wood ash stored for six months in a pile in an outdoor environment. The leaching of the first group of substances K, Ca, Mg, B, Cr, V, Cd and Ba, was highly affected by weather conditions and with a few exceptions, their contents in leachate remained below limits for drinking water. The second group Pb and Hg, were hardly detectable in the leachates, whereas leached amounts in the third group Zn, Cu, Ni and Co, actually was found to be higher in control than in the ash treatments. In upper part of the soil, 5-15 cm, underneath former ash piles, a low but significantly higher content of K was found. No other changes in amounts of substances could be seen as an effect on soil from full scale wood ash storages. Results indicate a low environmental impact on soil from storage of wood ash.

*Keywords: wood ash; leaching; storage; soil; transports*

## INTRODUCTION

In this study we monitored leachate from wood ash stored in a pile in an outdoor environment during six months. Our aim was to contribute with knowledge about leaching behavior and risks connected to storages of wood ash, and more generally leaching from piles affected by various weather conditions. Impacts on soil from storage of wood ash was also included in the study as well as different transport scenarios for recycling wood ash to the forest.

Bio-energy output from Swedish forests has more than doubled the last 10 years [7] [8] and as nutrient rich parts as needles and branches (grot) is also taken out, the nutrient export from the forest site has increased by a factor of three to five [9][10][11]. To counteract depletion of nutrients in forest soils, wood ash is returned to the forest. Apart from nitrogen, wood ash contains all the nutrients and trace elements that were in the wood before combustion. The ash must be hardened before spreading to make it less reactive. The ash self hardens when stored in an outdoor environment for 3-6 months and according to the waste act this should be done on a paved area. However, wood ash which is meant to be recycled to the forest has naturally very low amounts of polluting elements and shall also fulfill limit values, set up by the Swedish Forest Agency [2]. As it is so that the storage is during a limited period of time and the ash shall be transported, not only to one place but too several smaller areas, this has given rise to the thoughts of storing the ash closer to the spreading area. However, the ash would then probably be stored in a non-paved area, as the number of paved areas in forests is scarce. If storage close to the spreading area could be done, the distance for transports connected to recycling the ash would presumably be decrease by a factor of two or three.

To get permission to store ash on a non paved area, there must be enough data available which can ensure that there are no environmental risks associated to the storage. Most risk assessments are based upon addition of excess water to the ash. Thus it is difficult, or not yet shown, how a figure given from an extraction with excess water should be translated to the total amount of leached elements from ash storages [12][13]. Collecting leachates from landfills where ash is stored also has its problems, as it often is contaminated with elements from other wastes being stored at the landfill.

## METHOD

### Leaching experiment

The leaching experiment construction had three troughs/trays covered by a chemically inert titanoxid coating, Topsafe Icopal Noxite. In the troughs one pile of 200 kg (fw) fresh ash and one pile of hardened ash was placed and in the last one no ash was added at all and thus used as control (Fig 1). There were no replicates of the treatments. Both ashes originated from the same power plant Halmstad Energi, and had a metal content below the recommended limits for recycling [1]. Water was added so that both ashes had the same water content of 31,7 % at the experimental start. The hardened ash had self hardened during one year and was crushed and sieved before experimental start it. The troughs had a slope of 5 degrees and underneath the end of the slope the leachate water was collected in bath tubes. There were 13 samplings occasions during the experimental period 2011-04-02 to 2011-08-31 in total 152 days.



Figure 1. Experimental setup at start of 2011-04-02. b) Fresh ash at end of experiment 2011-08-31

### Soil sampling

Five soil samples were taken from the soil underneath the former ash pile and five samples 10 meter outside the former pile. This was done at two soil depths 5-15 cm and 20 -30 cm, with a total of 10 samples per storage area. The samples were pooled together by layer and "treatment" under and outside the former ash pile. This was done at five storage areas, whereas the soil samples from the sixth area, Kagghamra, were kept separate, to get the within area variation.

### Analyses

Fresh, mineral soil samples, were sieved through an 2 mm mesh and thereafter extracted with EDTA 0,02 M och  $\text{BaCl}_2$  0,1 M. EDTA as described by Lakanen & Erviö (1971) [1] fresh sample equivalent to 20g dry weight was shaken in a reciprocal shaker for 1 hour with 100 ml EDTA pH 4,65 L/S quota 5.

Leachates from the troughs with ashes were analyzed for: pH, konduktivitet Ca, Mg, K, B, Ba, Cu, Zn, As, Pb, Cd, Cr, Hg, Ni, V.

Analyses of water samples were done without an acid digestion pretreatment. Watersamples and extracts (EDTA and  $\text{BaCl}_2$ ) was acified with 1 ml nitric acid (suprapur) per 100 ml before analyses with 200.7 (ICP-AES) for Ca, Mg, K, B, Ba och 200.8 (ICP-SFMS) för Cu, Zn, As, Pb, Cd, Cr, Ni, V. Analyses of Hg with AFS according to SS-EN ISO 17852:2008.

### Statistics

Differences in contents of substances in EDTA- och  $\text{BaCl}_2$  extract of soil between soil samples from outside the former ash pile and samples from under the former pile were tested with a paired T-test. Values from mixed samples; 5 sample spots from each depth and treatment (treatment= soil where ash has been stored and soil outside where no ash has been stored). Soil samples from Kagghamra

were not mixed before statistical test, where an unpaired T-test  $n=5$  was used. The outdoor leaching experiment had no replicates and statistic calculations were not performed on the dataset.

## RESULT AND DISCUSSION

### Evaporation rates

The total amounts of leachate collected from troughs with ash and from the control trough, were clearly different (Fig 2a). The control trough gave all together 271 and 214 liters more leachate than the troughs with fresh ash and hardened ash, respectively. The total amounts leached were 1247.5, 1307 and 1521 liters for fresh ash, hardened ash and control, respectively. This is likely to be an effect of higher evaporation rate from the ash piles which had a larger total surface area than the flat control trough. The ash piles dark and water adsorbing ash surface was also very likely to have contributed to the higher evaporation rate. This effect should be expressed the most when the weather alternates between intense sun and periods with not to heavy rain falls. The total amounts of leached substances will therefore, in the same proportion as for the less volume leached, become reduced whenever the evaporation is increased.

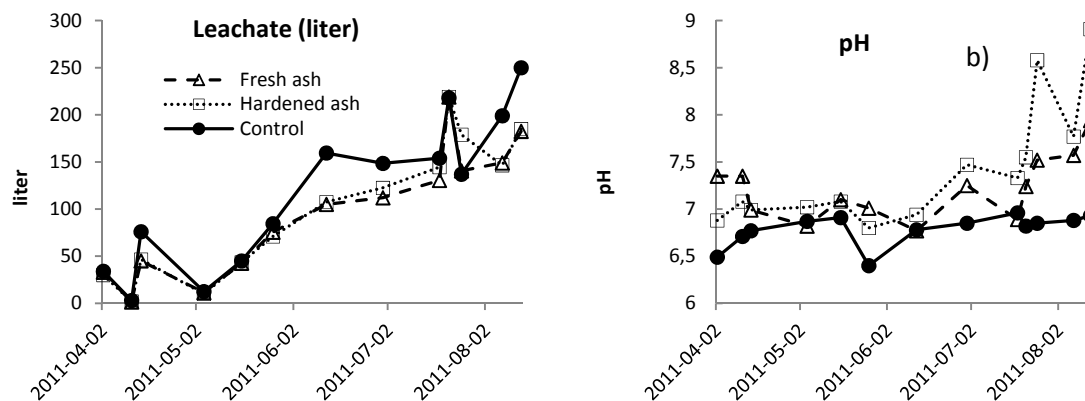


Figure 2. a) Amount (L) of leachate; b) pH in leachates collected from ash leaching study during 2011-04-02 to 2011-08-31. Statistics  $n=1$ .

### Leaching affected by weather conditions

Three general leaching patterns was observed for substances leached in this study. Where the first group of substances, calcium (Ca), magnesium (Mg), potassium (K), boron (B), chromium (Cr), vanadium (V), cadmium (Cd) and barium (Ba) had higher contents in leachates from the two trays with ash compared to the control (Fig 3 and 4; Table 1), however the contents were much lower or lower than the limits for drinking water set up buy the Swedish National Food Agency [3]. The elements in this group either occurs in high amounts in the ash or is easily leached or both and are thus the ones that have the most potential to be affected by the weather conditions.

Initially all substances in this group had temporary higher content in leachate the two first sampling events, followed by two months with low (K, B, Cr, V) or fairly low (Ca, Mg) contents. During this period control and the two leachates from the ashes were hardly separated in any of the substances in this first group. After this point, two to three months from start, conductivity in leachate water increased, which probable was due to an increase leaching of potassium. All other substances in this group followed this leaching pattern for potassium, more (Cr, B) or less (As, V, Ca, Mg) (Fig 3 and 4). The pH in the leachate from the troughs with ash is surprisingly low and near neutral until the last months of the experiment where the other substances in this group also peaks (Fig 1b and 2).

A leaching pattern like this could possibly have to do with formation and dissolution of a protecting salt crust on the ash piles surface. A light grey crust was observed on the ash surface some time after experimental start, probably made up by crystallized salts as KCl and other precipitates being more or

less stable [4][5]. At the end of the experimental time there was a period with more intense and heavy rain falls which could have cause the easily leached salts to dissolve and furthermore, earlier unexposed less stable ash made available for leaching.

Leaching of substances from ash is known to be highly influenced by three factors 1) the ingoing substances in the ash; 2) pH; 3) accessibility of substances. However, as rain and sun comes and goes the water content on the ash piles surface must be highly variable over time as well as the spatial distribution. Along with the water content the two factors, pH and accessibility, also changes and the degree of complexity increase by the ongoing hardening process of the ash. Thus, to specifically find out which reactions and to what extent they occur, it requires more ingoing studies. However, as an example of possible reactions; the formation of ettringit ( $\text{Ca}_6\text{Al}_2(\text{SO}_4^{2-})_3(\text{OH})_{12} \cdot 26(\text{H}_2\text{O})$ ) is known to be able to control  $\text{Ca}^{2+}$  dissolution at pH 10-12 and it could also enclose  $\text{K}^+$  when formed which then is leached out when dissolved [4][5].

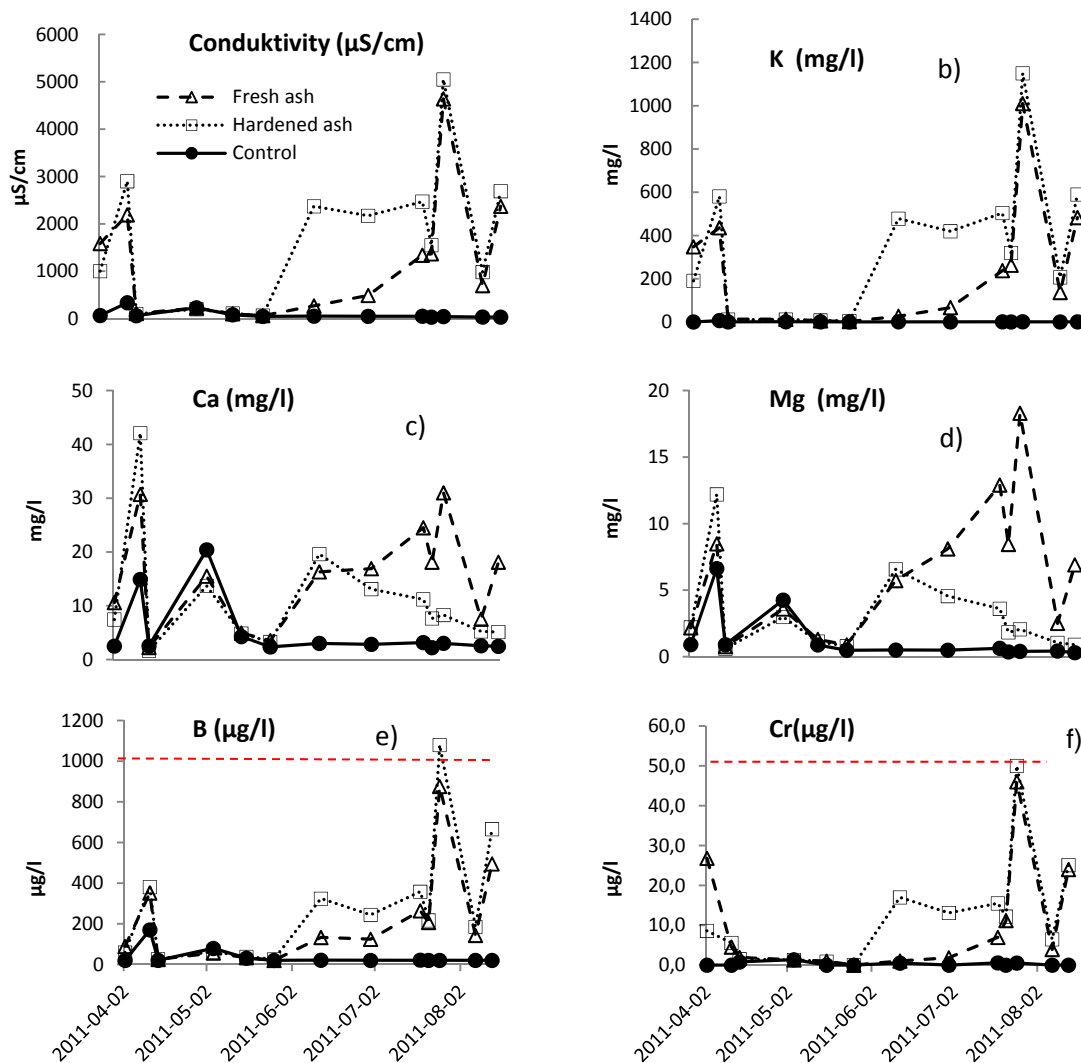


Figure 3. a) Conductivity (mS/m); b-d) Contents of K, Ca, Mg (mg/l) in leachates; e-f contents (µg/l) of B and Cr in leachates from wood ash leaching experiment. Dotted line = limit value for drinking water. Statistics n=1.

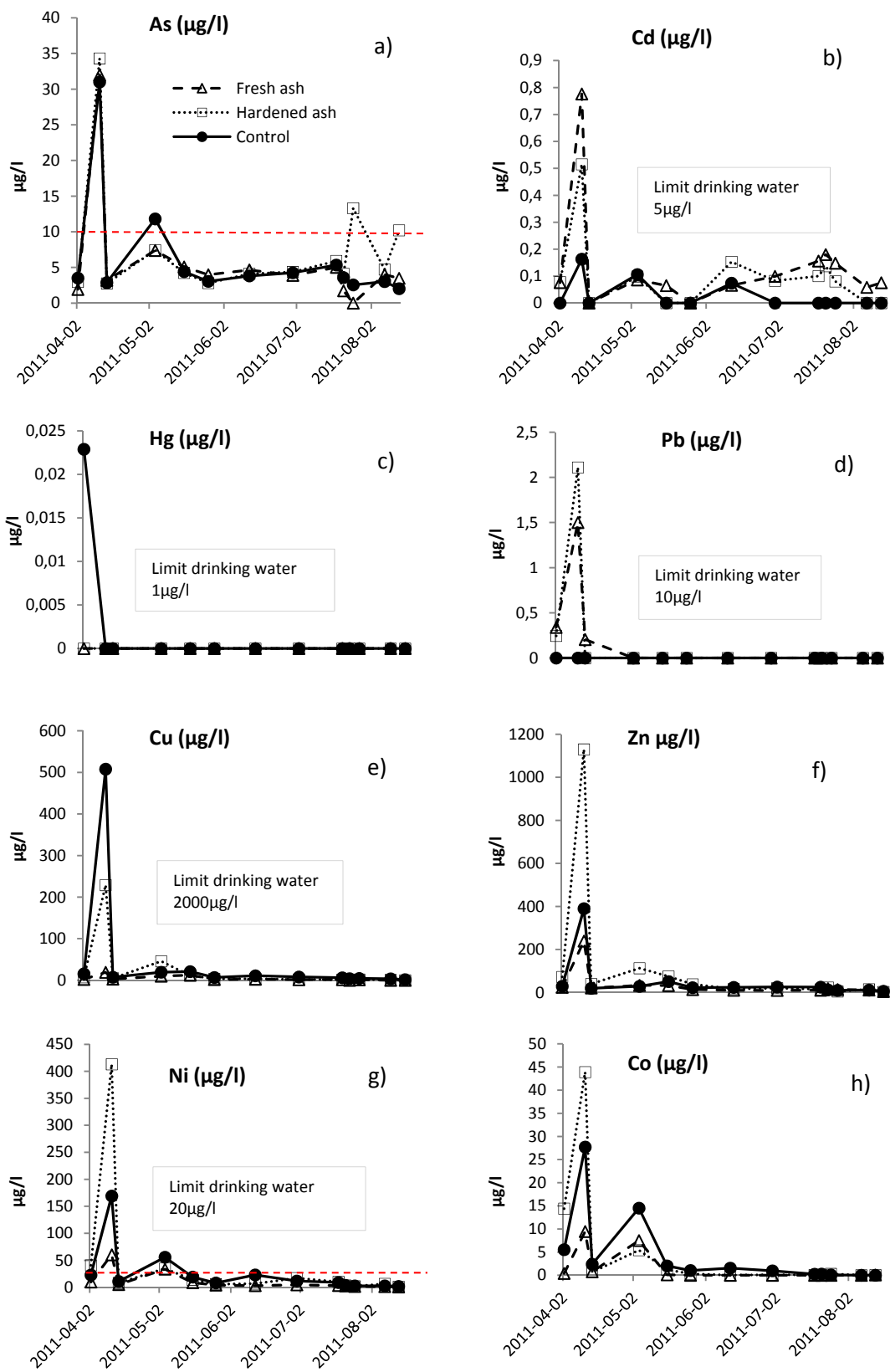


Figure 4. Amounts ( $\mu\text{g/l}$ ) of As, Cd, Hg, Pb, Cu, Zn, Ni and Co in leachate collected from ash leaching study during 2011-04-02. Dotted line = limit drinking water. Statistics  $n=1$

### Leaching hardly detectable for Pb and Hg

At the first leaching collection there were small amounts of Pb and Hg detectable, in the two ash treatments for Pb and only in the control treatment for Hg. Except for this first collecting event, there were no detectable amounts of these two metals (Fig 3). Both Hg and Pb is known to be strongly bound when pH is high and other studies of leaching from wood ash have also shown very low leaching of these two substances [6].

### Leached amounts of Zn, Cu, Ni, Co highest in the control

For all elements in this group there were a peak in their contents at the second collecting event for the leachates (Fig 3). For Ni it was actually high above the limit for drinking water but this was also found for the control. The total amounts leached were actually sometimes higher in the control compared to the ash treatments (Table 1) (Co mg 0,21; 0,79 and 1,32 for fresh ash, hardened ash and control, respectively).

Amounts of phosphor (P) in leachates did not differ between control and the two ashes, but as the leachate, unfortunately, was contaminated with P by an unknown source giving unreasonably high values data is not shown.

Table 1. Total leaching (mg) from piles of hardened and fresh ash and the leached amounts as shares (%) of total amounts at the beginning of the experiment. n=1

	Fresh ash		Hardened ash		Control
	leached (mg)	share (%)	leached (mg)	share (%)	leached (mg)
Calcium (Ca)	20697	0,21	11162,7	0,08	4378,1
Magnesium (Mg)	9523	0,56	3122,2	0,15	789,7
Potassium (K)	362844	5,89	599280,3	9,51	1730,3
Bor (B)	350,5	1,95	515,4	2,47	32,4
Copper (Cu)	2,3	0,02	3,9	0,03	10,8
Zinc (Zn)	17,3	0,01	28,7	0,02	27,7
Arsenic (As)	4,2	0,30	8,4	0,84	5,3
Led (Pb)	0	<0,02	0	<0,02	0
Cadmium (Cd)	0,1	0,01	0,1	0,01	0,1
Mercury (Hg)	0	<0,02	0	<0,02	0
Chrome (Cr)	16,2	0,25	23,3	0,27	0,8
Nickel (Ni)	4,1	0,20	10,3	0,52	13,1
Vanadium (V)	8,8	0,14	25,3	0,53	3,5

### Full size wood ash storage and effects on soil

There was relatively high potassium leaching found for the ashes in the leaching experiment (Fig 2a), however, the highest conductivity values were far below what is found for example in sea water. There was, however, a significantly higher potassium content in the upper soil horizon, 5-15 cm (EDTA extraction), in the soil where the former ash storages had been placed compared to the control when tested with *Paired T-test*, including 6 abandoned full scale ash storages; Control mean 0,158 (stdev 0,240); Ash 1,397 (1,308 ) p-value=0,04.

In between the six storages in the study, the variation in K, Ca and Mg increase was large, and for e.g. Vrå accounted for by far the greatest K increase (Fig 5), whereas Kagghamra actually had no significance for higher K values; T-test p= 0,289. The increase of K in Vrå was great as the soil had low K levels previous to the ash storage; control 0,002 (mg/g dw), whereas the soil underneath the former ash pile had a mean value of 0,33. Even though the increase was about 170 times in Vrå the K content was still not high in the soil where ash had been stored. Figure 5 illustrates the variation between the six storages and to make any risk assessments the actual contents in the soil must also be considered. An eventually increase of K in the soil after an ash storage depends on many factors as the content of K in the stored ash, amounts of K from start, the soils ability to retain cations and amounts of precipitation.

There were indications for a cat-ions exchange in the soil underneath the former ash pile. The K- ions leached from the ash in to the upper soil horizon, could probably been exchanged for cat-ions in the soil. The cat-ions that originally came from the soils upper horizon were then later adsorbed in the lower soil horizon. In the upper soil horizon, 5-15 cm, there were significantly lower contents of Ni and Cd and Zn (nearly significant) in soil underneath the former ash pile;  $p= 0,02, 0,01$  and  $0,07$  , respectively (Table 2). This was seen in the  $BaCl_2$  extraction and for Ni also in the EDTA extraction. In the soil horizon underneath, contrary, there were significance for higher contents of Cd and Zn in the soil under the former ash pile;  $p= 0,02$  and  $0,04$ , respectively. No other changes in amounts of substances could be seen as an effect on soil from wood ash storages (Table 2).

*Table 2. Mean values in soil (mg/g dry weight), sampled from six abandoned storage areas (not paved) of wood ash. Control=outside the former ash pile. Ash= samples from below the former ash pile. Soils extractions = EDTA or  $BaCl_2$  (substances not shown=not detectable values). Mean values and standard deviation values are given. Soil depth 5-15 cm,  $n= 6$ ; Soil depth 20-30 cm  $n=5$ .  $p= p$ -value Parad t-test, stars gives possible statistical certainty of difference between ash- and control spots, \* =  $p<0.05$ , \*\* =  $p<0.01$ ,sf= level of significance.*

EDTA extraction mg/g dw												
5-15 cm							20-30 cm					
	Control	stdev	Ash	stdev	p	sf	Control	stdev	Ash	stdav	p	sf
Ca	3,794	8,995	0,739	1,339	1,34		0,315	0,587	0,420	0,458	0,30	
Mg	0,016	0,022	0,023	0,012	0,38		0,005	0,005	0,021	0,013	0,06	
K	0,158	0,240	1,397	1,308	0,04	*	0,020	0,025	0,678	0,597	0,07	
$\mu\text{g/gdw}$												
As	0,033	0,064	0,016	0,033	0,24		0,001	0,002	0,027	0,051	0,30	
B	0,007	0,017	0,180	0,369	0,31		0,000	0,000	0,075	0,074	0,09	
Ba	5,673	7,997	4,570	2,836	0,72		2,912	1,860	4,081	2,205	0,34	
Cd	0,033	0,016	0,028	0,025	0,68		0,012	0,006	0,018	0,009	0,02	*
Co	0,130	0,129	0,285	0,430	0,28		0,083	0,075	0,130	0,103	0,40	
Cr	0,148	0,079	0,360	0,540	0,35		0,041	0,018	0,143	0,174	0,29	
Cu	0,541	0,410	1,099	1,265	0,20		0,302	0,338	0,817	0,900	0,12	
Ni	0,122	0,049	0,175	0,233	0,58		0,041	0,024	0,087	0,062	0,99	
Pb	2,877	1,639	2,626	3,631	0,82		0,664	0,223	1,051	0,773	0,23	
V	0,216	0,178	0,373	0,442	0,23		0,152	0,162	0,268	0,257	0,11	
Zn	1,750	1,459	3,090	2,947	0,34		0,430	0,249	1,836	1,285	0,04	*
$BaCl_2$ extraction mg/g dw												
5-15 cm							20-30 cm					
Ca	0,290	0,393	0,193	0,091	0,48		0,189	0,237	0,156	0,070	0,752	
Mg	0,006	0,010	0,008	0,013	0,45		0,006	0,013	0,009	0,012	0,777	
K	0,155	0,232	1,434	1,212	0,03	*	0,000	0,000	0,677	0,620	0,059	
$\mu\text{g/g dw}$												
Cd	0,020	0,015	0,004	0,004	0,02	*	0,009	0,007	0,004	0,004	0,166	
Co	0,019	0,012	0,010	0,008	0,15		0,014	0,007	0,007	0,006	0,198	
Ni	0,118	0,051	0,044	0,054	0,01	**	0,109	0,041	0,047	0,057	0,03	*
Pb	0,223	0,216	0,017	0,026	0,07		0,067	0,057	0,016	0,028	0,09	
Zn	0,496	0,436	0,104	0,194	0,07		0,292	0,332	0,064	0,094	0,20	

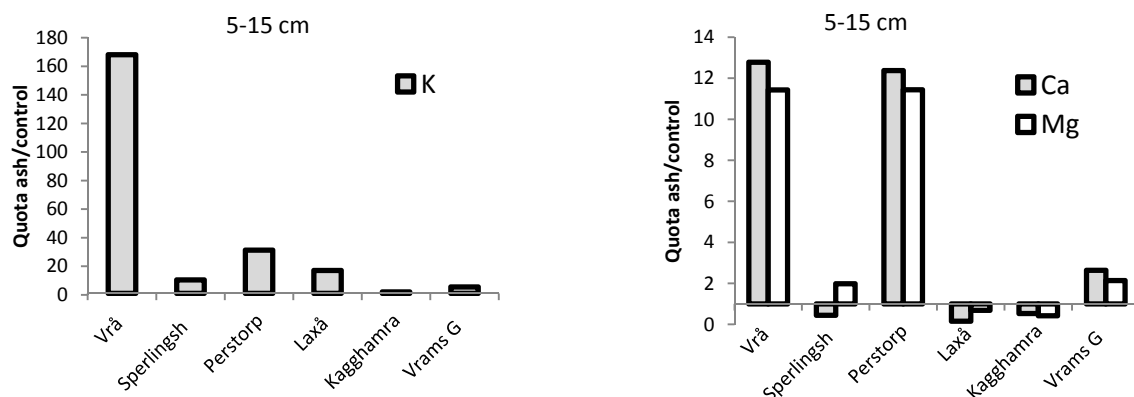


Figure 5. Difference between K, Ca and Mg in control and ash soil, calculated separately for every storage area by a quota between contents in soil for ash/control. Values > 1 = contents higher in ash soil than control. EDTA extraction, soil depth 5-15 cm. Control soil=samples outside ash pile. Ash soil= samples from beneath the former ash pile.

### Less transports when given possibilities to store ash closer to the spreading area

Calculations were made for advantages from the possibility to use unpaved areas for wood ash storage, which would then allow, storage closer to the spreading area. Data on transports connected to handling of wood ash storage (> 250 ton) and spreading was given from Askungen Vital AB during 2010-2011. During this time, the ash was stored pending for spreading at 16 different storages, whereof three close to the spreading area. The ash originated from 30 different ash producers.

In total, the use of unpaved areas close to the spreading area, for storage of wood ash decreased the total distance for transports with 661 km, and gave costs reduction of 807 000 SEK (90 000 €), according to calculations in this example. In 1 out of 19 cases, the cost reduction was greater than the evaluated cost increases due to application for a permit from local authorities as the county which can vary a lot, 5 000-20 000 SEK (550-2242 €). For the calculations a mean of 40 000 SEK was used.

The greatest cost and transport reduction was found for long distances and larger amounts of ash. However, it also seemed to be advantageous having the storage closer to the spreading area, even when handling comparatively small amounts of ash. Here the environmentally benefits in reduced transports is clear but if there is an economically benefit for the ash spreading company is, though, highly influenced by the costs for permit as mentioned above. The complexity in the system increase with the numbers of storages which requires time to administrate and furthermore the possibilities for synergies and flexibility might decrease. Taken all together, a combination of permanent paved storages and smaller unpaved non permanent storages areas for wood ash should be the most favorable for the environment and the economy.

### Conclusions

Results in this study indicate a low environmental impact on soil from storage of wood ash. It was found that substances being relatively mobile or occurring in large amounts, leached out from the wood ash, whereas less mobile substances Zn Cu, Ni and Co leached out to a very low degree or in the same amount as in the control; and/or were not detectable as for Pb, Hg. Other potentially hazardous substances as B, Cr, V, Cd, As had contents in the leachates that was very low and below the limit for drinking water. The soil below six former full sized wood ash storages had an overall low content of all substances in the soil outside as well as in the soil underneath the former ash piles. However the K content in soil below the former ash pile was significantly higher, and this cat-ion increase might have caused, together with other cat-ion surplus from the ash (Ca, Mg) a cat-ion exchange with ions in the upper soil horizon. Apart from this, there was no significance for any changes in contents of substances in the soil where wood ash had been stored. According to this data, there should be low environmental risk to store wood ash on an area that is not paved.

Even though the leachate experiment in this study points towards low risks with wood ash storages, a very much smaller ash pile was used in this study in comparison to an in practice full scale storage, which is inevitably a draw back when it comes to assessments of environmental risks. We could assume that the amount of water reaching the ash pile by rain will increase in the same proportion as the size increase of the pile, so that amounts in leachate becomes more or less the same regardless of the size of the pile. However, many other factors could also influence the leaching when up scaled, such as the height, heterogeneity, diffusion rates, so mechanisms behind up scaling should really be looked at more closely.

Anyway, there is no doubt about that a possibility to store wood ash close to the spreading area will save the environment a lot of transports. Taken all together, the assessment is that a combination of permanent paved storages and smaller storages areas close to the spreading area (paved or not paved) should be the most favorable for environment and economy.

## REFERENCES

- [1] Lakanen, E. and R. Ervio. A comparison of eight extractants for the determination of plant available micronutrients in soils. *Acta Agraria Fennica* 123/1971. p. 223-232.
- [2] Anderson, S., Rekommendationer vid uttag av avverkningsrester och askåterföring. Skogsstyrelsen Meddelande 2/2008. Jönköping 2008.
- [3] Livsmedelsverkets föreskrifter om dricksvatten. SLVFS 2001:30
- [4] von Brömssen, M., Lindström, N., Hedman, K. Svensson, M.; Flygaskors egenskaper i våt miljö. Värmeforsk Rapport 1104, Stockholm, 2009
- [5] Fjällberg L., Lagerblad B., Moosberg B., Bjurström H., Styrtd utlakning ur bioaska som sprids i skogsmark. Värmeforsk Rapport 940, Stockholm, 2005.
- [6] Yamauchi S., • Saitoh K., • Sera K., Wada Y., Kuwahara M.; Multielement analysis using PIXE for beneficial use of ashes from a biomass power plant. *J Wood Sci* 54/2008 p.162–168
- [7] Skogsstatistisk årsbok.; Skogsstyrelsen, Jönköping, 2010
- [8] Skogsstyrelsens årsredovisning.; Skogsstyrelsen, Jönköping, 2010
- [9] Akselsson, C., Westling, O., Sverdrup, H., Holmqvist, J., Thelin, G., Ugglå, E. and Malm, G.; Impact of harvest intensity on long-term base cation budgets in Swedish forest soils. *Water, Air, and Soil Pollution: Focus* 7/2007 p. 201-210.
- [10] Akselsson, C., Westling, O., Alveteg, M., Thelin, G., Fransson, A-M. and Hellsten, S.; The influence of N load and harvest intensity on the risk of P limitation in Swedish forest soils. *Science of the Total Environment*. 404/2008, s. 284-289.
- [11] Akselsson, C. & Westling, O.; Regionalized nitrogen budgets in forest soils for different deposition and forestry scenarios in Sweden. *Global Ecology and Biogeography* 14/ 2005, s. 85-95.
- [12] Berggren Kleja, D.; Metaller's mobilitet i mark  
<http://www.naturvardsverket.se/Documents/publikationer/620-5536-4.pdf>, Naturvårdsverket, Stockholm, 2006
- [13] Westling O., Larsson P.E.; Översättning av resultat från asklakningsförsök I laboratorium till fältförhållanden. Svenska Miljöinstitutet, Rapport B1660, Göteborg, 2006