Quality requirements for wood ash as K component in recycled NPK fertilizers

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Abstract – Bottom ash originating from stem wood often have sufficient low level of heavy metals to be used as fertilizers or liming material in agriculture. The optimal composition of bottom wood ash (BWA) is a high concentration of K and a relative low concentration of Ca. For use in a NPK mixture, annual effect on soil pH should not be larger than neutralizing the normal acidification of agricultural soils. A liming effect of 200–300 kg CaO equiv ha^{-1} will be suitable for a fertilizer that is to be used annually for cereals in Norway. In pot experiments application of BWA together with mineral N showed that BWA released both plant available P and K, but had no effect on crop growth applied without nitrogen supply.

Keywords: Bottom wood ash, fertilizer, heavy metals, liming,

INTRODUCTION

In Norway grate furnace is the most common technology in bio energy plants, giving the largest volumes of ash as bottom wood ash (BWA) and a relatively small volume as fly wood ash (FWA). Norwegian bio energy plants usually collect bottom and fly ash together in one container. Such ash is normally only suitable for deposition in landfilles due to high concentrations of heavy metals and black colour caused by some residual organic C (TOC). As some heavy metals are known to be concentrated in fly ash [1], like cadmium and zinc, a study of chemical properties of bottom and blended ash from different Norwegian bio energy plants was performed. The aim of the investigation was to determine if collection of BWA and FWA separately could decrease the level of cadmium and zinc to a level acceptable for use in organic fertilizers or soil amendments. Some of the bio energy plants used only stem wood chips, other chips of whole trees, and some chips of stem wood and branches. BWA which had sufficient low concentrations of heavy metals to be used as components in organic fertilizers in Norway was selected for use in pot experiments for evaluation of release of plant nutrients.

MATERIAL AND METHODS

Material

Ash was sampled from different bio energy plants operated by Akershus Energi AS in 2011. It was intended to sample BWA, FWA and blended ash from all plants, but due to technical problems only BWA and blended ash could be sampled. At the Årnes plant stem wood (Mjøsen) and cereal waste was burned. At the other plants stem wood (Viken), periodically combined with chips of tops and branches (GROT) from Viken were used. The properties of these samples can be compared with BWA analyzed previously [2]. Ash from the Årnes plant was selected for use in pot experiments.

A two year pot experiment was established in a greenhouse, using sand with very low content of readily available P and K as growth medium (AL extractable). Spring barley and spring wheat were grown the first and the second year respectively. The following treatments were applied at 80 and 160 kg N ha^{-1} each year: meat and bone meal (MBM Mosvik), meat and bone meal (MBM Hamar), composted catering waste (CCW), composted fish manure (CFM), and calcium nitrate, with or without addition of bottom wood ash from Årnes (BWA). BWA was applied at 35 kg K ha^{-1} at 80 kg N ha^{-1} and 70 kg K ha^{-1} at 16 kg N ha^{-1}. A treatment without any fertilizer was used as reference. The pots in the barley experiment were given a surplus irrigation of 28 mm that should cause leaching at Zadoks 14, while the moisture in the wheat experiment was kept on an optimal level during the whole experimental period.

A one year pot experiment with Italian ryegrass (*Lolium multiflorum* var. *italicum* cv. Macho) was carried out outdoor under a roof using various waste resources as fertilizer: Mixtures of different N-rich waste and K-rich bottom wood ash were compared with the fertilisation effects of calcium nitrate (minN), bottom wood ash (BWA) and an unfertilised control. The fertilization levels were set to 150 kg N ha^{-1} (120 kg K ha^{-1} in BWA) and 300 kg N ha^{-1} (240 kg K ha^{-1} in BWA). The different waste resources are briefly described in Table 1. The soil used was a sandy loam of morainic origin (17 % clay), which was sieved using a 4 mm mesh to sort out the gravel. TOC of the soil was 3.2 g/100 g, pH (H_2O) was 6.5, and the level of P (AL-extractable) was <3 mg/100 g.

There were three replicate pots per treatment in both experiments.

Table 1: Description of the waste resources used in pot experiment with ryegrass.

Waste resource	Short name	Nutrient	Description
Bottom wood ash	BWA	K	Biomass ash originating from a grate fired boiler system of the company Akershus Energi AS, located in Årnes (63°96'N,10°23'E), Norway. Parent material consists of timber being unfeasible for industrial use and residues from the local mill - both sources being clean for or having low contents of heavy metals.
Meat and bone meal	MBM	N and P	Stabilised, sanitised and pelletized meat and bone meal originating from the slaughterhouse in Mosvik (63°82'N,11°01'E), Norway.
Composted fish sludge	CFS	N and P	Composted sediments (feed residues and excrements) from a flow-through hatchery of the company Åsen settefisk AS (63°61'N,11°05'E) in Trøndelag, Norway. The sludge is composted by reactor physiology of the company Global Enviro International AS.
Neutral Dynea compost	Dynea 2009	N	Parent material is a mixture of wood chips and N-rich by-products resulting from chemical industry activities of the international company Dynea ASA, which is located in Lillestrøm (59°96'N,11°05'E), Norway. The material was composted in windrows outside.
Acid Dynea compost	Dynea 2004	N	Same parent material as Dynea 2009. During storage of the waste resource an acidification process is happening: Polymers of formaldehyde are breaking down to formic acid, which gradually lowers the pH in the material to around 3.5.

Methods

The total contents of P, Ca, Mg, K, S and trace elements (Cd, Cr, Cu, Hg, Ni, Pb, Zn) in ash samples were determined after dissolution with nitric acid (7 M HNO_3) according to the Norwegian standard 4770 by simultaneous ICP-AES according to ISO 11885. Readily available P (P-AL), K (K-AL), Mg (Mg-AL) and Ca (Ca-AL) in soil were determined on ICP-AES after extraction with a solution composed of 0.4 M acetic acid and 0.1 M ammonium lactate (pH 3.75) in a solid-to-solution ratio of 1:20 (w/v) [3]. pH (H_2O) in soil was determined in a soil-water suspension (1:2.5).

Analysis of variance (ANOVA) was performed with ash supply, N fertilizer and N level as class variables.

RESULTS AND DISCUSSION

The chemical properties of the ash samples varied considerably, depending on material combusted, technology in the bio energy plants, and separation of ash fractions (Table 1). The level of cadmium and zinc was significantly lower in bottom ash than blended ash of BWA and FWA. BWA from Årnes was very clean and had high concentration of K relative to Ca compared to BWA Eidsvoll. The ash samples from Eidsvoll and Lillestrøm had high concentrations of Cr. The high levels of Cr may be related to corrosion processes, as severe corrosion was observed at Lillestrøm after sampling of ash blend2. According to Norwegian regulations [4] both BWA Årnes and the blend ash from Årnes can be applied on agricultural land. BWA Eidsvoll and the stem wood ash from Lørenskog are allowed to be used in urban greening. Previous investigations [2] have showed that BWA of stem wood of spruce and pine may have sufficient low concentrations of heavy metals to be allowed used on agricultural land. So far there has been no systematically investigations on ash quality in Norwegian bio energy plants, and it is therefore uncertain how large quantities of ash that are potentially available in a quality allowing recycling in agriculture or urban greening.

Table 1. Chemical composition of some ash types from bioenery plants in Akershus, Norway

	Unit	Årnes Stem wood + cereal mill waste		Lillestrøm Stem wood + GROT		Lørenskog Wet ash blended		Eidsvoll Stem wood	
		Bottom	Blend	Blend1	Blend2	Stem wood	Stem wood+ GROT	Bottom	Blend
P	g/100 g DM	1.6	2.2	0,82	1,4	1,1	1,2	0,37	0,87
K	g/100 g DM	6.9	10.0	6,5	7,2	7,4	4,1	4,0	7,1
Ca	g/100 g DM	14.0	12.0	15	31,0	21,0	23	14.0	25.0
Mg	g/100 g DM	1.7	1.9	1,2	3,3	1,6	2,6	1.8	3.1
Cd	mg/100 g DM	0.015	0.27	0,43	0,99	2,2	18	2,9	27
Zn	mg/100 g DM	54	490	110	160	130	1200	200	1900
Ni	mg/100 g DM	13	32	32	140	28	23	18	23
Cr	mg/100 g DM	21	21	180	1300	23	35	120	180
Cu	mg/100 g DM	43	77	120	110	120	81	49	90

Based on previous investigations [2] ash with Ca/K ratio similar to BWA Årnes was assumed to be more suitable for use as component in a recycled NPK fertilizer than ash with Ca/K ratio similar to BWA Eidsvoll. BWA Årnes was therefore selected for use in pot experiments in combination with N rich organic waste derived fertilizers. The effects of the treatments on crop growth and uptake of plant nutrients have been presented elsewhere [5, 6], while the effects on soil properties after harvest are discussed in this paper.

In both pot experiments BWA application gave no effect on plant growth without N application [5, 6], but calcium nitrate + BWA gave increased uptake of P and K compared to use of only calcium nitrate. Application of BWA gave significant increase in soil pH after harvest. In the sandy soil the pH increase was 0.43 after two seasons with application of BWA, while pH increased by 0.23 in the sandy loam soil which had higher buffer capacity. However, in the ryegrass experiment on sandy loam the BWA applications leveled out a pH decrease caused by N application (Figure 1). Similar pattern was also observed in the experiment on sandy soil (Table 2). In a previous experiment with BWA with Ca/K ratio 8.6 pH in a sandy soil increased by 0.5 after one single application of 1200 kg BWA ha^{-1}[2].

Application of BWA significantly increased the level of residual readily available P, K, Mg and Ca in both experiments compared to treatments without ash (Table 2 and 3).The effect of BWA application on P-AL after harvest varied between the two experiments. On the sandy soil it was a tendency of increased effect on P-AL of BWA if applied together with P rich organic fertilizers as MBM and CFM compared to calcium nitrate or applied alone (Table 2). On the sandy loam soil BWA gave almost the same increase in P-AL in all combinations with N fertilizers (Table 3). In both experiments application of BWA had significant influence on residual K after harvest (Table 2 and 3. In the sandy soil the reserves of readily available P and K were almost totally depleted by plant uptake (Table 2), causing total crop failure [5]. The combination of calcium nitrate + BWA gave high yields both of barley and wheat, and showed that P and K applied in BWA could be taken up by the crop if the N supply was adequate [5].

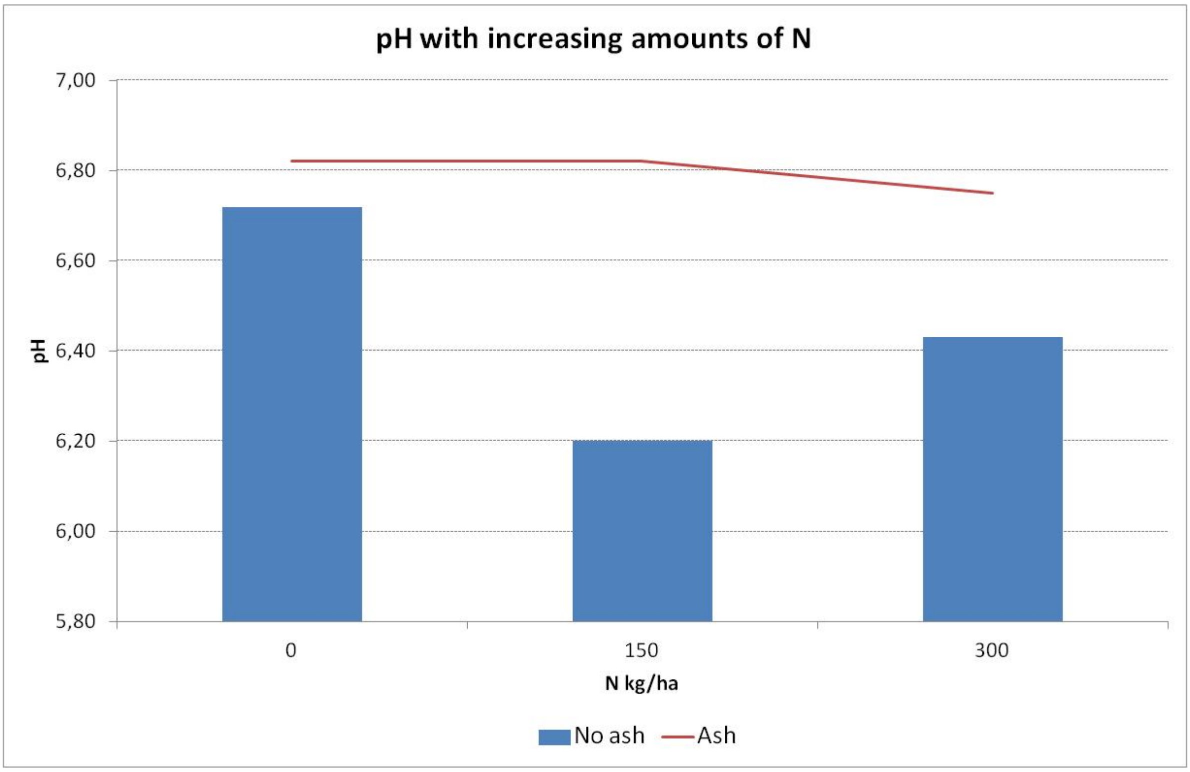

Figure 1. pH in sandy loam after harvest of ryegrass after N and BWA application

Table 2. Chemical analyses of soil after harvest of wheat in sandy soil

Treatment	pH	P-AL	K-AL	Mg-AL	Ca-AL
		mg/100 g			
Control	7.20	1.6	4.6	2.0	21.9
Control + BWA	7.51	1.8	4.3	2.8	30.3
Calcium nitrate	7.28	1.5	1.8	1.5	28.7
Calcium nitrate + BWA	7.70	1.6	2.5	2.1	35.7
MBM Mosvik	7.10	2.7	1.8	1.7	28.0
MBM Mosvik + BWA	7.47	6.4	3.5	2.8	43.0
MBM Hamar	7.00	4.0	1.0	1.8	28.3
MBM Hamar + BWA	7.68	5.9	4.3	2.7	40.3
CCW	7.05	1.3	2.3	2.0	24.3
CCW + BWA	7.55	2.0	5.3	2.6	30.7
CFM	7.08	2.7	1.7	1.9	28.0
CFM + BWA	7.39	3.6	2.7	3.0	36.0

Table 3. Chemical analyses of soil after harvest of ryegrass in sandy loam soil

Treatment	pH	P-AL	K-AL	Mg-AL	Ca-AL
		mg/100 g			
Control	6.72	2.5	3.5	12.5	247
Control + BWA	6.82	4.8	7.8	15.5	268
Calcium nitrate	6.70	2.6	4.0	12.7	264
Calcium nitrate + BWA	6.93	4.1	5.5	14.8	283
MBM Mosvik	6.56	9.2	3.7	13.1	264
MBM Mosvik + BWA	6.77	12.3	6.3	15.8	287
CFM	6.48	5.1	3.7	12.9	257
CFM + BWA	6.75	7.9	7.0	16.4	284
Dynea 2009	6.57	2.8	3.6	12.8	244
Dynea 2009 + BWA	6.69	4.2	6.4	14.7	258
Dynea 2004	6.52	2.6	3.5	12.3	247
Dynea 2009 + BWA	6.75	4.8	6.5	15.4	267

The two soils used in the experiment had very different levels of readily available Mg and Ca (Table 2 and 3). In the sandy soil with low levels of Mg-AL and Ca-AL, BWA application cause a relatively large increase in residual levels after harvest, indication both supply of Mg and Ca as plant nutrients and liming effect. In the sandy loam soil the initial levels of Mg and Ca was so high, that an increase caused by BWA application was of minor importance for supply of plant nutrients (Table 3)

CONCLUSIONS

Bottom wood ash (BWA) may have so low concentrations of heavy metals that it can be used in agriculture. There are large differences in ash quality between different bio energy plants, and it is therefore a system for quality control for ash is needed in order to select ash types for allowed applications.

If BWA is applied without sufficient N supply, the effect on crop growth is minimal and the plants do not take up the potential available plant nutrients supplied by the ash. The experiments with applications of calcium nitrate with and without application of BWA showed that P and K were supplied in plant available form by the ash, and ash application was important in order to avoid P and K in soils to be depleted. In addition BWA increased the levels of readily available Mg and Ca in soil after crop harvest. As expected the effect of BWA on soil pH was higher on a sandy soil with low content of organic matter than a sandy loam with TOC around 3 g/100 g. the BWA type used in this experiment gave not higher increase in pH levels than neutralizing acidifying effect of N fertilizers and a small pH increase which was not significant in comparison to the unfertilized control. An ash that is suitable for use in fertilizer mixtures for agricultural use should therefore have low concentrations of heavy metals, a Ca/K ratio of 3 or less, and a K concentration of 6 g/100 g DM or higher.

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