Biomass ashes: characteristics and potential for use as fertilizer

Ehmann Andrea*, Lewandowski Iris
University of Hohenheim, Institute of Crop Science, Chair of Biobased Products and Energy Crops, Fruwirthstr. 23, 70599 Stuttgart, DE
*Corresponding author: a.ehmann@uni-hohenheim.de

Abstract
Biomass combustion produces large amounts of ash. These ashes certainly have potential value as fertilizer, but this has not been studied in detail. To test the fertilizing effect, three biomass ashes from wheat grains, miscanthus and wood chips were applied at two levels to spring wheat and perennial ryegrass plants in a pot experiment in summer 2012. The investigated ashes showed high contents of phosphorus, potassium, calcium and high pH values. The resulting dry matter yields of the tested crops led to the conclusion that there was a tendency for the ashes to have positive yield effects but no significant differences between ash treatment and control were found. Absolute and relative plant uptakes of K were higher than those of P. The expected increase in soil pH due to highly alkaline ashes was buffered by the soil substrate. In summary, biomass ashes indeed affected crop growth to some extent, but an optimal solution for the integration of ashes into a fertilizer strategy remains to be found.

Introduction

In the context of increasing renewable energy use, the combustion of biomass shows high potential because it is an efficient and almost CO_2-neutral form of energy production. The rising number of biomass-based power plants creates the need for a sustainable use of the ashes generated during the combustion process. These ashes contain high levels of essential plant nutrients, such as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Their use as fertilizer would 1) avoid the need for disposal, 2) help to close nutrient cycles, and 3) conserve already limited nutrient resources, particularly phosphorus. However, presently there are few publications on nutrient contents and fertilizing effects of biomass ashes. The objective of this study was to test the effect of three biomass ashes on crop growth of spring wheat and perennial ryegrass on a pot-experiment scale. The work can be considered a pilot test for a possible field-scale trial with biomass ashes.

Material and methods

Characterization of biomass ashes

Wheat grains, miscanthus and wood chips were burnt in a 100 kW biomass heating plant at the experimental station of Hohenheim University, Ihinger Hof. The resulting ashes were analyzed for their mineral contents and pH. Plant available P and K were quantified using calcium acetate-lactate extraction method (VDLUFA vol. 1 A 6.2.1.1). For the determination of Mg and pH, soil was dissolved in $CaCl_2$ solution and measured with an AAS and a pH meter, respectively (VDLUFA vol. 1 A 6.2.4.1; VDLUFA vol. 1 A 5.1.1). The heavy metal load was not measured – it is assumed to be very low because natural biomass grown on non-contaminated soil was combusted and only bottom ash was used for fertilization. The investigated ashes contained high levels of P, K and Ca (Table 1).

Table 1: Chemical characterization of biomass ashes (P_w = water-soluble P)

	P	P_w	K [% DM]	Ca	Mg	pH
Wheat grain ash	10.89	1.05	16.82	11.37	3.67	10.5
Miscanthus ash	2.42	0.16	17.02	6.44	1.95	11.3
Wood chips ash	10.76	0.04	20.04	12.24	3.50	11.8

These nutrient loads may look very high at a first glance, but they are not entirely plant available. This is particularly apparent for P: the water-soluble fraction P_w makes up less than 10% of total P. The alkalinity is also high making biomass ashes especially suitable for use on acid soils. Moisture content was similar in all ashes with an average of 1.8%.

Pot experiment

Spring wheat and perennial ryegrass plants were treated with three biomass ashes (see Table 1) in a pot experiment at Hohenheim in 2012 to test their fertilizing effect. Ashes were applied at two levels. Table 2 provides detailed information on the experimental design. Despite its lower agricultural relevance, spring wheat was selected because the start date was too late for winter wheat. Ryegrass was selected due to its ability to cope with a wide range of growth conditions. The applied rates of 25 and 50 dt ash ha^{-1} were partly adapted from other studies [1], [2] and calculated down to pot size.

Table 2: Overview of the pot experiment with biomass ashes conducted at Hohenheim in 2012

Crops	Spring wheat Perennial ryegrass	(*Triticum aestivum* "Scirocco") (*Lolium perenne* "Lacerta")
Seeds per pot	wheat: 22 plants per pot ryegrass: 20 g m^{-1} ≙ 0.65 g per pot	
Ashes	cereals (wheat grains) miscanthus wood chips	CA MA WCA
Ash dosage	medium: 8 g per pot ≙ 25 dt ha^{-1} high: 16 g per pot ≙ 50 dt ha^{-1} untreated control (CON): only crops, no addition of ash	
Mode of ash application	before sowing, ash was added to soil surface and mixed with top layer by hand	
Soil	1/3 standard soil, 1/3 sand, 1/3 loamy soil from nearby field 4 kg substrate in square pots (18 cm x 18 cm) containing 145 mg P, 275 mg K; pH 6.9	
Duration	8 weeks, June - August 2012	
Other treatments	regular weed control by hand; additional watering as required; 200 mg NH_4NO_3 added to each pot after 4 weeks; soil sampling before and after experiment	

The experiment took place at Stuttgart-Hohenheim in south-west Germany (9°20'N, 48°71'E, 389 m above sea level; annual precipitation ø 698 mm, temperature ø 8.8 °C). The pots were stood on tables in a 'wirehouse'- exposed to outdoor conditions but protected from birds and rodents. Both shoots and roots were harvested and fresh and dry matter yields were determined. Plant samples were dried to a constant weight at 60 °C and then milled to 1 mm. Plant samples were analyzed for P, K, Ca and Mg by microwave digestion (VDLUFA vol. III 10.8.1). Soil samples were analyzed for P, K, Ca and Mg content and pH value using the same method as for the ash analyses (see above). Data for Ca and Mg are not shown. Results were statistically evaluated using SigmaStat 3.5 (Systat Software Inc., Chicago, Illinois, USA). Analyses of variance and Tukey Tests for comparison of means were done at $P \leq 0.05$.

Results and discussion

Crop growth

The dry matter yields of the tested crops suggest that the ashes tended to have positive as well as negative effects (Table 3). However, the results did not show significant differences and there was no distinct pattern visible.

Table 3: Mean DM biomass yields of crops depending on biomass ash and applied amount

	CA medium	CA high	MA medium	MA high	WCA medium	WCA high	CON
	[g DM per pot]						
Spring wheat	29.0 ± 2.1 106%	28.5 ± 2.4 104%	25.6 ± 4.4 93% ±	26.1 ± 3.6 95%	27.4 ± 1.9 100%	28.6 ± 4.1 104%	27.5 ± 1.8 100%
Ryegrass	22.7 ± 0.9 97%	24.0 ± 2.0 102%	24.0 ± 2.2 102%	21.6 ± 4.5 92%	22.0 ± 0.5 94%	22.7 ± 4.6 97%	23.5 ± 1.9 100%

Observed values in spring wheat and ryegrass are not significantly different. Percentages show performance of treated pots in comparison to untreated control (=100%).

The CA treatment - especially the medium dose - showed a positive trend in spring wheat. MA did not increase yields and thus was not recommendable for wheat. Wheat yield increased with the dose of WCA; high doses seem to be advantageous here.

In ryegrass, the medium dose of CA tended to inhibit growth, whereas the high dose tended to stimulate it. Both doses of WCA lowered the yield compared to the control. The high dose of MA had a particularly negative influence. Similar effects of wood ash on ryegrass to those seen in this study have been previously observed [1], [3].

The fact that ash applications did not significantly increase yields is possibly a consequence of the limited duration of the pot experiment. Both crops had not reached their maximum growth by the time of harvest. The low yield of the plants treated with MA can be explained by the lower nutrient content of this ash (Table 1). In comparison to the presented results, the same doses of CA and MA increased the yield of mustard plants in a trial of Frick [4]; the high dose of MA increased mustard yield by as much as 94% compared to the control. This trial had almost the same duration as the one described here.

One explanation for these varying effects of the same ashes may be the different growth rates of wheat, ryegrass and mustard. Less distinct effects were observed in wheat, which can be seen as relatively slow-growing in this context. Ryegrass, which has a medium growth rate, showed a higher nutrient uptake than wheat, and mustard, a fast-growing crop, reacted with large yield increases [4]. Harvesting all crops at the stage of maximum biomass production or at least at the same growth stage would allow better comparison of these results.

Nutrient uptake

The nutrient pool includes the nutrients of the soil substrate plus the nutrients from the applied ashes. Absolute plant uptake expresses the nutrient amount that was found in harvested plant material per pot. The relative nutrient uptake is defined as the nutrient uptake of the plants in relation to the nutrient pool. Absolute and relative nutrient uptakes were higher in pots with ash application than in control pots (Table 4). P and K uptake in ryegrass was higher than in spring wheat for all treatments except WCA. Ryegrass plants had already covered the complete soil surface, formed a dense root system and produced more shoots per pot than wheat. This explains the higher nutrient uptake compared to spring wheat.

Table 4: Nutrient pool, absolute and relative plant uptake for P and K per pot

	Ash	**Ash dose**	**Phosphorus**			**Potassium**			**Soil pH**
			Nutrient pool [mg P per pot]	Abs. plant uptake [mg P per pot]	Rel. plant uptake [%]	Nutrient pool [mg K per pot]	Abs. plant uptake [mg K per pot]	Rel. plant uptake [%]	
Spring wheat	CA	medium	1016.0	58.1	5.7^{d}	1620.5	530.2	32.7^{b}	7.6
		high	1887.5	64.0	3.4^{e}	2965.7	546.7	18.4^{c}	7.5
	MA	medium	337.7	51.1	15.1^{b}	1636.7	463.8	28.3^{b}	7.6
		high	530.9	52.2	9.8^{c}	2998.1	539.9	18.0^{c}	7.6
	WCA	medium	1005.1	58.3	5.8^{d}	1878.2	520.5	27.7^{b}	7.6
		high	1865.8	60.7	3.3^{e}	3481.1	578.1	16.6^{c}	7.5
	CON	-	144.5	47.5$^{n.s.}$	32.9^{a}	275.3	408.3$^{n.s.}$	148.3^{a}	7.5
Ryegrass	CA	medium	1016.0	62.3^{ab}	6.1^{d}	1620.5	607.1^{bc}	37.5^{b}	7.3
		high	1887.5	65.9^{a}	3.5^{e}	2965.7	662.7^{a}	22.3^{d}	7.3
	MA	medium	337.7	62.5^{ab}	18.5^{b}	1636.7	651.8^{ab}	39.8^{b}	7.4
		high	530.9	56.9^{bcd}	10.7^{c}	2998.1	599.7^{ab}	20.0^{de}	7.4
	WCA	medium	1005.1	57.1^{bc}	5.7^{d}	1878.2	579.5^{c}	30.9^{c}	7.4
		high	1865.8	53.7^{cd}	2.9^{e}	3481.1	550.0^{ac}	15.8^{e}	7.3
	CON	-	144.5	48.1^{d}	33.3^{a}	275.3	445.7^{d}	161.9^{a}	7.5

Different letters indicate significant differences between treatments within each column (n.s. = not significant).

The high values of >100% for relative K uptake in both crops stand out. However, it is not possible that crops take up more K than available in the pots. Hence, in this case either the K content of the soil may have been underestimated or the K content of the harvested crops may have been overestimated through the methods applied. Such effects can, for example, occur if the harvested plant biomass is contaminated by soil. Positive correlations exist between the available nutrient pool and absolute plant uptake in wheat. These are quite strong for P (R^2=0.92) and slightly weaker for K (R^2=0.83). The correlation for ryegrass was not significant.
Typical K concentrations in wheat and ryegrass are 1.4% and 1.8%, respectively [5]. The values found for CON plants agree with these data, whereas the concentrations in treated plants exceed them (wheat 1.9% K and ryegrass 2.7% K). In contrast, P contents were quite low in all plants, particularly in the untreated pots: wheat had 2.0% P instead of 4.8% [5], but this should not be overrated due to the early growth stage. Ryegrass plants contained 2.6% P (treated) and 2.1% P (untreated) instead of 3% P [5]. The low P contents may be either a consequence of early harvest or insufficient P availability. Though MA contained only 2.4% P (Table 1), this did not lead to a significantly lower plant uptake. All three ashes had similarly high K contents (16.8-20.0%), which led to higher K than P contents in pots. Additionally, K usually has better plant availability than P. This explains why absolute and relative K uptake in plants was higher than for P.
Although a considerable change in soil pH was expected, the pH only rose from 6.9 at the beginning to an average of 7.5 in all pots at the end of the trial regardless of the ash dosage. This may be on account of the soil substrate containing one third field soil with high loam content and therefore buffering the alkaline ash effects. The same ash treatments on sandy soils with lower buffering capacities would probably lead to higher pH increases and consequently to an immobilization of micronutrients.

Conclusion and perspectives

As ashes contain no nitrogen, they can only serve as a complement to other fertilizer types. One possible option is the combination with N-rich residues such as organic waste. This combination led to promising yield effects in Norway [6]. In agreement with other authors, we recommend testing ashes in nutrient-poorer substrate which does not obscure the fertilizing effect. Furthermore, a longer trial period could result in a more distinct pattern of the ashes' performance, especially in wheat harvested at an early growth stage. In summary, biomass ashes affected crop growth and nutrient content to a certain extent, but it remains to be studied how they can be integrated into a fertilizer strategy and how nutrient loads of ashes can be matched with crops' needs. Ashes have promising potential for use as fertilizers due to their high loads of essential plant nutrients. We were able to confirm a general tendency of higher nutrient uptakes and increasing crop yields after ash application.

Acknowledgements

This work was part of a Humboldt reloaded research project, funded by the German Federal Ministry of Education and Research.

References

[1] Schiemenz K, Eichler-Loebermann B, 2010. Biomass ashes and their phosphorus fertilizing effect on different crops. Nutr Cycl Agroecosyst 87, 471-482
[2] Bougnom BP, Niederkofler C, Knapp BA, Stimpfl E, Insam H, 2012. Residues from renewable energy production: Their value for fertilizing pastures. Biomass and Bioenergy 39, 290-295
[3] Lopez E, Padilla E, Bachmann S, Eichler-Loebermann B, 2011. Effects of Biomass Ashes on Plant Nutrition in Tropical and Temperate Regions. Journal of Agriculture and Rural Development in the Tropics and Subtropics 110, 51-60
[4] Frick M, 2011. Pflanzenbauliche Verwertungsmöglichkeiten von Aschen aus der Biomasse-verbrennung. Bachelor's thesis, University of Hohenheim
[5] Rowell DL, 1997. Bodenkunde: Untersuchungsmethoden und ihre Anwendungen. Springer Verlag, Berlin Heidelberg, Germany
[6] Brod E, Haraldsen TK, Breland TA, 2012. Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment. Agricultural and Food Science 21, 332-347